TECHNICAL REPORT

Implementation of EcoAIM™— A Multi-Objective Decision Support Tool for Ecosystem Services at Department of Defense Installations

ESTCP Project RC-201115

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14. ABSTRACT

This report describes the demonstration of the EcoAIM decision support framework and GIS-based tool. EcoAIM identifies and quantifies the ecosystem services provided by the natural resources at the Aberdeen Proving Ground (APG). A structured stakeholder process determined the mission and non-mission priorities at the site, elicited the natural resource management decision process, identified the stakeholders and their roles, and determine the ecosystem services of priority that impact missions and vice versa. The EcoAIM tool was customized to quantify in a geospatial context, five ecosystem services – vista aesthetics, landscape aesthetics, recreational opportunities, habitat provisioning for biodiversity and nutrient sequestration. The demonstration included a Baseline conditions quantification of ecosystem services and the effects of a land use change in the Enhanced Use Lease parcel in cantonment area (Scenario 1). Biodiversity results ranged widely and average scores decreased by 10% after Scenario 1. Landscape aesthetics scores increased by 10% after Scenario 1. Final scores did not change for recreation or nutrient sequestration because scores were outside the boundaries of the baseline condition. User feedback after the demonstration indicated positive reviews of EcoAIM as being useful and usable for land use decisions and particularly for use as a communication tool.

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ACRONYMS AND ABBREVIATIONS

ACES	A Conference for Ecosystem Services
ACUB	Army Compatible Use Buffer
ACOE	U.S. Army Corps of Engineers
AHP	Analytical Hierarchy Process
APG	Aberdeen Proving Ground
BPF	biophysical production functions
BRAC	Base Realignment and Closure
BSR	Business for Social Responsibility
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance
DEM	Digital Elevation Model
DoD	Department of Defense
DSS	decision support system
ES	ecosystem services
ESTCP	Environmental Security Technology Certification Program
EQCC	Environmental Quality Control Committee
EUL	Enhanced Use Lease
GIS	geographic information system
GSO	Garrison-Support Organizations
GUI	graphic user interface
IBOD	Installation Board of Directors
INRMP	Integrated Natural Resources Management Plan
ITAM	Integrated Training Area Management
JPEO-CBD	Joint Program Executive Office for Chemical and Biological Defense
LCTA	Land Condition Trend Analysis
LU/LC	land use/land cover
NEPA	National Environmental Policy Act
NPL	National Priorities List
NGO	non-government organization
NPDES	National Pollutant Discharge Elimination System
P8	Program for Predicting Polluting Particle Passage thru Pits, Puddles and Ponds
PO	Performance Objective
RAT	Riparian Analysis Toolbox
SEBI	Streamlining European Biodiversity Indicators
SETAC	Society for Environmental Toxicology and Chemistry
TMDL	total maximum daily load
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
UXO	unexploded ordnance

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The Exponent team also coordinated with organizations at Cape Canaveral Air Force Station (Cape Canaveral) and Patrick Air Force Base (Patrick AFB) within the 45th Space Wing in Florida, and the Army National Guard Maneuver Training Center, Fort Pickett, Virginia (Fort Pickett). The Exponent team coordinated closely with many individuals at the U.S. Army's Aberdeen Proving Ground; in particular, the leadership of Deidre DeRoia is acknowledged. Support for the effort was also provided by Bryant DeBruyne, John Paul and John Wrobel. Helpful advice was provided by the technical support team for the ESTCP environmental program. In addition to the authors listed on the cover of this report, invaluable technical input for model development was provided by the following Exponent staff: Roxolana Kashuba (statistical analysis of the significance of results), Svetlana Semenova (recreational model), Linda Ziccardi (nutrient sequestration model), John Buonagurio (vista aesthetics) and Charles Menzie (Principal technical review). The report was prepared with the editorial and graphics assistance of Rick Nelson and Betty Dowd of Exponent.

EXECUTIVE SUMMARY

OBJECTIVES OF THE DEMONSTRATION

The goal of the Demonstration at Aberdeen Proving Ground (APG) is to show that EcoAIM™™ can support effective land-use management decisions by identifying and quantifying trade-offs in ecosystem services (ES) under varying operational scenarios. Specific objectives of the Demonstration are to:

- Identify three or more ES that are deemed to be essential to sustaining the mission at APG
- Develop biophysical production functions (based on scientifically vetted mathematical models) that quantitatively relate changes in the provision of ES to responses to changes in land use/ land cover
- Develop geospatial models that incorporate the biophysical production functions
- Display changes in ES provisioning using one or more realistic land-use change scenarios on a scale that is relevant for decision making.

This Demonstration had six Performance Objectives:

1) Demonstrate that quantification of ES is well founded
2) Quantify three or more ES
3) Display quantification of three or more ES in geospatial context
4) Develop maps of ES flows associated with the installation, and provide a clear and accurate description of activities involved in the mission
5) Quantify shifts in the value of benefits from ES under different mission scenarios
6) Ensure ease of use and utility of the tool for decision making.

This Demonstration met all success criteria for each Performance Objective.

TECHNOLOGY DESCRIPTION

EcoAIM™ consists of two components:

- A decision support framework
- A geospatial modeling tool.

Decision Support Framework

The decision support framework is developed as part of an initial problem formulation step in EcoAIM™, and it consists primarily of a scalable and iterative structured stakeholder engagement process. The stakeholder engagement process is designed to:

- Help Project personnel understand the objectives and priorities of the installation mission as they relate to ES
- Identify the stakeholders and their roles, and the land-use decision-making process at the installation
- Help installation personnel identify the ES that are of primary concern to mission support and ES are most likely to be affected by execution of the mission
- Identify the biophysical endpoints that are valued by stakeholders.

The information garnered from these stakeholder interactions is used to identify the models that would best describe the biophysical production functions that link endpoints to land-use changes. The stakeholder engagement is also intended to determine the importance of stakeholder preferences regarding ES to land-use decisions, and if sufficiently important, to elicit preference weightings for ES.

Geospatial Modeling Tool

The second part of EcoAIM™ is a geospatial modeling tool consisting of GIS-based software that is programmed as a ToolBox within an ArcGIS framework. The tool is composed of five individual models, reflecting the ES of concern that have been identified by installation personnel using the decision support framework:

- Vista aesthetics
- Landscape aesthetics
- Recreational opportunities
- Habitat provisioning for supporting biodiversity
- Nitrogen sequestration.

Each model is founded on scientifically vetted approaches and studies in the peer-reviewed literature. With the exception of nitrogen sequestration, all underlying models were developed as part of this Demonstration, and are a "first-off" in the modeling of ES. These first-off models were developed based on thorough reviews of the scientific literature, and they rely on identification and quantification of geospatial variables that are have the greatest influence on each ES. The nitrogen sequestration model is based on the combination of EPA's P8 model and University of Maryland's RAT model, two models that met the overall objectives of quantifying this ES.

All models are programmed directly into EcoAIM™, so that ArcGIS users do not have to upload new software to their system. Results of each model are quantified by pixel in a geospatial area on either a grid-cell or habitat-patch basis. For each model, a distribution of the relative value of each geospatial areas is plotted, and a Jenks natural breaks classification method is used to categorize each spatial area into a measure of "ES value." This ES value facilitates a common metric, so that all ES can be compared. In addition, multiple ES values for a selected parcel can be averaged, and these parcels can be compared to each other in different land-use scenarios.

The Demonstration consisted of the following tasks:

1) Site selection
2) Site-specific problem formulation
3) Field verification
4) Selection of biophysical models
5) Site-specific implementation
6) Documentation
7) Technology transfer.

Selection of APG as one of three demonstration sites was based on Exponent's history of working at the installation, APG's expressed interest in EcoAIM™, and their unique location on the Chesapeake Bay, a nationally important waterbody.

The site-specific problem formulation task consisted of developing an understanding of ES importance to military mission sustainability, the benefits derived from ES, how natural resource decisions are made, selection of key ES for quantification, and selection of biophysical models that best represent ES at APG. This task was accomplished with an initial teleconference meeting and two onsite stakeholder engagement workshops. These meetings allowed Project personnel to understand APG's goals, missions, and visions for the future; the decision process, stakeholder involvement, roles, and responsibilities; and the ES of most importance for decision making.

Field verification at APG was not required, because significant data gaps were not apparent. The GIS layers and information provided by APG had sufficient spatial scale and resolution for the Demonstration. Several detailed layers that were obtained were results from APG's own extensive ground-truthing surveys, so Project personnel were not required to verify data.

The task of selecting biophysical models was based on the land-use plans, mission requirements, and visions of APG's future elicited from the site-specific problem formulation task. Models for consideration had to meet the criteria of being previously validated, having the ability to evaluate uncertainty and variability in outputs, and being applicable across different environments and installations within a geospatial context in an ArcGIS framework.

Site-specific implementation of EcoAIM™ at APG was accomplished with three demonstrations. The first demonstration of the EcoAIM™ prototype was at APG and included a discussion of the scientific basis behind each EcoAIM™ model, a real-time presentation of the vista aesthetics model, and a preview of the remaining models. The second and third demonstrations were presented via teleconference and presentation slides. The second demonstration was focused on presenting the technical aspects of the tool and was aimed at GIS analysts and others familiar with ArcGIS software. The third demonstration was aimed at all end users in the Natural Resources Branch, presenting an overview of the basic functioning of the tool, the results of each model, and the results of a feasible and realistic land-use change scenario. Feedback concerning the EcoAIM™'s usability and utility was requested and received through a survey.

The documentation for this Demonstration includes this report and the EcoAIM™ tool. In addition, posters and platform presentations will be submitted at a scientific conference at the end of 2014. Two manuscripts will be submitted to a peer-reviewed scientific journal. These presentations and articles will showcase the Demonstration at APG as a case study.

Technology transfer is the final task for this Demonstration. EcoAIM™ and supporting documentation will be delivered to the installation in October 2014. EcoAIM™ will be delivered via a CD to be installed as an ArcGIS Toolbox and Add-in file. Limited technical assistance will be available for APG's GIS analysts.

DEMONSTRATION RESULTS

The Demonstration results were positively received by APG personnel. Results from each model were presented to APG as both baseline conditions and after a hypothetical change in the Enhanced Use Lease (EUL) area, wherein two buildings and a recreational trail replaced portions of the existing forest and wetland areas (Scenario 1).

Habitat Provisioning for Biodiversity

The model of habitat provisioning for biodiversity results showed that the large wetlands adjacent to Chesapeake Bay were of the greatest quality (scores of 10), and the small, isolated wetlands in the cantonment areas were of much lower quality. Large, contiguous forests in the downrange area in Aberdeen scored high ES values, due to the high edge habitat heterogeneity and proximity to freshwater sources. Forests in Edgewood had lower quality scores due to their proximity to roads and built-up areas. Most grassland patches scored high (7–10), especially those that had large areas and were near water and forests. Under Scenario 1, the average biodiversity score for the EUL decreased by 10% due to the new buildings being closer and the increased fragmentation of the forests and wetlands.

Landscape Aesthetics

The landscape aesthetics model results indicate a wide range of aesthetics quality. In general, wetlands along Chesapeake Bay had high scores because of their association with more water bodies and higher vegetative/water interspersion. Low-scoring wetlands were mostly isolated, small wetlands located inland. The large forest patches in the downrange area had some of the highest scores due to their large area and edge complexity. Some small Edgewood forests also scored high, due to their intrinsic aesthetic characteristics such as high tree density. Under scenario 1, the overall landscape aesthetics score increased by 10% due to the increase in patch richness and Shannon Diversity Index scores. Although this increase seems counter-intuitive, the literature supports the concept that preferences for a greater number and greater diversity of land-use types increases the perception of greater aesthetics. The addition of two buildings and a trail (two new land-use types) caused the increase in landscape aesthetics value.

Vista Aesthetics

The vista aesthetics model results show that, in general, with all else being equal, a greater viewshed area produces a greater overall vista aesthetics value. The patch richness score and the Shannon Diversity Index vary, depending on the point of view of the observer and the preference weight (assigned by user) of patch types. Under scenario 1, the view obstruction due to the hypothetical six-story buildings decreased the viewshed area effected no significant changes in the Shannon Diversity Index or the patch richness score.

Recreational Opportunities

The recreational opportunities model results show that grid cells with the highest overall scores possess attributes such as access to roads and boat-launch sites and are in near residential and work areas. Areas with lower scores are greater distances away from residential and work areas and are not accessible by roads. There was no change in the recreational score under scenario 1. Due to the high scores already determined in the Baseline condition, the increase in raw scores was outside the initial model parameters, and thus, the overall ES scores remained unchanged at "10."

Nutrient Sequestration

The nutrient sequestration model results show that total nitrogen loadings were greatest in the small wetlands downstream of the cantonment areas. However, because of these high loadings and intrinsic characteristics (wetland buffer width and vegetation type), these wetlands also sequestered the greatest amounts of total nitrogen. In contrast, larger wetlands downstream of the downrange areas that did not have loadings influenced by built-up areas were found to sequester relatively less total nitrogen than their cantonment wetland counterparts. Scenario 1 results did not change overall EUL average scores. Because the Baseline condition scores for this model were already low, the decreases in raw scores were outside the limits of the model, and the overall ES scores remained unchanged at "1."

COST ASSESSMENT

Based on a cost model, the total cost of implementing EcoAIM™ is $41,250. A fundamental assumption of the cost model is that the site has typically collected geospatial data, including:

- Land use/land cover layer
- Digital Elevation Model
- Wetland, forest, and grassland detailed layers
- Road layer
- Biological survey data.

Per-site costs by major activity are estimated as follows:

- Procurement of geospatial data—$4,000 based on experience at APG, Fort Pickett, and Cape Canaveral/Patrick Air Force Base.
- Selection of biophysical models—$7,000 for literature reviews and development and application of the model selection matrix.
- Structured stakeholder engagement—$4,500 for stakeholder orientation meetings, interviews, and survey instruments. This estimate does not include quantitative preference elicitation.
- Programming—$15,300 associated with development of new models, user interface programming, and developing inputs for scenario(s).
- Training—$1,750 associated with training site personnel to run the tool.
- Running scenarios—$4,000 associated with running the tool and preparing and presenting results.
- Technical assistance—Labor associated with providing remote technical assistance (between installations).

For the purposes of estimating labor costs, two labor categories and rates were assumed: Technician at $50/hr and Project Manager/Supervisor at $100/hr.

The primary cost drivers in assessing whether to implement EcoAIM™ at a facility include:

- The degree of stakeholder engagement needed—Whether external stakeholders need to be included, and the relative sensitivity of the surrounding community to mission support, are key determinants of the degree of stakeholder engagement needed.
- The need to develop additional ES models or refine existing models—EcoAIM™ is limited to the biophysical models presented in this report.
- The accessibility and availability of appropriate GIS layers, data, and background information—No data acquisition costs were incurred in this demonstration; however, acquisition of specialized data could add considerably to costs.

The life-cycle costs when implemented operationally are estimated as annual maintenance costs and software upgrading costs, using best professional judgment, and in consultation with users to determine reporting needs, amount to $23,264 for a three-year life cycle.

The three installations selected for this demonstration do not currently use any tools for assessing tradeoffs on ES provisioning as a result of land management actions. Therefore, there is no basis of comparison for implementation costs.

IMPLEMENTATION ISSUES

The following project implementation issues were encountered:

- **Availability of Installation Personnel**—Limited availability of installation personnel resulted in long lead times to schedule onsite and teleconference meetings and obtain necessary information and data, and partially defined the scope of the stakeholder engagement activities. Government shutdowns during October 1–16, 2013, and those due to weather, further strained the project schedule.

- **Restriction on Software Use—**The U.S. Army's Certificate of Networthiness program required Exponent to develop the geospatial model on a backward-compatible ArcGIS platform. This significantly increased the amount of time needed for backward programming and forward compatibility programming (in anticipation of when an upgrade is made) and limited the flexibility in developing customized graphical user interfaces (GUIs).

- **Non-Centralized Data Storage—**The existence of multiple repositories of geospatial data required ongoing and multiple iterations of requests for GIS layers during the entire demonstration, including to within a month of completing this report.

- **Access to Personnel—**Access to some APG personnel was hindered by the existing chain of command. Exponent requests of personnel in other branches, such as the Recreation Director, were met with requisitions for approval by higher authorities.

The anticipated implementation issues based on experiences at APG as a demonstration site are:

- **Customization—**the custom build of models in EcoAIM™ to assist with decision making based APG's notional missions and visions of the future may not be translatable to other installations. A stakeholder engagement process will be needed to assess the needs of other sites.

- **Stakeholder engagement specialist—**an expert in military culture and ES in natural resource management planning will be required to invite the relevant employees, elicit and develop consensus among installation personnel for a notional mission on which to base EcoAIM™ ES models, BPFs and measurement endpoints.

- **Data availability—**the scenario-building capability and output from EcoAIM™ are heavily dependent on baseline input data at each site. Comparisons among multiple sites will require data that are sufficiently available and of high enough quality (i.e., spatial extent, resolution, and accuracy) at all sites to create common baseline conditions.

As of the date of this report, EcoAIM™ has been implemented at Aberdeen Proving Ground. EcoAIM™ The Demonstration will essentially conclude in October 2014 with the delivery of the software. Exponent will provide limited technical support immediately following delivery of the software to the installation.

1 INTRODUCTION

This demonstration project entails the development of a decision-support system framework and software tool, EcoAIM™, that will enable explicit consideration of tradeoffs in ecosystem services (ES) for alternative land management scenarios. EcoAIM™ is intended to assist in the development of natural resources management strategies that help maintain mission readiness, illuminate and help resolve land management conflicts, and consider tradeoffs in ES across the installation. This demonstration project has involved customizing the EcoAIM™ geospatial analysis tool to the specific physical/biological environment, decision-making environment, and mission prerogatives at Aberdeen Proving Ground (APG).

Implementation of EcoAIM™ includes:

- A stakeholder engagement process to identify management objectives and missions, define the flow of ES, define the decision-making process, and determine how key ES affect mission support
- Customization of the EcoAIM™ geospatial software tool for the quantitative evaluation and visualization of ES trade-offs under alternative management scenarios.

The demonstration project was fully implemented at APG and entailed the assessment of all key ES that significantly influence mission readiness. The following sections describe the background of the project, project objectives, and regulatory drivers.

Ecosystem services are benefits provided to people by the environment, either as products or processes. Examples of ES include processes such as nutrient removal by wetlands, and products such as habitat for birds and timber by forested areas. The Millennium Ecosystem Assessment (2005) identified the following categories of ES: provisioning (e.g., water), regulating (e.g., flood mitigation and carbon sequestration), supporting (e.g., nutrient cycling in a watershed), and cultural (e.g., recreation and aesthetics, and in the context of this demonstration project, needs specific to the military).

ES at Department of Defense (DoD) installations are inextricably linked to military missions and operations. Military activities have impacts on the natural resources and provisioning of ES. For example, artillery training can cause soil compaction and fires that change the mosaic of vegetation cover and essential habitat for some species. Adverse effects on ES can also originate from areas outside of the military installation. The sustainability of military activities also relies on ongoing provisioning of ES. For example, natural habitats offer unique and valuable training platforms, and their degradation may also reduce the quality of the training mission. Finally, ES include benefits that might be considered tangential to the mission, but are still highly valued by internal or external beneficiaries (e.g., recreational opportunities for installation personnel and the surrounding community). Incorporation of ES into land management decision making offers opportunities to maximize the value of ES across the installation while preserving ES mission support.

Explicit consideration of ES, from both the ecological and mission readiness perspectives, can help resolve land management conflicts for military and non-military stakeholders.

1.1 BACKGROUND

DoD is responsible for the stewardship of more than 30 million acres of land, and expends approximately $4 billion per year on management of these lands and associated air, water, and other natural assets to meet regulatory and mission requirements (Hewett 2008). Natural resources are an integral part of installation assets, and they are critically important to the success and sustainability of missions. Environmental stewardship is often a goal in its own right, but is also critical to achieving military missions. DoD must comply with federal environmental laws that may dramatically restrict activities; for example, protection of habitat for threatened or endangered species. In addition, DoD lands and natural assets that were previously in rural, undeveloped areas are increasingly under pressure from encroachment; for example, urban development and above-average population growth around Fort Bragg, North Carolina (Knott and Natoli 2004). Such encroachment is not compatible with many military live-fire training and testing activities and can inhibit the Army's ability to train and test their warfighting capabilities (Knott and Natoli 2004). In the case of APG, natural resources need to be considered in light of the land-use changes that are occurring, currently and in the near future. See Figure 1 for a conceptual diagram of the relationship between ES and selected activities at military installations.

Regulatory compliance and development pressures can interfere or conflict with an installation's operational missions, including training and testing, and can exert corresponding impacts on force readiness and capability. These conflicts can be manifested in myriad ways. For example, preservation of natural habitat for special-status species can limit the use of such areas for training, and protection of wetlands can limit options for development. Similarly, maintenance of natural areas and enhancement of access for recreation can enhance aesthetic values and the quality of life for both civilian and military personnel.

Traditional approaches for managing natural assets are driven by specific regulations or policy directives and often miss opportunities to account for the total inherent value of ES, because trade-offs in ES are not apparent. Explicit consideration of ES enriches the information available to decision makers and may help achieve better outcomes related to ES tradeoffs. To accomplish this, it is important to have the means available to characterize natural resource assets and identify the ES they provide. Such decision frameworks and tools should include a process for identifying and communicating clear management objectives. It is also important to identify the most appropriate and scientifically defensible ecosystem production functions that are meaningful to and easily understood by stakeholders. EcoAIM™ provides a flexible, transparent, and user-friendly framework and geospatial tool to help decision makers at an installation visualize the provisioning of ES and run alternative scenarios to see how their mission activities will affect ES at the site.

Figure 1. Conceptual illustration of the relationship between ecosystem services and military installations

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1.2 OBJECTIVE OF THE DEMONSTRATION

The goal of the demonstration at APG is to show that EcoAIM™ can support effective land-use management decisions by identifying and quantifying trade-offs in ES under varying operational scenarios. Specific objectives of the demonstration are:

- Identify three or more ES that are deemed to be essential to sustaining the mission at APG
- Develop biophysical production functions (based on scientifically vetted mathematical models) that quantitatively relate changes in the provision of ES to response to changes in land use or land cover
- Develop geospatial models that incorporate the biophysical production functions
- Display changes in ES provisioning using one or more realistic land-use change scenarios on a scale that is relevant for decision making.

1.3 REGULATORY DRIVERS

There are several regulatory drivers for managing natural infrastructure at military installations, including but not limited to the following: Section 117(c) (3) of Title 10 of the United States Code, Executive Order 13327 *Federal Real Property Asset Management,* DoD Directive 4715.1E, Executive Order 13352 *Facilitation of Cooperative Conservation*, and the Readiness and Environmental Protection Initiative (REPI) from 10 USC, Sec. 2684a.

Programs have been implemented at most DoD installations to assist DoD land managers in monitoring the conditions of the natural resources at their installations. An example of such a program is the Land Condition Trend Analysis (LCTA) Program developed by the U.S. Army. LCTA is used to assess the condition of vegetation and wildlife populations to help identify training areas that may be over- or under-used. LCTA data can be used to make land management decisions concerning how these areas should be used in the future. In addition to military mission support, the LCTA program has helped the Army ensure the sustainability of its land and has provided information for use in natural resource management plans, environmental assessments, and environmental impact statements.

ES are also an important part of evaluating remedial plans for contaminated lands and waters. In this respect, explicit consideration helps guide appropriate actions (e.g., limiting ecological impacts of remediation), as well as aiding in the identification of green technologies that can enhance ES at the installation. Notable examples are wetland creation to treat water, and use of poplar tree species to remedy contaminated groundwater.

Key regulations and relating to the management of ES at military installations include the following:

- National Environmental Policy Act (NEPA)
- Sikes Act (Public Law 86-797) which includes the 1997 amendment that requires Integrated Natural Resource Management Plans
- Endangered Species Act
- DoD 4715.03 Natural Resources Conservation Program
- DoD Installation Master Planning Unified Facilities Criteria

Other important regulatory drivers for APG include:

- U.S. Federal Laws and Executive Orders
  - Fish and Wildlife Conservation Act
  - Lacey Act
  - Clean Water Act
  - Migratory Bird Treaty Act
  - Executive Order 13186, Responsibilities of Federal Agencies to Protect Migratory Birds
  - Bald and Golden Eagle Protection Act
  - Title 10. Armed Forces, Subtitle A–General Military Law, Part IV. Service, Supply and Procurement, Chapter 159. Real Property; Related Personal Property; and Lease of Non-Excess Property, §2684.
  - Executive Order 11990, Protection of Wetlands
- State of Maryland Laws and Local Regulations
  - Maryland hunting laws and regulations
  - Maryland Chesapeake Bay Critical Area Protection Program
  - Maryland Coastal Zone Management Program
  - Maryland Forest Conservation Act
  - Maryland Forest Management Practices
  - Harford County Forest Management Ordinances
- U.S. Army and APG Regulations
  - Army Regulation 200-1 Environmental Protection and Enhancement
  - Army Regulation 200-3 Natural Resources – Land, Forest, and Wildlife
  - Army Regulation 200-2 Environmental Effects of Army Actions
  - Army Regulation 200-3, 4-8 Base Attractiveness and Scenic Values

- Army Regulation 350-19 Sustainable Range Program
  - APG Regulation 200-6 Hunting and Trapping regulations
  - APG Regulation 210-10 Fishing regulations
  - APG Regulation 210-26 Outdoor recreation
- DoD Directives and Instructions
  - DoD Directive 3200.15 Sustainment of Ranges and Operating Areas (2003)
  - DoD Directive 3200.15 Sustainment of Ranges and Operating Areas (2003)
  - DoD Directive 4715.1 Environmental Security (1996)
  - DoD Instruction 4715.3 Environmental Conservation Program (1996)
- Cooperative Agreements and Memoranda of Understanding
  - Cooperative Plan Agreement for Conservation and Development of Fish and Wildlife Resources on Aberdeen Proving Ground
  - Cooperative Agreement between the Department of Defense and Environmental Protection Agency concerning Chesapeake Bay Activities
  - Memorandum of Understanding between the DoD and USFWS to Promote the Conservation of Migratory Birds.

In addition to the regulatory drivers listed above, an Integrated Natural Resources Management Plan (INRMP) for APG is reviewed each year and revised at least every five years to comply with requirements under Army Regulation 200-3. The most recent INRMP (released in 2009) covers the period 2009–2014. The INRMP describes the natural resources, strategies for natural resource management, and their interrelationship with the military mission at APG. Since the 2001–2005 INRMP, the land-use planning at APG has changed greatly due to Enhanced Use Leasing (EUL), Base Realignment and Closure (BRAC) and joint use of APG facilities. EUL is currently being developed in the cantonment area, which includes several retail spaces and office spaces for military contractors. APG is currently a BRAC-gaining installation. It is also a host to 66 installation tenant commands with activities that have direct or indirect effects on the natural resources. Tenants with the largest impacts on the environment include Edgewood Chemical and Biological Center; Aberdeen Test Center, Research, Development and Engineering Command; and Ordinance Mechanical Maintenance School. The natural resources managers at APG are tasked with sustaining an environment that provides realistic training and testing experiences. The Army is also responsible for the management of natural resources to allow for range sustainability (APG 2009).

Based on the land-use changes occurring at APG, the multiple uses of natural resources by installation tenant organizations, their mission of managing the environment for range sustainability, and compliance with regulations and directives, led to the need for a tool and process for managing ecosystem services for multi-objective decision making.

2 TECHNOLOGY AND METHODS

2.1 DESCRIPTION OF TECHNOLOGY AND METHODS

The EcoAIM™ geospatial tool is founded on GIS technology. GIS technology can be defined as any information management system that integrates, stores, edits, analyzes, shares, and displays geographic information for informing decision making. The EcoAIM™ tool uses the ArcGIS software platform and includes a customized set of Toolboxes that include user interface screens for data input, analysis, and display of results, as well as embedded models for predicting changes in the value of selected ecological indicators in response to changes in environmental or spatial variables.

Implementation of EcoAIM™ is achieved within a decision support framework for problem formulation that relies on an iterative stakeholder engagement process. The stakeholder engagement process is designed to enable elicitation of preferences among stakeholders, which in turn, is aimed at quantifying overall ES value. Thus, the decision support framework of EcoAIM™ can range from very formal, quantitative decision analysis to a less formal and more flexible approach. A formal decision support framework process consists of highly structured intensive stakeholder engagement using decision analysis tools such as Analytical Hierarchy Process (AHP) and choice experiments to elicit quantifiable preference weightings that are then applied to quantify tradeoff in ES under different land management scenarios. This approach leads to a fairly rigid quantification structure and the need to update the decision analysis periodically as management priorities and stakeholder and beneficiary preferences change over time. A less formal decision support framework consists of stakeholder engagement to elicit general preferences regarding ES and management prerogatives, as well as understanding of decision-making processes at different levels of management. This approach leads to design of a flexible quantification structure wherein the tool user can incorporate preference weights to explore the influence of preferences on total ES provisioning.

2.2 OVERVIEW OF TECHNOLOGY AND METHODS

Figure 2 presents a schematic diagram of the EcoAIM™ framework.

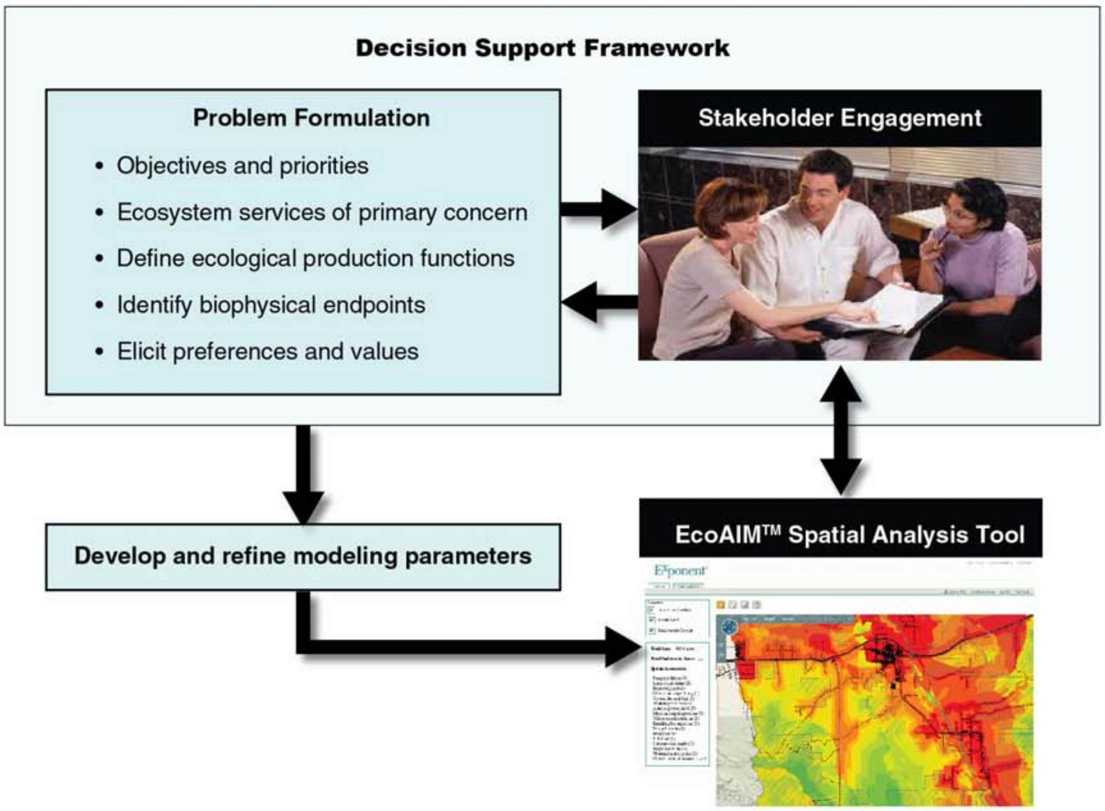

Figure 2. Schematic diagram for the implementation of EcoAIM™

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2.2.1 Decision Support Framework

The three functions of the Decision Support Framework are as follows:

1) Define the "decision space," including:
   - Determine management goals and objectives at the installation. (For APG, it was not necessary to determine the management goals and objectives of outside stakeholders, as indicated by feedback from APG staff).
   - Identify stakeholders, including those groups that derive benefits from ES at the installation (hereafter termed the "beneficiaries").[1] The beneficiaries at APG include APG tenants who require areas for testing and building of new spaces.
   - Describe the roles and responsibilities of beneficiaries.
   - Identify the key ES at the installation.
2) Identify ES that are valued by beneficiaries and the underlying biophysical processes that generate the ES (hereafter referred to as biophysical production functions, or BPFs).
3) Develop a process for selecting biophysical models that best represent the BPFs.

Defining the management goals is a key first step that frames the entire decision-making process for a particular site or situation, including determining the key ES that drive decisions. The conceptual model for ES quantification is based on BPFs, where the goal is to identify an ecosystem product or function that is directly important for human well-being (e.g., provisioning, regulating, etc.) and is relatively easy to measure, and the importance of which is intuitively apparent to a wide range of end users.

Figure 3 illustrates the concept of BPFs and measurement endpoints using the example of an emergent wetland. In this illustrative example, a wetland provides a variety of intrinsic BPFs that are either inputs to higher level processes or products or that are directly valued (used) by humans. For example, by virtue of their water-holding capacity, wetlands lower the frequency and intensity of flood events—a process that offers a direct benefit to humans. Similarly, primary production by algae supports a complex food web, the upper trophic levels of which are used directly by humans for food, recreation, or aesthetic pleasure—thus, primary and secondary production are biological processes that are inputs to higher processes that result in direct benefits to humans.

[1] It is important to distinguish between beneficiaries and "stakeholders" in the context of this demonstration project, because beneficiaries are key to the determination of which ES will be quantified and what metric(s) will be used for quantification. The term "stakeholders" refers to a broader group of individuals (including beneficiaries) who have key roles in environmental or mission-critical decision making, or otherwise have a vested interest in the outcome of decisions.

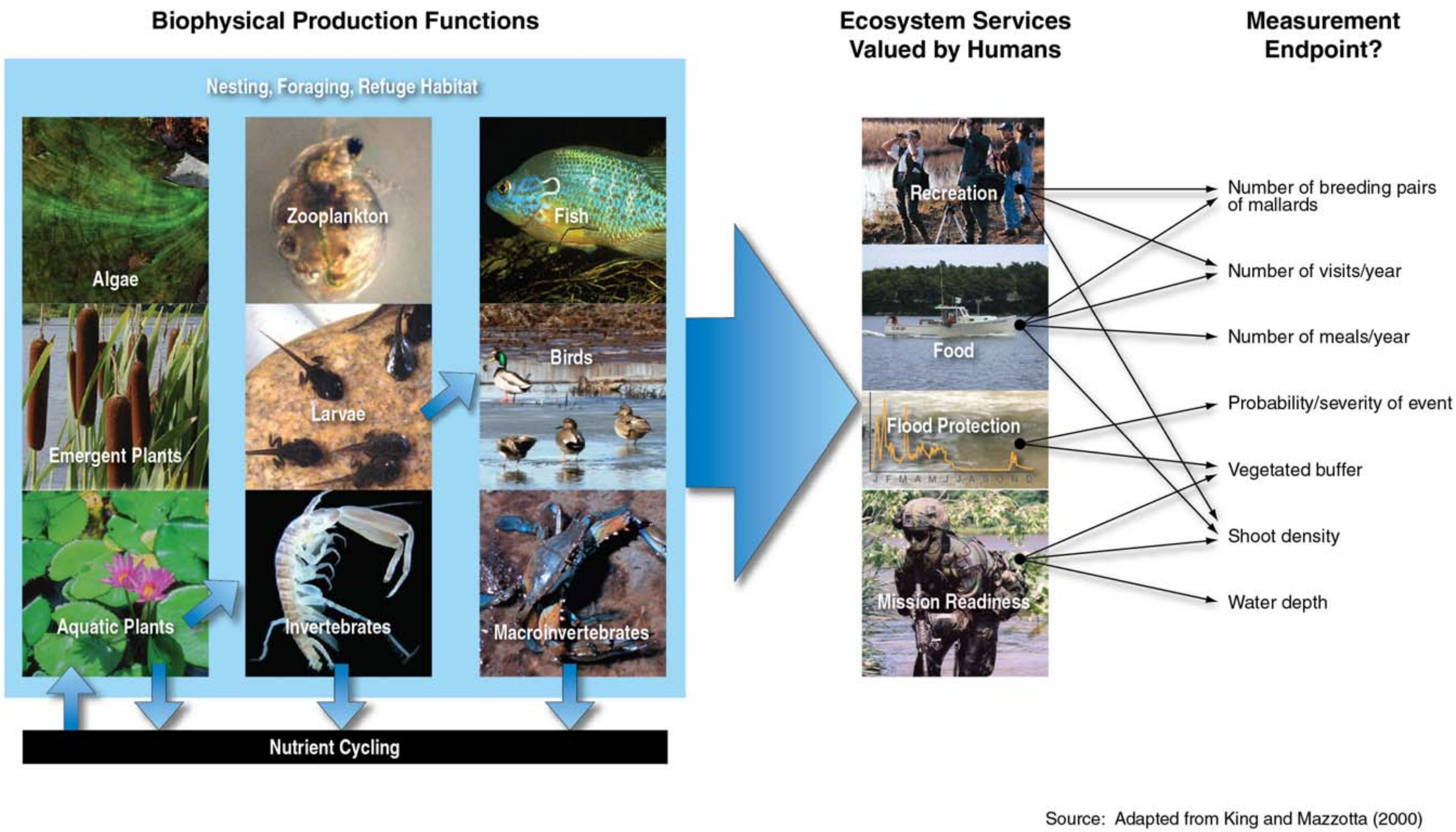

Figure 3. An example of biophysical production functions and ecological endpoints within the flow of ecosystem services provided by emergent wetlands

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This demonstration project focuses on identifying and implementing scientifically defensible BPFs that most closely model outputs that beneficiaries care about, and to characterize the uncertainty in cases where only imperfect matches can be made. This approach is based on the premise that, as long as uncertainties and assumptions are defined clearly, it is better to have imperfect information than no information when making decisions.

2.2.2 Biophysical Production Functions, Measurement Endpoints, and ES Valuation

EcoAIM™ applies biophysical analysis and scientific knowledge regarding BPFs to give decision makers the ability to distinguish between management scenarios in terms of gains and losses and ecological endpoints that are important to beneficiaries. Typically, this menu of changes presents the decision maker with trade-offs. The ecological outcomes are expressed as endpoints, providing decision makers with information to make judgments about the trade-offs.

Economic analysis informs the decision by "scaling" the ecological changes. When monetary valuation is practical, ecological changes are translated into dollar amounts that can be compared to other monetary costs and benefits. Dollar values allow the ecological outcomes to be compared on the basis of a single metric. However, monetary valuation requires the use of data and methods that add substantially to the assessment burden. Typically, each benefit or cost stream arising from the natural landscape must be analyzed with different data and econometric methods. It is common in studies to see only a single environmental benefit monetized, because of the costs of such studies. Therefore, a comprehensive evaluation of benefit streams, in practice, precludes comprehensive monetary valuation. EcoAIM™ provides a more practical approach of comprehensive assessment over monetization. Although this approach does not produce results in dollars, it is a practical way to inject important economic information into the assessment of relative costs/benefits of multiple ES.

2.2.3 Role of Structured Stakeholder Engagement in the Decision Support Framework

The structured stakeholder engagement process starts with a framework for defining goals and objectives relative to resource management at the military installation (Figure 4). Structured stakeholder engagement is a commonly used tool for determining the environmental positions of employees at an organization, community members, and nongovernmental organizations (NGOs). Studies have identified cases in which stakeholders (e.g., employees, consumers, shareholders, and public authorities) have influenced comprehensive organizational environmental practices or management systems. The use of stated preference methods is also well documented in the published literature in ES studies. Stated-preference valuation has been shown to improve survey responses by stakeholders and to provide additional information about intermediate ES that might otherwise be overlooked and unvalued (Johnston et al. 2011).

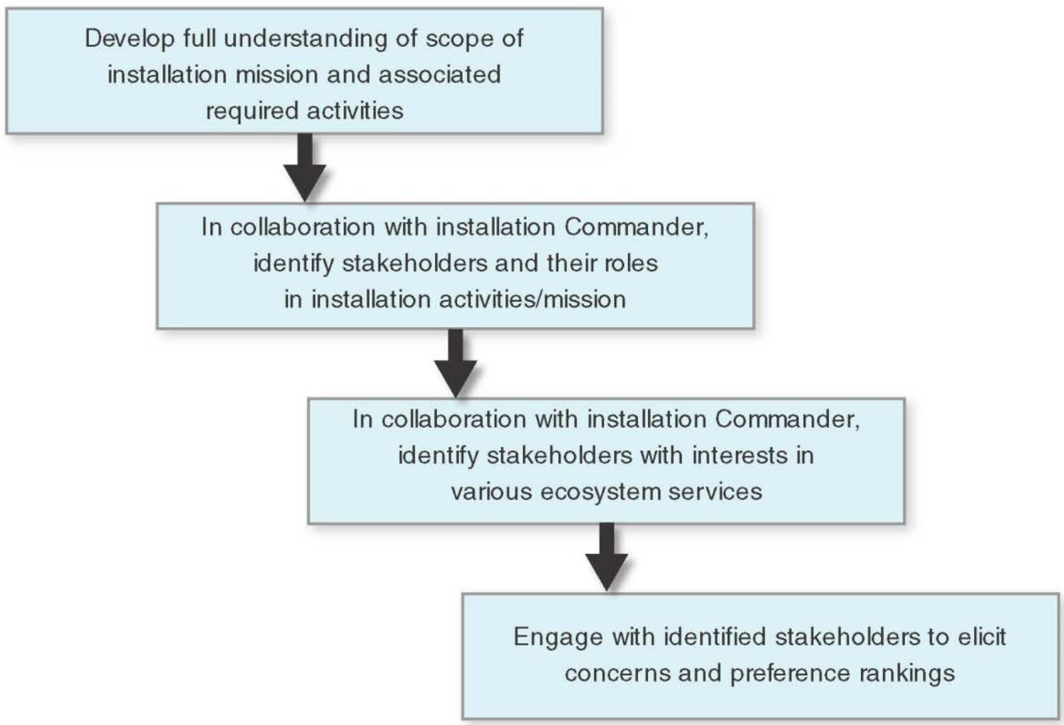

Figure 4. Structured stakeholder engagement process

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In Step 1 of the decision support structure (DSS) described above, the decision space is defined. This includes the social landscape, with comprehensive mapping of stakeholders, such as the decision makers (e.g., installation commander, higher ranking officials), internal stakeholders (e.g., non-DoD leaseholders who use the site), and external stakeholders (outside community, other interest groups). At APG, several representatives from the Natural Resources group attended the meetings, as well as representatives from Master Planning and environmental contacts at tenant organizations.

The stakeholder engagement process at APG included a combination of telephone interviews, semi-structured face-to-face interviews, and two on site meetings. Baseline information was collected about the stakeholders' level of ES knowledge, how stakeholders use and value ES, and the link between ES effects on missions and vice versa. At APG, telephone interviews were conducted initially, to understand how natural resource management decisions are made and how information flows among the departmental organizations. Other information garnered through telephone interviews included the organizational structure at APG, identification and recommendations of other stakeholders to contact, and the role that each person interviewed played in natural resource management, or their involvement in environmental decision making.

Another critical activity that is part of the structured stakeholder engagement process is to work with DoD land managers or other appropriate decision makers at the installation to complete an exercise to weight their preferences and needs regarding the ES onsite, given the input from the stakeholder groups. The results of the weighting process determine the types of ES chosen for evaluation and the relative value or weight placed on those services by various beneficiaries. The relative weighting is essential for the quantitative evaluation of trade-offs. That is, weighting factors will allow the end user to determine the overall ES benefit under scenarios where some ES increase and others decrease. However, due to difficulties in scheduling another workshop, and after further discussion with personnel, it was apparent that the multi-objective nature of decision making at APG would not lend itself to hard-coding preference valuations into the tool. Because there was no clear distinction as to who the end user of EcoAIM™ would be, and what their mission objectives would entail, it was decided that functionality would be built into the tools to allow for user-supplied preference weightings. Preference weighting options are included for the patch richness calculation and in the ranking of the three aesthetic calculations in the aesthetic models, and in overall ranking of ES for the final ES score.

Different management scenarios will lead to different ecological outcomes. For example, one management alternative may result in a "10 percent increase in biodiversity" and "100 additional pounds of total nitrogen sequestered in wetlands," while another may lead to a "20 percent increase in recreational opportunities" and "50 pounds increase in sequestration of total nitrogen by wetlands." It is possible to translate these different bundles of outcomes into single monetary estimates to compare the two scenarios. Doing so, however, is time consuming, methodologically difficult, often controversial, and leaves the "weighting or valuation" in the hands of economic experts.

2.2.4 Geospatial Analysis Tool

At the core of EcoAIM™ is a desktop geographic information system (GIS)-based application designed to run on a PC. Database inputs to the tool are pulled from existing databases. The tool provides a structure for spatial inventory of ES organized by habitat patch or grid cell (in the case of recreational opportunity). Each identified habitat patch in a study area is evaluated for ES with scientifically robust methods and existing validated models. Habitats are ranked relative to other habitats and to the larger geographic context (e.g., sub-basin, landscape, geopolitical boundaries) based on their weighted ES value (as determined by the end user) or quantified in an absolute manner using specific metrics (e.g., pounds of nitrogen removed per acre per year; see Section 2.2 for more detail on metrics).

GIS technology allows land and wildlife managers to use standard sources of land cover, vegetation, and other habitat data, such as remote imagery from aerial photographs and satellite sensors. In addition, GIS databases that include surface water, climate data, elevation, and ecological land types are also commonly available throughout the United States. Therefore, GIS-based habitat models can be applied quickly to large geographic areas. Using this information in combination with the modern understanding of wildlife-habitat relationships available in both the published and grey literature allows evaluation of management activities and conservation planning at the landscape scale.

2.2.5 ES Models

Models were developed or chosen from scientifically vetted models (if available) to quantify BPFs. The following models have been developed for incorporation into the EcoAIM™ geospatial model:

- Aesthetics, composed of two sub-models
  - Vista aesthetics
  - Landscape aesthetics
- Recreational opportunities
- Habitat provisioning for supporting biodiversity
- Nitrogen sequestration.

These models are programmed directly into the EcoAIM™ tool, so that the user does not have to upload new software to their system. Results of each model are quantified by pixel in a geospatial area and displayed on either a grid-cell or habitat-patch basis. The relative value of each geospatial area is then plotted on a distribution. The Jenks natural breaks classification method is used to categorize (data bin) the spatial areas into a measure of "ES value." The Jenks natural breaks classification method is a data clustering, optimization method commonly used in ArcGIS. The method runs iterations of the data (pixels in this study) such that the average variance is minimized for pixels within a group and maximized between groups. By grouping pixels with this method, distinct categories of ES value can be created and displayed on maps.

This ES value facilitates a common metric in which several ES values can be compared. Alternatively, multiple ES values for a particular location can be averaged (using weighting factors on each ES, as determined by the end user), and locations within an installation can be compared to ascertain their relative importance to the totality of desired services.

The EcoAIM™ interface will allow decision makers to input the relative weights on some of the measurement parameters in each of the ES. By using this input interface, the decision maker can conduct a sensitivity analysis of the key input variables and evaluate the importance of each when selecting among alternative management scenarios. The EcoAIM™ output consists of maps and distribution plots of relative values of ES by ES type and geographic areas of interest.

2.2.6 Development of EcoAIM™

EcoAIM™ was developed in 2008 to be used on corporate-owned lands and initially included five ES—carbon sequestration, pollutant sequestration, flood control, habitat provisioning as a proxy for biodiversity, and recreation/aesthetics at a preliminary screening level of assessment. The tool was used to evaluate ES at Wellesley College in Massachusetts and at a downtown brownfields site in Sacramento, California, as proofs of concept to demonstrate its feasibility to potential corporate clients. The Sacramento site proof demonstrated the value of a parcel of real estate after ecological restoration and valuation of ES on the site. EcoAIM™ was also applied to two confidential corporate sites on the eastern seaboard using the original five ES models. A poster was presented at the SETAC 29th Annual Meeting titled, "Ecological asset inventory and management (EcoAIM™) tool: A screening approach for identifying and managing ecological assets" (Law et al. 2008).

In October 2010, Exponent was invited to participate in the Ecosystem Services, Tools, and Markets Working Group of Businesses for Social Responsibility (BSR). Tool developers were asked to use their ES tool to address two corporate-relevant questions: "Where would be the ideal site for a new residential project that would have the least impact on ecosystem services?" and, "In what areas would focused ecosystem-services-related investments offer potential benefits?" To answer these questions, a focused approach was taken with the biodiversity model component of EcoAIM™. Using publicly available data that included impervious surfaces, vegetation cover, property boundaries, and species habitats, EcoAIM™ identified and evaluated four areas for a residential development and located the areas where minimal investments in restoration would garner the greatest increase in biodiversity ES. For this demonstration, users were able to "drill down" to the details of each restoration site to review the data inputs, the preference weightings that were used, and the final evaluation factors that determined the optimal restoration area.

2.3 DEVELOPMENT OF TECHNOLOGY AND METHODS

The customization of the EcoAIM™ tool was guided predominantly by results from the initial stakeholder interviews and workshops at APG. The ES of most concern to APG beneficiaries were discussed in the October 23, 2012, meeting. During discussions, it was determined that there were several different types of missions and different types of natural resources on which these missions rely. The ES that would have the greatest effects on the varied missions, and vice versa, were discussed. It was determined that aesthetics, recreational opportunities, biodiversity, and nutrient sequestration were of greatest importance to APG.

The notional mission (that which was agreed upon by the beneficiaries at the meeting, not necessarily the official mission at APG) is to maintain a brain trust at the installation. APG personnel concluded that having appealing aesthetics and sufficient recreational opportunities could help recruit and retain employees. In addition to aesthetics and recreation, APG would be able to enhance its image as good citizen in the Chesapeake Bay area by managing onsite wetlands for nutrient (total nitrogen) sequestration. Biodiversity was deemed to be highly important to APG beneficiaries because of the installation's location on a major migratory flyway for several species of neotropical birds, as well as its high-quality habitat for resident birds in the Chesapeake Bay watershed, such as bald eagles and several species of songbirds.

Progress at several points of the project was detailed in the following scientific conference posters and presentations.

- At the Society of Environmental Toxicology and Chemistry (SETAC) 2010 annual meeting, EcoAIM™ was introduced as a tool for evaluating ES in a platform presentation titled, "Perspectives on the application of ecological services: An introduction to the session" (Menzie 2010) and highlighted in a poster titled, "Ecosystem service considerations for corporate land management: Emerging ecosystem service tools and a case study of comparative tool application" (Booth et al. 2010).

- At the SETAC 2011 conference, the EcoAIM™ decision framework and model was presented in a poster titled, "A decision framework and model to assess ecosystem services at three military installation sites" (Booth et al. 2011). In this poster, the groundwork for the EcoAIM™ methodology (including the structured stakeholder engagement process) was presented.

- At the SETAC annual meeting in 2012, the Booth and Law (2012) poster titled, "Ecosystem services as a new paradigm for environmental and social impact assessment — Implications for large development projects" was presented. The EcoAIM™ framework was used as an example to show how ES can inform the environmental and social impact assessment process for large development projects.

- In 2012, Booth et al. presented a poster at the SETAC Europe annual meeting in Berlin and the Ecosystem Services Partnership meeting in Portland, Oregon. In this poster, titled, "The ecosystem services triad: Linking stakeholder engagement, biophysical models and ecological production functions to develop indices of ecosystem services for biodiversity," the EcoAIM™ structured stakeholder engagement process, development of BPFs, and an example result from the San Pedro project were presented.

- In the winter of 2012 at the biennial meeting of A Conference for Ecosystem Services (ACES), Booth et al. (2012b) presented a poster titled, "The role of structured stakeholder engagement in developing ecological production functions: Linking stakeholder value to ecosystem services at a military installation." In this poster, the results of the APG stakeholder meetings were presented, and benefits of the structured stakeholder engagement meeting were discussed.

- EcoAIM™ was implemented at a confidential site on the eastern seaboard for a corporate client and results were presented in a webinar to selected members of BSR with interests in ES.

- EcoAIM™ has been acknowledged as a potential tool for in-house ES specialists by three confidential industry clients. There is potential for EcoAIM™ to be used in ES evaluation at sites in North America and Latin America.

- Two manuscripts (in progress) will be submitted to peer reviewed scientific journal and results of this demonstration will be presented at the December 2014 ACES conference.

2.3.1 Models

The EcoAIM™ tool is composed of five models (vista aesthetics, landscape aesthetics, recreation, biodiversity support, and nitrogen sequestration) that can be used independently or together. Each model measures a set of landscape or patch parameters that link directly to the ES being modeled. "Landscape" is defined as an area composed of a mosaic of interacting patches or ecosystems. Landscapes are characterized by the heterogeneity among the patches, creating a mosaic of different biotic and abiotic processes. A "patch" is defined as a discrete area of relatively homogeneous biological and physical conditions (Dale et al. 1994). For this demonstration, a patch is delineated by LU/LC data and defined by APG through ground-truthing. For example, a forest patch can be a mid-successional, tulip poplar–dominated area, a grassland patch can be an infrequently mowed range area dominated by grasses, and a wetland patch can be an estuarine intertidal emergent.

With the exception of the nutrient sequestration model (in which measurement endpoints are in pounds of nutrients/year), the measurement endpoints for all the models are "ecosystem service scores." These scores are based on the Jenks natural break algorithm, in which raw parameter scores are summed and "binned" based on the distribution. Thus, each patch or grid cell is ranked relative to other patches and grid cells.

2.3.1.1 Aesthetics Model

Beneficiaries at APG stated that attracting and retaining talented employees was an important notional mission, and the visual aesthetics of the natural areas at the installation are key for this mission. The aesthetics component of natural resources management has been discussed as an important aspect of landscaping areas that are frequented by visitors and important personnel at APG, especially areas near the gate entrances and cantonment areas. Several studies have confirmed that green spaces in an urban environment are important to maintaining a quality workforce. Natural spaces allow employees to informally meet, share ideas, and build stronger relationships. Psychological studies have found that natural environments in work areas can decrease stress levels (Bolund and Hunhammar 1999; Coder 1996). Desk workers who can view nature from their office windows experience 23% less time off for sickness than those who do not have a view. Those with views also report greater job satisfaction (Warwick District Council [undated]).

The aesthetics model is based on published environmental, social, psychological, and landscape architectural theory journals. Literature was reviewed to help develop a model of the human experience in viewing natural environments. It was revealed that people experience nature at two spatial scales. The first is the vista scale, which involves the natural aesthetics at a far distance, often looking toward a horizon. This view can be from the ground level, or from a certain height, such as in a building and looking out a window. The second scale is at the landscape level. This is reflected by a person standing at ground level and looking at a patch in front of them. This landscape aesthetic reflects the experiential aspect of a person interacting with and immersed in the natural environment.

Several studies have reported on the perceived benefits of natural areas and methods of quantifying their aesthetic aspects. Most studies included participants that were shown photographs and surveyed for their thoughts on what made their view aesthetically pleasing. For example, Leopold and Marchand (1968) developed a rating scheme for riverscapes, and participants were asked to rank, by importance, the characteristics (such as width, slope, and flora) that were considered important for natural beauty. The aesthetics model consists of three linked sub-models: Landscape aesthetics for forests, landscape aesthetics for wetlands, and vista aesthetics. Table 1 presents a summary of the biophysical production functions, variables, measurement basis, and default weightings used in the three aesthetics sub-model(s). The specific attributes of the aesthetics model are described in the following sections.

Vista Aesthetics Sub-Model

Studies of what makes natural areas aesthetically pleasing often cite variation as a key part of the experience. Landscape variations can include different colors, textures, forms, and densities. It is more attractive to have large spaces broken up, defined, and framed with defined foregrounds and backgrounds (Tyrväinen et al. [undated]). The three variables measured in the vista aesthetics sub-model that relate to heterogeneity and size are as follows.

Patch Richness: One of the metrics that is considered important in vista aesthetics is patch richness, or simply the number of different types of land uses or land covers in the field of view (Schirpke et al. 2013). This metric is the weighted sum of the different patches in the field of view. Preferences for the weights are assigned by the user. For example, the user who prefers seeing forests and open water can assign high weights to these patches and low weights to cemeteries, landfills, and parking lots.

Table 1. Aesthetics Model—
Summary of Biophysical Production Functions, Variables, Measurement Basis and Default Weightings

Landscape Aesthetics for forests = **Σ** (weighted forest aesthetics scores) *current results do not have weighting
Landscape Aesthetics for wetlands = **Σ** (weighted wetland aesthetics scores) *current results do not have weighting
Vista Aesthetics = **Σ** (weighted Patch Richness score, weighted Viewshed Area score, weighted Shannon Diversity Index score)

Forest Landscape Aesthetics Sub-Model

Parameter	***Data Source***	***Metric***	***Ecological Production Function***	***Default Weight (%)***
Landform contrast	Forest LU/LC	Difference in relative relief of forest to surrounding landform	Difference between the average forest elevation and the elevation of the adjacent landform (within the 100 m ring buffer), divided by the average width of the forest	none
Edge complexity	Forest LU/LC	Edge complexity	Perimeter and total area of forest as measured by ArcGIS; plugged into: = Perimeter / 2 sq.rt. Pi x Area (from Smardon and Fabos 1983)	none
Surrounding land use contrast	Forest LU/LC	Number of surrounding land uses	Count of number of different land uses within 100 m ring buffer	none
Surrounding land use diversity	Forest LU/LC	Proportion of different surrounding land use types in	Count of number of different land uses within 100 m ring buffer; weighted sum of land cover types (e.g., Forest =5, Open space = 4, Water =3, Wetland =2, Built-up areas =1	none
Forest size	Forest LU/LC	Area	Area as measured by ArcGIS	none
Vegetative interspersion	Forest stand shape file	Number of tree species	Count of different tree species within each forest patch	none
Forest density	Landsat TM image; field survey information	Tree canopy cover	Percent of tree canopy cover; ArcGIS extrapolates canopy information from forest survey to other areas using aerial photos; (process assigns each pixel in the forest coverage to the % canopy cover that has the maximum likelihood of belonging to)	none
Forest age	Forest stand shape file	Age of trees	Age of trees based on forest layer	none

Wetland Landscape Aesthetics Sub-Model

Initial assumptions and data processing:

- Adjacent wetlands are aggregated into one continous wetland (currently, adjacent wetlands are separated in the GIS data layer)
- Impervious surfaces and open water layers override wetland layer (in situations where different layers show overlapping; to be most conservative)
- Stream centerlines are buffered by 3 m to encompass width of smaller streams
- Roads are buffered by 5 m to encompass full width of roads

Parameter	***Data Source***	***Metric***	***Ecological Production Function***	***Default Weight (%)***
Landform contrast	Wetland LU/LC	Difference in relative relief of wetland to surrounding landform	Difference between the average forest elevation and the elevation of the adjacent landform (within the 100 m ring buffer), divided by the average width of the forest	none
Wetland edge complexity	Wetland LU/LC	Edge complexity	Perimeter and total area of forest as measured by ArcGIS; plugged into: = Perimeter/ 2√∏ x Area (from Smardon and Fabos 1983)	none
Water body size	Wetland LU/LC and open water layer	Area inside wetland	Area of total open water area inside wetland, as measured by ArcGIS	none
Associated water body diversity	Wetland LU/LC and open water layer	Area of total open water bodies (such as rivers, bay but excluding wetlands) inside 100 m buffer ring	Area of the total open water within a water body inside the 100 m buffer ring	none
Surrounding land use contrast	LU/LC	Number of land cover types within 100 m buffer ring of wetland	Count of number of different land cover types within buffer; weighted sum of land cover types (e.g., Forest =5, Open space = 4, Water =3, Wetland =2, Built-up areas =1)	none
Wetland Size	Wetland LU/LC	Area of wetland	Area of wetland as measured by ArcGIS	none
Vegetation-Water interspersion	Wetland LU/LC	Perimeter of vegetation within wetland	Count of number of pixels along vegetation perimeter within a wetland	none

Vista Aesthetics Sub-Model

Parameter	***Data Source***	***Metric***	***Ecological Production Function***	***Default Weight (%)***
Patch richness	LU/LC, DEM, forest canopy height and user-defined offset	Number of patch types	Count of number of patch types within viewshed by ArcGIS; weighted sum (e.g., forest =4, wetland =3, buildings = -1)	none
Shannon Diversity Index	LU/LC, DEM, forest canopy height and user-defined offset	Shannon Diversity Index value	Shannon Diversity Index equation for patch types	none
Viewshed area	LU/LC, DEM, forest canopy height and user-defined offset	area	Total visible surface area in viewshed	none

Diversity: Several researchers have studied the importance of variation and heterogeneity of the landscape (Ritters et al. 1995; Plexida et al. 2013). Study participants have stated that structural elements (such as a grove of trees) can enhance the "texture" of the landscape. In addition, participants preferred to see different types of landforms, such as buildings, forests, and water, and at different proportions (Schirpke et al. 2013). This variable is measured using the Shannon Diversity Index calculation, which reflects how many different types of patches there are and accounts for the proportion that each patch type constitutes in the field of view. The more patch types there are with varying proportions, the greater the Shannon Diversity Index value. The calculation is:

Shannon Diversity Index = $-\Sigma p_i \ln p_i$;
where p_i is the proportion of patches belonging to a patch particular type.

Viewshed area: The viewshed area is the area of land that is visible by an unimpeded line of sight, from a single point (Gret-Regamey et al. 2007). In general, study participants preferred patch areas that were greater in their field of view (Ritters et al. 1995). This variable is measured in ArcGIS based on the digital elevation model (DEM) and land use/land cover (LU/LC) layer, by accounting for the location and elevation of the observer, the angle of view, and obstructions to the view. Figure 5 illustrates the calculation of viewshed area.

Landscape Aesthetics Sub-Model

Numerous social studies have involved surveys of how people view the natural environment and what they deem as aesthetically pleasing. Aside from the ecological value of wetlands, wetlands are also culturally important. Wetlands close to schools are valued for their educational characteristics, and accessibility by trails, roads, and boats allows wetlands to be recreationally important (Smardon 1983). Particular types of wetlands, such as tidal marshes, bogs, and freshwater marshes, rate fairly high for aesthetics. Study participants who were shown photos of different wetland types in Massachusetts rated wooded upland and marshes as the most preferred types. In addition, it was found that 50% of the photos taken by trail hikers were of freshwater marshes (Smardon 1983).

In general, forests are considered to be representative of natural areas. The attractiveness of forested areas includes areas that have native vegetation, trees, and wildlife. Survey respondents indicate that areas that are too formal; have too much concrete; are too open, bare, flat, or monotonous; and lack trees are unattractive (Nassauer 1995). The forest condition is important, with people preferring a "natural" stand, versus areas that have been harvested recently or consist of tree plantations. Most had a preference for variability, including mixed crown heights, some shrubbery and low-height plants, different species of trees, different age structures, and forests with minimal indication of harvest or fire damage (e.g., stumps, snags, wood piles, and burns) (Ribe 1989, 2009; Gobster 1999). Forested areas with positive values of scenic quality include aspects of large trees, low tree densities, closed tree canopies, native species, and distant views. An optimal tree density of 53 trees per acre and limited understory density, are associated with positive perceptions, because these densities allow for viewing of distances but still screen out developed areas. However, tree densities that are too great are perceived as areas with some fear

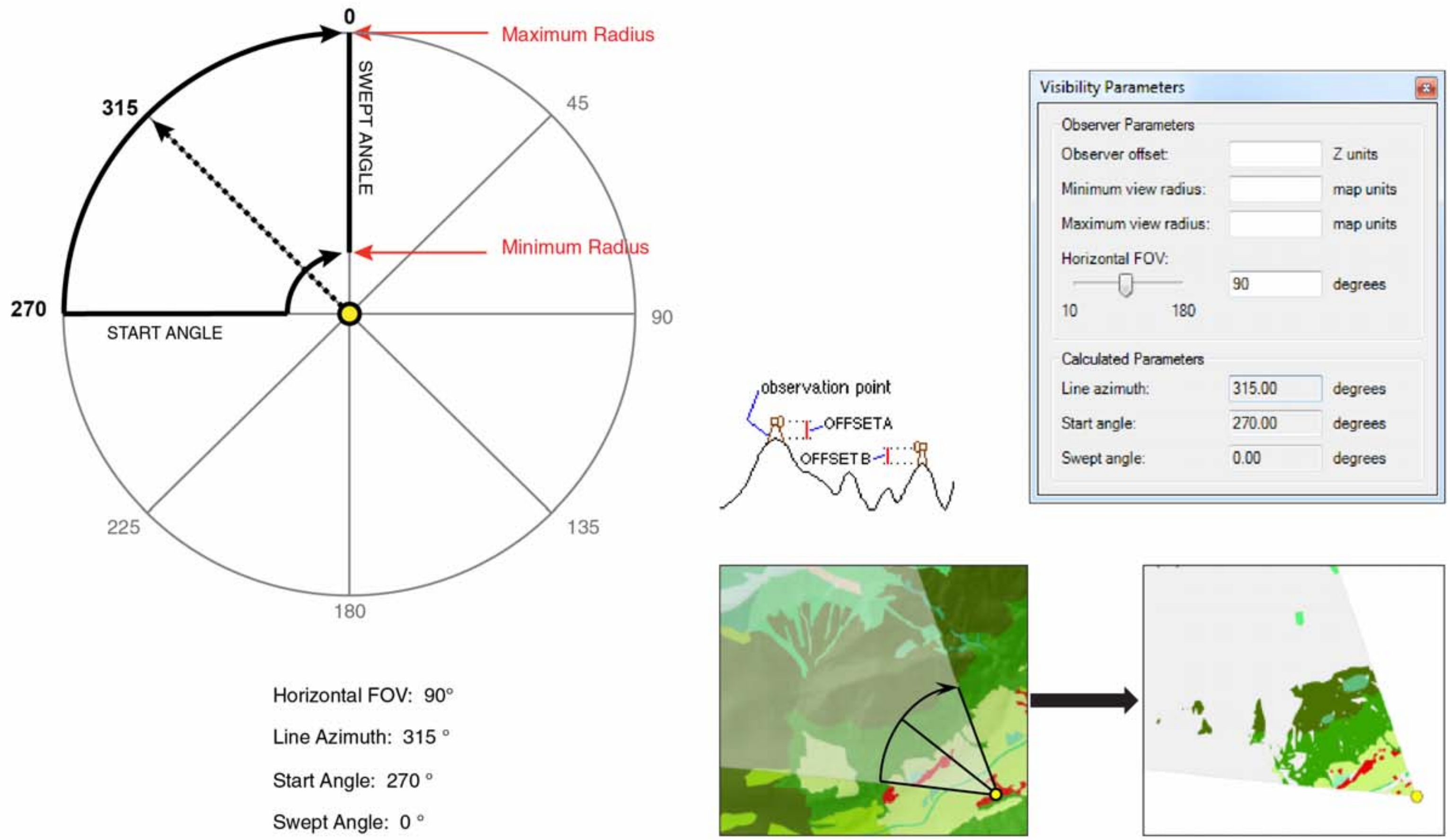

Figure 5. Vista aesthetics—visibility parameters

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and endangerment (Coder 1996). For areas with trees, a mix of species and a combination of other landscape types are more appreciated (for example, trees, brush, and fields) (Tyrväinen et al. 2005).

The parameters measured for each forest and wetland includes the following.

Landform contrast: Studies about perceptions of patches identified the steeper slopes on the sides of wetlands as providing greater landform contrast, making it more aesthetically pleasing than wetlands with more gradual slopes and reduced contrast (Smardon 1983). Similarly, people preferred perceiving a difference between two landforms (Smardon and Fabos 1983). The absolute value of the difference between the relative relief of the wetland/forest patch and the adjacent landform is measured for this parameter.

Edge complexity: In studies with participants describing their preferences for forest aesthetics, there is a preference for maximizing the edge-to-area ratio. In forests with harvest, people prefer the edges to be undulating, making them less noticeable and more "natural" (Gobster 1999). The shape of a forest patch is usually indicative of the intensity of human impact. When shown pictures, study participants greatly prefer irregular shapes (i.e., more natural) over straight edges (i.e., unnaturally maintained by humans) (Frank et al. 2013). Similarly, a wetland with an edge or border, especially if it is sinuous, is one of the most important scenic qualities (Smardon 1983). The calculation to measure the sinuosity of the wetland/forest edge is:

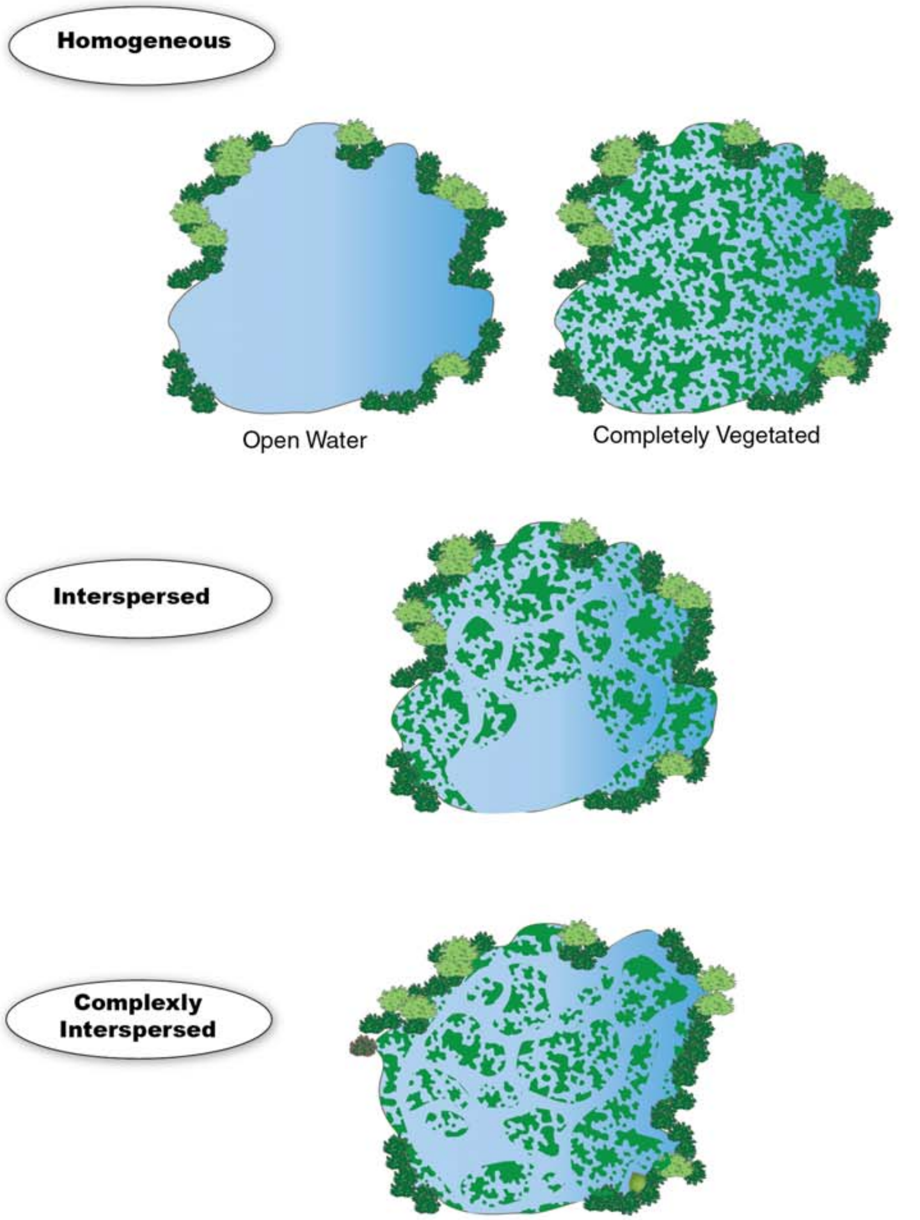
$= P / 2 \sqrt{\Pi \times A}$; where P = perimeter and A = area (Smardon and Fabos 1983).

Surrounding land-use contrast: Ribe (1989) reported that people prefer variation in scenery as they travel along a corridor. Wetlands that have surrounding contrasting upland landforms are considered important in defining a sharp visual image of the wetland and providing a feeling of an enclosed space. Through the use of preference testing, wetlands that are adjacent to open water, forest, and agricultural lands were deemed visually appealing (Smardon 1983). This variable is measured as the number of land cover types found within a 100-m buffer delineated around each forest or wetland. The 100-m buffer corresponds to an assumed "experiential" aesthetics envelope of 100 m from the point of observation. The aesthetic appeal beyond 100 m is calculated in the vista aesthetics model. The 100-m buffer for all other landscape aesthetic measurements was determined in the same way.

Surrounding land-use diversity: In addition to the surrounding land-use contrast, people also prefer to see different proportions of land uses (Ribe 1989). This parameter is measured as the weighted sum of the total different land-use types within a 100-m buffer delineated around each forest or wetland. The model is set up so that preference weights for each LU/LC category are assigned by the user. This is an important functionality due to the widely varied landscapes occupied by DoD installations, including desert, high mountain, shoreline/coastal, lowland mixed forest, western fir forests, and others). For example, whereas open water may rank highest in terms of viewshed preference on a coast/shoreline site like APG, it would be irrelevant for a desert site like White Sands, New Mexico, or the Yakima Training Center in Washington State.

Size: Wetland size is important, and some studies have found that aesthetically pleasing wetlands are large, possibly because it is related to recreational value and biodiversity (Smardon 1983). Large forest tracts are also more desirable than small patches of forest. This parameter is a measure of the total area of the wetland or forest.

Vegetative Interspersion: The surface pattern or texture of a wetland is an important aspect of its aesthetics. Surveys show that people prefer completely interspersed, grouped vegetation patterns on the water surface (see the last picture in Figure 6. This parameter is a count of the total number of pixels along the perimeters of vegetation groups within a wetland.



Source: Adapted from Smardon.

Figure 6. Types of vegetation-water interspersion patterns in wetlands

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Similarly, people prefer forested areas with natural-looking groupings of trees over evenly spaced tree plantation-like forests (Ribe 1989). If detailed forest survey information is available, this is measured as the number of different tree species within each forest patch; otherwise, this parameter is measured in the same way as wetlands.

Forest density: Study participants who were shown pictures of forests had greater appreciation for forests that had greater canopy cover, or areas with smaller openings than larger ones (Gobster 1999). This variable is simply a measure of the percentage of canopy cover in each forest patch.

Water-body size: Water provides a sense of naturalness, attracting and holding a viewer's attention and creating a calming effect (Nasar and Li 2004). For wetlands, as well as with other water bodies, the larger the water body, the more aesthetically pleasing it is. Water-body size is a measure of the area of water inside a wetland boundary.

Associated water-body diversity: Wetlands that are adjacent to rivers, small lakes, ponds, and saltwater bays and inlets are optimum environments from a visual perspective (Smardon 1983). This variable is simply a count of the total number of open water bodies (excluding other wetlands) inside a 100-m buffer delineated around the wetland.

Recreational Opportunities Model

In addition to aesthetics, APG stakeholders considered recreational opportunities as an important component in achieving the notional mission of attracting and retaining talent. Availability of recreational opportunities in proximity to one's workplace provides additional physical activities and contributes to improved health. Scientific literature shows that park and trail use increases the frequency of exercise, and subsequently, has been linked to lower body mass index and blood pressure, among other health benefits. Several investigations on constraints that influence recreation participation list time, transportation, safety, and cost (Stanis et al. 2009). Therefore, having access to several recreational activities within the military installation would give additional opportunities to the military personnel for exercising and enjoying the outdoors. A greater understanding of the specific characteristics that influence one's choice for selecting certain recreational activities and provide greater value associated with those activities could help APG stakeholders in their decision making on future land management at the site. The value one places on recreational activities is determined by both human perception of site attributes (e.g., site beauty, sense of remoteness) and physical constraints to participation in these activities (road access, availability of parking). To understand human preferences as they relate to site attributes that increase or decrease site value, a number of studies have been conducted. In this model, we rely on existing published literature that provides information on the importance of certain site characteristics that influence participant's decision to engage in recreational activities. Based on this literature, we identified specific site characteristics that are positively related to recreational opportunities that are available at the APG site (Table 2).

Table 2. Recreational Opportunity Model--
Biophysical Production Functions, Variables, Measurement Basis, and Default Weightings

= Σ weighted recreation parameters
Base layer: Grid (500m x 500m)

Parameter	***Data Source***	***Metric***	***Ecological Production Function***	***Default Weight (%)***
Proximity to residential/work areas	Built-up area from LU/LC	distance	Euclidian distance between each pixel in a grid and its closest built area, as measured by ArcGIS, and then averaged.	17
Access to road and parking	Road and parking areas from LU/LC	distance	Euclidian distance between each pixel in a grid and its closest road/parking area, as measured by ArcGIS, and then averaged.	17
Aesthetics	Results generated by EcoAIM landscape aesthetics model	Forest and wetland landscape aesthetic scores	Overlay landscape aesthetic scores. Weighted average score (based on proportion of area) in each grid cell. Get the aesthetic score (wetland, or forest, or wetland if there is an overlapping of wetland and forest) of each pixel in a grid, then averaged.	17
Slope	Digital Elevation Model	slope	Average slope of pixels in each grid cell	8
Biodiversity	Results generated by EcoAIM Habitat Provisioning for Biodiversity model	Overall biodiversity scores	Overlaid biodiversity scores, with wetland proceeding forest, which proceeding grassland. All three types of biodiversity scores have a same weight of 1. Weighted average score (based on proportion of area) in each grid cell.	8
Trail length	Unpaved roads layer	length	Trails connecting with each other were first ‘unioned’ (connected) together; then length calculated. The length of each continuous trail is assigned to each grid cell that the trail intersects with.	6
Trail connectivity	Unpaved roads layer	Number of connection nodes, excluding loop nodes	Trails connecting with each other were first unioned together; then total number of connection nodes (excluding loop nodes) calculated. The number of connection nodes of each continuous trail is assigned to each grid cell that the trail intersects with.	6

Parameter	***Data Source***	***Metric***	***Ecological Production Function***	***Default Weight (%)***
Trail shape (loop)	Unpaved roads layer	Number of loop nodes	Trails connecting with each other were first unioned together; then total number of loop nodes as counted by ArcGIS. The number of loop nodes of each continuous trail is assigned to each grid cell that the trail intersects with.	6
Proximity to boat launch sites	The locations of non-secure boat launch sites (the secure sites can be included as needed)	Distance along roads to boat launch sites in secure and/or non-secure areas	Distance along road between each pixel in a grid and its closest non-secure boat launch sites, as measured by ArcGIS, and then averaged.	17

The recreational activities considered in the model were selected based on review of the information provided on APG's "Family and Morale, Welfare & Recreation" website.[2] The following onsite activities were determined as most popular and important to personnel and visitors:

- Boating (e.g., kayaking, crabbing, fishing)
- Running, hiking, walking, birdwatching (grouped as activities that take place on trails)
- Picnicking and camping
- Hunting (both deer and waterfowl).

The recreational opportunities model was developed by first identifying the measurable attributes that characterize each recreational opportunity, measuring these attributes, assigning a weight to each attribute based on its importance to the activity, and calculating an overall recreational score for each parcel of land. The calculated score is composed of several parameters that are applicable to each site, and the overall score reflects a combination of factors that may increase or decrease the score. Therefore, for a site to receive a high score, it should not have any physical constraints to recreational activities, such as poor road accessibility or area closure. For example, a site may have a very high score associated with its aesthetics but a very low score as a result of difficult access from the road or no available parking. In that case, the site's overall score would be influenced by both factors, and positive attributes would be outweighed by the negative characteristics that constrain site access.

Unlike the aesthetics and biodiversity models, the recreational opportunities model is based on a 500- × 500-m grid overlay on the entire installation. Each 500- × 500-m grid cell receives an overall recreational score (each grid cell is composed of 10,000 5- × 5-m pixels). The recreational attributes that are measured in this model include the following:

1. Proximity to residential/work areas
2. Access from road and parking
3. Aesthetics/scenery
4. Slope
5. Biodiversity/wildlife
6. Trail length
7. Trail connectivity
8. Trail shape
9. Proximity to boat-launch sites

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[2] http://www.apgmwr.com/recreation/odr/index.html

Proximity to Residential/Work Areas: It has been shown that convenience of recreational site location and proximity to everyday activities such as one's workplace or residence play an important role in regular physical activity. Studies of outdoor recreation potential found that areas near populous areas have greater recreational benefits (Weyland and Laterra 2014; van Riper et al. 2012). Because travel time to a recreational site is a constraint on engaging in recreational activities (Stanis et al. 2009; Termansen and McClean 2004), it was deemed necessary to evaluate this parameter in the model. The value for this parameter was measured as the average Euclidean distance (i.e., straight-line distance) from each of the pixels that constitute the grid cell to the nearest built-up area.

Access from Road and Parking: A survey by Weland and Laterra (2014) found that the benefits from outdoor recreational activities increase with higher road density. This finding implies greater value associated with recreational activities in proximity to a road and a parking lot. In addition, because transportation to a site is a commonly acknowledged constraint to recreational participation (Stanis et al. 2009; Wetzstein and Green 1978; Klinsky 2000; van Riper et al. 2012), a parameter characterizing access to a recreational site from a road or a parking lot was included in the model. This parameter is measured as the average Euclidean distance from each of the pixels that constitute the grid cell to the nearest road or parking lot.

Aesthetics/Scenery: Several recreation-based surveys (e.g., Stanis et al. 2009; Klinsky 2000; Termansen and McClean 2004; van Riper et al. 2012) found that one of the most important site attributes for physical activity at outdoor recreation sites is attractive scenery or aesthetics. Specific characteristics embedded in this parameter include enjoyable scenery, such as lakes, rivers, panoramic view points, and others. Enjoying scenery and aesthetics has been positively associated with increased physical activity (Brownson et al. 2001; King et al. 2000; Wetzstein and Green 1978). The EcoAIM™ landscape aesthetics model (described in the Aesthetics Model section) reflects the natural characteristics of a site that contribute to increasing its aesthetic value. This aesthetic value is independent of the characteristics that make a site suitable for recreation, although areas with higher aesthetics contribute to higher recreational value. For this recreational opportunities model, aesthetics or scenery of a particular recreational site was measured with the EcoAIM™ landscape aesthetics model for forests and wetlands. The aesthetics score for each forest and wetland patch was overlaid on the recreation grid cells, and each pixel in the cell was assigned the overlaid aesthetic score. The grid cell aesthetic value is calculated as the area-weighted average for the grid cell based on the corresponding patch from the aesthetics model.

Slope: The topography of recreational areas is important to participants involved in recreational activities such as hiking, running, and birdwatching, especially in forested areas (Klinsky 2000; Weyland and Laterra 2014). Studies show that an area with undulating topography or mild to moderate slopes is more desirable than a flat area for recreationists in natural areas (Termansen and McClean 2004; van Riper et al. 2012). A steep slope, however, may preclude participants from engaging in recreational activities or may make those activities impossible. The lack of hills in one's neighborhood was reported as one of the reasons for inactive lifestyles (King et al. 2000). The value for this parameter is measured as the average slope angle for each of the pixels that make up a grid cell, using the Digital Elevation Model (DEM).

Biodiversity/Wildlife: Studies show that recreation areas that provide opportunities for sighting of wildlife are considered ideal (van Riper et al. 2012). The same study shows wildlife viewing as one of the most common recreational activities. A study comparing participants in consumptive activities (e.g., hunting and fishing) and non-consumptive activities (e.g., birdwatching) found little difference in the value that participants in both groups placed on biodiversity. Differences between the two groups were generally attributed to differences in specific geographic locations (van Riper et al. 2012). Therefore, it is assumed for this model that the presence of biodiversity and wildlife is an important characteristic for measuring the value of the site. This parameter is especially important for the APG recreational model, because it has an influence on several recreational activities that take place on site, including walking, running, and birdwatching. Therefore, this parameter may change the value of the area associated with any of these three activities. For this parameter, the results from the Habitat Provisioning component of the biodiversity model were overlaid on each grid cell, and an area-weighted average was calculated for the grid cell based on the corresponding patch from the biodiversity model.

Trail Length: Surveys of individuals participating in recreational activities indicated that the most important attribute in recreational sites for physical activity is the presence of paths (Stanis et al. 2009; Wetzstein and Green 1978). For the purposes of this model, it is assumed that the greater the trail length, the more desirable the area is for recreational activities such as hiking, running, and birdwatching. This parameter is measured as the total distance of the trail. Each grid cell containing a portion of a trail is assigned the trail length score for that particular trail.

Trail Connectivity: Given the importance of paths in recreational activity, Stanis et al. (2009) has recommended that site managers pay particular attention to trail design and connectivity. Trails with a greater number of connection nodes to other trails provide greater flexibility and options for hiking, walking, and running. To characterize this parameter, the number of connection nodes on each trail was counted (excluding loop nodes). Each grid cell that overlays a trail is assigned the connectivity score of that trail.

Trail Shape: Similar to trail connectivity, trail shape is also an important aspect of recreational activities such as hiking, running, and birdwatching. Looped trails allow recreators to walk or jog along a trail and arrive at their starting point, usually where they may have parked their car or from where they started walking. In this model, the trail shape is defined as either linear or looped. For each trail, the number of loop nodes is counted. Each grid cell that overlays a trail is assigned the loop score of that trail.

Proximity to Boat Launch Sites: It has been shown that participants in recreational activities value access to uncrowded boat ramps and availability of parking near ramps (Siderelis and Moore 1998; van Riper et al. 2012). Similar to proximity to roads and parking areas, the proximity to a boat launch site is included in this model to characterize areas that allow water-related recreational activities (e.g., boating, crabbing, and fishing). There are several boat launch sites within the boundaries of onsite secured areas. While some of these secured areas are restricted to visitors at all times, others are open for recreation when special access permission is given. The times of access are not known by Project personnel, so boat launches within secure areas were not included in this model. End users can include secured boat launch sites by updating their base layers. This parameter is measured as the average distance between each pixel in a grid cell and the closest, non-secure boat launch site.

Additional Features: The EcoAIM™ recreational opportunities model allows the user to "turn off" areas that are closed to recreation. APG has guidelines that list specific times and locations that are closed to visitors, such as periods during deer-hunting season, or when areas are being used for testing and training. Stanis et al. (2009) stated that safety is an important consideration for recreational areas. To recognize this attribute, EcoAIM™ allows the user to remove closed areas from consideration as recreational sites, based on APG's area-specific and time-sensitive data. At this writing, all recreational sites were included in the recreational model, because sensitive information about secure sites was not shared with Project personnel.

Habitat Provisioning for Biodiversity Model

APG is situated in the Chesapeake Bay watershed. Due to the increasing development in other portions of the watershed, the installation is a highly valued habitat for its biodiversity, especially for Neotropical migratory birds, forest interior-dwelling birds, and bald eagles. Migration places extreme stress on Neotropical migrant birds, who must find stopover locations to replenish fat reserves, rest, and find adequate cover from predators and adverse weather. Migrants have greater diversity in larger forest blocks (McCann et al. 1993). Nearly 80% of the birds known to breed in Maryland are Neotropical migrants. This guild experiences serious population decline, because they are highly dependent on suitable breeding grounds (Weber et al. 2008). Forest-interior dwelling birds are of concern to the Chesapeake Bay watershed, because they require large, contiguous tracts of habitat to breed successfully (McCann and Battin 1999). Contiguous forests are becoming scarcer as more development occurs. Of particular importance to APG is its provisioning of habitat for specially protected bald eagles. Bald eagle nests are surveyed regularly, and activities are often arranged such that they occur outside a 500-m nest buffer. Land-use change has been forecasted as the largest driver of biodiversity loss over the next 100 years (Beaudry et al. 2013).

The habitat provisioning for biodiversity model is based on several individual variables for each habitat patch-type base layer—forest, wetland, and grassland. The model is based on scientific literature about landscape and habitat features that are preferred by a high diversity of birds and other animals. Habitats are not only important indicators of biodiversity in itself, but are also connected to vegetation assemblages and animal species in a variety of ways (Bunce et al. 2012). In the absence of biological survey or census data (i.e., individual counts, capture-recapture data), habitat analysis is a good proxy for assessing the biodiversity potential of a spatial area.

For the purposes of this model, bird biodiversity was chosen as an appropriate surrogate to represent all species diversity (DeLuca et al. 2004; Feest et al. 2010). Several studies have shown that the evaluation of bird guilds can be used effectively to assess the general health of an ecosystem. In particular, forest birds are considered an "umbrella species," because their survival depends on many other plants and animals (Weber et al. 2008). Birds (along with butterflies) were chosen to be monitored for the European Environment Agency's Streamlining European Biodiversity Indicators (SEBI) program to provide a pan-European process of monitoring biodiversity (Feest et al. 2010).

The scientific literature has produced several types of models that relate habitat indicators or variables to biodiversity or assemblages of species or taxa (Bunce et al. 2012). Each of the variables chosen for measurement and inclusion in the biodiversity model has been proven to be indicators of quality habitat in the scientific literature, and each is linked to habitat structure, spatial configuration, and landscape variation (Duelli and Obrist 2003). Several papers have developed methods that relate measurable habitat features at various spatial scales to species richness, biodiversity, or probability of a habitat being ideal for specific organisms (Ashcroft et al. 2012; Beaudry et al. 2013; Debinski et al. 1999; Alkemade et al. 2009; Boykin et al. 2013; Bunce et al. 2012; Dauber et al. 2003; De Caceres and Legendre 2009; Dettners and Bart 1999; Lehmann et al. 2003). However, in the event of a lack of site-specific species information, a habitat patch approach was developed. No existing model incorporates patch measurements and overall biodiversity together in a GIS environment. In addition, logistics such as the high mobility of large mammals and birds in a landscape, make it difficult to develop a relationship between ecosystems and biodiversity (Loreau et al. 2001). Because several scenarios can lead to animals selecting poor habitats or avoiding quality habitat (e.g, incomplete information, time lags, site fidelity, etc.), researchers are advised to first establish a baseline in which a species adheres to patterns of ideal habitat selection (Johnson 2007). In the case of the APG bird survey, the study spanned only a 2-year period. To use site-specific data such as this, a long-term monitoring plan would help establish general trends and patterns of habitat usage. The approach used in EcoAIM™ relies on the LU/LC, based on the premise that land cover data are especially valuable for predicting species distribution, and that the data sources are relatively easy to obtain (e.g., DEM, boundaries, drainage, forest management, roads, protected areas, etc.) (Kerr and Ostrovsky 2003, Kushwaha [undated]). A species richness, species abundance, and protection status component was included in the model, in the event that a robust data set was available. The habitat provisioning for biodiversity BPF is calculated as the weighted sum of all the biodiversity variables. The weights used in the default Demonstration are based on best professional judgment, but can be changed by the end user. Table 3 lists biophysical production functions, variables, measurement basis, and default weightings for the Habitat Provisioning for Biodiversity Sub-Model.

Table 3. Habitat Provisioning for Biodiversity Sub-Model--
Biophysical Production Functions, Variables, Measurement Basis, and Default Weightings

Habitat Provisioning for Biodiversity in Each Forest Patch
= Σ weighted forest parameters

Habitat Provisioning for Biodiversity in Each Wetland Patch
= Σ wetland parameters

Habitat Provisioning for Biodiversity in Each Grassland Patch
= Σ grassland parameters

Base layer: Wetland, forest and grassland patches

Parameter	***Data Source***	***Metric***	***Ecological Production Function***	***Default Weight (%)***
Area	wetland, forest and grassland patches	Area	Area as measured by ArcGIS.	15 (w, f, g)
Edge habitat heterogeneity	wetland, forest and grassland patches	heterogeneity of pixels within 100 m x 100 m grid cell	Shannon Diversity Index on the edge of wetland, forest and grassland.	15 (w); 10 (f, g)
Distance from road	Road layer	distance	Euclidian distance between each pixel in a patch and its closest road, as measured by ArcGIS, and then averaged.	15 (w, f, g)
Distance from built areas	Built areas LU/LC (includes buildings, facilities, cemetery, etc. but excludes roads and parking lots)	distance	Euclidian distance between each pixel in a patch and its closest built area, as measured by ArcGIS, and then averaged.	15 (w, f, g)
Isolation/fragmentation	wetland, forest and grassland patches	distance	Minimum Euclidean distance between one patch type (e.g., forest) to another patch of the same type.	15 (w, f, g)
Distance from mid-point to edge	Wetland and forest patches	distance	Euclidian distance between each pixel in a patch and its closest edge, as measured by ArcGIS, and then averaged.	11.25 (w); 5 (f)
Shape complexity	wetland, forest and grasslands patches	Shape complexity	Shape complexity = Perimeter/(2 * square root (pi x area)) from Smardon and Fabos 1983)	11.25 (w); 5 (f); 3.75 (g)
Number of soil types	Soil layer	number	Count of number of unique soil types intersecting each patch.	2.5 (w, f); 3.75 (g)
Distance to nearest waterbody	Forest and grassland patches and water layer (includes wetlands, surface waters and Chesapeake Bay)	distance	Euclidean distance of each pixel within a patch to the nearest waterbody, then averaged.	15 (f); 7.5(g)

The measured variables include the following and are described in more detail below:

- Area
- Edge habitat heterogeneity
- Distance from road
- Distance from built areas
- Isolation/fragmentation
- Distance from mid-point to edge
- Shape complexity
- Number of soil types
- Distance to nearest waterbody
- Topographic relief
- Invasive species
- Distance to nearest forest (for grasslands only):
- Species richness, abundance and protection status

Area: Patch size is one of the most vetted variables that describe good quality habitat. In general, larger habitats support more species and individuals (Boulinier et al. 1998; Linden et al. 2012; DeGraaf et al. 1998; Dale et al. 1994; Dauber et al. 2003; Ng et al. 2013; Schindler et al. 2008; Walz 2011; Saab 1999; McIntyre 1995). Ashcroft et al. (2012) found that patch size has a great influence on a species' persistence in the area if relatively homogeneous patches of habitat can be identified. A study by Dalang and Hersperger (2012) found that the larger the habitat patch, the better the quality for survival of species. Patch size effects were negative for species that prefer edges, positive for species that prefer interior areas, and negligible for generalist species that can use both edge and interior habitats. There is a positive correlation of patch size to interior bird species. Migrant birds were found to be more resilient to patch habitat loss and fragmentation. As patch sizes decreased, resident birds were more affected (Bender et al. 1998). Researchers conclude that, for forests in Maryland, patch size was very important in the highly fragmented Mid-Atlantic region, and that larger forest patches have the highest probability of providing for the least common species of forest birds (DeGraaf et al. 1998). A study of woodlands in Massachusetts found that the size of the woodland patch explained 79% of total species richness and 75% of the Shannon Diversity Index (Tilghman 1987).

Edge habitat heterogeneity: Diversity and patch richness correlates well with species richness, because many species are associated with a single patch type (Crist et al. 2000; Dauber et al. 2003; Ng et al. 2013; Schindler et al. 2008; Walz 2011; Lindenmayer et al. 2000; and Saab 1999). Patch richness is the number of patch types present (Dale et al. 1994). Some species prefer the elements of a landscape more closely related to edges (Walz 2011). For some species, additional habitat complexity is important, so that they can seek refuge and have access to greater food resources (Kovalenko et al. 2011). This variable is measured as the Shannon Diversity Index of the 400 pixels within each 100- by 100-m grid cell overlaid on edges (where two different land covers are adjacent to each other).

Distance from road: The degree of disturbance of forested areas was found to correlate with road density, the distance to the nearest built-up area, density of human settlement, and degree of imperviousness (Walz 2011). In particular, interior-dwelling birds had greater preference for areas farther away from roads (Blair 1996; Tilghman 1987). This variable is measured as the average Euclidean distance of each pixel in the patch from the nearest road pixel.

Distance from built areas: As areas became more urbanized, researchers found shifts in bird species numbers (Blair 1996; Tilghman 1987). Cam et al. 2000 found that relative species richness is affected by the number of urban patches. In particular, mid-Atlantic resident bird species richness and abundance were less sensitive to changes in land use, in contrast to Neotropical migrants, which declined the most dramatically with increasing urban development (Larsen 2008). This variable was measured as the average Euclidean distance to each pixel in the patch from the nearest built-up (e.g., building, parking lot) area pixel.

Isolation/fragmentation: The negative influences of fragmentation on species richness have been widely documented (Cam et al. 2000; Weber 2004; Lindenmayer et al. 2000). The gap width between habitat patches is important for animals to physically be able to cross to another patch of the same type. Connectivity is a critical component for animal dispersal, population persistence, and maintenance of ecological functioning. The use of corridors allows individuals or genes to flow to other areas, increases recolonization, positively affects immigration rates, and decreases the risk of local extinctions (Ng et al. 2013; Pardini et al. 2005; Schindler et al. 2008). The spatial distribution of similar patches, and rarity of patches, are vital for a species' survival (Dale et al. 1994), and a habitat that is connected to other habitats is assumed to have a higher value for biodiversity conservation (Ng et al. 2013). In landscapes with fragmented habitat patches, the less isolated habitats are generally more conducive to species, because they can be easily settled and are amenable to a constant influx of new individuals (Walz 2011). A 22-year study concluded that forest fragmentation reduced the number of forest species but increased temporal variability in a number of species (due to higher local extinction and turnover rates) (Boulinier et al. 1998). In forested areas, fragmentation reduces diversity, increases the number of edge species, and reduces the number of interior birds (McIntyre 1995). Saab (1999) found that areas close to other patches were one of the predictors of high species richness. This variable is measured as the minimum Euclidean distance between two patches of the same type.

Distance from mid-point to edge: The distance from the mid-point of a habitat patch to the edge has been described as a predictor for quality habitat (Ashcroft et al. 2012; Dale et al. 1994; Linden et al. 2012; Pardini et al. 2005; Walz 2011). This variable is for species that require fairly homogenous patch types to survive. Due to disturbance of the preferred patch type, and proximity to a different patch type, edge effects can create uninhabitable space for some species. Forest patches near edges are often linked to nest predation and increased rates of brood parasitism (Helzer and Jelinski 1999). This variable is measured as the average Euclidean distance between each pixel in a patch and its closest edge pixel.

Shape complexity: Shape complexity uses a perimeter-to-area ratio calculation to provide a measure of the complexity of a patch shape. It is generally assumed that natural areas have more complex shapes (Dale et al. 1994). Shape affects the number of species—irregularly shaped habitats generally include more plant species, and consequently, a greater number of animal species (Walz 2011). Helzer and Jelinski (1999) found that area and shape are among the strongest predictors of individual species presence and overall species richness. This variable is measured as

$= P / 2 \sqrt{\Pi \times A}$; where P = perimeter and A = area (from Smardon and Fabos 1983).

Number of soil types: The number of soil types has been used in a number of habitat models for various animals (Boykin et al. 2013; Dauber et al. 2003; Elith et al. 2009; Lehmann et al. 2003; Noss 1998; Walz 2011; Lindenmayer et al. 2000). This variable is the count of unique soil types within each patch.

Distance to nearest waterbody: Organisms require fresh water, and access to a source is vital (Tilghman 1987). The distance that a species can travel to a freshwater source varies among species. However, it is assumed that a habitat patch with a freshwater body within its boundaries, or that is near an adjacent waterbody, are preferable to most species (Boykin et al. 2013; Crist et al. 2000; Elith et al. 2009; Noss 1990). Erwin (1996) also found that estuarine areas are important for birds in the mid-Atlantic coastal region and are crucial for nesting sites. The distance to the nearest waterbody is measured in the forest and grassland patches only, not wetlands. This variable is measured as the average Euclidean distance of each pixel in a patch to the nearest waterbody.

Topographic relief: Scientifically vetted methods, such as ecological niche modeling and other approaches, have used topographic relief as a variable for developing relationships with habitats (Dauber et al. 2003; Elith et al. 2009; Lehmann et al. 2003; Linden et al. 2012; Noss 1990). Boykin et al. (2013) used elevation, slope, and mountain ranges (and others) to model terrestrial vertebrates (amphibians, birds, mammals and reptiles) in the Southwest region of the United States. A habitat model by Dettners and Bart (1999) related nine forest-dwelling songbirds in southern Ohio to their topographic microhabitat preferences, such as slope, surface morphology, and land surface curvature. This variable is measured as the average slope of each pixel in the patch.

Invasive species: After habitat loss, the next-greatest threat to biodiversity is invasive species (Zevit 2013). Species that are introduced threaten and endanger native organisms due to their ability to outcompete for limited resources. Invasive species are opportunistic and will dominate areas that have been subjected to recent habitat disturbance, and as such, are synergistic or additive in their effects with habitat loss (Didham et al. 2005). This variable is measured as the total area of invasive species.

Distance to nearest forest (for grasslands only): Several studies have found that grasslands located closer to forested areas had a greater density of grassland birds (Lindenmayer et al. 2000; Ribic and Sample 2001). In addition, grassland birds have significantly more decreased population associated with disturbance than forest birds (Brawn et al. 2001). This variable is measured as the average Euclidean distance between each pixel in a grassland patch and the closest forest patch pixel.

Species richness, abundance, and protection status: Several scientists using bird and other animal counts have found statistical relationships between habitat features and species abundance (Zaniewski et al. 2002; Guisan and Zimmermann 2000; Vallecillo et al. 2009; Pardini et al. 2005; Osborne et al. 2001; Lehmann et al. 2003). Most of these papers specifically focused on an individual species in highly specialized environments. However, multiple-species bird counts conducted in multiple habitats would provide a more meaningful evaluation of bird demographics and habitat quality. Other similar models, such as ecological niche modeling, were also explored but were deemed inappropriate for the spatial scale of our analyses. Ecological niche modeling requires large spatial-scale data, such as climate, to relate habitats as far as one continent to another.

The EcoAIM™ biodiversity model also includes input for biological survey data, as individual counts, species counts, and protection status. If robust count data are available for a parcel, the number of individuals, number of species, and their protection status (federal or state endangered, threatened, or common) can be incorporated as an additional variable in this model. This variable is included as the number of counts of individuals multiplied by rank—3, 2, or 1—for endangered, threatened, and common species, respectively.

For this APG demonstration, this variable was not included in the final calculation, because sufficient biological survey data were not available. In 1995 and 1996, a bird survey was completed to inventory Neotropical migratory landbirds at APG (McCann and Battin 1999). To determine the statistical robustness of this data set, correlation relationships were tested with the breeding pair observations and the variables discussed above, in the habitats in which they were observed. The results indicated weak relationships between bird counts and most habitat variables. It was concluded that the survey was not sufficient for use in the biodiversity model, because the sampling technique was flawed. Surveyors waited only 5 minutes to observe (by sight and sound) birds in their vicinity. To get a more definitive count and identification of birds, most survey techniques require a 5-minute "resting" period after arrival of the researchers, to allow the birds to settle down. The observers then count and identify birds over a 20-minute period. Table 3 presents BPFs, variables, measurement basis, and default weightings for the habitat provisioning for biodiversity model.

Nutrient Sequestration Model

The Chesapeake Bay is subjected to inputs of excessive nutrients. Although point sources are controlled by the National Pollutant Discharge Elimination System (NPDES) program, nonpoint sources have increased in recent decades, resulting in degraded water quality. Nonpoint sources are often irregular events linked to runoff, atmospheric deposition, and seasonal agricultural activities. The control of nonpoint pollution is often based on land management activities (USEPA 2008). The Chesapeake Bay states (Delaware, District of Columbia, Maryland, New York, Pennsylvania, Virginia and West Virginia) established a total maximum daily load (TMDL) in December 2010. The program was implemented to restore clean water in the streams, creeks, rivers, and the Bay itself. The TMDL sets watershed limits of 185.9 million pounds of nitrogen (25% reduction), 12.5 million pounds of phosphorus (24% reduction), and 6.45 billion pounds of sediment (20% reduction) per year. The excess of nutrients in Chesapeake Bay causes algal blooms, and their decomposition creates low oxygen levels that are detrimental to important aquatic life such as fish, crabs, and oysters (USEPA 2013).

Based on feedback from stakeholders, it was determined that nutrient sequestration potential of wetlands was an ecosystem service that could meet APG's goals of being a good neighbor and corporate citizen within the Chesapeake Bay watershed. Within APG's boundaries, there are 2,599 wetlands, totaling 11,020 acres, making wetlands 28% of the total area. APG's wetlands are highly valuable, especially when other wetlands in the watershed are being affected by increasing development and land use changes. Wetlands have the potential to intercept nutrients moving from upland sources to aquatic ecosystems. The flow path of water moving through wetlands is defined as the "buffer" (Baker et al. 2006).

Given the large number of nutrient models already published and vetted, it was more efficient to incorporate an existing model that evaluates this ES than to develop a new concept. Several of these models were reviewed and evaluated to meet the functionalities needed for EcoAIM™—i.e., assisting with decision making regarding wetland disruption, conservation, enhancement, and tracking potential pollution mitigation and water quality credits and offsets. For incorporation into EcoAIM™, the chosen model had to meet the following criteria:

- Open source (free to use and re-program)
- Spatially explicit to be used in ArcGIS
- Can be applied rapidly with a minimum of readily available input data
- Can quantify water quality improvement provided by wetlands
- Can be applied for stormwater management planning
- Scientifically validated, either in the peer-reviewed literature or from frequent use by experts in the field.

Several well-known models, such as SWAT, SPARROW, and the WaASP7 models, were reviewed but were determined to be inconsistent with the needs of an ecosystem services approach. Two nutrient models, linked in EcoAIM™, did have the ability to meet Demonstration criteria—U.S. EPA's P8 model (Palmstrom and Walker 1990) and the University of Maryland's Riparian Analysis Toolbox (RAT; Baker et al. 2006; Tarboton and Baker 2008) (Figure 7).

The P8 model stimulates nutrient transport in drainage basins. This model calculates the stormwater sewered and unsewered areas of various land uses (e.g., commercial, residential, agricultural, open space, etc.) contributing to each drainage basin. The P8 model then provides the amount (as pounds/year) of nutrients and selected pollutants being discharged in each drainage basin.

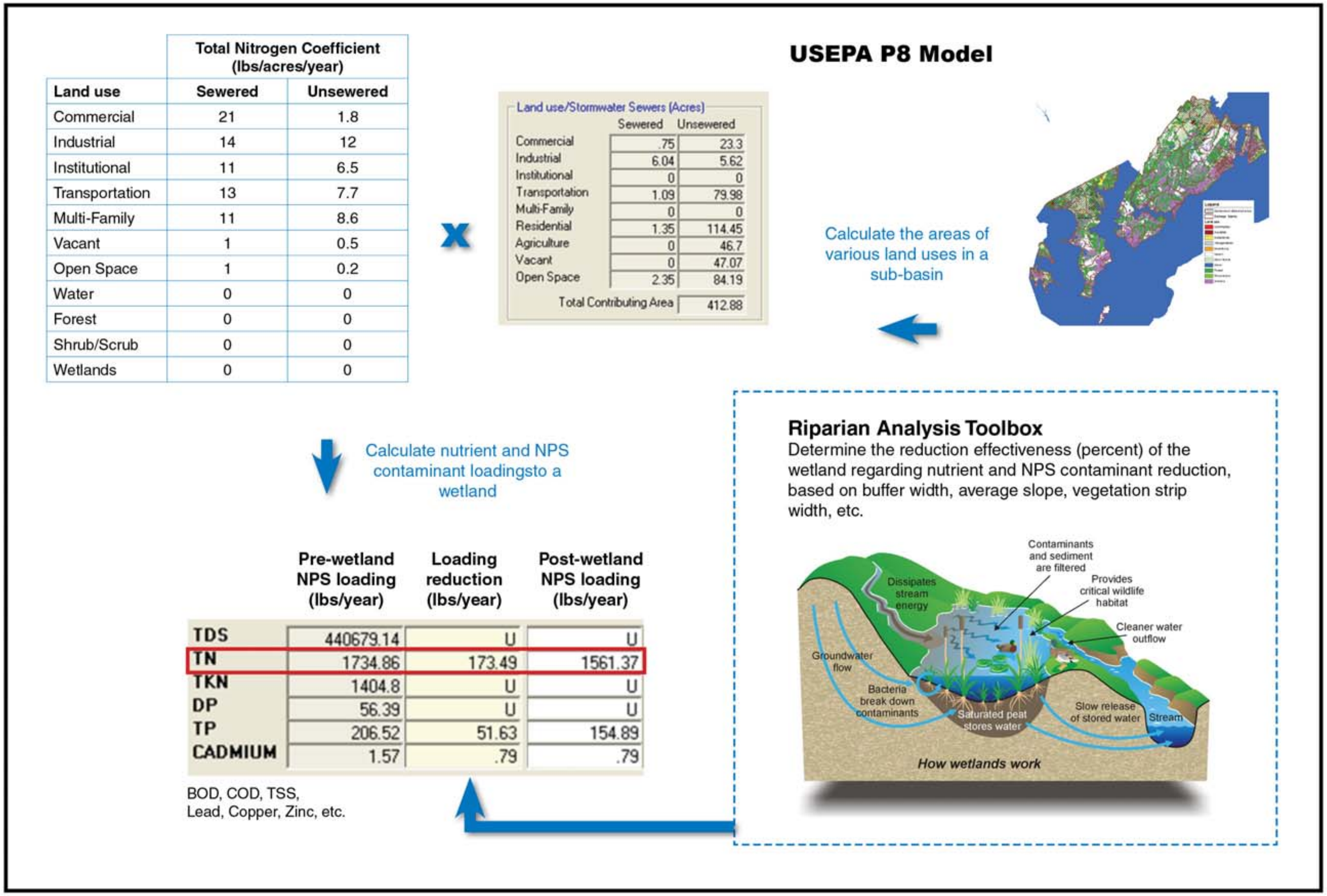

Figure 7. Schematic depicting the relationship between the USEPA P8 model (Walker 2007) and the Riparian Analysis Toolbox (http://ches.communitymodeling.org/models.php) Model in EcoAIM™

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The RAT model is an ArcGIS ArcToolbox add-in (CCMP 2014). This model is composed of three tools: 1) riparian delineation tool, 2) buffer-width calculator, and 3) strategic prioritization tool. EcoAIM™ incorporates only the first two tools. The riparian delineation tool uses topography or the DEM to define riparian zones based on elevation. The buffer-width calculator computes flow pathways and identifies the pixels in the buffer areas. The output from this calculation is the delineation of the wetland buffer width in each wetland. Based on the width and the vegetation type in the wetland, the mean nitrogen removal effectiveness (%) is calculated based on regression equations from USEPA (2005).

The EcoAIM™ nutrient sequestration model calculates the difference between the loadings (from P8) and the loading reduction (from RAT), resulting in the post-wetland loading (pounds/year) for each wetland. Table 4 presents the biophysical production functions, variables, measurement basis, and default weightings for the nutrient sequestration model.

2.4 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY AND METHODS

APG currently uses ArcGIS to assist with natural resources management decision making, though in a fairly limited capacity. Based on Exponent's discussions with APG planning personnel, ArcGIS is generally used to identify potential land-use conflicts by drawing a polygon (to represent a building or activity footprint) and visually evaluating the ArcGIS layers that overlap or are immediately adjacent to the drawn polygon. It appears that the GIS system used at APG is not used in a quantitative sense to calculate potential environmental effects, and there is certainly currently no tool being used to estimate the effects of a land-use change on the provision of ecosystem services.

The Natural Resources Branch currently meets regulatory and stewardship needs via interaction with other departments and organizations at APG (e.g., environmental personnel at tenant organizations, and Master Planning) during the NEPA process. As a result of this process, the Natural Resource Branch provides advice and guidance to the Installation Board of Directors, Installation Council of Colonels, and the Environmental Quality Control Committee. Decisions affecting natural resources are made at parallel levels of organization: by the tenant organizations (which have their own environmental personnel) and the garrison through the Natural Resources Branch, which is responsible for environmental permitting for all activities conducted on APG.

The Master Planning Branch produces a Short- and a Long-Range Component Real Property Master Plan, as required by Army Regulation 210-20, which outlines the strategic plans for growth (Atkins 2012). The current approach for developing these Master Plans includes developing an Existing Conditions Assessment, Land Development Patterning, and Future Development Planning. Master Planners hold a Visioning Session over several days, involving several personnel from the Garrison and Garrison-Support Organizations (GSOs), wherein discussions focus around the existing conditions and the ideal direction for the future. The Master Plans are based on the guiding principles developed at the Visioning Session. Aside from the use of ArcGIS, it is not currently known whether the Master Planning Branch uses any tools that assist with meeting regulatory and environmental stewardship requirements.

Table 4. Nutrient (Total Nitrogen) Sequestration Sub-Model—
Biophysical Production Functions, Variables, Measurement Basis, and Default Weightings

Total Nitrogen discharged from each wetland = Pre-wetland Total Nitrogen Loading per Year (result of P8 model) – Loading Reduction per Year (result of RAT and literature values)

Parameter	***Data Source***	***Metric***	***Ecological Production Function***	***Default Weight (%)***
USEPA P8 model	LU/LC	Loadings of nutrients per year	Measure area of land uses/land covers in each of the sub-basins in the watershed; P8 provides coefficients to calculate loading of total nitrogen for each land use (lbs/yr); assume total nitrogen loading ends up in the wetland; scale down the total nitrogen loadings to individual wetlands based on the wetland size.	none
University of Maryland Riparian Analysis Toolbox (RAT)	LU/LC	Loading reductions per year	RAT measures buffer width around each wetland; use literature values for coefficient of total nitrogen reduction.	none

EcoAIM™ is an innovation in ES analysis, because it combines a DSS (including a stakeholder engagement process to elicit values) with a geospatial analysis tool that uses spatially explicit data sets and scientifically defensible models to predict changes in ES under different land management alternatives. Using existing data sets and models with limited manual input from users omits potential data errors and decreases the time and level of effort needed for implementation. Most of the data sources, such as information about landscape features, are typically used routinely by land managers within most organizations. Other important data sets (e.g., National Wetland Inventory) are in the public domain or can be obtained at reasonable cost. The installations selected for this demonstration have robust data sets for the natural resources onsite (e.g., land use and land cover; DEM), and it is expected that this is the case across the Department. Complementary data from ongoing or additional site-specific studies can be added at the user's discretion.

EcoAIM™ is spatially and temporally scalable. Spatial scales can range from site-specific habitats or a parcel at an installation to watershed or larger landscape dimensions. Temporal scales are incorporated such that modeling scenarios can be developed for short (<10 years), mid-range (10–50 years), and long (>50 years) time frames. For example, an existing land cover can be changed to scrub-shrub, mid-successional forest, or mature forest.

Scalability allows the DoD decision maker to use a tiered approach to analyzing ES in a landscape portfolio. Large areas of land can be compared to each other, and areas of particular interest can be identified for further analysis, changing the focus from the landscape level to an individual habitat patch. Preference weightings for ES (or specific locations) can be assigned by the end user to explore how changes in management practices would affect both an individual ES and a compilation of all services. Conversely, EcoAIM™ identifies the values of ES that should be maximally protected, enables selection of appropriate management practices, and identifies associated trade-offs. The tool allows installation decision makers to develop their own scenarios by changing land-use and land-cover designations, as well as preference weights for key variables, including ES.

The information generated from EcoAIM™ provides value to military installations by providing the ability to successfully perform desired training exercises or military missions while minimizing environmental degradation or regulatory requirements; or by assessing the impacts of certain decisions on the sustainability of mission. Value can also be gained as a result of cost savings by minimizing land management requirements or remedial actions. For example, maintained fields or grassy areas on the installation might be converted to natural grasslands, thereby reducing the cost of lawn maintenance while enhancing other ES such as habitat for desirable species. Value can also be derived by leveraging pollution mitigation credits or water quality credits to offset areas of lower ecosystem quality. The tool may also help in decision making regarding overall land management options (e.g., retention, sale, or lease). As developed in this demonstration, EcoAIM™ is intended to be transferrable across a wide range of installations for all branches of service within DoD, and to have the flexibility to accommodate additional ES not currently modeled (e.g., carbon sequestration or spiritual values).

The stakeholder engagement process is critical to identify priority ES to include in the tool, the endpoints to be measured, and biophysical production functions. EcoAIM™ is customizable based on the EcoAIM™ information gleaned from the stakeholder engagement. Thus, the stakeholder engagement process must be led by a specialist who can develop a consensus on the notional mission that will guide the customization of EcoAIM™ for the appropriate end users or department.

EcoAIM™ is intended to be a decision-support tool allowing land managers and other decision makers to develop alternative future scenarios and evaluate how those scenarios affect the provision of key ES on a facility. It also allows decision makers to explore "what-if" scenarios relative to some variables within models, as well as in relation to alternative stakeholder preferences regarding ES valuation. As a scenario-building and sensitivity analysis tool, EcoAIM™ is not intended to be a deterministic tool and provide an answer to a specific question, nor is it intended to develop definitive quantitative estimates of how any one ES will be affected in any given scenario.

EcoAIM™ also does not provide monetary estimates of the value of ES, and as such, cannot be used to develop an absolute estimate of overall ES cost or ES benefit. Because of the inherent problems associated with economic benefits transfer, EcoAIM™ does not use currency as a valuation unit. It is possible that monetary values can be assigned to entities that currently have a market, for example, carbon markets or regions with wetland and biodiversity banks.

EcoAIM™ data are client provided and not independently verified. Like all models, the quality of the output is dependent on the geospatial data. GIS information can EcoAIM™vary in terms of how current they are, their accuracy, their availability, and their spatial resolution. Thus, it is incumbent on the user of the tool to be aware of any inaccuracies in the underlying geospatial data and either correct those inaccuracies prior to using the tool or use that knowledge in the interpretation of EcoAIM™ results.

Technical limitations for the tool are based on its platform in ArcGIS. EcoAIM™ is a Toolbox add-in that can only be used on ArcGIS versions 10.0 and higher. In addition, the end users must also have the Spatial Extension on their system. Currently, APG is on version 10.0 and any upgrades to version 10.1 in the next few years will not affect the use of EcoAIM™.

Due to the expertise and experience needed in operating ArcGIS, a decision maker will be required to work with a GIS specialist to operate EcoAIM™. Any scenario-building and changes to input data will require reliance on personnel with basic ArcGIS proficiency.

Based on past experiences with using EcoAIM™ at other sites, the distributions of pixels or patches are not normal, and using the Jenks natural break method of classification provides the optimization for discerning sufficient differences such that the ten categories can be displayed on maps. Thus, EcoAIM™ is currently programmed with only the Jenks method as the only categorization technique. In the event that a site has data that is more normally distributed, other categorization techniques could be more optimal, such as quantiles.

The output from EcoAIM™ is highly dependent on spatial scale of the input data. The relative ranking of pixels and patches in the scenario function are based on the baseline watershed data. For this reason, the ES values from one site cannot be compared to those at another watershed. To make compatible comparisons, the end users must load GIS data from the two or more differing watersheds. Then based on the distributions of values for each variable, determine appropriate category criteria to be applied to all sites. This is currently not a limitation for APG's intended use of EcoAIM™, but this limitation should be kept in mind if the DoD plans to compare several different sites.

3 PERFORMANCE OBJECTIVES

This section presents the performance objectives that are the primary criteria for evaluating the EcoAIM™ demonstration at APG. Meeting these performance objectives is essential for successful demonstration and validation. The Performance Objectives are presented via qualitative and quantitative variables. Table 5 lists the Performance Objectives for this demonstration project, along with the corresponding metric(s), data requirements, success criteria, and a summary of results.

3.1 PERFORMANCE OBJECTIVE NO. 1: DEMONSTRATE THAT QUANTIFICATION OF ECOSYSTEM SERVICES IS WELL FOUNDED

ES are ecological benefits (processes and products) or benefits to humans that are provided by ecosystems. Examples of ES include processes, such as nutrient removal by wetlands and carbon sequestration by woodlands, as well as products, such as breeding or nesting habitat for birds, clean drinking water, and clean air. The concept of ES provides a fundamental basis for effectively managing the conflicts posed by competing interests at DoD installations so as to ensure both mission and environmental sustainability. There are no standard methods for measuring (quantifying) ES, and investigators in the field of ES assessment generally adopt one of two approaches: monetary quantification using econometric methods or nonmonetary quantification. As described earlier in this demonstration plan, EcoAIM™ focuses on nonmonetary quantification; however, it does not exclude econometric methods, especially where reliable markets might exist by which to estimate the dollar value of an ES unit (e.g., board feet of timber or pounds of blue crab).

This performance objective is intended to document that the nonmonetary approaches used in this demonstration are generally well accepted in the professional community.

3.1.1 Metrics

This performance objective is qualitative; therefore, the success in meeting the objective will be determined based on an assessment of the degree to which documentation exists for the quantification of ES, and the use of such quantification to support environmental and social management decisions. This assessment includes an evaluation of the application in practice of biophysical models in the development of BPF, as well as the application in practice of structured stakeholder engagement in environmental DSS. Finally, the practical application of ES quantification methods and tools depends on the degree of availability of data regarding key variables in BPFs. Data can be site specific or can consist of proxy data (e.g., from similar areas nearby) or well-accepted assumptions regarding key variables. The availability of data in each of these categories will be assessed relative to data availability for existing ES quantification case studies.

Table 5. Performance Objectives

Performance Objective	***Metric***	***Data Requirements***	***Success Criteria***	***Results***
1. Demonstrate that quantification of ES is well founded	• Degree of documentation and_validation of models in the scientific literature or in application • Degree of availability of onsite or proxy data or well-accepted assumptions	• Scientific literature on ecological functions and processes, case studies • Site-specific biophysical data, data from literature on comparable sites, validated assumptions	• EPFs and models are well documented and peer reviewed in the scientific literature†; if EPFs are not well documented or scientifically defensible, or data are insufficient for future validation, project documentation adequately describes the uncertainty, implications of the uncertainty, and the data requirements to reduce uncertainty† • Onsite data or proxy data are sufficient to validate EPFs in the future via monitoring†	• EPFs and models are well documented in the peer reviewed literature (see Section 2.2) • The onsite data that were provided by APG were sufficient to validate EPFs in the future via monitoring

Performance Objective	*Metric*	*Data Requirements*	*Success Criteria*	*Results*
2. Quantify three or more ES	• **Carbon sequestration ES**: Tons carbon/year [c] • **Biodiversity ES:** Relative ranking (quantile) of habitat quality within basin/sub-basin[a] • **Pollutant sequestration ES:** mass/unit area/ year • **Aesthetics ES:** vista and landscape aesthetics with relative ranking of patches[c] • **Recreational Opportunities:** relative ranking within defined grid overlay [c]	• Land use/land cover (LU/LC) data and preferably vegetation mapping • LU/LC, data on special status species distribution, preferably mapping • Possible ground-truthing of habitat extent and quality via visual reconnaissance and field metrics (e.g., percent cover, presence/absence of invasive species, etc.) • Scientifically defensible EPFs or uncertainty assessment/ sensitivity analysis from Performance Objective No. 1	• Estimates of carbon sequestration/storage by land-use type are within ranges reported for similar LU/LC types in the literature for field investigations* • Relative ranking of habitat quality agrees well with existing literature on natural areas of the basin* • Estimates of pollutant removal potential by land use type are within ranges reported for similar LU/LC types in the scientific literature for field investigations*	• Carbon sequestration was not a modeled ES because results from the stakeholder engagement process did not deem this ES important to APG's missions and visions • Based on reviewed literature, there is agreement that several variables measured in the model are important for habitat quality (see Section 2.2) • Estimates of pollutant removal potential for wetlands are within the ranges reported for similar LU/LC types based on EPA's validated P8 model and regression equations from USEPA (2005) • Relative ranking of aesthetics agrees with existing literature on aesthetics of natural areas (see Section 2.2) • Relative ranking of recreational opportunities agrees with existing literature on potential recreation in natural areas (see Section 2.2)

Performance Objective	*Metric*	*Data Requirements*	*Success Criteria*	*Results*
3. Display quantification of three or more ES in geospatial context	• **General:** Graphical representation (e.g., color coding by value range, radar diagram, etc.) of ES across the assessment area: a. **Carbon sequestration ES:** Tons of carbon/year-acre by LU/LC type and/or vegetation type[c] b. **Biodiversity ES:** Quantiles (relative ranking) of biodiversity value within patches c. **Nutrient sequestration ES:** Nutrient removal potential within wetlands onsite d. **Aesthetics:** Quantiles (relative ranking) of biodiversity value within landscape and patches[c] e. **Recreation:** Quantiles (relative ranking) of recreational opportunity value within installation[c] • Feedback from decision makers and evaluation of ground-truthing results indicate an acceptable level of accuracy and spatial resolution†	• Same data requirements as for Performance Objective No. 2	• Comparison of aerial photos and satellite images with thematic maps for a >85% concurrence agreement between data sets* • Feedback from decision makers indicates a consensus concurrence[b] that spatial resolution is adequate for decision-making; in the case of ground-truthing, sample of points selected indicates >85% concurrence with mapping †	• Comparison of the LU/LC map provided by APG is within 85% concurrence agreement when compared to satellite photographs • Feedback during the two demonstration presentations did not indicate that the spatial resolution was problematic. EUL layers provided by APG for the Scenario 1 demonstration was at the appropriate resolution for decision making. No ground-truthing was required.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
4. Develop maps of ES flows associated with the installation and provide a clear and accurate description of activities involved in the mission	• Demonstrated understanding of ES and how they relate to activities at the installation • Demonstrated accuracy of investigator's portrayal of current and future mission and decision-making process	Information from interviews with installation decision makers, tool users, and beneficiaries of ES and site-related environmental documents on: • Mission activities at present and in the future, how mission-critical activities affect ES and rely on ES, how ES provide non-mission critical benefits, and major resource conflicts • Description of stakeholders/ beneficiaries and decision-making authorities and processes	• Documentation from installation decision makers via interviews showing consensus concurrence[b] that the investigators and decision makers have a clear understanding of ES flows and the relationship between ES flows and mission-critical and non-mission-critical activities • Documentation from installation decision makers via interviews showing consensus concurrence[b] that the investigators have described key decision-making authorities and processes for actions affecting or affected by ES†	• There was consensus from stakeholders at the August 2013 stakeholder meeting that indicated that Exponent Project personnel and APG staff had a clear understanding of ES flows and the relationships between ES flows and mission-critical and non-mission-critical activities • Exponent Project personnel have confirmed with staff from the Natural Resources Branch that the schematic diagrams illustrating decision-making authorities and processes affecting or affected by ES are described accurately (see Figures 9, 10, and 11)

Performance Objective	Metric	Data Requirements	Success Criteria	Results
5. Quantify shifts in the value of benefits from ES under different mission scenarios	• Significant absolute change in the value of each ES under different scenarios • Relative change in ES values across different scenarios are consistent with the expected biophysical responses of the ecosystem	• Same data requirements as for Performance Objective No. 2 • Values for EPF input variables (existing data or inferred, depending on availability) • Preference weightings for ES as elicited from interviews with stakeholders (e.g., installation comman-der, regulators, and other users of the geographic footprint)	• For any given alternative scenario, the value of two or more ES are outside the reasonable statistical confidence limits of the value under baseline conditions * • Difference in one or more ES values between baseline and one or more scenarios reflects actual changes (direction and relative magnitude) in biophysical characteristics (determined by best professional judgment)†	• For the alternative scenario, Scenario 1, the value of two or more ES are outside the reasonable statistical confidence limits of the value under baseline conditions • The difference in one or more ES values between baseline and Scenario 1 reflects actual change, and the biophysical characteristics can be reported in the direction and relative magnitude in change. For ES values that started (baseline) at the lowest or highest ES values, any decreasing or increasing values in Scenario 1 did not effect a change because these are outside the natural bounds based on the baseline case.

Performance Objective	***Metric***	***Data Requirements***	***Success Criteria***	***Results***
6. Ease of use and utility of the tool for decision-making	• Ability of user and decision maker to use tool with minimal knowledge of decision analysis, ecology, or GIS • User's understanding regarding the output of the tool and utility of output within the existing decision-making framework	• Information from interviews with users on the amount of training required, the utility of the users' manual, and utility of tool for decision-making	• Users are satisfied with the degree of training needed to use the tools and the tool's ease of use • The decision maker effectively uses the tool to create scenarios, present results to other stakeholders, and make resource management decisions†	• Based on survey feedback and verbal discussion after the two Demonstration presentations, users concurred that they are satisfied with the degree of training needed to use the tool and the usability of the tool • Based on survey feedback and verbal discussion after the two Demonstration presentations, users concurred that they could effectively use the tool to create scenarios, present results to stakeholders and make resource management decisions

Notes: † = qualitative criteria
* = quantitative criteria

[a] Habitat types will vary by installation. For example, forests, wetlands and grasslands were selected for APG
[b] Consensus describes the process of making decisions collaboratively. A consensus-oriented process is one in which people work together to reach as much agreement as possible, generally developing a solution that all find acceptable. They then use decision rules to finalize the decision. Concurrence is a decision rule by which all examine and formally agree to accept the decision developed through the consensus process. Concurrence usually allows for a statement of non-concurrence by one or more of the participants.
[c] Carbon sequestration was not modeled for APG because stakeholders did not consider this to be a priority. Instead, aesthetics and recreation were added as important ES.
[1] Detailed list of materials and analytical costs provided in Final Report

3.1.2 Data Requirements

The assessment of this performance objective relies on a review of a variety of publicly available literature, including:

- Ecological functions and processes and biophysical models presented in the scientific literature or generally accepted by government agencies for regulatory or planning purposes
- BPFs developed and presented in the ecological and economics literature
- Case studies on the practical application of ES quantification presented in peer-reviewed journals, trade journals, government publications, or grey literature.

In addition, data regarding key variables in BPFs were obtained via publications, reports, and databases from the installations, the scientific literature on comparable sites, or by generally accepted assumptions in the scientific literature.

3.1.3 Success Criteria

This performance objective will be considered to have been met if a review of the literature indicates numerous examples of the practical application of ES valuation tools and methods, and that those methods have relied on sound underlying scientific principles. For example, BPFs and biophysical models used in the demonstration are well documented and scientifically defensible (e.g., shown to reasonably represent real-world conditions via ground-truthing), and the source, direction, and magnitude of uncertainty can be identified explicitly, if not quantified. In addition, this performance objective will be considered to be met if onsite data or proxy data are sufficient to validate the BPFs or biophysical models in the future via monitoring. In the event that BPFs or biophysical models are not well documented or scientifically defensible, or data are insufficient for future validation, this objective will be considered to be met if project documentation adequately describes the uncertainty, implications of the uncertainty, and the data requirements to reduce uncertainty.

3.2 PERFORMANCE OBJECTIVE NO. 2: QUANTIFY THREE OR MORE ECOSYSTEM SERVICES

The relative importance of the numerous provisioning, regulating, supporting, and cultural services provided by ecosystems is highly variable and dependent on place-specific environmental and socio-cultural characteristics. In most cases, environmental decision making is driven by a relatively small number of key ES. To limit the scope of this demonstration project, we propose to quantify four key ES at each installation. Based on our preliminary review of information for APG, it appears likely that the four principal ES to be evaluated will be one or more indices of biodiversity (e.g., availability and quality of habitat for songbirds), recreational opportunities, aesthetics, and pollutant retention. The specific ES to be quantified at each site will be determined as an outcome of the structured stakeholder engagement. As stated above, implementation of EcoAIM™ relies on stakeholder and beneficiary input to identify key ecosystem services to be evaluated; therefore, specific ES to be evaluated at each facility cannot yet be determined with finality. The stakeholder and ES mapping exercises (see Performance Objective No. 4 and Section 3.4) will serve to document the ES identification and selection process and the results. The final ES selected for each installation will be those services that are most closely tied to mission support and environmental decision making.

3.2.1 Metrics

Investigation of the existing application of ES quantification tools and approaches indicates that the following three ES categories are very often key to decision making:

- ES associated with biodiversity
- Recreational opportunities
- Aesthetics
- Pollutant sequestration.

Also, based on preliminary review of information for the three selected installations, these three ES also appear to be relevant to this demonstration project. There are various measures of biodiversity, and the specific metric to be used will be determined on a case-by-case basis, depending on the most sensitive variable(s). For example, diversity of vertebrates in terrestrial ecosystems is often a function of plant community diversity. In such cases, the specific proxy metric for biodiversity might be the number of species per plant community type in the assessment area, as compared to a pristine reference area (e.g., number of species of grasses, forbs, etc.) or a larger geographic area. It is expected that an overall metric for biodiversity will be developed based on the ranking of habitat quality for specific habitat patches on an installation relative to all available habitat within the basin or sub-basin of the installation. Similarly, the metric for recreation and aesthetics will be based on ranking of parcels relative to other parcels on the installation. The metric for pollutant sequestration will be mass per unit area per year (e.g., g N/m^2/year for phosphorus).

3.2.2 Data Requirements

In keeping with the overall objective of the demonstration project, the quantification of all services will rely on existing geospatial data that are publicly available, can be interpreted or derived from georeferenced satellite images or aerial photography, or are provided by each installation. The metrics outlined above will be derived from the geospatial data or installation data using scientifically defensible biophysical models. The geospatial data to be relied upon will generally consist of, but not be limited to, the following (depending on availability):

- Land elevation contours (e.g., from digital elevation map or surveyed for the site)
- LU/LC data with vegetation mapping (if available)
- Specific land uses for mission activities (e.g., designated training areas)

- Timber harvest/forest stand areas
- Natural land management areas such as hunting, fishing, wildlife viewing areas
- Data on special status species distribution
- Data on species abundance
- Prescribed burn areas.

Some critical data sets might be verified by ground-truthing at APG if data are outdated or have inadequate spatial resolution. In such cases, some additional field metrics may also be used, such as percent cover for vegetation and presence/absence of selected species.

3.2.3 Success Criteria

The success for meeting this performance objective will be determined by comparing the estimates of the ES provisioning for each ES with values reported by others in the literature, including applicable case studies. For example, this performance criterion will be met if estimates of pollutant removal potential by land use for the installation are within ranges reported for similar wetland types in the scientific literature based on field investigations. For biodiversity-related metrics, such as measures of habitat quality, the relative ranking of habitat on the installation will be assessed relative to the existing literature on natural areas of the basin, to determine whether the results of the quantification are consistent with general knowledge for the area (qualitative assessment). In some cases, it may be advisable to consult with local experts as an additional source of information regarding the results of the relative ranking. Additional success criteria will be developed for other ES as appropriate.

3.3 PERFORMANCE OBJECTIVE NO. 3: DISPLAY QUANTIFICATION OF THREE OR MORE ECOSYSTEM SERVICES IN GEOSPATIAL CONTEXT

One of the fundamental goals of the demonstration project is to provide an interactive tool for environmental decision makers that enable visualization of the relationships between land uses and the provisioning of ES. This visualization is key to understanding trade-offs in ES provisioning that occur under alternative decision scenarios. Both mission-supporting activities and the flow of ES from natural features have a spatial component. For example, certain training elements may rely on a specific land-cover type, such as mature mixed hardwood forest. This land-cover type, in turn, provides a wide range of ES that can be mapped to a specific area. Thus, portraying results in a geospatial context allows decision makers to visualize the spatial relationships between mission-supporting activities and ES. It is important that the spatial resolution of the mapping be sufficient to support decision making by stakeholders. Similarly, it is important that the accuracy of the mapping be quantified so that stakeholders understand any uncertainty propagated by any inaccuracies. This performance objective is associated with all three key ES selected for each site, plus any additional ES selected for APG.

3.3.1 Metrics

The metric for this performance objective consists of developing graphical representations (e.g., color coding by value range, radar diagram, etc.) of ES across the assessment area according to a variety of pre-defined, user-defined, or selected areas, including but not limited to:

- Geopolitical boundaries
- Natural features (e.g., watershed, surface water body, vegetation community)
- Site-specific features such as training areas.

The graphical representation of ES will be a function of the key mapped features described above, the biophysical models, and the BPFs. The metrics for this performance objective are:

- For graphical representation—color coding by value range, radar diagram, etc., of ES across the assessment area.
- For accuracy and spatial resolution, comparison of mapping results or input data sets to results of ground-truthing and/or consensus concurrence[3] from decision makers that spatial resolution is adequate to support decision making.

3.3.2 Data Requirements

The data requirements for Performance Objective No. 2 will also satisfy the data requirements for this performance objective.

3.3.3 Success Criteria

The utility to decision makers of the graphical representations of ES will depend largely on the accuracy and spatial resolution of the mapping. Therefore, the success for meeting this performance objective will be determined by comparing aerial photos and satellite images with thematic maps. Accuracy will be deemed to be acceptable if there is >85% concurrence between data sets. The value of 85% has been widely used as a target in thematic mapping via an image classification (e.g., McCormick 1999; Scepan 1999; Wulder et al. 2006) and is seen by many as a universal standard for thematic mapping in remote sensing (e.g., Fisher and Langford 1996; Weng 2002; Rogan et al. 2003; Bektas and Goksel 2004). In fact, it is rare to see any other target value specified in the literature. In addition, feedback will be solicited from installation personnel as a reality check on mapping accuracy, the value of spatial resolution, and possible ground-truthing of results (at APG).

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[3] Consensus describes the process of making decisions collaboratively. A consensus-oriented process is one in which people work together to reach as much agreement as possible, generally developing a solution that all find acceptable. They then use decision rules to finalize the decision. Concurrence is a decision rule by which all examine and formally agree to accept the decision developed through the consensus process. Concurrence usually allows for a statement of non-concurrence by one or more of the participants.

3.4 PERFORMANCE OBJECTIVE NO. 4: DEVELOP MAPS OF ECOSYSTEM SERVICE FLOWS ASSOCIATED WITH THE INSTALLATION, AND CLEARLY DESCRIBE ACTIVITIES INVOLVED IN THE MISSION

Successful implementation of any ES trade-off analysis requires an accurate and thorough understanding of the relationship between the provision of ES within a certain geographic context and the beneficiaries of said ES. This understanding is essential for decision makers to interpret the results of the analysis in a meaningful way. This understanding is also essential to select the highest priority ES to model in the demonstration. One of the early tasks in the demonstration project is to engage key stakeholders (beneficiaries as well as decision makers) in a dialogue that is aimed at mutual understanding of:

- Scope and nature of current and future mission activities that may affect ES
- The nature of adverse impacts on ES from installation activities
- The nature of adverse impacts on ES from off-base stressors (e.g., encroachment; water quality degradation, etc.)
- Whether and how installation activities may depend on ongoing provisioning of ES for successful execution of mission support activities.
- The roles and actions of decision-makers and the relationship between decisions and ES.

In addition, if installation leadership expresses a desire to include outside stakeholders in the demonstration project, it will also be important to define and describe the relationships between these stakeholders and ES provisions both within and outside the installation. This performance objective will aim to identify all ES on which mission readiness depends, as well as all ES potentially affected (positively or negatively) by activities at the installations. Information derived from mapping the dependencies and impacts and describing how the ES relate to mission readiness will be used to select the key ES that will be quantified at APG.

This performance objective will also entail flow of information in both directions between investigators and site personnel: a) from installation personnel to investigators regarding the nature of activities critical for mission support, decision-making process and structure, and non-mission-critical benefits derived from ES; and b) from investigators to installation personnel to ensure that installation personnel have a good understanding of the concept of ES and why ES are important to mission readiness and environmental decision making.

3.4.1 Metrics

This performance objective hinges on communication and common understanding of key issues and therefore will not be evaluated relative to quantitative metrics. Rather, decision makers, users of the tool, and other beneficiaries will review a graphic representation of the flow of ES within and across the installation relative to mission support activities, as well as charts that illustrate decision-making authority and activities at the installation. Feedback will be obtained from reviewers using interviews and will be incorporated into a final ES flow map for each installation. The ES flow maps and decision flow charts will be considered final when a consensus concurrence is achieved among stakeholders.

In addition, at the full implementation site, beneficiaries (internal and external [if appropriate] stakeholders, decision makers, and tool users) will be polled periodically during stakeholder engagement sessions to document their understanding of ES and how they relate to activities at the installation.

3.4.2 Data Requirements

The ES flow map(s) will be generated based on data derived from interviews with installation decision makers, tool users, and beneficiaries of ES and site-related environmental documents to describe:

- Current mission activities and how these activities might change in the future
- Stakeholder roles and responsibilities, including decision-making authority
- ES dependencies and impacts as related to mission activities
- Non-mission-critical benefits provided by ES flows (e.g., recreation and aesthetics)
- Major resource conflicts between the installation and outside stakeholders.

3.4.3 Success Criteria

Meeting this performance objective is critical to the success of the program. Therefore, it is important that the criteria be evaluated clearly. The success criteria focus directly on the end users—those whose decisions will most directly influence and be influenced by ES provisioning. The success for meeting this performance objective will be determined by documenting the results of interviews with selected installation stakeholders. Stakeholders will be selected to represent a cross section of roles and responsibilities. Emphasis will be placed on accurately characterizing the understanding of the relationship between mission readiness activities and ES, as well as the decision-making flow within the installation. The criterion for success for meeting this performance objective will be concurrence by those interviewed with our representation in text and graphics with the first two bullets identified in 3.4.2. Because the purpose of this task is to elicit the stakeholders' and beneficiaries' perceptions of those points, a consensus concurrence—that all individuals contacted are satisfied, or can "live with" our representation of their perceptions—will be considered success. Success in meeting the performance objective for the third, fourth, and fifth bullets in 3.2.4 will be consensus concurrence among stakeholders that they understand the concept of ES and understand the relationships (both impacts and dependencies) between installation activities and ES.

3.5 PERFORMANCE OBJECTIVE NO. 5: QUANTIFY SHIFTS IN THE VALUE OF BENEFITS FROM ECOSYSTEM SERVICES UNDER DIFFERENT MISSION SCENARIOS

One of the fundamental goals of the demonstration project is to provide tools for decision makers to evaluate trade-offs in the provision of ES directly resulting from alternative management actions. Evaluation of trade-offs will include ES that directly relate to the support of the military mission, as well as ES that are valued by the greater military community for non-mission-critical reasons (e.g., recreation and aesthetics). Trade-offs are evaluated by assessing how ES provisioning shifts under different mission scenarios. Figure 5, presented earlier, presents a conceptual illustration of how ES provisioning may shift under alternative management scenarios.

In addition to quantifying shifts in the provisioning of individual ES under different management scenarios, the demonstration project will also develop an aggregate value (or score) for the combined ES under each scenario based on the preference weightings of stakeholders. Tradeoffs will be evaluated quantitatively among the key ES at APG.

3.5.1 Metrics

Shifts in ES provisioning will be quantified as the difference between calculated values under two or more alternative management scenarios. This difference will be expressed as measurement units for ES, such as pollutant sequestration (e.g., g N/m^2/year), and as a percent change for ES that may be expressed as a relative value or rank value.

3.5.2 Data Requirements

The data requirements for evaluating this performance objective are the same data requirements as those for quantification of individual ES (Performance Objective No. 2). In addition, preference weightings for the various ES will be used as input to develop the aggregate ES score. The preference weightings will be derived from interviews with stakeholders (e.g., installation commander, regulators, and other users of the geographic footprint).

3.5.3 Success Criteria

Two criteria will be used to determine whether the demonstration project has succeeded in satisfying this performance objective. The first criterion is quantitative and consists of a comparison of the ES values for each ES under baseline conditions with the corresponding value under one or more management scenarios. If this difference is significant for at least two ES being modeled, then the performance objective is deemed to have been met. This determination will be made if the predicted value is outside the reasonable confidence limits of the value under baseline conditions and will be determined by statistical analysis of variable distributions in BPFs, as well as geospatial analysis using methods that may include bootstrapping. The specific method(s) to be applied will depend on the types of data sets and analyses inherent in the biophysical models, BPFs, and geospatial analysis. We recognize the possibility that installation personnel may indicate that there are only very small or no changes in mission-critical activities expected in the future, and that in such a case, the EcoAIM™ tool may not be able to detect any changes in some or possibly even all ES. However, the model will be run iteratively, to identify sensitive inputs and understand the resulting uncertainties. These runs will include the upper and lower bounds on the inputs, which may be cases that rarely occur but provide evidence of the model's value and correct operation.

The second criterion is qualitative and consists of an evaluation of whether observed differences in ES values (baseline versus one or more scenarios) are likely to reflect actual changes in biophysical characteristics determined by best professional judgment. This determination will be made by conducting a sensitivity analysis on key variables in the biophysical models and BPFs, as well as the preference weightings (for the aggregated ES value), and evaluating whether the results are generally consistent with known ecological relationships. The performance objective will be deemed to have been met according to the second criterion if the predicted change in one or more ES values and/or the aggregate value is consistent (e.g., is in the same direction and relatively proportional in magnitude) with changes in key variables that are known to be influential in the production of ecological processes or products.

3.6 PERFORMANCE OBJECTIVE NO. 6: EASE OF USE AND UTILITY OF THE TOOL FOR DECISION MAKING

The final performance objective relates to ease of implementation and usefulness. The overall value of any decision-making tool is at least partly a function of its ease of use and its ability to improve the process of gathering and presenting the information available for decision making. In addition, it is important for a decision-making tool to provide information in a form and manner that are easy to incorporate into the decision-making process.

3.6.1 Metrics

The metrics for evaluating this performance objective fall into two categories:

- The ability of the end user and decision makers to implement the tool with minimum knowledge of decision analysis, ecology, or GIS
- A clear understanding on the part of the user and decision maker(s) regarding the output of the tool and how the information can be used within the existing decision-making framework.

3.6.2 Data Requirements

Both metrics will be evaluated via iterative user feedback consisting of information compiled during the implementation and technology transfer phase (i.e., during user training) and via interviews with users to measure user satisfaction. For the first metric, a log will be kept of technical assistance provided during the implementation phase. An analysis of the type and frequency of technical assistance and the level of effort required for each incident will be used to evaluate the tool's ease of use and the clarity of the user manual. The second metric will be evaluated at the full implementation site by use of a semi-structured interview process. Depending on the number of users/stakeholders interviewed, it may be possible to phrase some questions using scalar format for responses to quantify certain types of data. The number of stakeholders or tool users is currently unknown, because stakeholder consultation cannot be initiated in advance of the final Demonstration Plan.

3.6.3 Success Criteria

This performance objective will be deemed to have been met if a) the frequency of technical assistance incidents, and the level of effort expended on each, decrease during the implementation phase, and b) the results of the interview process indicate that the tool is being used by decision makers to create and evaluate scenarios to present results to other stakeholders, and to make resource management decisions. Specific thresholds for determining success relative to these criteria will be determined in conjunction with installation stakeholders to ensure that the thresholds are meaningful and attainable. Thresholds can be based on a variety of metrics, including but not limited to degree of satisfaction with tool usability (e.g., number of times the tool was used during a certain period, types of decisions for which the tool was used, and whether use of the tool may have influenced a decision or decision outcome). Thresholds will be developed in conjunction with users during the technology-transfer phase of the demonstration.

4 SITE DESCRIPTION

APG was chosen as a demonstration site because of its diverse ecosystem, its extensive GIS data set and background information that can be drawn upon from past environmental projects, and Exponent's history with other DoD projects at the site. In recent years, this site has implemented several ecological restoration and remediation projects. Resource managers at APG have expressed an interest in this demonstration to understand water quality issues in the Chesapeake Bay watershed and management of important habitats for several bird species. APG also initially expressed interest in the management and trade-offs associated with maintaining the carrying capacity of animals (such as deer and waterfowl) that are important in the APG Morale, Welfare and Recreation Program, a program that provides personnel with recreational opportunities.

4.1 SITE LOCATION AND HISTORY

APG is a U.S. Army installation located on the northwestern shore of the Chesapeake Bay in southern Harford County and eastern Baltimore County, Maryland (Figure 8). The Bush River divides APG into the Aberdeen area on the east and the Edgewood area on the west. Edgewood is approximately 11,326 acres and includes Pooles Island, Carroll Island, and Grace's Quarters. Aberdeen is approximately 27,630 acres and includes Spesutie Island. Although APG also includes four other small properties in Harford County that are separate from the main installation (Churchville Test Area, Atkisson Dam and Reservoir, Van Bibber Water Filtration Plant, and Chapel Hill Water Filtration Plant), this project does not include these areas in the demonstration (EA 2008; APG 2009). The cantonment area is approximately 6,736 acres. The Installation also includes approximately 34,611 acres of water, consisting of some portions of Chesapeake Bay and estuarine rivers. Harford County is predominately rural, with residential and industrial centers such as Bel Air, Aberdeen, Havre de Grace, Edgewood, and Joppatowne (APG 2009).

Edgewood is currently listed as a National Priorities List (NPL) site. Although the APG is not an NPL site, it had several cleanup projects on the installation. The primary mission at APG is to provide active proving grounds for testing DoD weapons and technology. The installation also supports several tenants, such as the Public Health Command, the Air Force, Army Intelligence, and Army Research and Development. The site contains several office buildings, training centers, military housing, recreational facilities, an airfield, and commercial buildings (EA 2008). Because APG is an active proving installation, there are several areas for which information was not provided, and subsequently, in which the demonstration was not conducted for reasons of security and confidentiality. Once EcoAIM™ is transferred to the final end user, any additional and confidential data can be incorporated as input variables.

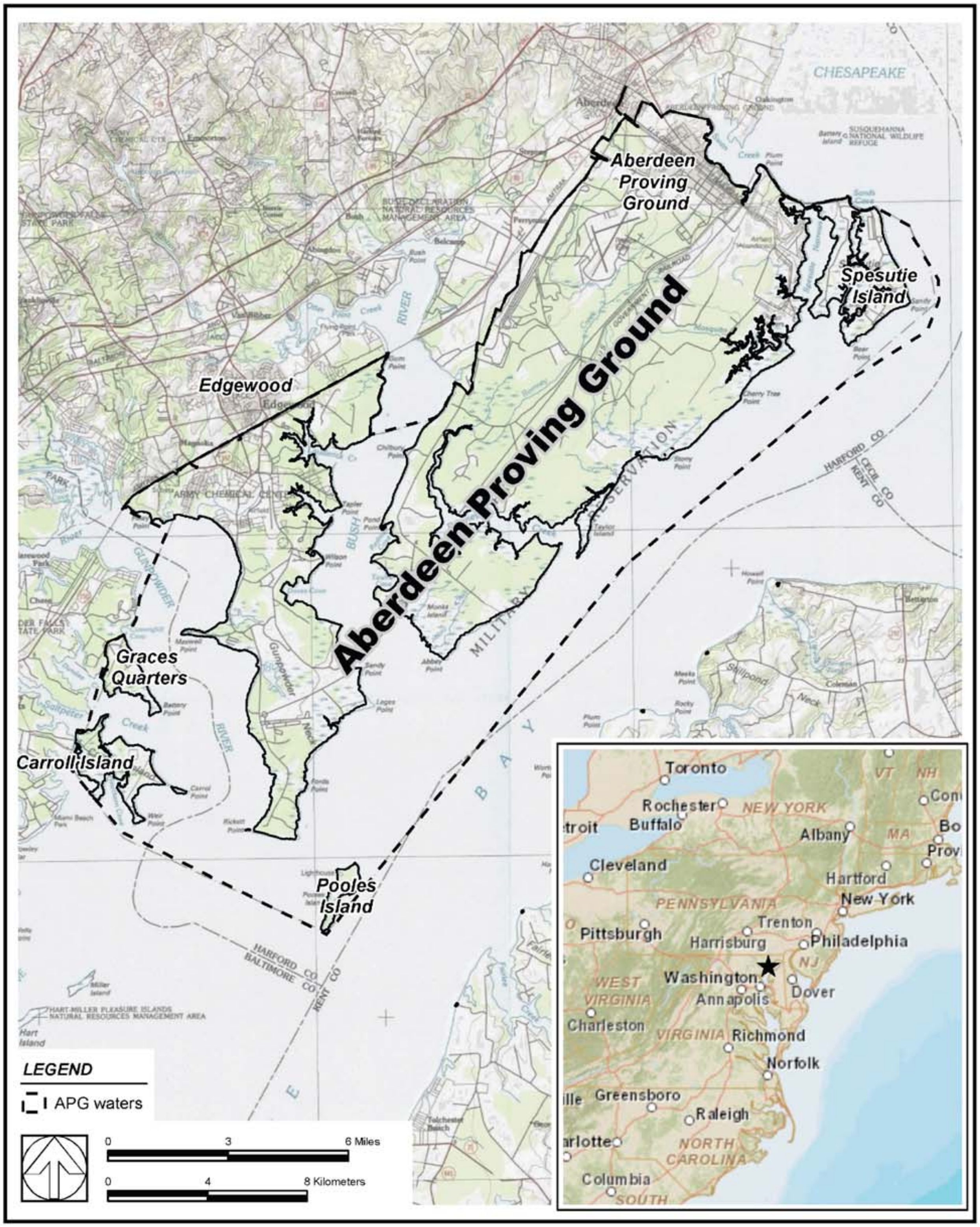

Figure 8. Aberdeen Proving Ground (APG) site location

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The Aberdeen area was established in 1917 as an ordnance proving ground, and in 1919, it became a formal military post. The Edgewood area was appropriated in 1917 by a Presidential Proclamation for primary use of testing and developing weapons systems, munitions, and chemical agents for military operations (GPC 2011). APG has been training Army Ordnance personnel since 1918, and the size of the installation allows for extensive research, development and testing of materials, vehicles, ordnance, and weaponry (APG 2009).

The installation is home to more than 70 different Garrison-Support Organizations (GSOs) involved with various military and scientific research, testing, and development, such as Army Public Health Command, Army Intelligence, and Army Research and Development. APG's overall mission is "to provide the highest quality installation management, operation and support services in a timely manner through the full involvement and commitment of our people." The military mission at APG has always been focused on developing and testing military material, and training officers and enlisted personnel to use and maintain ammunition. In 2003, the U.S. Army Research, Development and Engineering Command was established as the major subordinate command with a mission to provide the full spectrum of basic research, development, engineering, and analysis of Warfighter systems, including the integration of resources across the Army, DoD, universities, and other research centers (APG 2009).

4.2 SITE CHARACTERISTICS

4.2.1 Physical Site Characteristics

APG lies within the Atlantic Coastal Plain physiographic province at approximately 60 ft above sea level. The installation is fairly flat, with slopes usually within 2%. The topography at APG is characterized by low-lying wetlands and little change in elevation. There are several small creeks onsite that drain into the Bush and Gunpowder Rivers, tributaries to Chesapeake Bay, and directly to Chesapeake Bay. The western shore of Chesapeake Bay can range from low, marshy shorelines to steep (4.6–6.1 m high), eroding bluffs. The Patuxent Formation and Patapsco Formation, within the Atlantic Coastal Plain, yield groundwater and are used as off-Post public drinking water for nearby residential areas. Several Source Water Protection Plans are in place between APG and the City of Aberdeen and Harford County. Because the management of the Source Water Protection Areas is the responsibility of the compliance and/or restoration programs, it is not considered a natural resources function by the natural resources group at APG (APG 2009).

Climate at APG is characterized by both continental air and maritime air. Cold air masses are blocked by the Appalachian Mountains in the west, and the Chesapeake Bay currents have moderating effects that provide for warmer winters than inland areas (APG 2009). Due to its location in the Coastal Plain region, the area is warm, temperate, rainy, and moderately humid, without a dry season (APG 2011c). The mean annual precipitation is 102 cm throughout the year. Heavy snowfall occurs in January, and snow can accumulate until March. The Atlantic Ocean and Chesapeake Bay provide moderating effects for the cold, dry continental air masses (APG 2011c). The prevailing winds are from the northwest in the winter and southerly in the summer (APG 2009). The temperate climate at APG is similar to approximately 80% of the world's climate, making it an attractive installation for testing and training missions. The large expanse of the area makes it ideal for testing weapons that require adequate safety distances and noise attenuation. Prior to 1990, weapons were fired into the waters surrounding APG, and the Chesapeake Bay provided an additional measure of safety (APG 2009).

The Installation is composed of several vegetation types, consisting of 50% hardwood forest, 34% mowed/grassy areas, 13% marsh or marsh shrub, 2% bare earth, and 1% shrub habitat. The forested area is important because of the increasing scarcity of forested areas in the Chesapeake Bay watershed due to development. The majority of forested area is located within APG's secured area and can range in size from less than 1 hectare to more than 100 ha. Fragmentation of the forests is due to water courses, wetlands, open fields, and roads. The most ecologically important forested areas are unfragmented and riparian forests, which support a great variety of wildlife. The Chesapeake Bay Critical Area Management Program has deemed both forest types as important nesting areas for Neotropical migrant birds. The most common forest type includes sweet gum/water, oak, mixed oak, and yellow poplar/transition hardwoods. Sweet gum is a colonizing species of disturbed habitats and areas with poorly drained soils (APG 2011a).

Due to the low topographic relief (0–21 m above mean sea level) and shallow water table, APG provides ideal conditions for wetlands. Wetlands constitute about 2,226 ha at APG and have been increasing in acreage over the past 75 years. In contrast, wetlands in the rest of the Chesapeake Bay watershed have been lost due to rising sea level and development. Several wetland types can be found at the site, including emergent, forested, and scrub/shrub wetlands (APG 2011b).

4.2.2 Natural Resources

APG includes several types of natural resources—forests, fields, swamps, beaches, streams, rivers, pools, marsh, bay, islands and mud flats. APG manages its natural resources by dividing the installation into the cantonment area, security area, and Critical Area. The cantonment area is unrestricted and is where the majority of developed areas are located (i.e., buildings and roads). Many of these natural areas are located "down range," behind a secure area that is restricted by control gates and fencing. These down-range areas are also the location of historical and current research, development, testing, training, and range facilities. This secure area has been protected from development, so these sites are also prime habitat in an increasingly developed watershed (APG 2009). The Critical Area is defined by the Maryland Chesapeake Bay Critical Area Protection Program (1984). It is the Chesapeake Bay water, land under the Bay, and upland within 1,000 feet of tidal waters of the Bay. Any forestry management programs in the Critical Area are subject to a comprehensive set of criteria for timber harvesting, preservation plans, conservation, and land-use conversion.

APG contains large areas of forested and wetland areas. Nearly 41% of the site is forested and an important habitat for wildlife. Within the Chesapeake Bay watershed, these forested areas are especially important habitat due to the increasing development and loss of quality habitat throughout the rest of the watershed. Much of the forested area is in the downrange portion, in secured areas, and fragmented by water bodies, open fields, and roads (APG 2011a). Forest patches on the installation range from early successional to mature forests, and contain medium to large trees (15–24 inches diameter at breast height). The majority of forested areas are located in areas that were historically and/or currently used as firing ranges. Due to the presence of unexploded ordinance (UXO) (either in tree trunks or in soils), commercial harvesting of trees is unsuitable (APG 2009). The forest patches provide important ES, such as maintaining water quality in streams and wetlands. Trees provide soil stabilization, protection from erosion, and thermal protection. Riparian forests offer important habitat for species that prefer proximity to streams, and the increased humidity provides habitat for herpetofauna. The roots provide cover for fish and aquatic invertebrates (Mar-Len 2009).

Wetlands compose nearly 28% of the APG property. Due to the low topographic relief at the site and the shallow water table, APG contains many wetlands that are documented in the U.S. Fish and Wildlife Service's National Wetlands Inventory. Tidal marshes are located on the shorelines of Chesapeake Bay, Bush River, and Gunpowder River (APG 2009). Similar to forested areas, wetlands are increasingly becoming more important in the Chesapeake Bay watershed, as more area is becoming developed (USEPA 2013). The wetlands on the installation contribute significantly to improving the quality of water in the upper Chesapeake Bay (APG 2009). In addition to being essential habitat, the wetlands at APG also act as natural filters for pollutants and nutrients that eventually would have reached Chesapeake Bay. In particular, nutrient sequestration by APG wetlands is of particular importance because of the existing TMDL established in the 64,000-square-mile Chesapeake Bay watershed (USEPA 2013b).

4.2.3 Impacts of Military Mission on Natural Resources

Due to APG's presence, habitat that is scarce in other parts of the Chesapeake Bay watershed has thrived and prevented residential and industrial development in the area. Within APG, development at APG has been restricted mainly to the cantonment area, with little development down range in the secure area. However, for some testing facilities, clearing has occurred and has resulted in fragmentation and some losses of biodiversity. In addition, the disturbance has permitted an increase in opportunistic species (e.g., brown-headed cowbirds that interfere with habitat use by other species) and invasive species. Two such invasive plants, the autumn olive and the multiflora rose, are so common at APG that they are an established part of the local ecology (APG 2009).

One of the largest planned use changes to occur at APG in the last few years is the Base Realignment and Closure Act (BRAC). Since 2005, civilian presence at the installation has increased substantially, and the number of military personnel has decreased. The BRAC-gaining activities have included relocation of several tenant organizations, such as the U.S. Army Communications-Electronics Research Development and Engineering Center, the Joint Program Executive Office for Chemical and Biological Defense, and the Army Research Laboratory. APG is undergoing the development of new facilities, building renovations, and building demolition (Goodwin 2008).

Excessive noise from testing and training activities at the installation has not been problematic for fauna. A study of the effects of weapons testing on bald eagles, which are thought to be sensitive to noise disturbance, found that the noises had negligible to zero effect on their nesting and roosting behavior.

APG implements the Integrated Training Area Management (ITAM) program, which integrates mission requirements with natural resource management practices, to ensure that sustainable quality training environments are available. The ITAM program provides a framework for making decisions on the use of training and testing lands, and identifies and assesses land-use alternatives. Any damage to lands from military use are addressed in this program. In some weapons-testing areas, concentrations of UXOs and other contamination affect the area. APG has a program for conducting UXO clean up when ranges close.

4.2.4 Impacts of Natural Resources Management on Military Mission

APG (2009) states that the protection of bald eagles is the single and most definitive effect of natural resource management on the military mission. Although delisted from the federal endangered species list in 2007, the bald eagle continues to be protected under the Bald and Golden Eagle Protection Act and the Migratory Bird Treaty Act. A bald eagle management plan for APG was developed in 2009. During nesting season (Dec 15 to June 15), military activity is limited within 500-m buffers of active nests. In addition, all year round, habitat modifications are limited within these nest buffers. In 1977, there was one bald eagle breeding pair at APG, and by 2008, the number had grown to 48 pairs (APG 2009).

As listed above, in Section 1.3, Regulatory Drivers, wetlands at APG are regulated and protected from development with Section 404 of the Clean Water Act. In addition, all federal agencies are directed to avoid both long- and short-term adverse impacts with the destruction and modification of wetlands. These restrictions place some constraints on the placement of new development.

Currently, information about rare and protected species is provided to tenant organizations through the ITAM and the NEPA programs. Because mission activities take precedence over these species, tenants often modify their activities when possible, to protect these species and their habitat (APG 2009).

4.2.5 Biodiversity

The presence of a diversity of species indicates a healthy and well-functioning natural ecosystem (NatureServe 2008). Biodiversity is important to the military mission, because it:

1) Aids in environmental compliance and averts legal conflicts
2) Helps maintain a high quality of life for installation personnel
3) Provides realistic training for personnel
4) Protects installation resources
5) Helps with external relations beyond the installation boundary (NatureServe 2008).

Wildlife at APG consists of more than 40 species of reptiles and amphibians, 250 species of birds, and more than 40 species of mammals (EA 2008b). Common amphibians include bullfrog, green frog, northern cricket frog, American toad, and red-backed salamander. Reptiles commonly found at APG include spotted turtle, common snapping turtle, black rat snake, northern water snake, and eastern garter snake. The most common mammals are red fox, white-tailed deer, eastern cottontail rabbit, muskrat, gray squirrel, striped skunk, groundhog, and beaver. Common waterfowl include mallards, American black ducks, wood ducks, and Canada geese. Common raptors on APG include American kestrel, eastern screech owl, great horned owl, turkey vulture, osprey, red-tailed hawk, and bald eagle. Neotropical migratory birds that stop over at APG include common yellowthroat, indigo bunting, eastern towhee, gray catbird, and white-eyed vireo (EA 2008c).

Due to its ideal habitat conditions, surveys for threatened and endangered species and species of concern have been conducted at APG. No federally listed species have been identified during the last survey (in 1999), but 62 vascular plants were found that are listed by the Maryland Natural Heritage Program. At present, the bald eagle is the only protected species known to occur at the installation. It is estimated that 7% of Maryland's breeding population of bald eagles is supported by APG (APG 2009).

APG is situated on the Atlantic Flyway, a major migratory route, and is a critical habitat for neotropical migratory birds, providing stopover areas for resting, feeding, nesting, and rearing young (EA 2008b; APG 2009). DoD has policies and roles concerning the protection and conservation of resident and migratory birds and protection of vital habitat that are consistent with the military mission. DoD supports the "Partners in Flight" cooperative effort by federal, state, and local agencies aimed at conserving Neotropical migratory birds and land birds (APG 2009).

4.2.6 Recreational Opportunities

The Army Morale, Welfare, and Recreation department provides recreational opportunities to personnel on APG. The major outdoor facilities include golf courses, boat docks, tennis courts, athletic fields, shooting ranges, and picnic and camping areas (EA 2008c). Throughout most of APG, public access is restricted due to safety and security considerations related to UXOs, hazardous materials, and weapons testing. Access to hunting and fishing areas is controlled by Range Control.

The Installation monitors the activities of approximately 200 commercial fishing operations, whose combined harvest from APG's waters totals $4 million per year. In addition, APG hosts approximately 1,000 hunters per year (APG 2009).

APG has an overall goal of maintaining game species at a population level that supports biodiversity, ecological health, and mission requirements. It does not promote increasing game populations for the sole purpose of recreational hunting. The predominant game species are white-tailed deer, wild turkey, eastern cottontail rabbit, gray squirrel, groundhogs, bobwhite quail, mourning dove, and American woodcock. Small mammalian game species are predominant in edge habitat areas, and the heterogeneity of conditions provides good habitat.

The bow-hunting area encompasses the majority of APG land, excluding the northern boundary. Shotgun and muzzleloader deer-hunting areas are available throughout the entire site. Designated waterfowl hunting areas are located along most of the shorelines. Trapping areas are located in the southwestern portion of APG (APG 2009). Deer-hunting areas are open and closed according to mission requirements, not by population counts or other ecological considerations. Deer-hunting revenue to the installation amounts to $20,000 to $30,000 a year. In 2009, the estimated number of deer on site was between 2,000 and 4,000 animals. Hunting activities help APG maintain a Maryland Department of Natural Resources population goal of 1,250 to 1,875 deer. One noted problem with the APG deer-hunting program serving as an effective means of reducing the deer herd is UXO. A large proportion of ideal deer habitat is located in the secured downrange areas where hunting is restricted due to the presence of UXO. APG anticipates integrating a herd management program with their hunting program to maintain healthy deer populations and preserve vegetative areas for other species (APG 2009).

The Installation protects and manages fisheries to provide sustainable yields as set by the State of Maryland and NOAA National Marine Fisheries Service. APG waters are spawning and nursery habitats to 50 species of finfish. The predominant commercial fish are white perch, yellow perch, blue crab, eel, and striped bass. Recreational sport fishing by APG personnel is popular for species such as largemouth bass, smallmouth bass, striped bass, pumpkinseed, bluegill, yellow perch, crappie, catfish, and common carp. The Program Manager of Outdoor Recreation, Directorate of Community and Family Activities, administers recreational sport fishing on the installation. APG waters are closed to the public on weekdays and are open on weekends and holidays when the waters are not being used for military missions. Similarly, APG creeks and rivers are also closed to the public at all times. Swimming, SCUBA, and other activities in which people are outside of a vessel and touching dry or subaqueous land at any time, are illegal in APG waters due to UXO hazards (APG 2009).

Due to the habitat quality at APG, non-consumptive uses of wildlife, such as birdwatching and photography, have become popular on the site. The Department of the Army and other organizations established the Watchable Wildlife Programs on federal property in 1990 (APG 2009).

4.2.7 Aesthetic Values at APG

The majority of natural areas are located in the secure downrange areas, so most development is focused on the cantonment area. Open fields in the cantonment area are mowed infrequently, but lawn areas near buildings are mowed and groomed regularly. The areas near buildings are generally landscaped for aesthetic value. APG subscribes to the Landscaping Standard of the Installation Design Guide as part of the U.S. Army Corps of Engineers (ACOE) program, intended to enhance services and improve the quality of life at Army installations. As part of the ACOE Program, the criteria and requirements of the Base Attractiveness Program in AR 200-3, 4-8 Base Attractiveness and Scenic Values, are incorporated (APG 2009). In general, the buildings at APG are less than 40 feet tall, and tracts of trees are present to offer a balance to elevated structures (EA 2008c).

5 TEST DESIGN

This section describes the application of the decision support framework and EcoAIM™ geospatial model results. Because this demonstration project consists of applying the management tool, the test design is not a field exercise, although some verification was conducted with potential users at APG to validate assumptions or complete key data gaps.

5.1 CONCEPTUAL TEST DESIGN

The demonstration at APG is organized into seven broad tasks:

1. Site Selection
2. Site-Specific Problem Formulation
3. Field Verification
4. Selection of Biophysical Models
5. Site-Specific Implementation
6. Documentation
7. Technology Transfer

5.1.1 Task 1: Site Selection

APG in Maryland was selected for full implementation of the Project. Sites were selected based on discussions with environmental managers at these and other installations, input from our Project Liaison Officer, and other contacts. Other installations that were considered included Fort Pickett in Virginia and Cape Canaveral/Patric AFB in Florida, Joint Base Lewis/McChord (Army/Air Force) in Tacoma, Washington, and Lackland AFB in San Antonio, Texas. As discussed in Section 4.0, APG was chosen as the site for full EcoAIM™ implementation (i.e., includes stakeholder engagement workshops and site visits) because of Exponent's history of working at the Installation, APG's expressed interest in EcoAIM™, and their unique location on the Chesapeake Bay, a nationally important waterbody.

5.1.2 Task 2: Site-Specific Problem Formulation

This task consists of developing a thorough understanding of the importance of ES to mission sustainability, the benefits derived from ES, how decisions are made regarding activities that affect ES, selection of key ES for quantification, and selection of biophysical models to represent the provisioning of ES at APG. This task was accomplished over several discussions with Installation personnel, through teleconference calls and site visits, as described in our structured stakeholder engagement section (Section 2.1). The following sections are summaries of the information gathered about decision making and the process of eliciting preferences from APG stakeholders regarding the importance of ES.

5.1.2.1 Initial Stakeholder Engagement Meeting

On March 12, 2012, a teleconference call was held with five personnel from the Natural Resources Branch. The participants included the Acting Chief, Garrison Wildlife Biologist, Installation Forester, and two ecologists. The purpose of this call was to introduce the Project and Exponent Project personnel and have an open discussion about environmental impacts of activities, how decision making occurs in their Branch and at the Installation level, how input is contributed to decision-making, and other similar topics.

During this call, the Project team learned that mission-related activities at APG ranged from office-based analytics to field testing of weapons and transportation platforms. Other activities requiring large land-use footprints include Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) data collection and transmission equipment such as satellite dishes. Training missions are no longer conducted on the Garrison. In addition, some of the higher impact activities, such as testing large weapon systems in downrange areas, are gradually moving to more remote sites, such as Yuma Proving Ground in Arizona. The timetables for mission-related activities can range from quick-turnaround requests from theater for tests on various deployed or soon-to-be deployed systems, to well-established research and development activities with long time and planning horizons.

The second objective of this teleconference was to understand the authority relationships and the chains of command related to decisions that affect land use and the environment. Exponent Project personnel learned that decision-making activities that have a land-use or environmental impact follow multiple paths. The Garrison Commander's (GC) office holds landlord responsibilities for the overall facility. The GC office is staffed by the General in Residence with the highest rank. As such, it rotates among the various tenant commands as their Commanders change. There are currently 11 to 13 general officers at APG. The Deputy Garrison Commander serves as the installation commander. Figure 9 illustrates the chain of command for the Environmental Division.

The Natural Resources Branch is responsible for the environmental decisions at the installation. However, each tenant or Garrison Support Organization (GSO) also has its own mission, independent from that of APG. APG's mission is to facilitate the missions of the GSOs, and thus, APG operates in a support position. The GSO environmental staff report up through their GSO, not through the Installation.

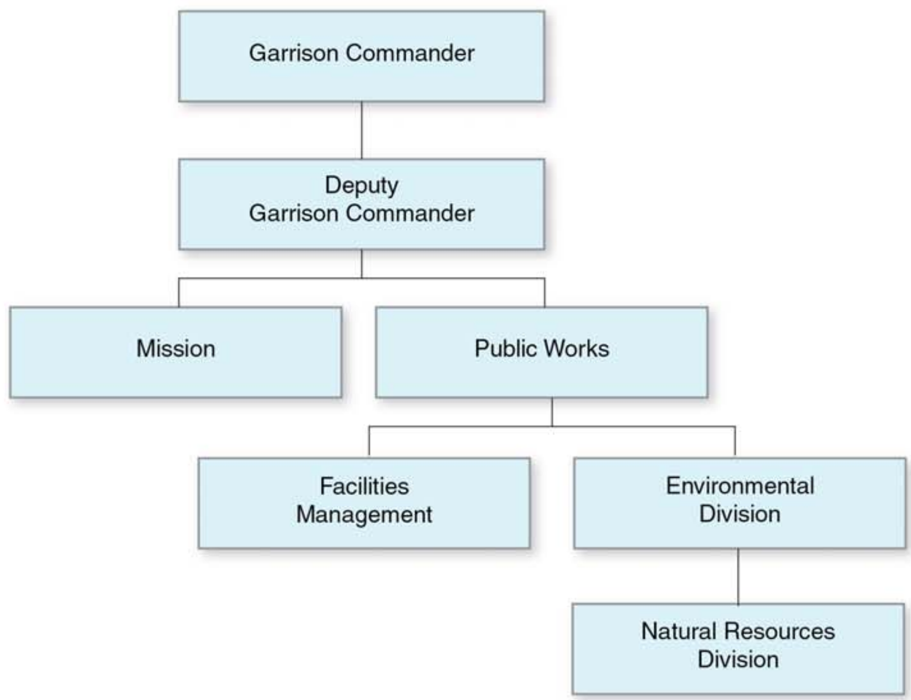

Figure 9. APG environmental division chain of command

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In addition to the formal organization, there is an Installation-wide Environmental Quality Control Committee (EQCC), chaired by the GC and attended by representatives of all tenant organizations. The committee meets at least quarterly to help plan, execute, and monitor actions and programs with environmental implications. The committee makes recommendations and advises the GC (AR 200-1, 2007). The Installation Board of Directors (IBOD) is composed of all personnel of general officer rank in residence, and an Installation Council of Colonels, with membership drawn from all tenants. Both groups are relatively new and have some type of environmental subcommittee that provides advice and guidance to the GC.

The Facilities Management Division also includes the Master Planning Branch. Master Planning takes into account the long-term activities at the Installation, as well as any small but high-profile quick-turnaround requests from theater. Theater support constitutes about 10% or less of all Facilities Management Division activities.

Exponent Project personnel learned that each CSO develops a mission plan that includes the location and expected impact of all activities. Each activity requires the generation of a NEPA filing with a Record of Environmental Consideration, and lists all categorical exclusions[4] and actions with environmental impacts. This NEPA process stimulates the flow of information to the Natural Resources Branch, because it is the single point of contact for NEPA. The Natural Resources Branch assigns a subject-matter expert to perform a review and provide feedback to the GSO regarding compliance requirements. If the project has a large enough impact on the environment, the subject-matter expert will also recommend an Environmental Assessment.

APG personnel stated that there is currently no formal mechanism for community interaction, except some interactions with citizens on the Restoration Advisory Board to address Superfund activity. Several of the Environmental Division personnel are engaged in environmental issues and organization in the community as private citizens and serve as an *ad hoc*, informal information conduit to the Installation, and vice versa.

The teleconference ended with positive remarks about EcoAIM™ being used to assist with short- and long-term land-use planning, identifying locations for testing, and providing information for their 20-year master plan. Participants also thought EcoAIM™ would be used as a communication tool to help visualize future installations to the Installation Board of Directors and Installation Council of Colonels.

5.1.2.2 First Stakeholder Engagement Workshop

Exponent Project personnel visited APG on July 11–12, 2012. This onsite workshop was designed for meeting Natural Resources Branch personnel, presenting an overview of the Demonstration project, obtaining introductions to other Branches that have input into natural resource management decisions, and conducting a site reconnaissance tour. The objective of this

[4] Categorical Exclusions are categories of actions with no individual or cumulative effect on the human or natural environment, and for which neither an Environmental Assessment nor an Environmental Impact Statement is required. The use of a Categorical Exclusion is intended to reduce paperwork and eliminate delays in the initiation and completion of proposed actions that have no significant impact. (Title 32 Part 651.28, Environmental Analysis of Army Actions).

meeting was to understand the background of environmental priorities, roles of environmental staff, and any constraints on natural resource decision making.

During a two-hour informal discussion with several Natural Resources Branch and Master Planning personnel, we learned about compliance through Master Planning, additional information about decision making, and the general spatial layout of the Installation. Decisions about the management of environmental impacts are made through two parallel structures: the installation has the Natural Resources Branch, and each GSO also has an environmental point of contact. However, because the Garrison is the land owner and permit holder, all environmental permitting for all activities takes place at the installation level. Figure 10 presents a mind map generated during meetings at APG and shows the stakeholders involved in the decision processes at APG, and Figure 11 is a mind map that illustrates how natural resource information flows through the installation.

The Exponent Project personnel visited with the Chief of Infrastructure, Security, Installation and Community Relations at the Joint Program Executive Office for Chemical and Biological Defense (JPEO-CBD). This discussion provided insight about planning and employee culture changes from a high-level perspective.

The following morning, discussions continued with two personnel from the Master Planning Branch. The conversation focused on the planning process that occurs at APG and the collaboration between the Garrison Master Planning personnel and contacts at some of the larger GSOs. Although there is some coordination at the Garrison level, it was concluded that the communication process could be improved from the current situation.

At the end of the site visit, a member of the Natural Resources Branch gave two Exponent Project personnel a “windshield tour” of the Installation. The tour consisted of the cantonment areas at both Aberdeen and Edgewood. Information about the history and usage of the site and individual buildings was provided. Exponent Project personnel noted the types of habitats available onsite, the degree of development, and areas that were to be demolished in the future. No access was given to secure downrange areas.

5.1.2.3 Second Stakeholder Engagement Workshop

Exponent Project personnel visited APG on Oct 23, 2012, for a second stakeholder engagement workshop. This workshop was intended to elucidate the dependencies that major tenants have on key ecosystem components and the visions they have for APG in the future. In addition, Exponent Project personnel wanted to understand APG’s priorities for modeling. The participants included two GSO environmental points of contact, a Natural Resources Branch representative, a Master Planner, JPEO-CBD, and a Garrison GIS specialist.

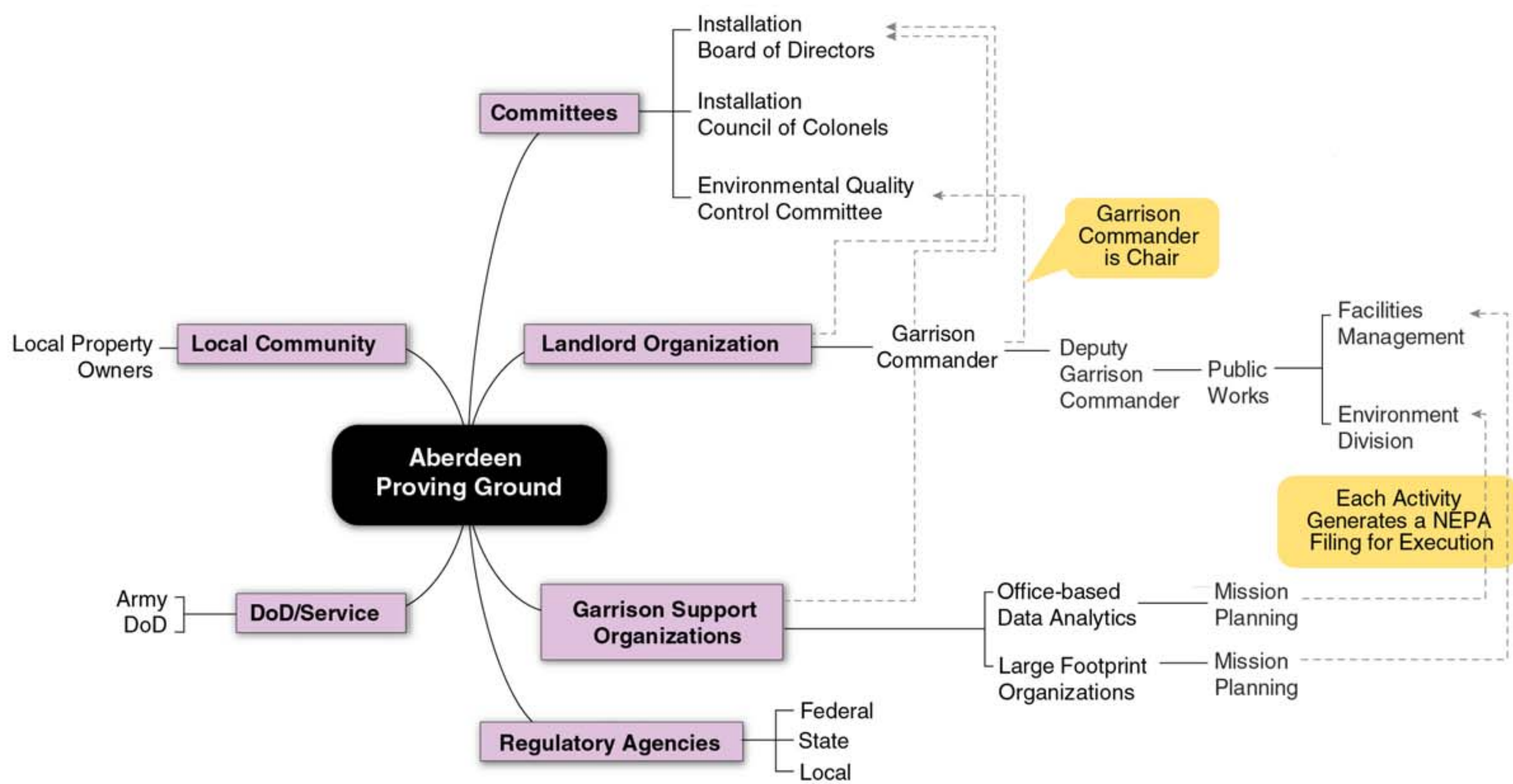

Figure 10. Mind map of stakeholder relationships at APG

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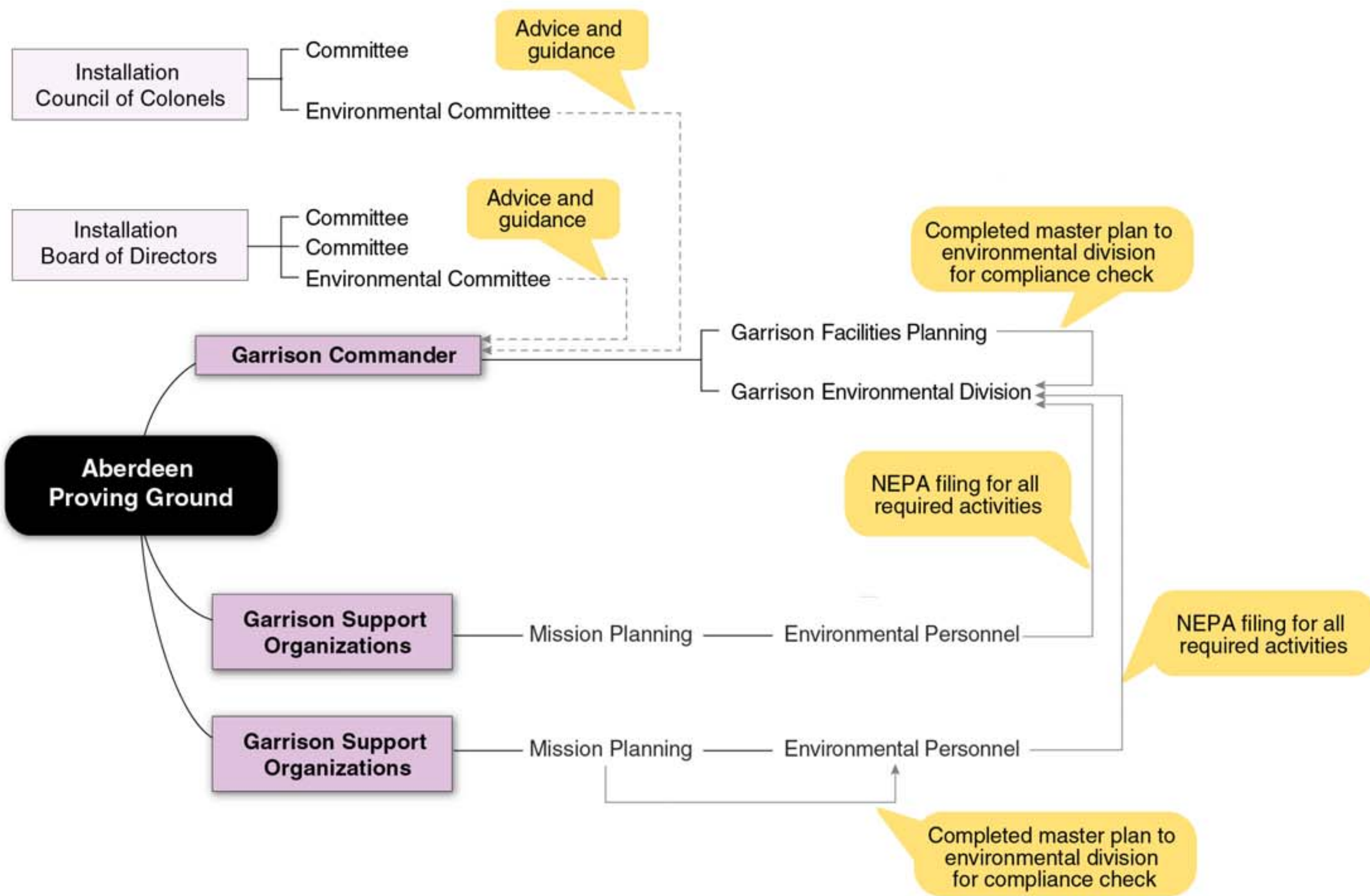

Figure 11. Mind map of information flow at APG

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During the course of the informal discussion, stakeholders discussed constraints placed on GSOs for some operational and mission activity by the Maryland Department of Environment, and environmental regulations placed on federally owned land. Participants also described some of their environmental requirements for mission support, their differentiation from other sites as a test facility, and the need for greater range areas for testing, as technology has changed to require larger spaces. EcoAIM™ was seen as a useful tool for deciding on parcels to use for operations, as well as for communicating beneficial effects of some of their cleanup and decommissioning areas to regulators. Participants stated that they foresee using EcoAIM™ in communicating land-use change proposals up the chain of command, and communicating the bald eagle protection program, the Army Compatible Use Buffer (ACUB) program, and other intangible environmental management benefits. In addition, they noted that APG has some of the higher quality water in the watershed, and they would like to capture the benefits of this protection to downstream areas.

When the discussion turned to the subject of future visions for the Installation and notional missions, it was apparent that a major focus was on retaining and attracting a talented workforce. Several of their Master Planning initiatives focused on demolishing "ugly" buildings and making spaces more functional for connecting people. In addition, recreation was discussed as a vital part of employee welfare, especially deer and waterfowl hunting and boating activities. The overall notional mission for APG is to physically be the center of a world-class research and development corridor, where it can attract partnerships with industry and universities (much like the Research Triangle in North Carolina). They want to see APG move toward a "campus-like" setting with military styling (e.g., memorials). The aesthetic conditions at APG are intended to send the message to employees that "your employer cares." This focus on aesthetics can help stimulate creativity, especially among the new generation of employees who have "experiential values." Participants agreed that current recruitment mechanisms may not compete with industry, but other factors such as aesthetics and quality of life at the Installation could be major selling points.

After discussion with participants, Exponent Project personnel decided that the ES of most importance to APG were aesthetics, recreation, biodiversity, and nutrient sequestration. In addition to identifying the models needed, Exponent Project personnel made contact with the appropriate APG staff for GIS data and background environmental and biological documents and data. The geographic scales to be used for modeling would be at the parcel or patch resolution biodiversity and recreation ES, and at a landscape scale for aesthetics and nutrient sequestration ES.

5.1.3 Task 3: Field Verification

Our initial scope of work proposed that field verification or "ground truthing" be completed if there were significant data gaps. The data provided by APG GIS personnel were sufficient for our Demonstration, so field verification was not required. In some areas, APG personnel had performed extensive forest surveys, wetland delineations, and biological surveys. All these details were captured in the GIS layers provided to the Project.

5.1.4 Task 4: Select Biophysical Models

Based on land use plans, mission requirements and visions of APG's future elicited from the stakeholder engagement workshops, it was determined that EcoAIM™ would include two aesthetics models, and models for habitat provisioning for biodiversity, recreational opportunities, and nutrient sequestration. Model selection criteria were based on the following:

- Degree of previous validation and the need for additional input data collection.
- Ability to quantitatively evaluate uncertainty and variability in model outputs. (In terms of evaluating uncertainty and variability, models with probabilistic components will be favored over deterministic models, all else being equal.)
- Applicability across environments and installations, compatibility of output with spatial/temporal analysis, compatibility (concordance or discordance) with BPFs and endpoints, and compatibility with the software platform for the geospatial analysis.

Figure 12 illustrates the technical approach in which biophysical models were selected.

Models that were reviewed but did not meet criteria are listed in Appendix B.

5.1.5 Task 5: Site-Specific Implementation

For this task, EcoAIM™ was implemented at APG as the first study site. Lessons learned from the demonstration at this site will be the basis of any refinements and modifications of EcoAIM™.

5.1.5.1 First Demonstration Presentation

Exponent Project personnel delivered an initial presentation of the geospatial tool at APG during a site visit on August 30, 2013. Several personnel from the Natural Resources Branch and JPEO-CBD attended. The meeting was intended to re-acquaint staff with the purpose of the Demonstration and the benefits of using a decision support tool, and to provide a demonstration of the existing prototype (two aesthetics models at the time). In addition, the scientific basis behind EcoAIM™ was discussed, and the upcoming biodiversity, recreation, and nutrient sequestration models were previewed.

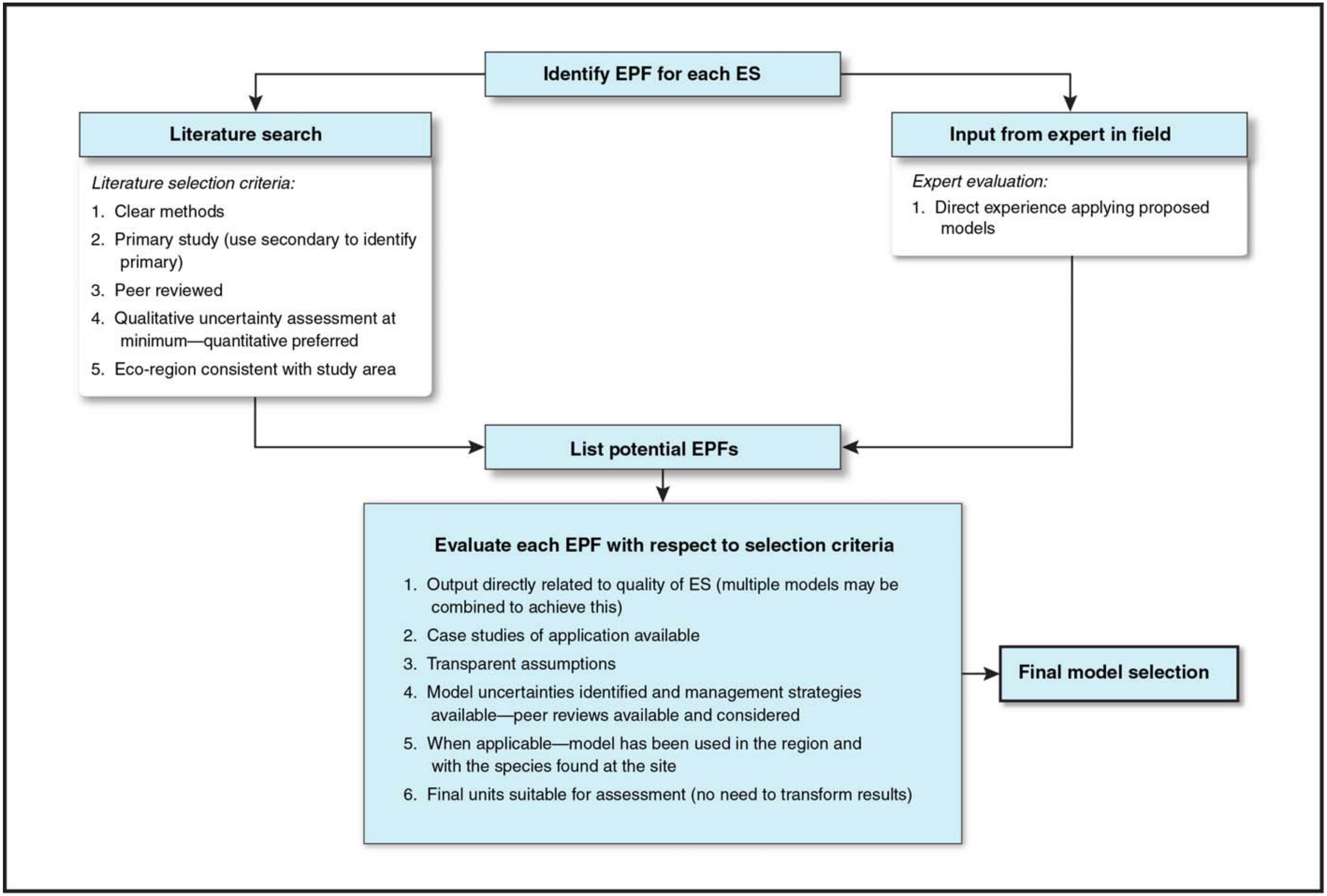

Figure 12. Schematic of model selection process

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The vista aesthetics model was presented in a real-time demonstration. APG staff were given the opportunity to pick several locations in which the model was run. Results of two locations were compared to each other. Due to the longer processing time required (~2–5 minutes), pre-generated results from the landscape aesthetics models were presented.

After the demonstration, Exponent Project personnel prompted informal discussion among the participants to elicit feedback on EcoAIM™ and its results. Comments were generally positive, with discussion based on how the two aesthetics models could be used in project planning in the near future. Personnel noticed that several of the cantonment areas with the lowest aesthetics scores were concentrated near the visitor entrances of APG. There was consensus that priorities and resource allocation for beautification would be beneficial in these areas, as they are used heavily by visitors and VIPs.

Through additional discussion of the results, there was no indication that APG personnel were concerned about the spatial resolution required to make decisions, and the ES flows and relationships to missions (POs 3 and 4). There were also no objections to a schematic diagram (Figures 10 and 11) reflecting Exponent Project personnel's understanding of the decision-making process.

5.1.5.2 Second Demonstration Presentation

The second demonstration of EcoAIM™ and modeled results occurred on February 28, 2014. This demonstration was presented as a webinar (with presentation slides and a teleconference). APG personnel included a representative from the Natural Resources Branch and a GIS specialist. The focus of this presentation was to provide detailed information about the technical aspects of EcoAIM™. Exponent Project personnel presented an overview of EcoAIM™ delivered as an ArcGIS Toolbox and the user interface, which includes the input data sources, variable measurement functions, output sources, and the output result imagery. EcoAIM™ was presented in an ArcGIS 10.1 version, so Exponent Project personnel also described areas where the toolbox may look different in an ArcGIS 10.0 environment. Also discussed was the forward compatibility capability (when APG updates their ArcGIS version), data requirements for input into the tool, and some key instructions for pre-processing data and updating data sets. (It was noted that some of the GIS layers have since been updated at APG but were not provided to the Demonstration Project).

In addition to describing the technical aspects of EcoAIM™, Exponent Project personnel introduced a potential scenario that could feasibly and reasonably occur at APG. The participants were asked about their thoughts on this scenario, and whether it would be a good case example for the Demonstration. APG staff indicated that they have been working on a site with characteristics very similar to this potential scenario. APG has been working on developing several parcels of land in the northern portion of the Aberdeen cantonment area. These parcels are currently forested areas that are gradually being cut down so that a large office park can be developed on the site. It was agreed that a demonstration with this real scenario would be appreciated by the Natural Resources Branch, and additional GIS data from the proposed site were obtained.

The EcoAIM™ usability and utility survey was presented and distributed (see Appendix C). The survey is intended to provide anonymized feedback about whether EcoAIM™ would be used at APG for natural resource decision making, how they see themselves using EcoAIM™, and whether they found EcoAIM™ easy to use, based on our demonstration presentation. A separate section in the survey requires feedback about EcoAIM usability and utility after the tool has been delivered to them.

5.1.5.3 Final Demonstration Presentation

The last demonstration occurred on March 17, 2014. This demonstration was presented as a webinar to ten personnel from the Natural Resources Branch. Participants were given an overview of EcoAIM™, re-introduced to the ES that were modeled, provided information about the scientific basis for each model and descriptions of the measurement basis for each biophysical production function, and shown the results from each ES model.

The initial portion of the presentation showed the modeled results of the current conditions, considered as the "Baseline" case for the entire spatial extent at APG. The second part of the presentation showed modeled results after land-use changes to an Enhanced Use Lease (EUL) parcel were made ('Scenario 1'). Based on discussions during the first demonstration presentation, Exponent Project personnel used the detailed GIS layers provided by APG of the EUL area and changed the land use from forested and wetland areas to a business park. Two theoretical large buildings (drawn as polygons) were placed on the map, and a theoretical trail was drawn, connecting a large wetland, running alongside the buildings, and ending at a paved road.

The mapped results of all EcoAIM™ models for the EUL Baseline and Scenario 1 cases were presented, and a side-by-side comparison was made to show the changes in ES values. The overall average ES values for the EUL were calculated, and the magnitude and directional changes from Scenario 1 were tabulated and graphed (POs 1, 2, 3, and 5). In addition, the results were discussed in terms of the key ES that changed in response to land-use changes, the illumination of unrecognized trade-offs, the sensitivity of each model (shown in default), and how differences among stakeholder preferences could affect results.

Feedback from participants was positive. There was great interest in the changes that occurred under scenario 1, because that scenario will be representative of real events occurring at the site in the near future. Discussion focused around landscaping changes and maximizing aesthetics in the EUL. There were also comments about trade-offs, especially among biodiversity, aesthetics, and nutrient sequestration (PO 6). The demonstration concluded with dissemination of the utility and usability survey and request for survey responses.

5.1.6 Task 6: Documentation

The documentation will be provided to support end users of EcoAIM™ and will include user instructions within the Toolbox. The documentation will provide a definition for each measured variable in each model and general instructions for input, and preference weighting. The Toolbox will also have information about the technical requirements of EcoAIM™, such as input requirements, pre-processing the data, and updating data.

In addition to tool roll-out, Exponent Project personnel are in the process of developing at least two manuscripts describing EcoAIM™ for submittal to a peer-reviewed journal. The first manuscript will introduce the technical approach of the EcoAIM™ structured stakeholder engagement process and the overall framework of the GIS tool. The Demonstration at APG will be showcased as a case study. The second manuscript will focus on the two aesthetic models, using results from the APG demonstration as an example. To Exponent's knowledge, geospatial tools similar to EcoAIM™ have not been developed and applied to assess vista or landscape aesthetics. EcoAIM™ and this Demonstration will also be showcased in a poster or platform presentation at the annual SETAC meeting in November 2014 and/or the biennial ACES conference in Dec 2014.

5.1.7 Task 7: Technology Transfer

The final phase of this Demonstration is the successful transfer of EcoAIM™ and supporting documentation to DoD and each of the installations. The current schedule for tool delivery is October 2014. EcoAIM™ will be delivered to each installation via a CD to be installed as an ArcGIS Toolbox and Add-in file. In addition, some limited technical support from Project GIS specialists will be provided to end users. After EcoAIM™ delivery, a follow-up usability and utility survey will be disseminated to elicit feedback, to determine a) the extent to which users are satisfied with EcoAIM™'s ease of use and degree of training provided, and b) whether the decision makers are effectively using the tool to create realistic scenarios, presenting results as a communication tool, and making natural resource management decisions.

5.2 BASELINE CHARACTERIZATION AND PREPARATION

A fundamental aspect of this demonstration project is that EcoAIM™ relies on existing information composed of publicly available regional geospatial data, as well as site-specific data collected under a variety of programs at each installation. No original data were collected for this Demonstration. Exponent Project personnel worked with the Natural Resources Branch to compile all available and relevant data, including GIS layers and field survey data to characterize habitat quality, species presence/absence data, or population data.

The data used in the current conditions "Baseline" results include the following GIS layers:

- Land use/land cover
- Forest stand (forest_stand_area.shp)
- Grassland (land_cover_area.shp)
- Wetland (wetland_area.shp)
- DEM
- Unpaved roads (road_area.shp)

The data layer used for the Scenario 1 modeling included:

- EUL (Forest Stand Delineation Map.pdf and forest_EUL_site.shp)

The reference material used for verification included:

- Aerial photos from Google Earth Pro.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY AND METHOD COMPONENTS

The technology and method of the demonstration project revolves around EcoAIM™, a geospatial analytical tool that incorporates biophysical models to represent BPFs. This section describes the geospatial tool and the methods that were employed to select the most appropriate and scientifically defensible biophysical models, and provides the biophysical models that are incorporated in the tool for APG. The data requirements are specific to the biophysical models that were selected for implementation. Key ES and modeling endpoints were determined by APG stakeholders during the structured stakeholder engagement process.

5.3.1 Geospatial Analytical Tool

The geospatial analytical tool is delivered as an ArcGIS Toolbox. This Toolbox was programmed in Python to function within the ArcGIS framework as a geoprocessing and geospatial analytical tool. EcoAIM™ makes use of the publically available and site-specific GIS data, and incorporates the five models as separate Toolboxes. Within each model, each measured variable is listed, such that the end user can run a specific variable and generate results. Input weightings for each variable are also available to the end user, so that the final ES value for each model reflects the user's preferences. For example, for the aesthetics model, the end user can weight forests and wetlands high and buildings and cemeteries low, such that the results provide high aesthetics scores for areas that are natural and low scores for built-up areas. The use of preference weightings also allows the end user to perform sensitivity analyses of the tool. As mentioned earlier, this flexibility is essential for the tool to be applicable to a wide range of environmental and social settings.

The EcoAIM™ Toolbox includes the five biophysical models with powerful simulation and visualization techniques, in order to effectively communicate results to system users and decision makers. Spatially linked biophysical data are used in models, and outputs from these models are displayed spatially on maps. The tool allows users to model the baseline case, and then draw a "polygon" on a map, and change the land-use category of that polygon. For example, a large swath of grassland can be changed to a mid-successional forest, or a forested parcel changed into a six-story building. Figure 13 shows the user interface of the EcoAIM™ Toolbox within ArcGIS 10.1 software.

The screen shot of the EcoAIM™ Toolbox shows an expanded menu (in blue box) of each measurement variable in the forest and wetland landscape models. The user interface also

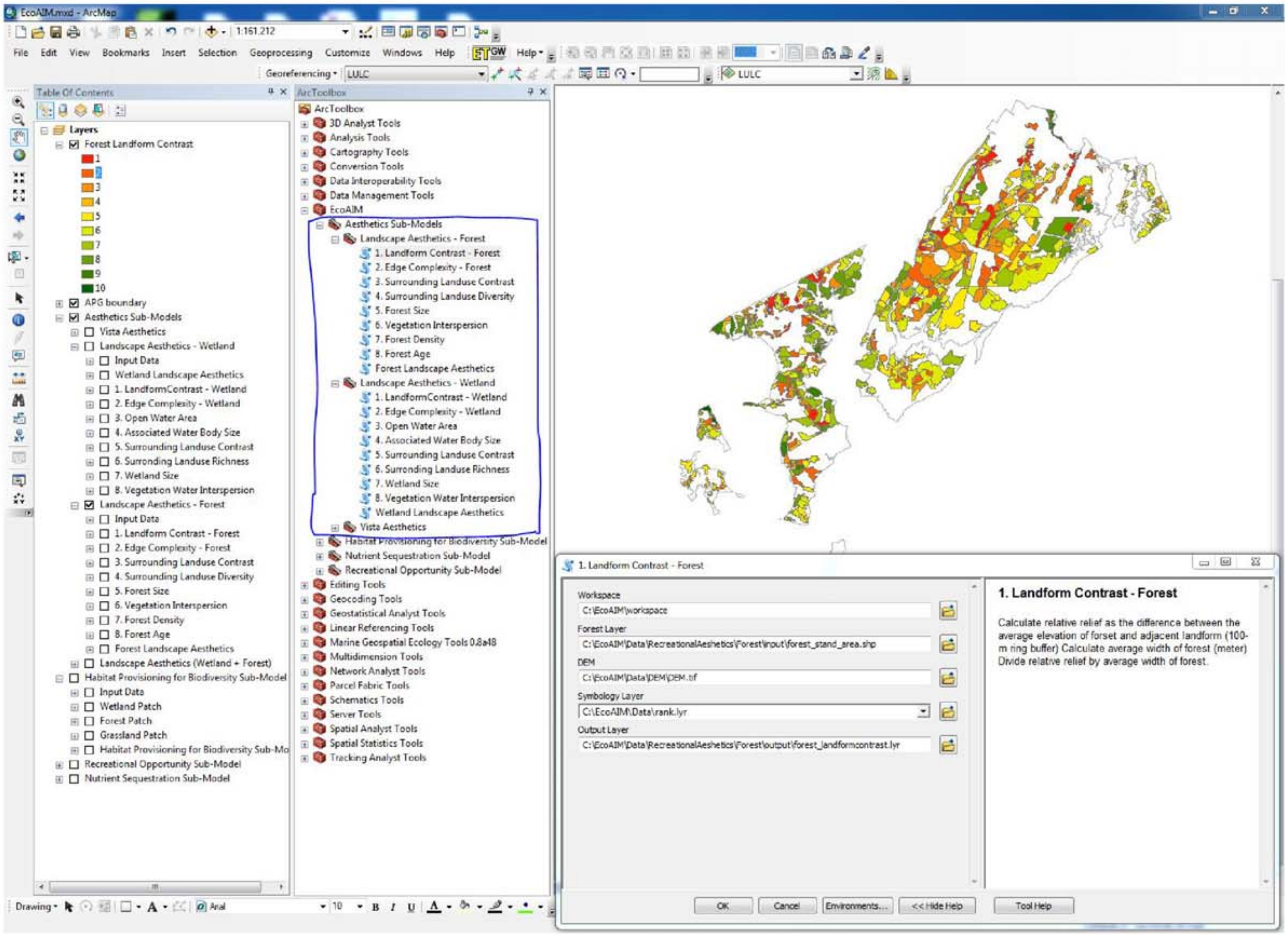

Figure 13. Screen shot of user interface

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includes the input data box, shown as the "Workspace," "Forest Layer," "DEM," "Symbology Layer," and "Output Layer." The input box also provides a description of how each variable is measured: "1. Landform Contrast – Forest." The screen on the upper right side shows the results of the variable calculation on a spatial basis.

Each of the variables that are measured for each BPF variable, and its scientific basis, is described in Section 2.2.

5.1 FIELD TESTING

Field testing was not required for this Demonstration. Instead, results were presented to decision makers and stakeholders at an onsite meeting and through two webinars (as discussed in Section 5.0). Prior to running EcoAIM™ for the Baseline and Scenario 1 demonstration, Installation personnel provided feedback on the representativeness and accuracy/precision of the input data.

During the demonstration of the tool, Exponent Project personnel provided an overview of the data used, the models, and results of the current ES values under current management. Exponent Project personnel also displayed a realistic and feasible scenario (previously vetted by APG staff) of a land-use decision for a large parcel of land (the EUL). APG participants were shown how the ES values changed through maps, tables, and graphs. Details of these results are presented in Section 5.6.

5.2 SAMPLING PROTOCOL

Sampling for biophysical data was not performed for this Demonstration. A site tour of the cantonment area was given to Exponent Project personnel by APG staff at the start of the project. Field survey results and GIS layers provided by APG personnel were used and deemed to be verified data sources. No ground-truthing of the data was required.

There is no equipment calibration or data quality assurance other than that described in Section 3.0, *Performance Objectives*, and Section 6.0, *Performance Assessment*. Therefore, no text is presented in the subsections of this section.

5.3 RESULTS

The following section is a detailed summary of all modeling results from the APG Demonstration. The results of the final ES score from each model are presented in figures. For individual variable results that contributed to the final ES score, see Appendix D.

5.3.1 Biodiversity Model Results

Figures 14, 15, and 16 show the results of the biodiversity model for wetlands, forests, and grasslands. Because each habitat patch was input into EcoAIM™ as a separate layer, output was also presented as separate layers. Patches with the greatest habitat provisioning for biodiversity have high scores (up to 10) and patches with low quality habitat have low scores (as low as 1). Generally, wetlands that are large and adjacent to Chesapeake Bay have scores of 10, and small, isolated wetlands, especially in the cantonment areas have low scores. Large, contiguous forests in the downrange area scored the highest values, especially in the Aberdeen portion of the installation. These areas had relatively high edge habitat heterogeneity and were in proximity to a waterbody, usually within its patch borders. Edgewood forests, in general, had lower quality forested habitats due to their proximity to many roads and built-up areas. The majority of grasslands had relatively high biodiversity scores (7–10), especially those that were large in area were near waterbodies and forests. Figure 17 is the combination of all three patch-layer results. If there were overlapping areas between layers in the input files, wetlands superseded forests, which in turn, superseded grasslands.

5.3.2 Landscape Aesthetics Model Results

Figures 18 and 19 show the results of the landscape aesthetics model for wetlands and forests. Because each habitat patch was input into EcoAIM™ as a separate layer, output was also presented as separate layers. Wetlands/forests with the best landscape aesthetics have high scores (up to 10), and wetlands/forests with low-quality habitat have low scores (as low as 1).

Generally, large, contiguous wetlands along the Chesapeake Bay have scores of 10, whereas isolated, smaller inland wetlands have low scores. The wetlands along the shoreline had the highest scores, because they were associated with more water bodies and demonstrated higher vegetative/water interspersions. The large forest patches in the downrange area scored some of the highest values, because they have relatively large acreages and greater edge complexity. A few of the smaller forest patches in the Edgewood cantonment area also scored high, because these areas had relatively high intrinsic aesthetic characteristics, such as greater forest density.

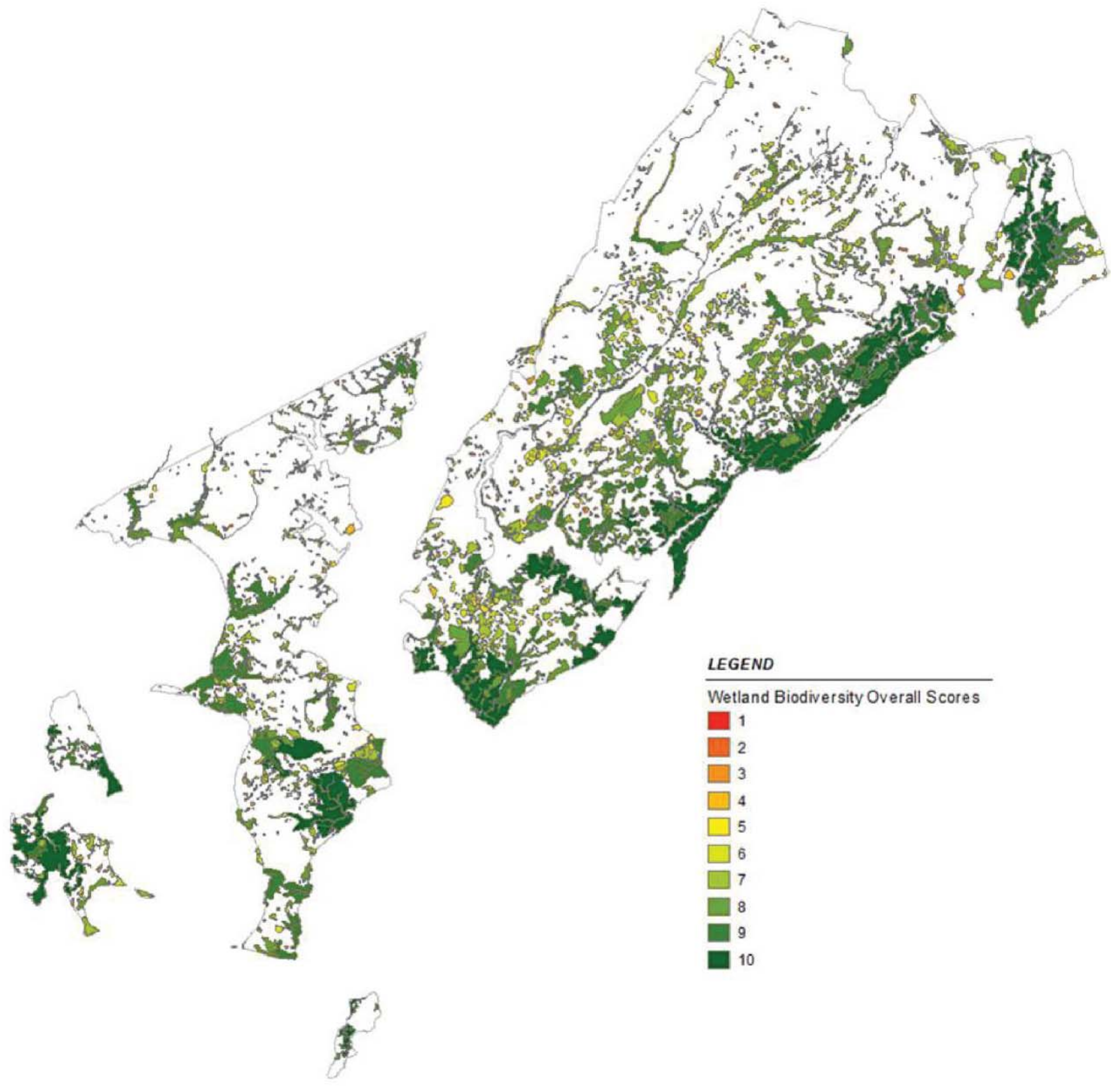

Figure 14. Wetland biodiversity results

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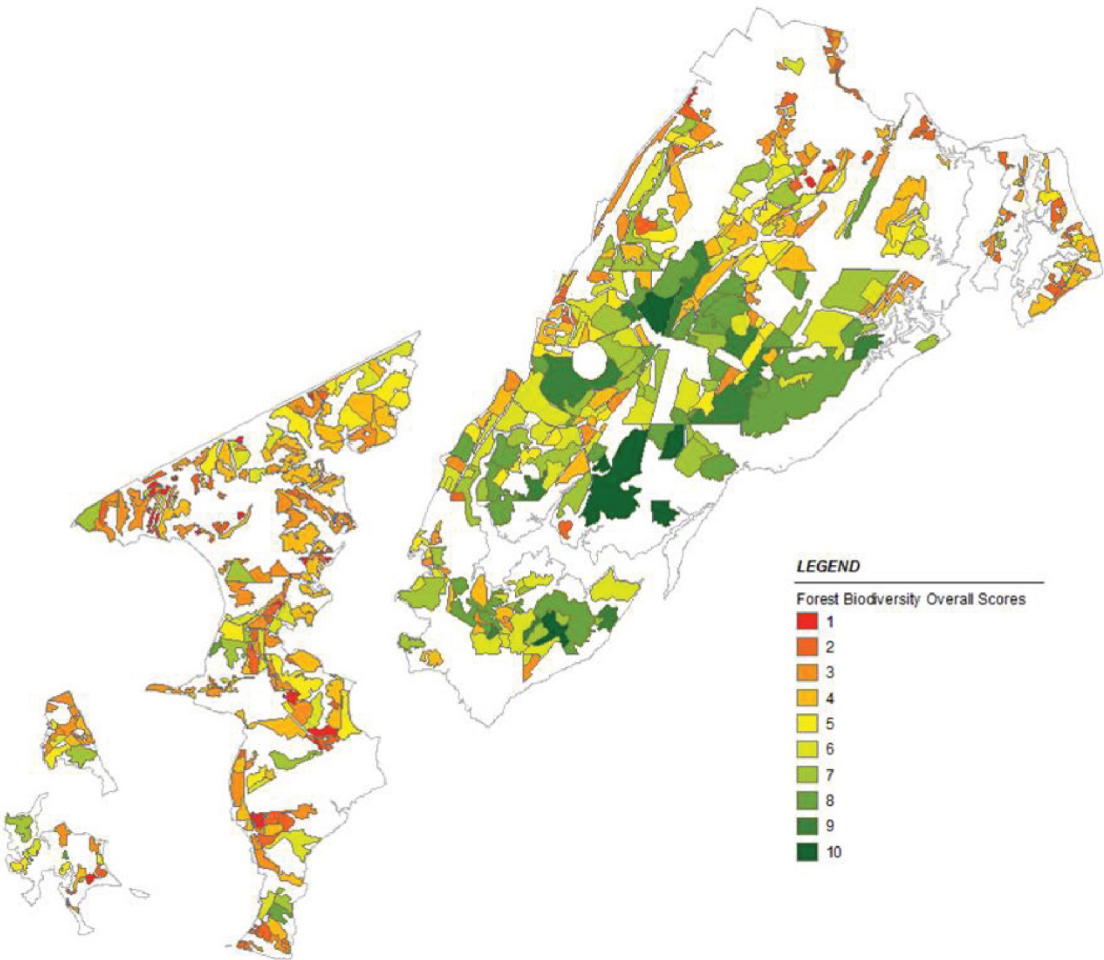

Figure 15. Forest biodiversity results

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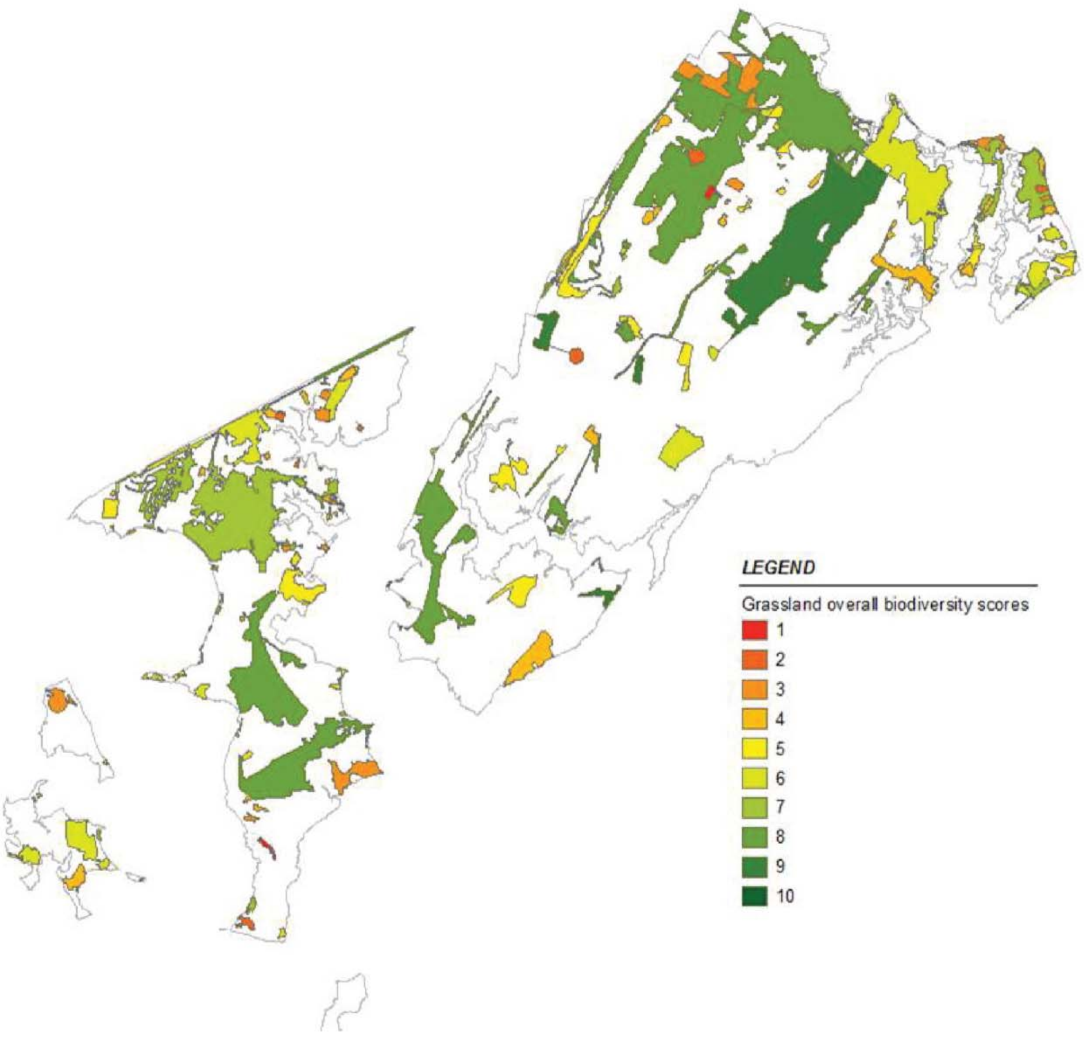

Figure 16. Grassland biodiversity results

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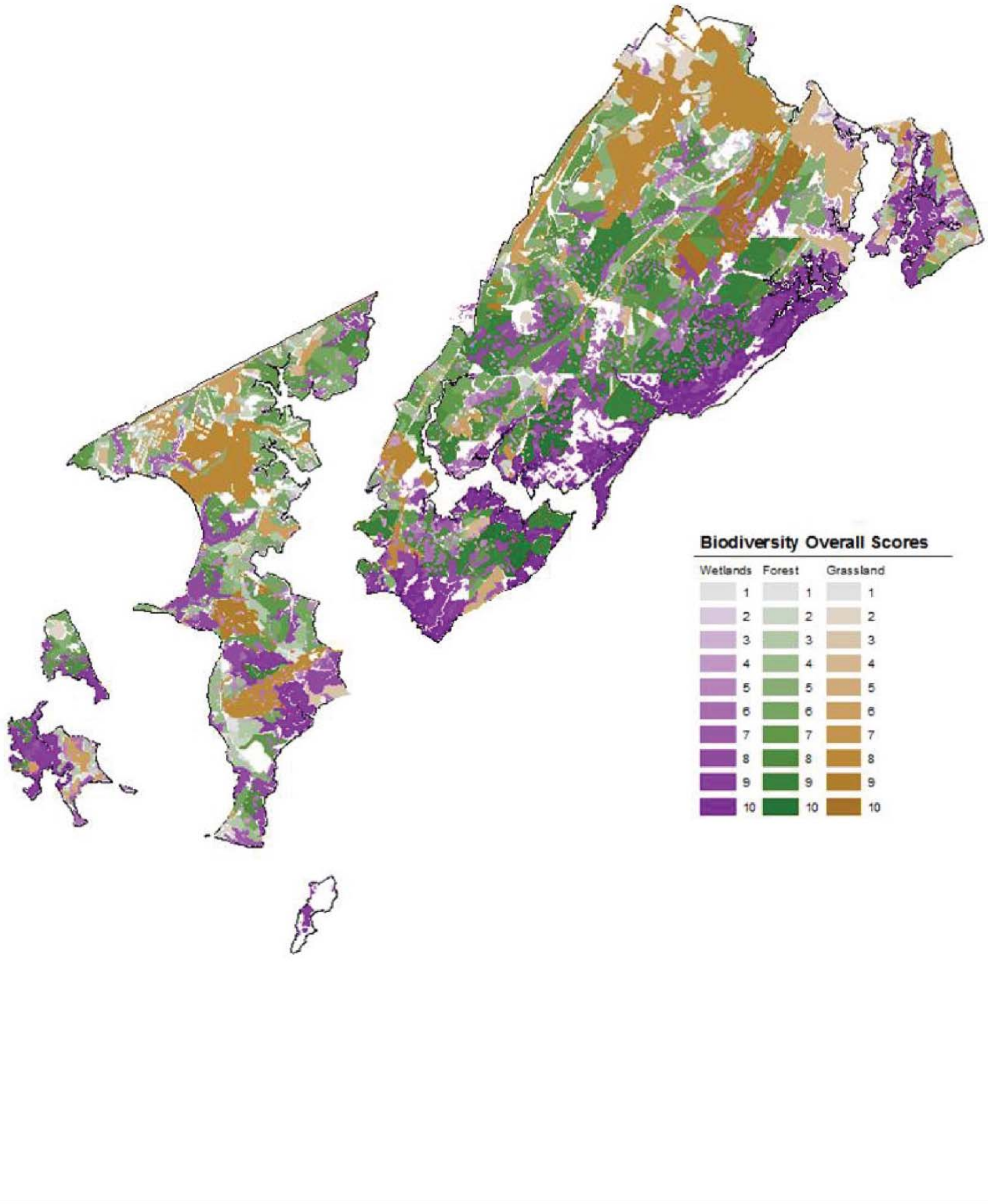

Figure 17. Wetland, forest, and grassland biodiversity results

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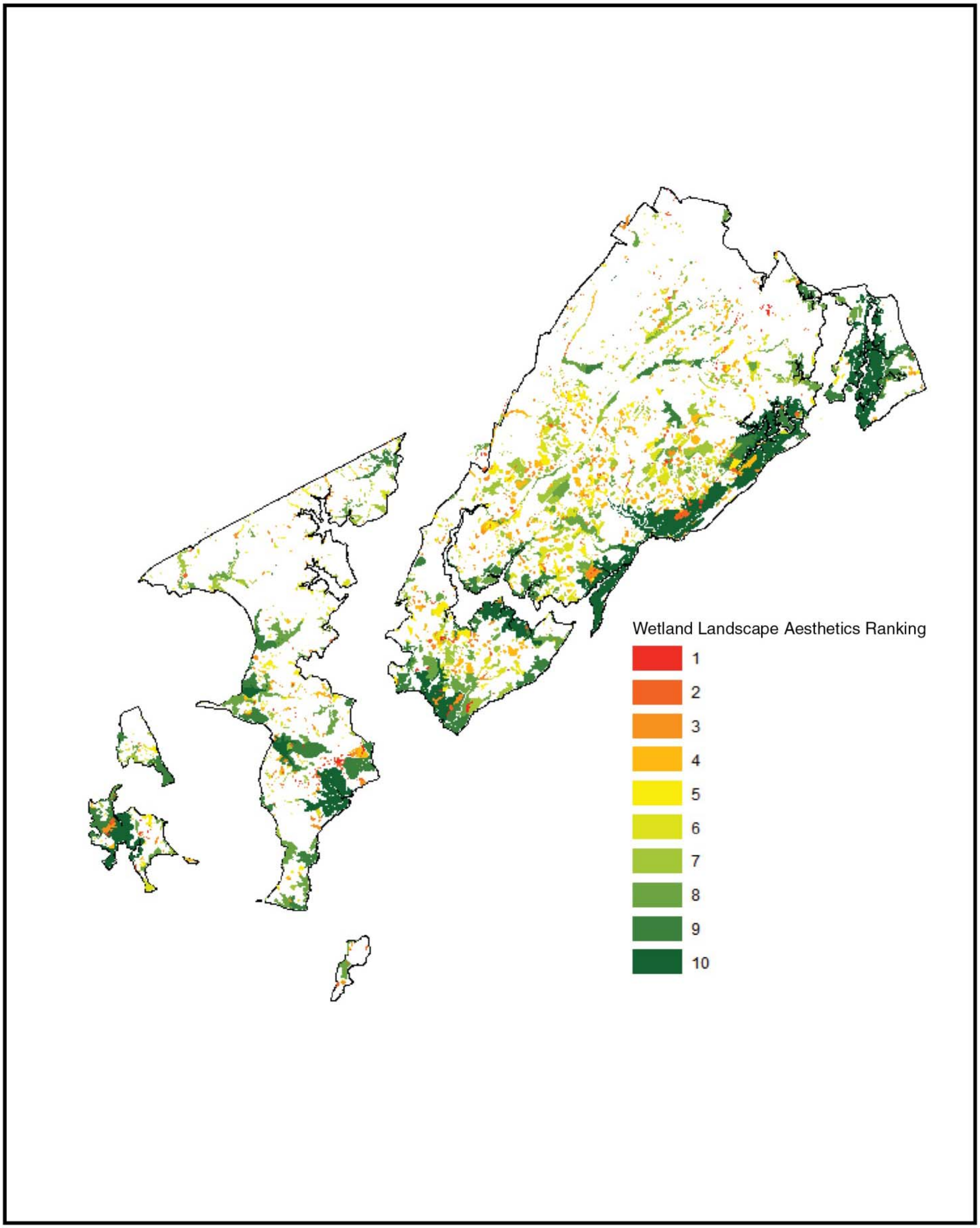

Figure 18. Wetland landscape aesthetics

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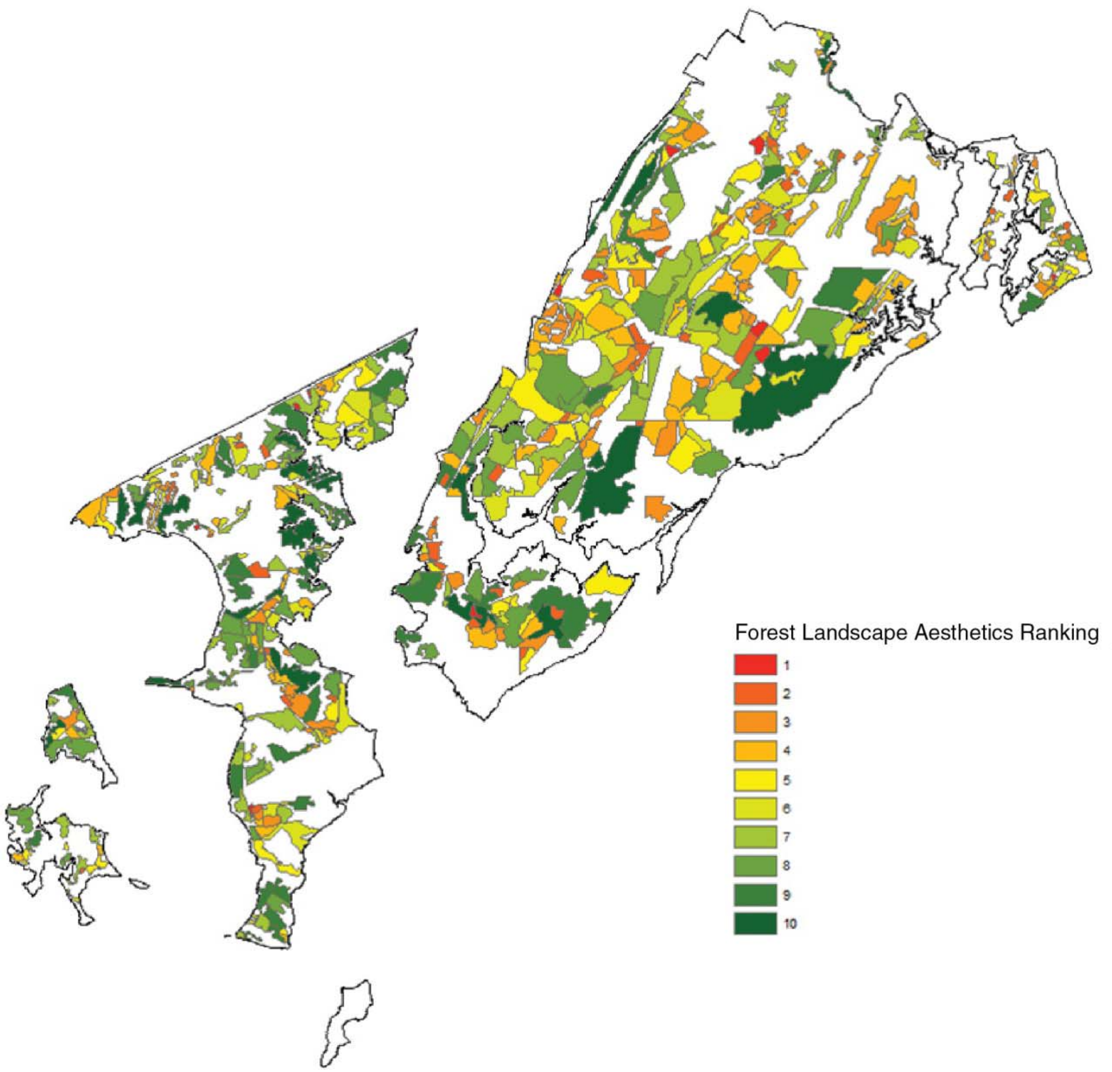

Figure 19. Forest landscape aesthetics

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5.3.3 Vista Aesthetics Model Results

Figure 20 shows the assessment results from the Vista Aesthetics model. The viewshed is delineated by drawing a line on the DEM, with the starting point of the line as the observation point and the line direction as the direction of view by the observer. The default elevation is 4.6 m (15 ft) above ground level, based on the ground elevation (from the DEM) at the point of observation. However, the user can designate another elevation (e.g., 3 or 6 m above ground elevation) to simulate a viewshed from an office window on a second or third floor. The view angle is set to a default value of 90°. The tool extracts visible pixels of land use in the viewshed area and calculates three landscape metrics characterizing the viewshed's vista aesthetics quality. All else being equal, the larger the viewshed area, the better the vista aesthetics quality. Viewshed area is largely a function of elevation above ground and obstructions to views (forest or buildings). Patch richness is the weighted sum of the number of different patch types in the viewshed, with lower weights applied to "less desirable" patch types. Shannon's Diversity Index is based on the number of different patch types and the proportional area distribution among patch types. The maximum value is reached when all patch types have the same area.

5.3.4 Recreational Opportunities Model Results

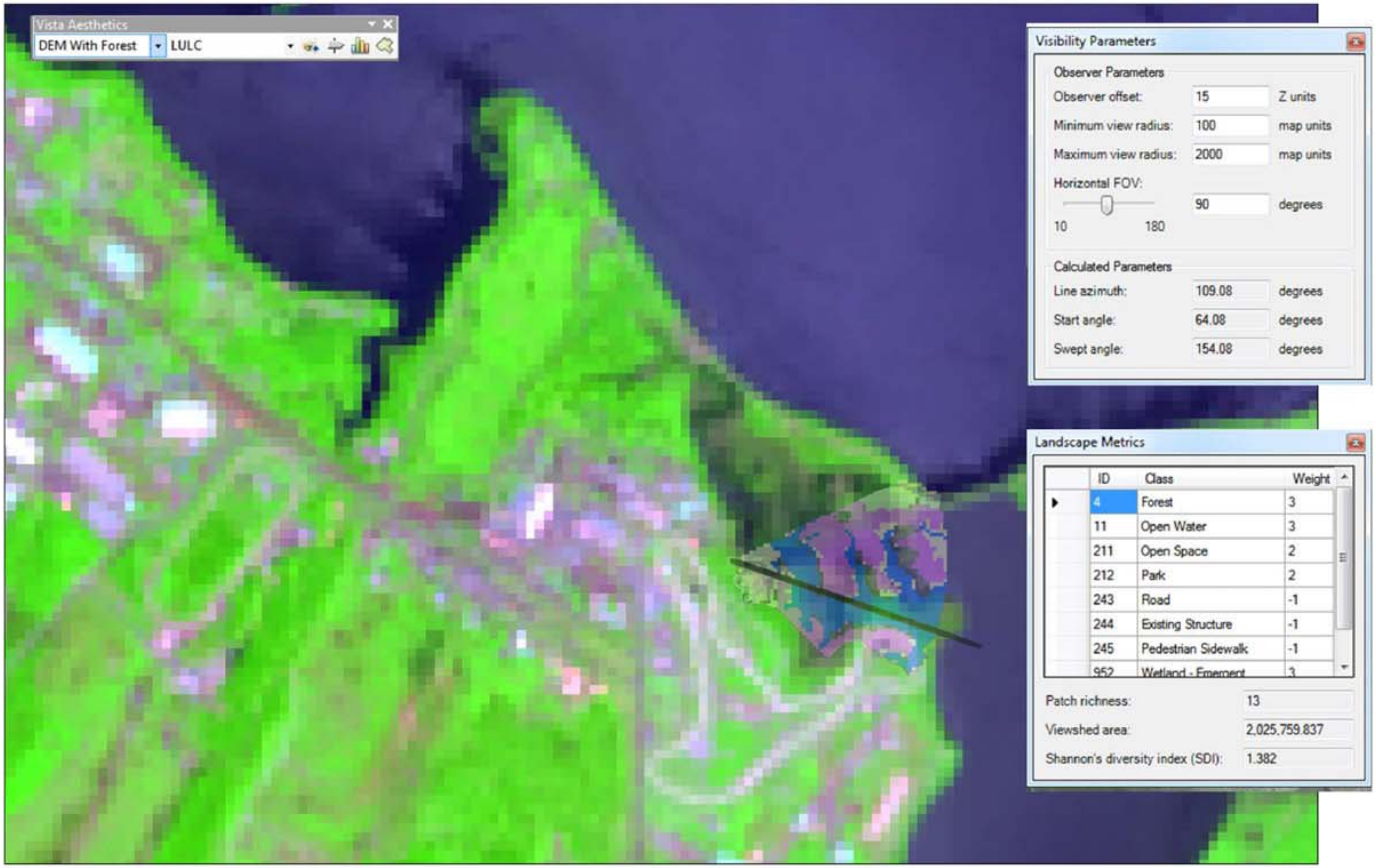
Figure 21 shows the results of the recreational model with calculated overall scores for each grid cell. Grid cells with the highest overall score for recreational opportunities (up to 10) have the following factors in common: access to roads, access to boat launch sites, and nearby residential and work areas. Additional factors that contribute to the highest overall score observed on the map are aesthetics, biodiversity, and slope. Some of the areas with lower recreational scores (2–5) are highly influenced by the lack of residential and work areas nearby. The areas along the Chesapeake Bay have scores of 3–4, despite the presence of some large wetlands in the area. These lower scores are explained primarily by the fact that the area is isolated from most residential and work locations and does not have ready road access. The recreational opportunity scores are highly influenced by accessibility, which is driven by the presence of roads and proximity to residential and work areas.

5.3.5 Nutrient Sequestration Model Results

Figure 22 shows the results of the total nitrogen loadings estimate before sequestration by wetlands, based on the P8 model. Wetlands receiving the largest nutrient loadings were displayed as red (up to 2,605 lbs/yr), and wetlands with lowest nutrient loadings were displayed as green (as low as 0 lbs/yr). In general, the smaller wetlands immediately downstream of the cantonment areas have relatively high nutrient loadings, because the drainage areas contributing total nitrogen are mostly from developed areas.

Figure 23 shows the amount of total nitrogen that can be sequestered by a wetland, based on its loadings (Figure 22) and the removal effectiveness, as determined by wetland width and vegetation type. The smaller wetlands immediately downstream of the cantonment area sequester greater amounts of nitrogen due to the higher inflows of nitrogen. The large, contiguous wetlands in the downrange area did not sequester as much total nitrogen, because relative to the small wetlands, there was less loading of nutrients (their drainage areas are not dominated by built-up areas).

Figure 24 shows the amount of nutrient after the sequestration by subtracting the nutrient loadings (Figure 22) and nutrient reduction (Figure 23). The smaller wetlands immediately downstream of the cantonment area still showed the highest nutrient loadings, but were reduced from pre-sequestration loading of 2,605 lbs/yr to post-sequestration loadings of 405 lbs/yr. In general, the smaller wetlands immediately downstream of the cantonment areas sequestered the greatest proportion of total nitrogen.



Note:
The Landsat image in the background of this figure is for illustrative purposes only. Models in EcoAIM use aerial images supplied by APG that are considered confidential to the Installation.

Figure 20. Vista Aesthetics

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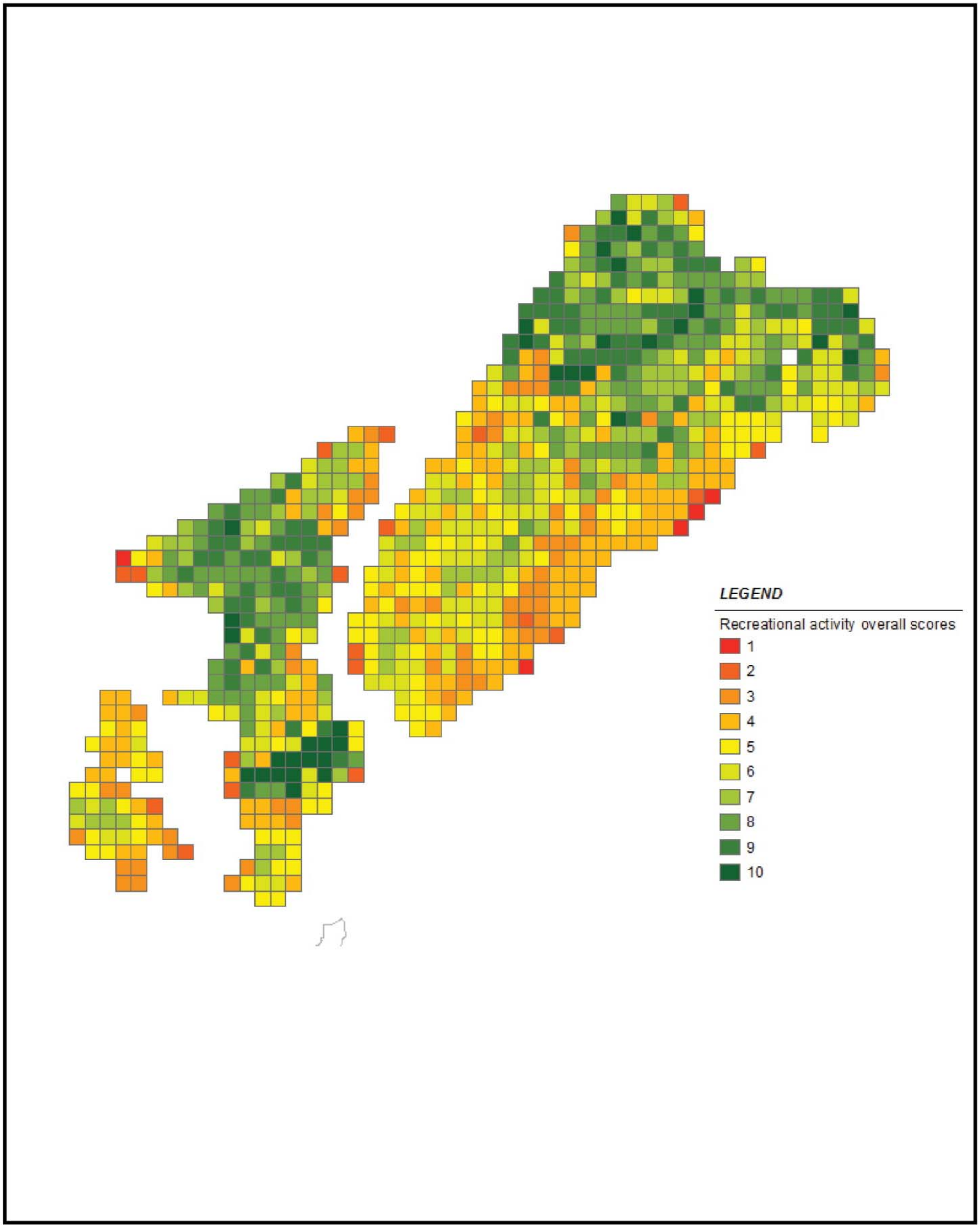

Figure 21. Recreational opportunities

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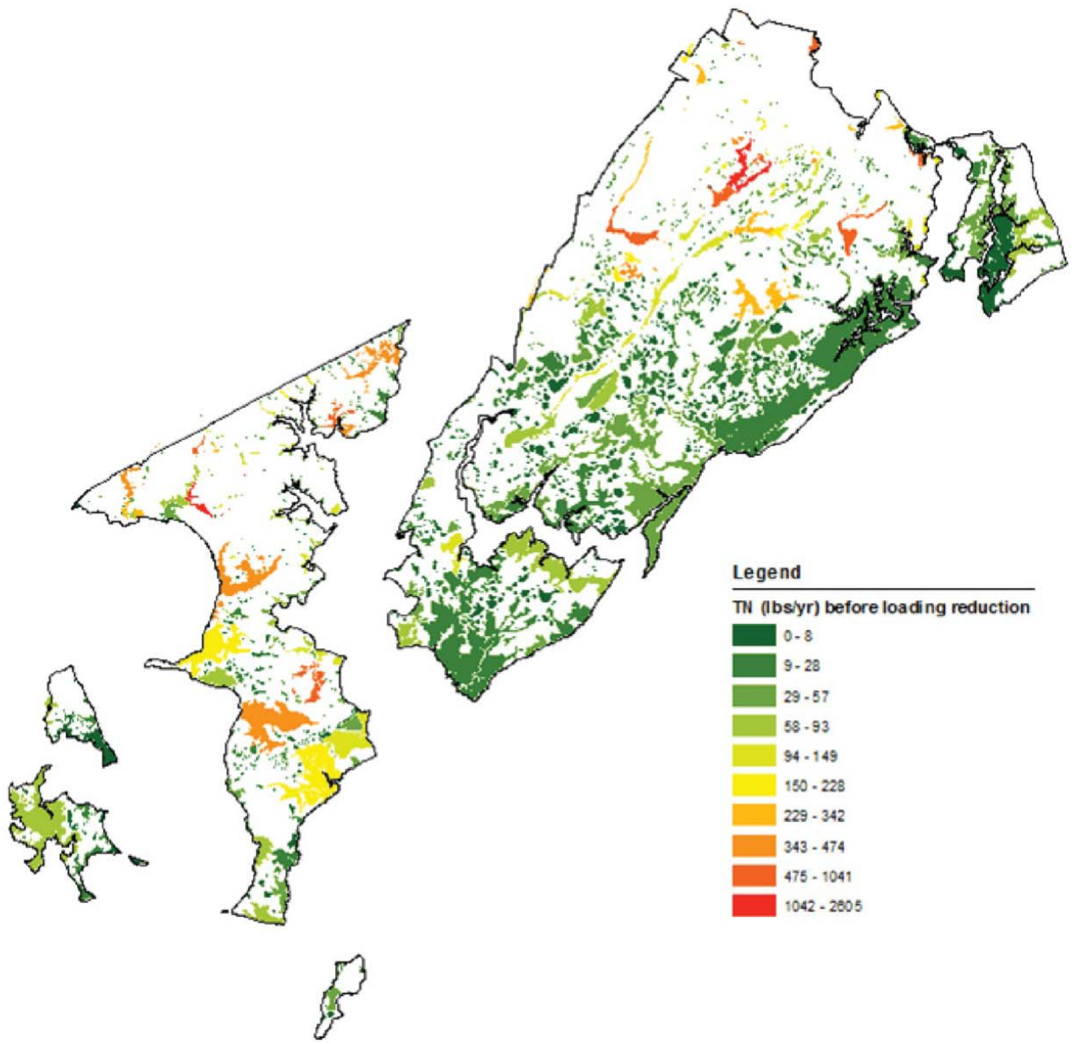

Figure 22. Total nitrogen loadings into each wetland prior to sequestration

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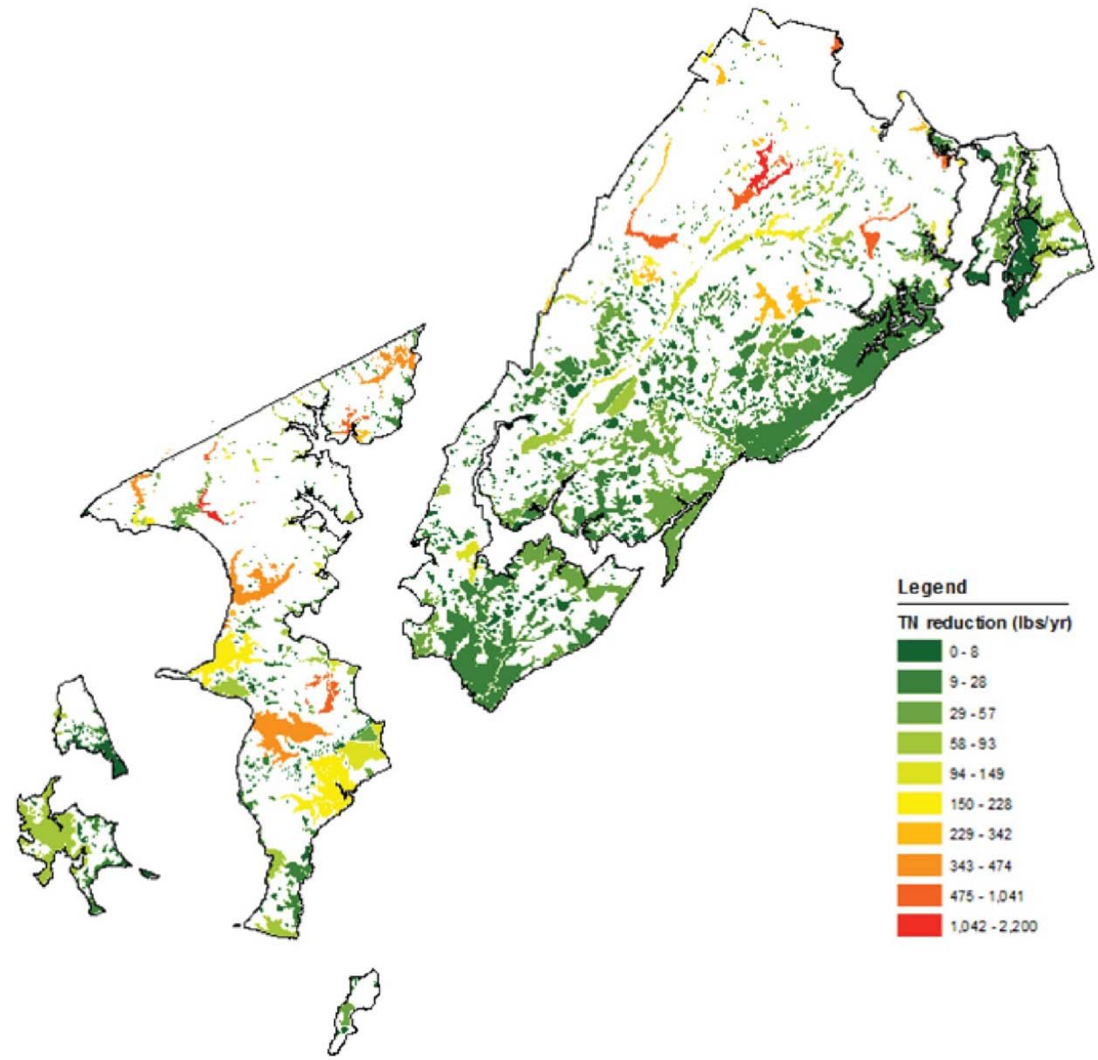

Figure 23. Total nitrogen removal from each wetland by sequestration

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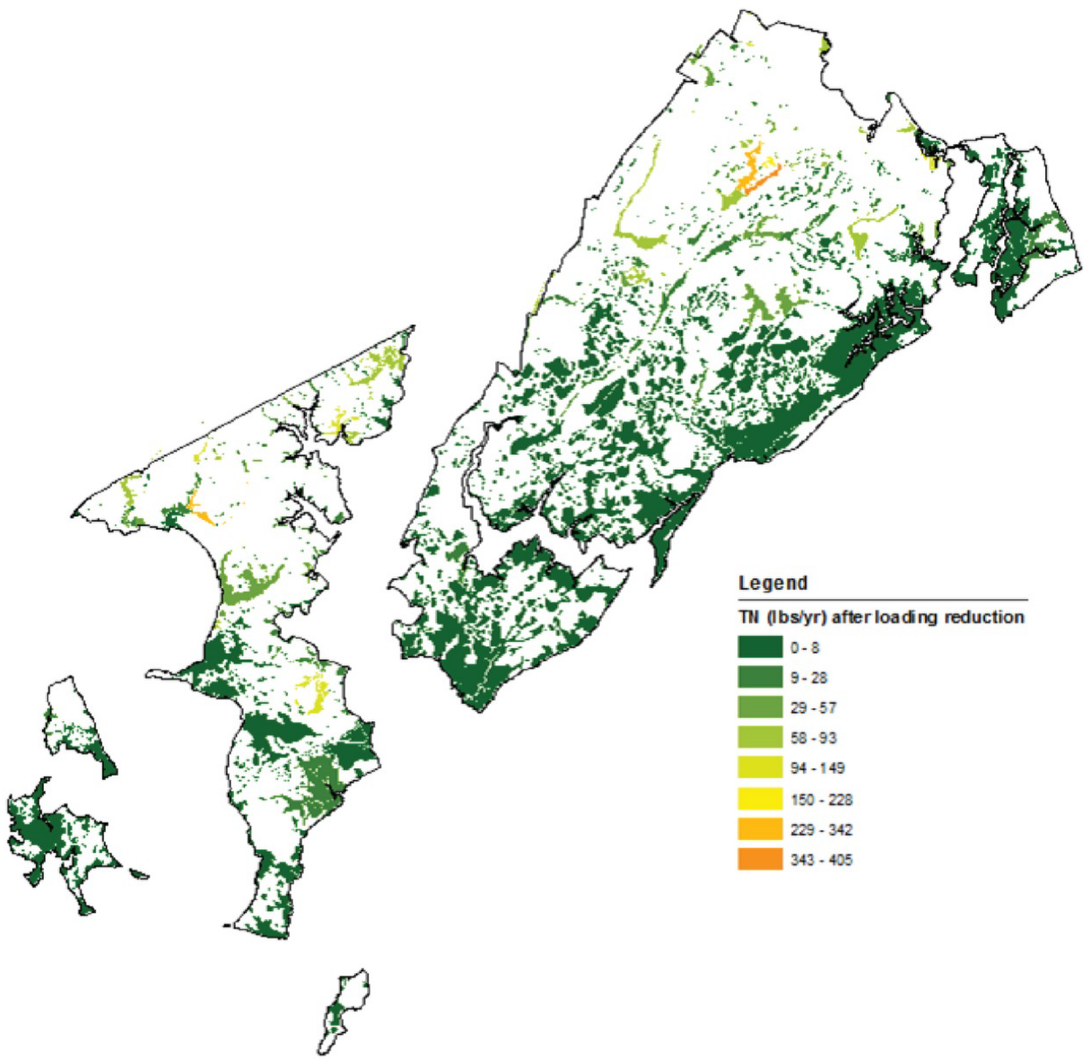

Figure 24. Total nitrogen outflow from each wetland after sequestration

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6 PERFORMANCE ASSESSMENT

This section summarizes the data analysis that was conducted to support the assessment of the six performance objectives.

6.1 PERFORMANCE OBJECTIVE 1: DEMONSTRATE THAT QUANTIFICATION OF ECOSYSTEM SERVICES IS WELL FOUNDED

This is a qualitative performance objective. The preponderance of the evidence in the peer-reviewed scientific literature indicates that the overall concept of ES quantification is well founded and broadly accepted as an environmental management technique. No statistical analyses were conducted in the evaluation of this performance.

Section 2.3 details some of the scientific literature that was reviewed. It is evident that many researchers have created models or a quantitative approach to valuing ES. EcoAIM™ incorporates two scientifically vetted models—EPA's P8 and University of Maryland's RAT models. Both models have been used by public agencies, academic researchers, and environmental consultants in the U.S. to model stormwater runoff (e.g., Wisconsin DNR 2012; Dotto et al. 2010; Tetra Tech 2005). The other models developed as part of this demonstration were created by Exponent based on research conducted by others.

Several types of biodiversity models are reviewed in the scientific literature, and several of these were determined to be inappropriate for the purposes of the Demonstration (e.g., ecological niche model, probabilistic models for individual species, habitat suitability index, GLOBIO3). Although these models related wildlife to LU/LC and specific habitat characteristics, they did not sufficiently model ES flow of habitat provisioning for biodiversity and provide an overall non-monetary valuation in the spatial resolution needed (by patch or parcel). In addition, most biodiversity models (especially Habitat Suitability Index models) require detailed site data on attributes that are key to a species distribution. Fairly extensive data collection would be needed to apply these models, and that requirement is in conflict with one of the primary objectives of the demonstration, which is to develop models that can be used with existing site data from an installation.

Similarly, recreation models that already exist in the scientific arena were not appropriate for the purposes of this Demonstration. Several approaches focus on monetary aspects of recreational importance (e.g., travel-cost calculation), and those that use LU/LC were particular to a specific recreational activity (e.g., snowmobiling). However, many references explored the specific attributes that make a parcel highly valued for recreational opportunities (e.g., Klinsky 2000; Siderelis and Moore 1998; Termansen and McClean 2004), and thus, the approach used in EcoAIM™ draws from this literature by developing spatial models around universally accepted attributes that influence recreational value. Therefore, the recreation model is considered to be well founded in the scientific literature.

EcoAIM™'s two aesthetic models are also founded on the existing scientific literature on natural beauty. Many papers used data from surveys that asked participants what they considered to be aesthetically pleasing in natural areas. Subsequently, follow-up studies related landscape features to those areas that were considered beautiful. EcoAIM™'s two aesthetics models capture the beauty-defining attributes that are measurable at the landscape or patch level. Based on the extent of peer-reviewed, aesthetics-related scientific literature, the EcoAIM™ aesthetics models are considered to be well founded on the current knowledge of this ES flow.

6.2 PERFORMANCE OBJECTIVE 2: QUANTIFY THREE OR MORE ECOSYSTEM SERVICES

This performance objective is a mix of quantitative and qualitative criteria. Quantitative criteria were evaluated on the basis of comparison with available and applicable literature values. The Demonstration Plan made provisions that if literature values are unavailable, a list of sources of uncertainty would be generated, and that a sensitivity analysis would be performed.

The quantitative estimates of nutrient sequestration in the scientific literature are similar to the results generated from EcoAIM™. The scientific literature reports that wetlands are highly variable in their effectiveness at removing surface-water nitrogen, depending on the vegetation type, soil type, wetland size, and geographic location. Forested wetlands have an estimated removal efficiency of up to 90%. Moreover, mature forests were 2 to 5 times more effective than thinned or managed forests. Soil types and buffer widths are major contributors to the effectiveness of nitrogen removal. Surface wetland removal of nitrate ranged from 12% to 74% effectiveness in peat/sand, and 81% for forested wetlands with sand (USEPA 2005). The meta-study by USEPA (2005) was used to generate a regression equation between the buffer widths and removal potential. The mean nitrogen removal effectiveness from the meta-study is 72.3% (USEPA 2005). Nutrient reduction from this Demonstration ranged from 0 to 3079 lbs/year (Figure 23). For wetlands at the maximum nitrogen loading rate, the reduction was approximately 85%. Wetlands that had intermediate levels of nitrogen loading had reductions of about 81%. Wetlands adjacent to Chesapeake Bay that had minimal loadings (<28 lbs/year) had removal efficiency of about 71%. In summary, the wetlands modeled by EcoAIM™ are within the quantitative range of values reported in the literature for similar habitats.

For the ES models that result in a relative ranking score (i.e., biodiversity, recreation, aesthetics), literature values that can be directly comparable are not available. However, there are scientific studies that explore the individual attributes that have significant impact on the ES and that are incorporated as measured variables in each model. For example, there are numerous studies on the effects of habitat fragmentation on biodiversity. The EcoAIM™ biodiversity model incorporates a measure of fragmentation to assess the overall habitat provisioning for biodiversity for each patch. Section 2.2 details the variables that were measured and included in the models. Based on modeling results, this Demonstration has shown that EcoAIM™ can quantify four ES (biodiversity, aesthetics, recreation, and nutrient sequestration) with its six embedded models (two models each for nutrient sequestration and aesthetics).

6.3 PERFORMANCE OBJECTIVE 3: DISPLAY QUANTIFICATION OF THREE OR MORE ECOSYSTEM SERVICES IN A GEOSPATIAL CONTEXT

This performance objective also consisted of a mix of quantitative and qualitative criteria. Quantitative criteria relate to two aspects of mapping accuracy: concurrence between aerial images and thematic maps, and determination of mapping accuracy based on ground-truthing. Because all GIS layers were provided by APG, with several layers ground-truthed for various surveys and site-specific projects, no field verification by Exponent Project personnel was required. It was assumed that the data provided were sufficiently up-to-date and relevant for their natural resource decision-making needs.

There was no target spatial resolution for the graphical representation of ES for this demonstration project, for the following reasons:

1) The spatial resolution of the analysis is directly related to the spatial resolution of data input files, and this will vary (e.g., 30-m pixels for National Land Cover Data [NLCD] thematic maps vs. aerial photos that might have sub-meter pixel resolution).
2) A major premise of the EcoAIM™ framework is that the tool relies on readily available data without the need for supplemental data collection.
3) The degree of spatial accuracy needed to support decision making is highly dependent on the nature of the decisions.

It was important for this Demonstration to determine whether the spatial resolution obtained is adequate to support decision making, and if not, what additional data might need to be collected. In support of this determination, additional GIS layers were requested for the EUL area, so that the baseline and Scenario 1 could be compared. No field verification was needed, because these detailed EUL layers were already the result of an intensive survey effort by APG staff.

The site-specific accuracy assessment is defined as the detailed agreement (concurrence) between thematic maps and reference data at specific locations. The reference data are assumed to be accurate, and to be the standard for comparison. Sources of reference data include APG's field data and higher resolution satellite images.

Pixel locations were randomly generated by ArcGIS. The sampling strategy was based on land-use features presented in the thematic map (e.g., wetland, forest, agriculture) and best professional judgment. By matching the thematic maps and reference maps, the overall proportion of correctly represented pixels estimated how accurately the thematic maps reflect the "true" situation. Most often, the data sets for comparison are not the same for mapping units. For example, land use/land cover (LU/LC) thematic maps from Landsat have a 30-m pixel size, which means that the predominant land cover within that 30-m (2.5 acres) will be represented by one pixel. The pixel in the LU/LC thematic map is assessed as "accurate" if the dominant feature for the pixel area is correctly identified compared to the reference data. The threshold for meeting the quantitative criteria is determination of >85% concurrence between thematic maps and reference data. The value of 85% has been widely used as a target in thematic mapping via image classification (e.g., McCormick 1999; Scepan 1999; Wulder et al. 2006) and is seen by many as a universal standard for thematic mapping in remote sensing (e.g., Fisher and Langford 1996; Weng 2002; Rogan et al. 2003; Bektas and Goksel 2004).

The aerial photo (2013) was compared to the LU/LC GIS layer (2007), because it is the underlying base layer for all four ES models. The accuracy of the LU/LC layer is rendered to be the accuracy of all thematic maps generated by EcoAIM™. Based on the 60 points in the LU/LC map generated by ArcGIS, the number of points that match with the aerial photo was 52, or 88.3% matching concurrence. By meeting this quantitative portion of this Performance Objective, the Demonstration has shown that EcoAIM™ can quantify the four ES in a geospatial context. Table 6 below presents the results of this comparison

Table 6. Comparison of LU/LC layer and aerial photos.

	Water	Open Space	Built-Up	Forest	Wetland
Water	0			1	1
Open Space		15		4	
Built-Up			7		
Forest				18	1
Wetland					13
Overall accuracy = 53/60 = 88.3%					

The qualitative criterion consisted of determining whether there is a consensus concurrence among installation decision makers that the spatial resolution of the mapping is sufficient to support customary decision making. This information was acquired through feedback from the two demonstration presentations. Per the Demonstration Plan criteria, Exponent Project personnel received feedback from five potential end users at APG. No concerns were voiced during the discussion about the spatial resolution of the presented maps. Spatial resolution issues were avoided early on, when Exponent Project personnel requested detailed base maps of the EUL for the scenario exercise. Considerations for spatial resolution were included as part of the request, and APG staff responded with maps that have been ground-truthed and used for their planning purposes. Thus, stakeholder feedback did not include problems associated with spatial resolution, and the qualitative portion of Performance Objective 3 was met.

6.4 PERFORMANCE OBJECTIVE 4: DEVELOP MAPS OF ECOSYSTEM SERVICE FLOWS ASSOCIATED WITH THE INSTALLATION, AND CLEARLY DESCRIBE ACTIVITIES INVOLVED IN THE MISSION

This is a qualitative performance objective. The degree of success in meeting this objective was determined based on the iterative interview process in the stakeholder engagement meetings and presentations. In particular, stakeholders at the August 2013 meeting were asked whether the Exponent Project personnel had correctly mapped the decision process (Figures 10 and 11) and accurately described some of the activities that would affect ES at APG. Feedback from APG staff indicated that EcoAIM™ was modeling the ES of value to their critical missions and non-critical missions. In addition, they pointed out how some of the modeled ES are affecting some of their current decision-making priorities and planning for the near future (e.g., EUL development) and the long term (notional mission of attracting talent).

Based on feedback from APG staff, this Performance Objective was met. Stakeholders provided consensus concurrence on a) the investigators' portrayal of current and future mission activities and roles, and responsibilities and methods of the environmental decision-making process; and b) stakeholders' understanding of the concept of ES and the relationship between mission-related activities and ES.

6.5 PERFORMANCE OBJECTIVE 5: QUANTIFY SHIFTS IN THE VALUE OF BENEFITS FROM ECOSYSTEM SERVICES UNDER DIFFERENT MISSION SCENARIOS

This performance objective consisted of quantitative and qualitative criteria. Qualitative methods were applied to evaluate the shift, in both direction and magnitude, of each of the ES modeled. Comparisons were made at the EUL site between the Scenario 1 conditions and baseline conditions. Results can be seen in Figures 25-33 for each ES. The average biodiversity score for the EUL decreased by 10% when two buildings and a trail were added to the site in Scenario 1. Conversely, these three additions increased the overall landscape aesthetics score by 10%. The average recreation score did not change. Many parcels had baseline levels in the highest category of scores, and changes due to Scenario 1 raised the raw scores, but the category scores did not change. The results were outside of the original modeled baseline data. Similarly, nutrient sequestration, which began in the lowest categories at baseline, did not change under scenario 1, because the decrease was outside the confines of the baseline model.

The Demonstration results for nutrient sequestration are consistent with the scientific literature. Changes in wetland area are related to the ability to sequester nutrients (USEPA 2005). The placement of a building on a large wetland (Scenario 1) decreased the area and, therefore, its potential to sequester nutrients. However, the majority of the wetlands in the EUL are upstream of the two hypothetical buildings and the trail, and therefore are unaffected by Scenario 1 changes. Raw scores and category scores did not change greatly for this ES.

The addition of an unpaved trail and the new proximity to two workplaces increased the overall recreational opportunity score. The importance of trails to recreationalists and the distance from urban areas, are attributes that make natural spaces more amenable for recreation. The overall scores in the modeling results also reflect this.

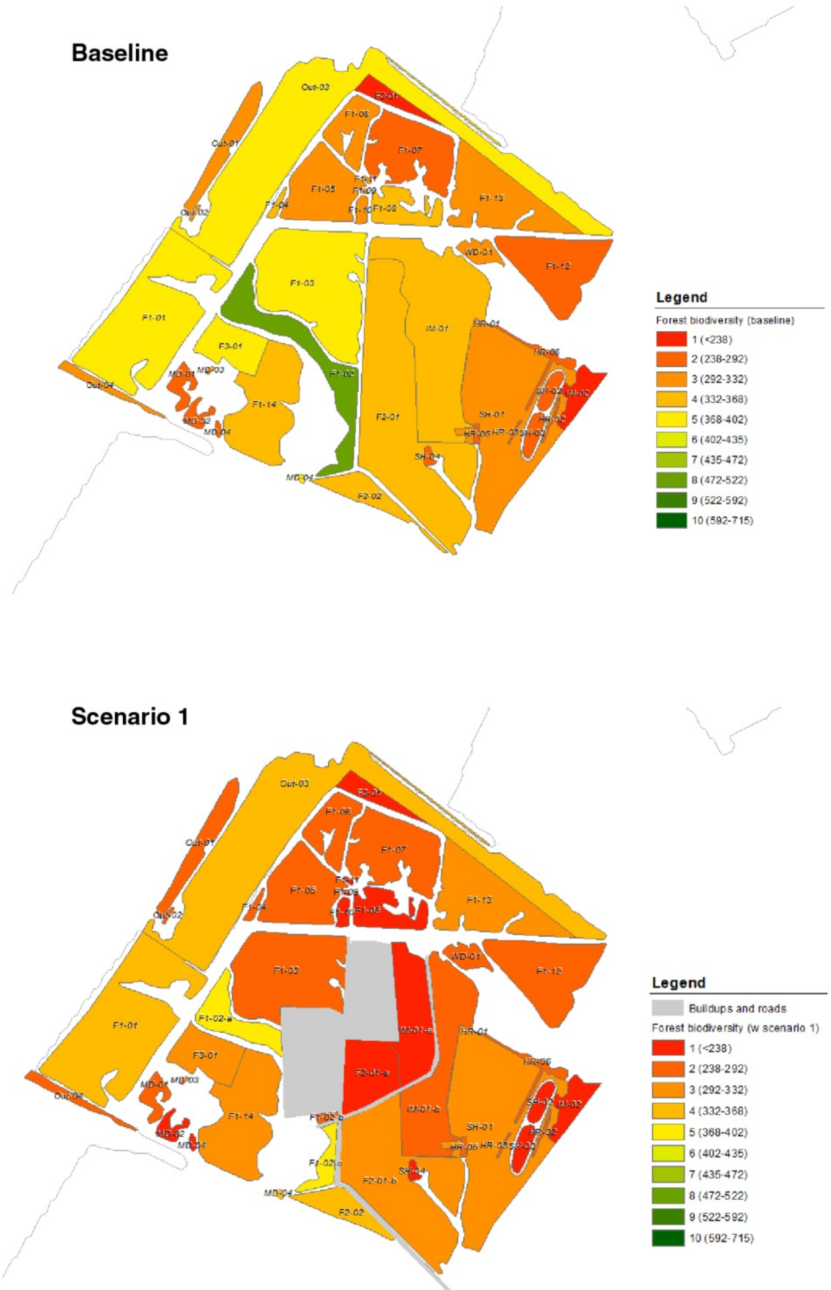

Figure 25. Comparison of Baseline and Scenario 1 forest habitat provisioning for biodiversity. Changes ranged from -30% to -10%.

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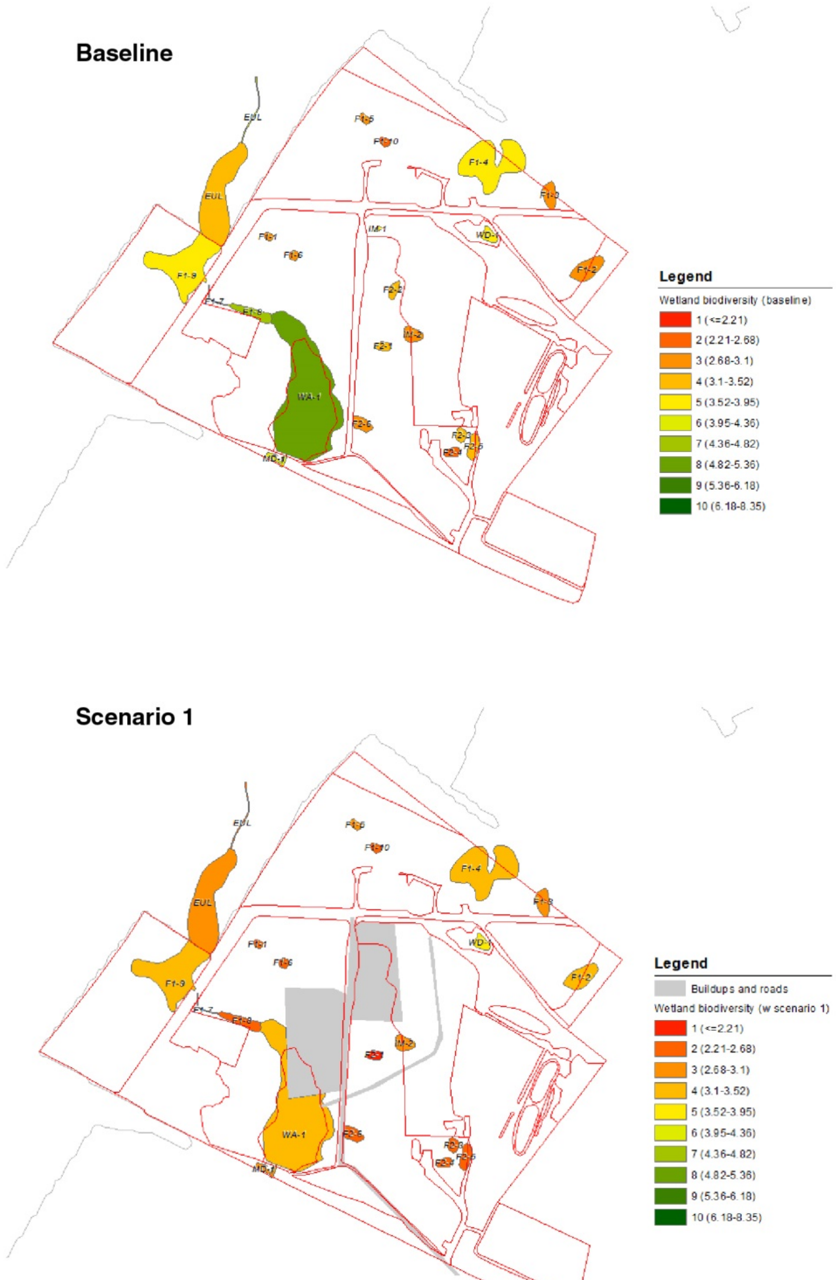

Figure 26. Comparison of Baseline and Scenario 1 wetland habitat provisioning for biodiversity. Changes ranged from -40% to -10%.

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Figure 27. Comparison of Baseline and Scenario 1 grassland habitat provisioning for biodiversity. Some raw scores decreased but remained in the same ES Value category so overall scores did not change.

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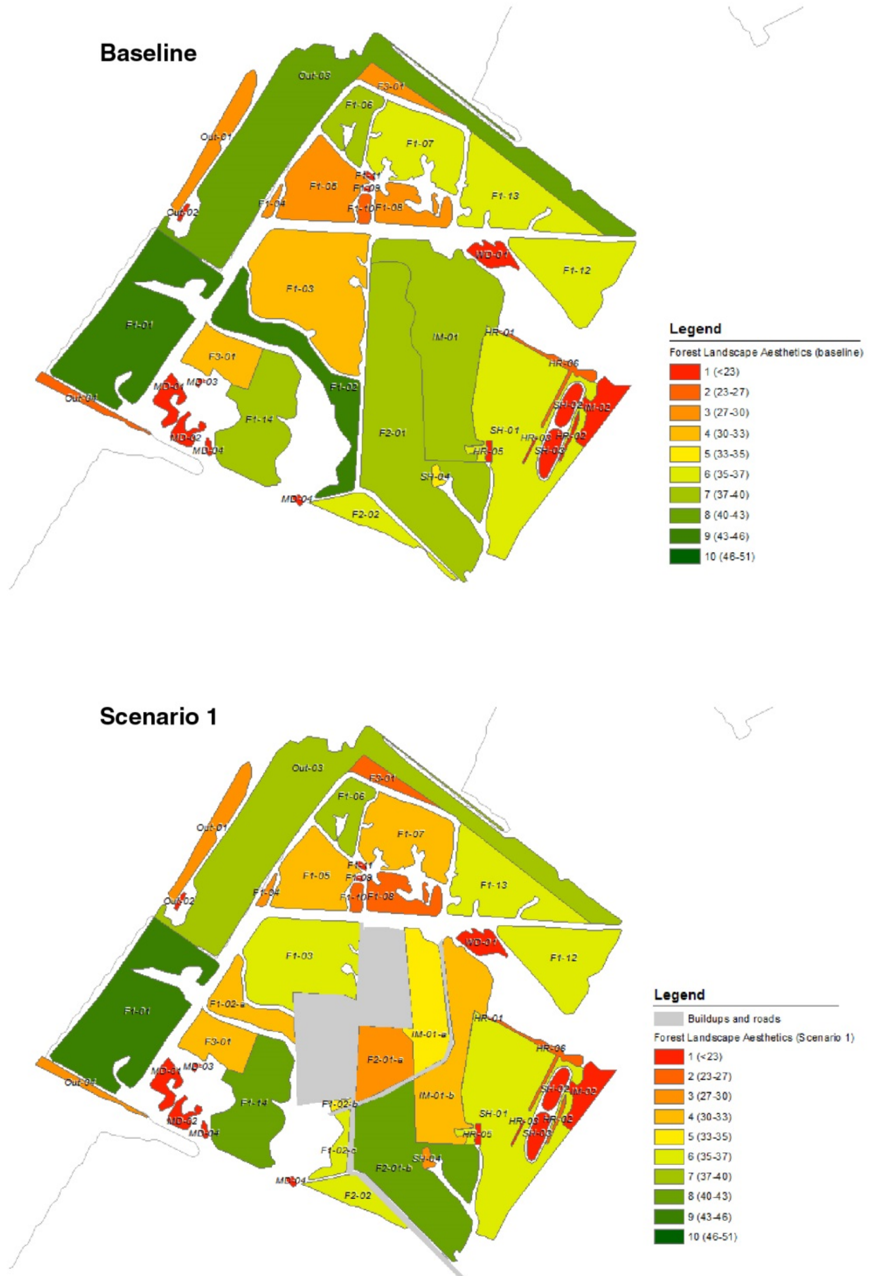

Figure 28. Comparison of Baseline and Scenario 1 forest landscape aesthetics. Changes ranged from -50% to 0%.

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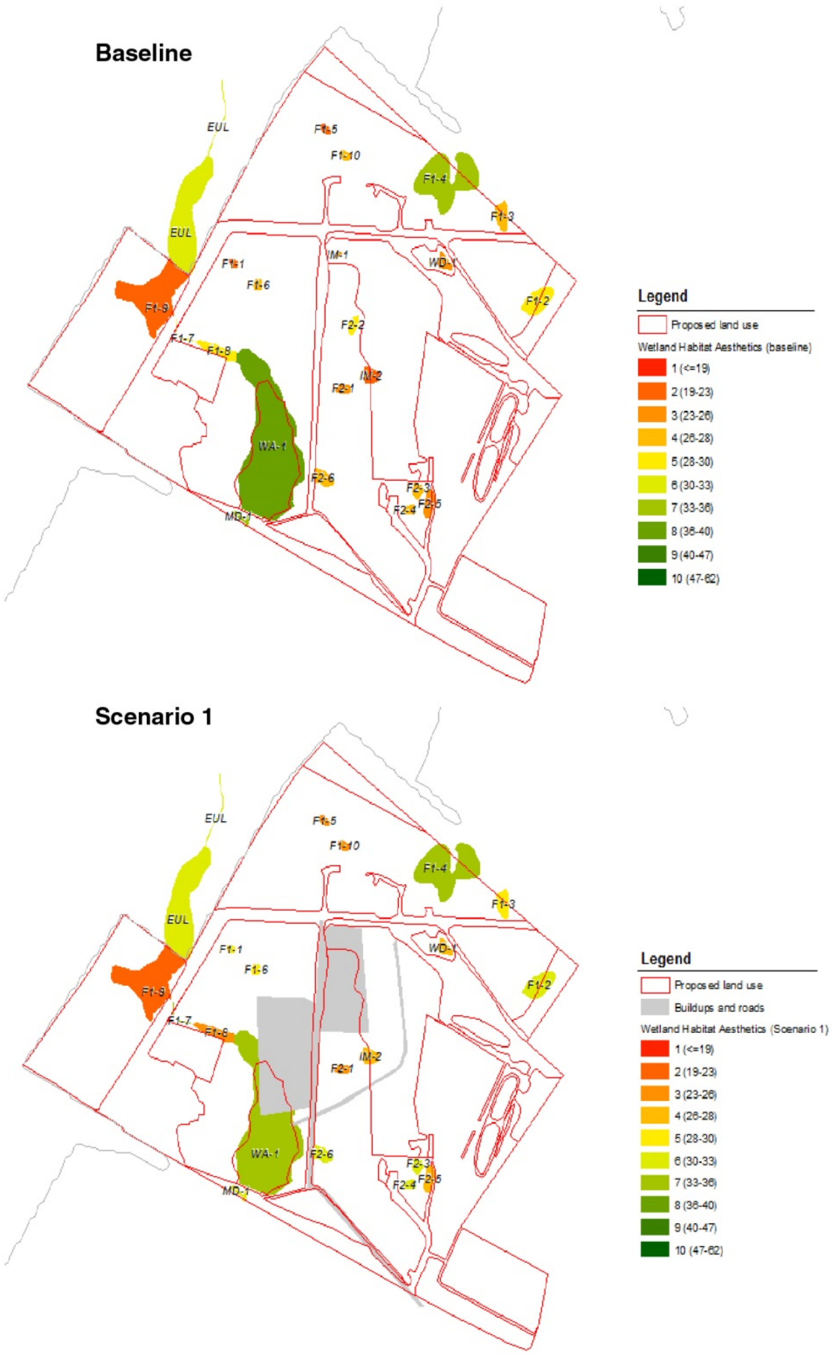

Figure 29. Comparison of Baseline and Scenario 1 wetland landscape aesthetics. Changes ranged from -10% to 30%.

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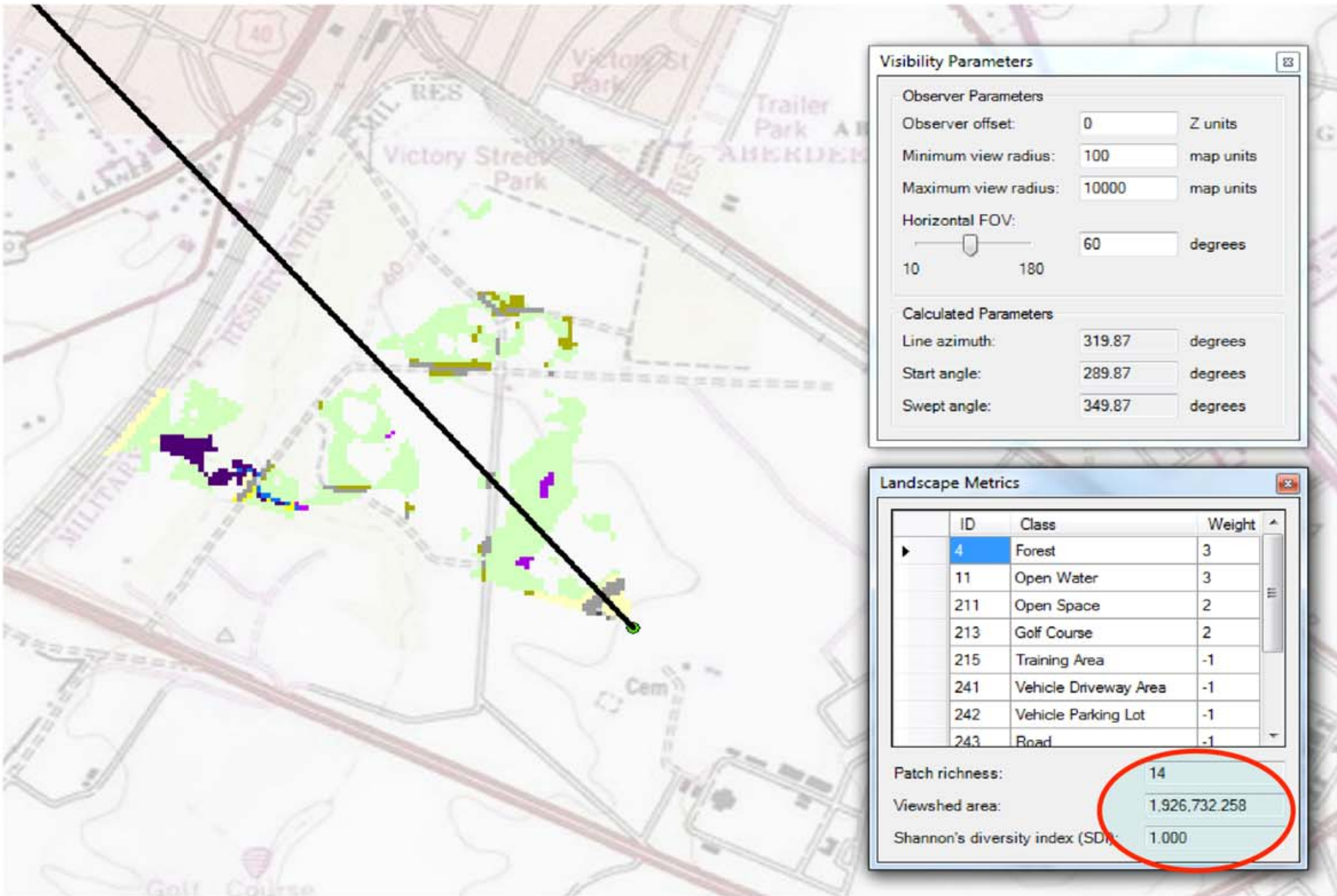

Figure 30. Baseline Vista Aesthetics

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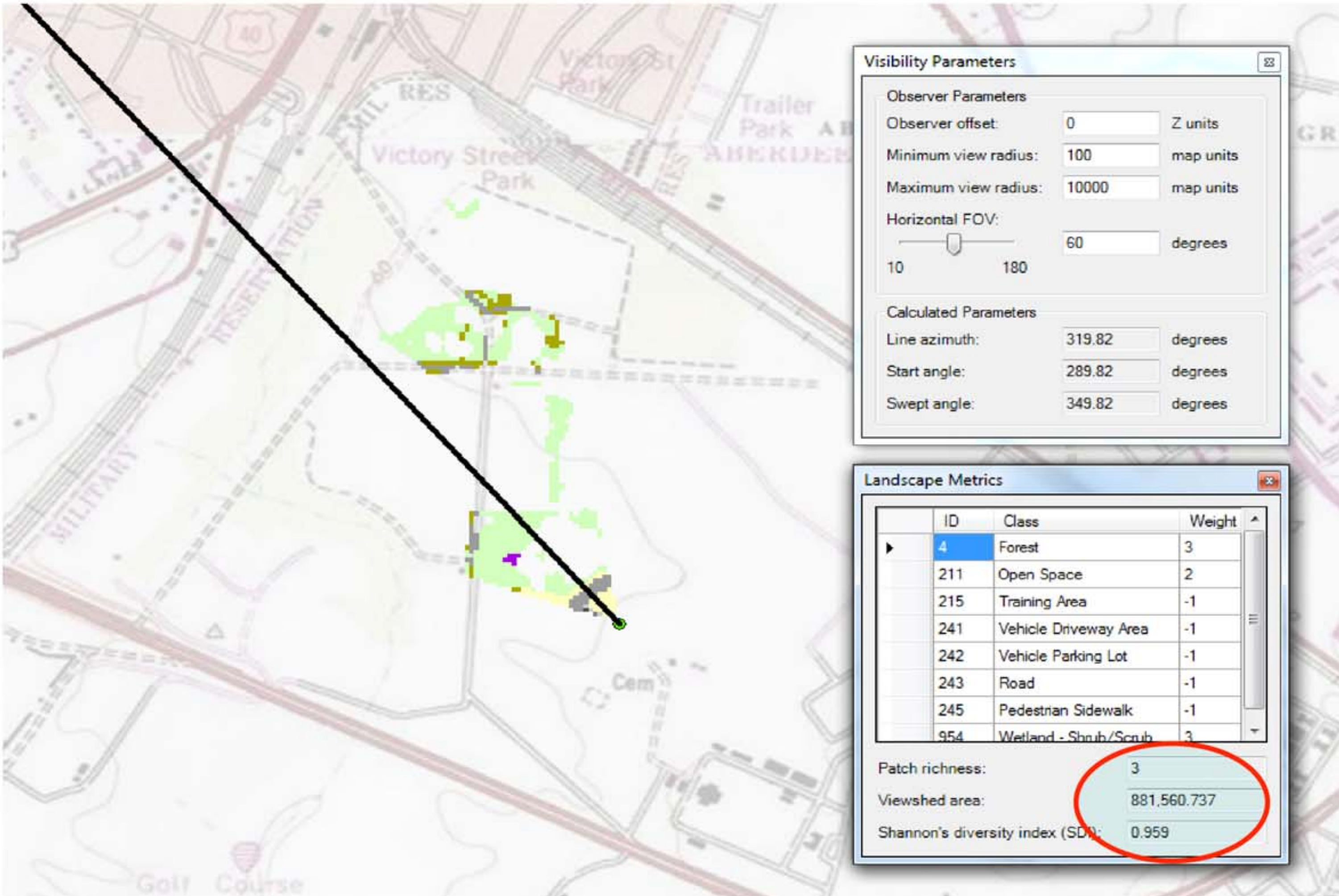

Figure 31. Scenario 1 Vista Aesthetics. Patch richness decreased by 85%, viewshed area decreased by ~54% and Shannon Diversity Index decreased by 4%.

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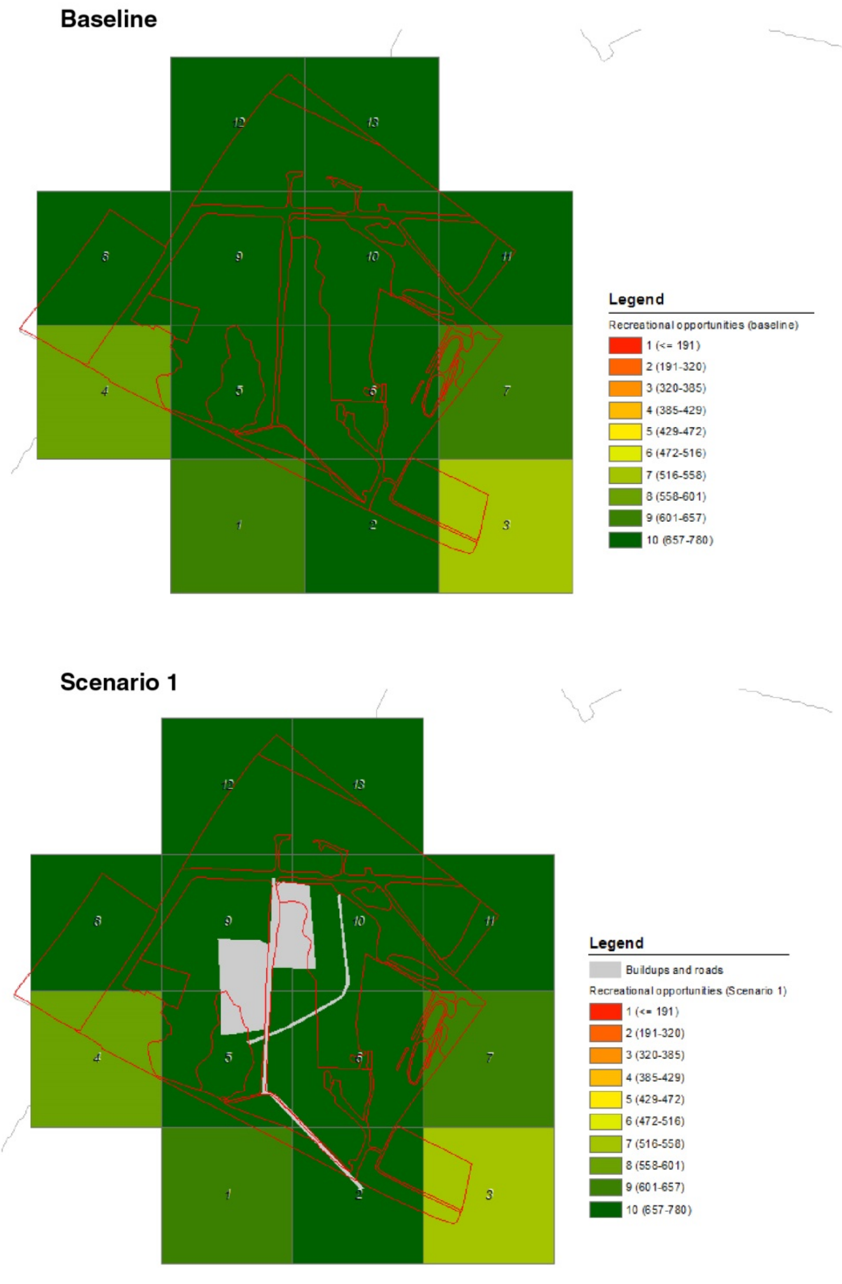

Figure 32. Comparison of Baseline and Scenario 1 recreational opportunities. Some raw scores increased but remained in the same ES Value category so overall scores did not change.

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Figure 33. Comparison of Baseline and Scenario 1 total nitrogen sequestration. Changes ranged from -10% to 0%.

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The decrease in the biodiversity score is validated by studies of fragmentation and proximity to built-up areas. The greater the two attributes, the lower the quality of habitat for wildlife. Section 2.2 describes these variables, and Figure D-1 in Appendix D shows that the addition of two buildings and a trail serve to fragment the forest and wetland patches and decrease the distance to buildings for nearby habitat patches. The addition of three new land uses in Scenario 1 increased the richness and Shannon Diversity scores in the landscape aesthetics model. Although this increase in scores seemed counter-intuitive, the literature supports the concept that human preferences for natural beauty include both a greater number and a greater diversity of land-use types (see Section 2.2).

Statistical and quantitative methods were applied to measure differences in the level of ES provided under baseline conditions and under an alternative management scenario. To avoid potentially violating assumptions of normality of the data distributions, a two-tailed nonparametric Wilcoxon signed rank test on paired observations was used to determine whether the difference between baseline and Scenario 1 is significantly different from zero at $p<0.05$ (see Appendix E for full reporting of results of the analysis). For each variable where an exact p-value could not be calculated due to ties (i.e., when two observations are equal, such that they share the same ordinal rank), a normal approximation with continuity correction was applied to approximate the p-value. When baseline and Scenario 1 are identical for a particular variable, a p-value cannot be computed and is reported as "NaN."

For three baseline forest patches that were divided into multiple patches in Scenario 1 (F1-02, F2-01, and IM-01), the average value across sub-patches was used as the Scenario 1 observation to compare to the original whole baseline patch.

For two wetlands that were eliminated in Scenario 1 (F2-2 and IM-1), a worst-possible value of zero was used for each variable, including overall score, in the biodiversity, aesthetics, and nutrient sequestration models.

The following model and variable combinations were significantly different between baseline and Scenario 1:

- Biodiversity forest: DistBlg, overall
- Biodiversity wetland: WtldSize, dist_road, dist_build, dist_edge, overall
- Landscape aesthetics wetland: VegInsp, overall
- Landscape aesthetics forest: overall
- Recreation: dist_build, bio_div, trail_len, train_inte, overall

The following model and variable combinations were **not** significantly different between baseline and Scenario 1:

- Biodiversity forest: FrstSize, edge_sdi, DistRd, ProxWtr, close, DistEdge, EgCmplx, soil, slope

- Biodiversity wetland: heter, dist_close, shp_cmplx, n_soil

- Biodiversity grassland: FrstSize, edge, DistRd, DistBlg, close, ProxWtr, dist_fores, EgCmplx, n_soil, overall

- Landscape aesthetics wetland: IndDiff, EdgeCmplx, Water, surWater, strLCctr, surLCdiv, WtldSize

- Landscape aesthetics forest: lndDiff, EgCmplx, strLCctr, surLCdiv, FrstSize, VegInsp, age_r, FrsDen

- Recreation: dist_road, aesthetics, slope, trail_loop, dist_boatNutrient sequestration wetlands: TN_reduction

The value of more than two ES under alternative mission scenarios was outside the reasonable confidence limits of the value under baseline conditions, and thus, this objective is considered to be met.

6.6 PERFORMANCE OBJECTIVE 6: EASE OF USE AND UTILITY OF THE TOOL FOR DECISION MAKING

This is a qualitative performance objective. Success in meeting this objective was determined from survey and verbal feedback from users and decision makers during implementation. Once the tool has been turned over to APG (October 2014), requests for technical assistance will be evaluated to determine the frequency of similar requests, trends in the numbers and subjects of requests, and reports for clarification of the users' manual. Semi-structured interviews will aim to determine whether and how often the tool is used to support decisions, and whether the information provided by the tool has resulted in improved decision making (such as more efficient analysis and/or better outcomes).

Feedback from the usability and utility survey from five participants indicates that most end users find EcoAIM™ to be a useful tool that will help them in site planning and communications. Questions about ease of use and the level of training required indicate that most personnel (with intermediate knowledge of ecology and GIS) would require no more than a day of instruction. Summary statistics could not be meaningfully calculated with the small sampling size.

7 COST ASSESSMENT

This section provides information that could be used to develop a cost estimate for full implementation of EcoAIM™ at a military installation.

7.1 COST MODEL

Table 7 presents a cost model for the implementation of EcoAIM™, including a list of cost elements and data that will be collected to track costs associated with each element. The total is $41,250. It is assumed that the site has typically collected geospatial data, including:

- LU/LC layer
- DEM
- Wetland, forest, and grassland detailed layers
- Road layer
- Biological survey data

Table 7. Cost Model

Cost Element	Data Tracked During the Demonstration	Estimated Costs
Procurement of Geospatial Data	• Personnel hours for assembling data and converting to consistent and compatible formats	• Technician, 60 hr., $3,000 • Project Manager, 10 hr., $1,000
Selection of Biophysical Models	• Labor associated with literature review and creating a final model selection matrix	• Technician, 40 hr., $2,000 • Project Manager, 50 hr., $5,000
Structured Stakeholder Engagement	• Labor associated with stakeholder orientation meetings, interviews, and survey instruments	• Technician, 10 hr., $500 • Project Manager, 40 hr., $4,000
Programming	• Labor associated with programming needed to run biophysical models in geospatial analytical framework (GIS) • Labor associated with user interface customization • Labor associated with Baseline conditions modeling	• Technician, 200 hr., $10,000 • Project Manager, 20 hr., $2,000 • Technician, 12 hr., $600 • Project Manager, 5 hr., $500 • Technician, 24 hr., $1,200 • Project Manager, 10 hr., $1,000
Training	• Labor associated with training installation personnel with EcoAIM	• Technician, 15 hr., $750 • Project Manager, 10 hr., $1,000
Procurement of Geospatial Data	• Labor associated with running different land use scenarios • Labor associated with production and communication of results	• Technician, 20 hr., $1,000 • Project Manager, 10 hr., $1,000 • Technician, 20 hr., $1,000 • Project Manager, 10 hr., $1,000
Running scenarios	• Labor associated with providing remote technical assistance	• Technician, 10 hr., $500 • Project Manager, 2 hr., $200
Technical Assistance	• Personnel hours for assembling data and converting to consistent and compatible formats	• Technician, 60 hr., $3,000 • Project Manager, 10 hr., $1,000
Total		$41,250

For the purposes of developing cost estimates, the following two labor categories and rates were assumed:

- Technician—$50/hr
- Project Manager/Supervisor—$100/hr

Other assumptions applied to the cost model are:

- Procurement of geospatial data—Cost model is based on experience at APG, Fort Pickett, and Cape Canaveral/Patrick AFP and is not expected to vary significantly from the estimate, due to the fact that the generally same geospatial data are expected to be available for most installations and to be usable by existing GIS systems.

- Selection of biophysical models—For EcoAIM™ in its current form, these costs have been borne by the Demonstration and are largely "one-off." However, implementation of EcoAIM™ at other installations may result in the desire to develop additional models such as a carbon sequestration model. The cost estimate presented below is based on blended total labor associated with development of "one-off" models and use of "off-the-shelf" models based on experience with biophysical model development for APG. Actual costs associated with developing additional models will largely depend on whether there are existing, vetted, public-domain models that will suit an installation's needs, or whether a specific accurate, validated model is needed.

- Structured stakeholder engagement—Labor total is based on APG experience, where only installation stakeholders were involved in the process, and the process stopped short of a formal exercise to elicit stakeholder preferences regarding measurement endpoints and ES. The level of effort associated with formal preference elicitations is highly dependent on the number and experience/background of participants and the objectives of the exercise, and can easily range over one order of magnitude in costs.

- Programming—Programming costs are largely one-time costs and, for the models included in EcoAIM™, have been assumed by this demonstration project. However, as noted above, application of EcoAIM™ at other installations may require development of new models, which in turn, will require additional programming in ArcGIS. The cost estimate presented below represents a blend of programming level of effort required for the models currently in EcoAIM™.

- Running scenarios—The cost estimate for running scenarios is based on actual experience running EcoAIM™ during this demonstration. Actual costs will depend primarily on the level of detail needed for input into alternative land use scenarios (e.g., drawing polygons and assigning new LU/LC attributes) and level of analysis and input needed to assign preference weighting for selected variables (e.g., in the vista and landscape aesthetics models).

7.2 COST DRIVERS

The primary cost drivers in assessing whether to implement EcoAIM™ at a facility will include:

- The degree of stakeholder engagement needed—Inclusion of non-installation stakeholders in the stakeholder engagement process and/or the need for quantification of stakeholder preferences will significantly increase costs above what is projected above. Increased costs will be associated with possibly hiring a public outreach expert and expert facilitator (may be the same person) and may significantly increase the level of effort for Installation personnel to attend meetings, workshops, focus groups, etc. Installations that experience severe encroachment issues, or installations where mission changes may affect the surrounding community, may require more intensive stakeholder engagement than installations not facing such issues.

- The need to develop additional ES models or to refine existing models—EcoAIM™ is limited to the biophysical models presented in this report. Inclusion of additional models, such as one for carbon sequestration, or refinement of one or more models will result in considerable additional costs, as illustrated in Table 4. Refinements to existing models might include the need to add specificity to the biodiversity model, to enable quantification of habitat for one or more endangered species. This might necessitate collection of field data on specific additional attributes that provide important resources for a listed species—for example, the presence of a specific vegetation type.

- The accessibility and availability of appropriate GIS layers, data, and background information—Like most models, output from EcoAIM™ is limited by the quality of the data used for input. For meaningful results, input data must have sufficient detail, resolution, and spatial extent to support the decisions at hand. Data with existing gaps or uncertainty may require validation with ground-truthing by trained specialists (e.g., ornithologists, wetland specialists).

7.3 COST ANALYSIS AND COMPARISON

The life-cycle costs when implemented operationally are estimated as annual maintenance costs and software upgrading costs, using best professional judgment and in consultation with users to determine reporting needs. This estimate is based on:

- A three-year time frame, assuming that ArcGIS is updated every three years. (Based on historical release dates, ArcGIS versions are updated approximately every 1.5 years.)
- The assumption that biophysical data collected by APG personnel are funded by other sources, and the GIS layers generated from those studies are used in EcoAIM™ (i.e., no data were collected specifically for operation of EcoAIM™).

- The assumption that upgrading of computer hardware is not included in this life-cycle estimate.
- The estimate for updating and pre-preprocessing new data is based on the current quality of data received from APG.
- The real discount rate from the Office of Management and Budget (OMB) (www.whitehouse.gov/omb/circulars/a094/a94_appx-c.html) is –0.7% for 3 years.

Life-cycle costs include the following elements:

- Software updates—
  - Technician, 20 hrs in Year 1, 5 hrs each in Years 2 and 3
  - Software purchase (i.e., ArcGIS v.10.1)—$3,500 for a license and $2,500 for the ArcGIS Spatial Analyst extension in Year 1
- Data updates and pre-processing—
  - Technician, 30 hrs for each year
- Operation (i.e., scenario-building and generating output)
  - Technician, 60 hrs in Year 1, 40 hours each in Years 2 and 3
  - Other APG personnel, 20 hrs in Year 1, 10 hours each in Years 2 and 3

Over the course of a three-year life cycle, it is estimated that operation of EcoAIM™ will have a present-value cost of $23,264.

The three installations selected for this demonstration do not currently use any tools for assessing tradeoffs on ES provisioning as a result of land management actions. Therefore, there is no basis of comparison for implementation costs.

8 IMPLEMENTATION ISSUES

This section provides information that will aid in the future implementation of EcoAIM™. A brief description is provided of issues encountered and lessons learned. The two most significant implementation issues encountered at the project level were:

- **Availability of installation personnel**—Due to existing demands on APG personnel, long lead times were required to schedule onsite and teleconference meetings and obtain information and data. This put pressure on the Demonstration schedule and required time extensions for the period of the Demonstration. This problem was exacerbated by government shutdowns associated with delays in congressional budget appropriations and threats of sequestration (October 1–16, 2013) and several days of federal government shutdown due to weather. The difficulty in obtaining APG personnel time was a major reason behind the decision to forego one additional formal structured stakeholder engagement meeting to elicit preference weightings for the key ES. (However, the other significant reason for changing the weighting capability was related to the decision-making structure at APG, which favored a more flexible, multi-user approach).

- **Restriction on software use—**The U.S. Army's Certificate of Networthiness program required Exponent to develop the geospatial model on a backward-compatible ArcGIS platform. APG is currently using ArcGIS v.10.0, whereas EcoAIM™ is programmed in v. 10.1. The differences in these two versions are sufficient that EcoAIM™ in its current state cannot be used with the older version. This significantly increased the amount of time needed for backward programming and forward compatibility programming (in anticipation of making an upgrade) and limited the flexibility in developing customized graphical user interfaces (GUIs). The user interface for EcoAIM™ relies on the standard ArcGIS GUI, which may not be as intuitive to non-ArcGIS users as it is to those with ArcGIS experience. These limitations also prevented Exponent from interacting in an ideal way with key APG staff, such as those from the Master Planning Branch and GIS staff in the Natural Resources Branch. (The demonstration was conducted on an Exponent-owned laptop using ArcGIS 10.1 at the onsite presentation, and using screenshots in PowerPoint slides in the last two demonstrations.) This could result in a major implementation obstacle in the event that there is a large degree of inconsistency in approved or in-use ArcGIS versions across installations or among branches of the military.

Less important implementation issues included the following:

- **Non-Centralized Data Storage—**The existence of multiple repositories of geospatial data required ongoing and multiple iterations of requests for GIS layers during the entire demonstration, including to within a month of completing this report. The point of contact for data did not always have the necessary access to the data, especially those that were several years old or resided in unknown locations. It is not known whether similar issues will arise at other facilities or if data management will be more centralized and easier to access.

- **Access to Personnel**—Access to some APG personnel was hindered by the existing chain of command. Exponent requests placed with personnel in other branches, such as the Recreation Director, were met with requisitions for approval by higher officials. Because this Demonstration project is not widely known outside of the Natural Resources and Master Planning Branches, it was difficult to obtain clearance to invite other personnel to the stakeholder meetings and presentations.

The anticipated implementation issues for EcoAIM™ based on lessons learned from using APG as a demonstration site are:

- **Customization**—The custom build of EcoAIM™ to APG's notional missions and visions of the future may not be translatable to other demonstration sites. The stakeholder engagement process elucidated a consensus on the representative notional mission, and as such, customization of EcoAIM™ to other sites will require a similar stakeholder engagement process.
- **Stakeholder engagement specialist**—the importance of the stakeholder engagement process to guide the customization of EcoAIM™ requires the services of a specialist who understands military culture as well as the concepts of ES in natural resource management and planning. The stakeholder engagement specialist must have sufficient information about the installation at an organizational level to invite the personnel that benefit from ES, the end users and the decision makers. They must also have the expertise to elicit responses that will help determine the ES, biophysical production functions and endpoints to be measured in EcoAIM™.
- **Data availability**—the scenario-building capability and output from EcoAIM™ are heavily dependent on baseline input data from the site. To use EcoAIM™ at multiple sites, data must be sufficiently available and of high enough quality for each site. Comparison of ES values across different sites will require that data from the watersheds of all sites be used to create a common a baseline conditions.

As of the date of this report, EcoAIM™ has been implemented only at Aberdeen Proving Ground. EcoAIM™ The Demonstration will essentially conclude in October 2014 with the delivery of the software and user's manual. Exponent will provide limited technical support immediately following delivery of the software to each installation.

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Appendix A

Contact Information

Appendix A: Points of Contact and Roles

Point of Contact Name	Organization Name Address	Phone Fax E-mail	Role in Project
Pieter Booth	Exponent 15375 SE 30th Place, Suite 250 Bellevue, WA 98007	Tel: 425-519-8709 Fax: 425-519-8799 E-mail: boothp@exponent.com	Principal Investigator
Sheryl Law	Exponent 1800 Diagonal Road, Suite 500 Alexandria, VA 22314	Tel: 425-214-2214 Fax: 571-227-7299 E-mail: slaw@exponent.com	Project Manager
Jane Ma	Exponent 15375 SE 30th Place, Suite 250 Bellevue, WA 98007	Tel: 425-519-8773 Fax: 425-519-8799 E-mail: jma@exponent.com	GIS Specialist and Programmer
Dr. Jessica Turnley	Galisteo Consulting 2403 San Mateo Blvd NE, Suite W-12 Albuquerque, NM, 87110	Tel: 505-889-3927 Fax: 505-889-3929 E-mail: jgturnley@aol.com	Stakeholder Engagement Coordinator
Dr. James Boyd	Resources for the Future 1616 P Street NW Washington, DC 20036	Tel: 202-328-5013 E-mail: boyd@rff.org	Consulting Natural Resources Economist
John Wrobel	Aberdeen Proving Grounds	Tel: 410-436-4840 Email: john.wrobel@us.army.mil	APG Point of Contact
Deidre Deroia	Aberdeen Proving Grounds	Tel: 410- 278-0536 Email: deidre.m.deroia.civ@mail.mil	APG Point of Contact

Appendix B

Models Reviewed for Nutrient Sequestration ES

Model	Developer	Description	Input Parameters	Model Outputs	Limitations	Platform	Conclusion
SWAT/ArcSWAT	USDA/ Texas A&M	Semi-distributed, continuous watershed simulator, daily time step; predicts the effects of management decisions on water, sediment, nutrient and pesticide yields	Numerous	Numerous	Designed for large, ungaged river basins	ArcGIS	Level of temporal detail too great for installation needs
SPARROW	USGS	Predicts sources, fate & transport of total nutrients and total phosphorus; regional interpretation of water-quality monitoring data; mass balance approach	Water-quality and streamflow monitoring data, land use/cover, water discharge	Yields, concentrations, source contributions to stream load	Large-scale watershed basis	SAS, Windows	Inappropriate scale for installation application
Chesapeake Bay HSPF	USEPA	Simulates nutrient loads for Chesapeake Bay running on a one-hour time step for over 18 years (1985-2005); TMDL/pollutant loading model	Land use/land cover grid, flow characters, precipitation data, DEM, water discharge data, watershed data	Total nitrogen/total phosphorus or pollutant loadings over time	Simulates nutrient loads for the whole Chesapeake Bay running on a one-hour time step for over 18 years	Fortran or BAINS	Insufficinet coverage of sub-watersheds and calibrations sites relevant to APG
PREWet	USACE	Estimates the removal efficiency for specific pollutants by a wetland	2 out of 3 from wetland volume, surface area, or mean depth; also avg. temperature, length, width, flow	TSS, total coliforrn bacteria, BOD, total N, total P, contaminants	Does not account for detrital deposition or sorption to sediments	Windows, C++	Not suitable; inadequate availability of input data
Water Quality Analysis Simulation Program (WASP7)	USEPA	Predict water quality responses to natural and man-made pollution for various management decisions	Numerous	Advection, dispersion, point and diffuse mass loading, and boundary exchange	Requires integration with a hydrodynamic model for flow and mixing coefficients	Windows	Too complex, too many input parameters for EcoAIM application
P8	USEPA	Urban catchment model based on land use/land cover; for designing and evaluating runoff treatment schemes for existing or proposed urban development	Land use/Land cover grid, export coefficients for different Land use/land cover types, DEM	Suspended solids, total phosphorus, total Kjeldahl nitrogen, copper, lead, zinc, and total hydrocarbons	Designed for small urban catchments	ArcGIS	Useful for evaluating stormwater management from cantonment areas
Riparian Analysis Toolbox	University of Maryland	Identifies biogeochemically active areas important for nutrient filtering; ranks existing buffers or candidate restoration sites by the amount of pollutant loading from upslope sources	DEM, land use/land cover grid, stream raster	For a given set of source cells, distinguishes between buffered and unbuffered pathways and ranks each streamside entry point based on cumulative contributing pollutant source area	Target at potential riparian restoration area	ArcGIS	Useful for "What-if" scenarios

Appendix C

Usability and Utility Survey and Responses

Survey for Usability of EcoAIM

Dear Participants,

Thank you for taking the time to complete this questionnaire. As part of our Demonstration Project, we are required to evaluate the ease and utility of our tool. We would like to ensure that the government funds used for this project will result in a useful tool for DoD. Your valuable responses will be used to help us refine Exponent's Ecological Assets Inventory and Management (EcoAIM) tool and evaluate its usability and effectiveness in making natural resource management decisions. We will anonymize responses in reports and presentations. Please email back to: slaw@exponent.com.

1. Do you think you would use a tool like EcoAIM? If yes, what circumstances would prompt you to use it. If not, why not?

2. Do you find EcoAIM easy to use? If not, explain why you find EcoAIM too complex for the purposes of your decision making?

3. Describe how you might use EcoAIM.

4. Would you be able to use EcoAIM independently or do you think you would need the support of a technical person (i.e., GIS specialist, ecologist)? What kind of technical support would you need?

5. Did you find that the various functions in EcoAIM (e.g., sub-models, scenario-building, creating output results, etc.) were well integrated? If not, please describe inconsistencies.

6. How much training do you think you would need to use EcoAIM? Example, few hours, 1 day, 2 days, etc.

7. Did you have difficulties when using EcoAIM for natural resource decision making? (Respond after tool has been transferred to you.)

8. Did you feel confident using EcoAIM for decision making? Why or why not? Please describe what you used EcoAIM for. (Respond after tool has been transferred to you.)

9. What did you need to learn before you could use EcoAIM in a satisfactory manner? (For example, ArcGIS, creating output, the underlying data, etc.). (Respond after tool has been transferred to you.).

10. Please indicate your level of knowledge in:

    a) Decision analysis -

Minimal				Extensive
1	2	3	4	5

    b) Ecology

Minimal				Extensive
1	2	3	4	5

    c) GIS

Minimal				Extensive
1	2	3	4	5

11. Describe which group or department you belong to: (Example, tenant organization at APG, Natural Resources Department, Master Planning, GIS, etc.)

Survey for Usability of EcoAIM

Dear Participants,

Thank you for taking the time to complete this questionnaire. As part of our Demonstration Project, we are required to evaluate the ease and utility of our tool. We would like to ensure that the government funds used for this project will result in a useful tool for DoD. Your valuable responses will be used to help us refine Exponent's Ecological Assets Inventory and Management (EcoAIM) tool and evaluate its usability and effectiveness in making natural resource management decisions. We will anonymize responses in reports and presentations. Please email back to: slaw@exponent.com.

1. Do you think you would use a tool like EcoAIM? If yes, what circumstances would prompt you to use it. If not, why not?
   Yes, I would use a tool like EcoAIM when reviewing proposed development projects for environmental effects. I would also use the tool for planning natural resources projects.

2. Do you find EcoAIM easy to use? If not, explain why you find EcoAIM too complex for the purposes of your decision making?
   Yes, the tool should be easy to use for anyone with basic experience using ArcGIS

3. Describe how you might use EcoAIM.
   We have already discussed using EcoAIM to plan landscaping projects within APG's cantonment areas and to provide better guidance to tenant organizations on landscaping around their buildings.

4. Would you be able to use EcoAIM independently or do you think you would need the support of a technical person (i.e., GIS specialist, ecologist)? What kind of technical support would you need?
   I think I would be able to use EcoAIM independently with occasional GIS support.

5. Did you find that the various functions in EcoAIM (e.g., sub-models, scenario-building, creating output results, etc.) were well integrated? If not, please describe inconsistencies.

6. How much training do you think you would need to use EcoAIM? Example, few hours, 1 day, 2 days, etc. A half-day (3-4 hours) hands-on training session would be adequate.

7. Did you have difficulties when using EcoAIM for natural resource decision making? (Respond after tool has been transferred to you.)

8. Did you feel confident using EcoAIM for decision making? Why or why not? Please describe what you used EcoAIM for. (Respond after tool has been transferred to you.)

9. What did you need to learn before you could use EcoAIM in a satisfactory manner? (For example, ArcGIS, creating output, the underlying data, etc.). (Respond after tool has been transferred to you.).

10. Please indicate your level of knowledge in:
    a) Decision analysis -

Minimal				Extensive
1	2	3	4	5

    b) Ecology

Minimal				Extensive
1	2	3	4	5

    c) GIS

Minimal				Extensive
1	2	3	4	5

11. Describe which group or department you belong to: (Example, tenant organization at APG, Natural Resources Department, Master Planning, GIS, etc.)
    DPW Environmental Division, Natural and Cultural Resources Branch

Survey for Usability of EcoAIM

Dear Participants,

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1. Do you think you would use a tool like EcoAIM? If yes, what circumstances would prompt you to use it. If not, why not? Yes, as one of the many tools to assist in making an educated decision.

2. Do you find EcoAIM easy to use? If not, explain why you find EcoAIM too complex for the purposes of your decision making? Yes, but I would personally chosen different focus areas that were important to the installation.

3. Describe how you might use EcoAIM. To assist in making informed decisions.

4. Would you be able to use EcoAIM independently or do you think you would need the support of a technical person (i.e., GIS specialist, ecologist)? What kind of technical support would you need?

   Would need the support of GIS

5. Did you find that the various functions in EcoAIM (e.g., sub-models, scenario-building, creating output results, etc.) were well integrated? If not, please describe inconsistencies.

   yes

6. How much training do you think you would need to use EcoAIM? Example, few hours, 1 day, 2 days, etc. one half day hands on instruction

7. Did you have difficulties when using EcoAIM for natural resource decision making? (Respond after tool has been transferred to you.) **we do not have tool yet**

8. Did you feel confident using EcoAIM for decision making? Why or why not? Please describe what you used EcoAIM for. (Respond after tool has been transferred to you.)

9. What did you need to learn before you could use EcoAIM in a satisfactory manner? (For example, ArcGIS, creating output, the underlying data, etc.). (Respond after tool has been transferred to you.).

10. Please indicate your level of knowledge in:

a) Decision analysis -

Minimal				Extensive
1	2	3	4	5

b) Ecology

Minimal				Extensive
1	2	3	4	5

c) GIS

Minimal				Extensive
1	2	3	4	5

11. Describe which group or department you belong to: (Example, tenant organization at APG, Natural Resources Department, Master Planning, GIS, etc.) natural resources management

Survey for Usability of EcoAIM

Dear Participants,

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1. Do you think you would use a tool like EcoAIM? If yes, what circumstances would prompt you to use it. If not, why not?

   Yes I would use Eco-Aim most likely during the Site Approval and REC review process for new work.

2. Do you find EcoAIM easy to use? If not, explain why you find EcoAIM too complex for the purposes of your decision making?

   From what I've seen, it seems to be pretty straight forward

3. Describe how you might use EcoAIM.

   I can see ECO-Aim being used as a what-if drill by engineers and environmental folks in finding a location for new development . I also see it being used as an after action tool to see what mitigation needs to be done to fix the problems caused by the new development.

4. Would you be able to use EcoAIM independently or do you think you would need the support of a technical person (i.e., GIS specialist, ecologist)? What kind of technical support would you need?

   I am a GIS specialist and I see no problem using ECO-Aim independently.

5. Did you find that the various functions in EcoAIM (e.g., sub-models, scenario-building, creating output results, etc.) were well integrated? If not, please describe inconsistencies.

6. How much training do you think you would need to use EcoAIM? Example, few hours, 1 day, 2 days, etc.

   I think I would need maybe an hour of training, or a good users manual in order to use EcoAIM to its fullest potential

7. Did you have difficulties when using EcoAIM for natural resource decision making? (Respond after tool has been transferred to you.)

8. Did you feel confident using EcoAIM for decision making? Why or why not? Please describe what you used EcoAIM for. (Respond after tool has been transferred to you.)

9. What did you need to learn before you could use EcoAIM in a satisfactory manner? (For example, ArcGIS, creating output, the underlying data, etc.). (Respond after tool has been transferred to you.).

10. Please indicate your level of knowledge in:
    a) Decision analysis -

Minimal				Extensive
1	2	3	4	5

    b) Ecology

Minimal				Extensive
1	2	3	4	5

    c) GIS

Minimal				Extensive
1	2	3	4	5

11. Describe which group or department you belong to: (Example, tenant organization at APG, Natural Resources Department, Master Planning, GIS, etc.)

Survey for Usability of EcoAIM

Dear Participants,

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1. Do you think you would use a tool like EcoAIM? If yes, what circumstances would prompt you to use it. If not, why not?

Yes – help determine effects of projects

2. Do you find EcoAIM easy to use? If not, explain why you find EcoAIM too complex for the purposes of your decision making?

yes

3. Describe how you might use EcoAIM.

Response to NEPA documents

4. Would you be able to use EcoAIM independently or do you think you would need the support of a technical person (i.e., GIS specialist, ecologist)? What kind of technical support would you need?

   Independently

5. Did you find that the various functions in EcoAIM (e.g., sub-models, scenario-building, creating output results, etc.) were well integrated? If not, please describe inconsistencies.

   yes

6. How much training do you think you would need to use EcoAIM? Example, few hours, 1 day, 2 days, etc.

Few hours – 1 day

7. Did you have difficulties when using EcoAIM for natural resource decision making? (Respond after tool has been transferred to you.)

8. Did you feel confident using EcoAIM for decision making? Why or why not? Please describe what you used EcoAIM for. (Respond after tool has been transferred to you.)

9. What did you need to learn before you could use EcoAIM in a satisfactory manner? (For example, ArcGIS, creating output, the underlying data, etc.). (Respond after tool has been transferred to you.).

10. Please indicate your level of knowledge in:
    a) Decision analysis -

Minimal				Extensive
1	2	3	4	5

    b) Ecology

Minimal				Extensive
1	2	3	4	5

    c) GIS

Minimal				Extensive
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Survey for Usability of EcoAIM

Dear Participants,

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1. Do you think you would use a tool like EcoAIM? If yes, what circumstances would prompt you to use it. If not, why not?

I would probably not use it in my job (Natural Resources Branch). There are many other regulatory constraints that control what we do and where we construct (i.e. wetlands, stormwater runoff, critical area, eagles, forestry). Although this tool is related to all of these items and I personally understand the benefits to ecosystems and not breaking them into pieces, it would come last on the list of considerations.

2. Do you find EcoAIM easy to use? If not, explain why you find EcoAIM too complex for the purposes of your decision making?

Yes

3. Describe how you might use EcoAIM.

It would be a nice visual to use for justification for siting a project in a specific area.

4. Would you be able to use EcoAIM independently or do you think you would need the support of a technical person (i.e., GIS specialist, ecologist)? What kind of technical support would you need?

   I would be able to use independently.

5. Did you find that the various functions in EcoAIM (e.g., sub-models, scenario-building, creating output results, etc.) were well integrated? If not, please describe inconsistencies.

   Yes

6. How much training do you think you would need to use EcoAIM? Example, few hours, 1 day, 2 days, etc.

A few hours

7. Did you have difficulties when using EcoAIM for natural resource decision making? (Respond after tool has been transferred to you.)

8. Did you feel confident using EcoAIM for decision making? Why or why not? Please describe what you used EcoAIM for. (Respond after tool has been transferred to you.)

9. What did you need to learn before you could use EcoAIM in a satisfactory manner? (For example, ArcGIS, creating output, the underlying data, etc.). (Respond after tool has been transferred to you.).

10. Please indicate your level of knowledge in:

a) Decision analysis -

Minimal				Extensive
1	2	3	4	5

b) Ecology

Minimal				Extensive
1	2	3	4	5

c) GIS

Minimal				Extensive
1	2	3	4	5

11. Describe which group or department you belong to: (Example, tenant organization at APG, Natural Resources Department, Master Planning, GIS, etc.)

APG Natural Resources Department

Appendix D

Presentation of ES Scores

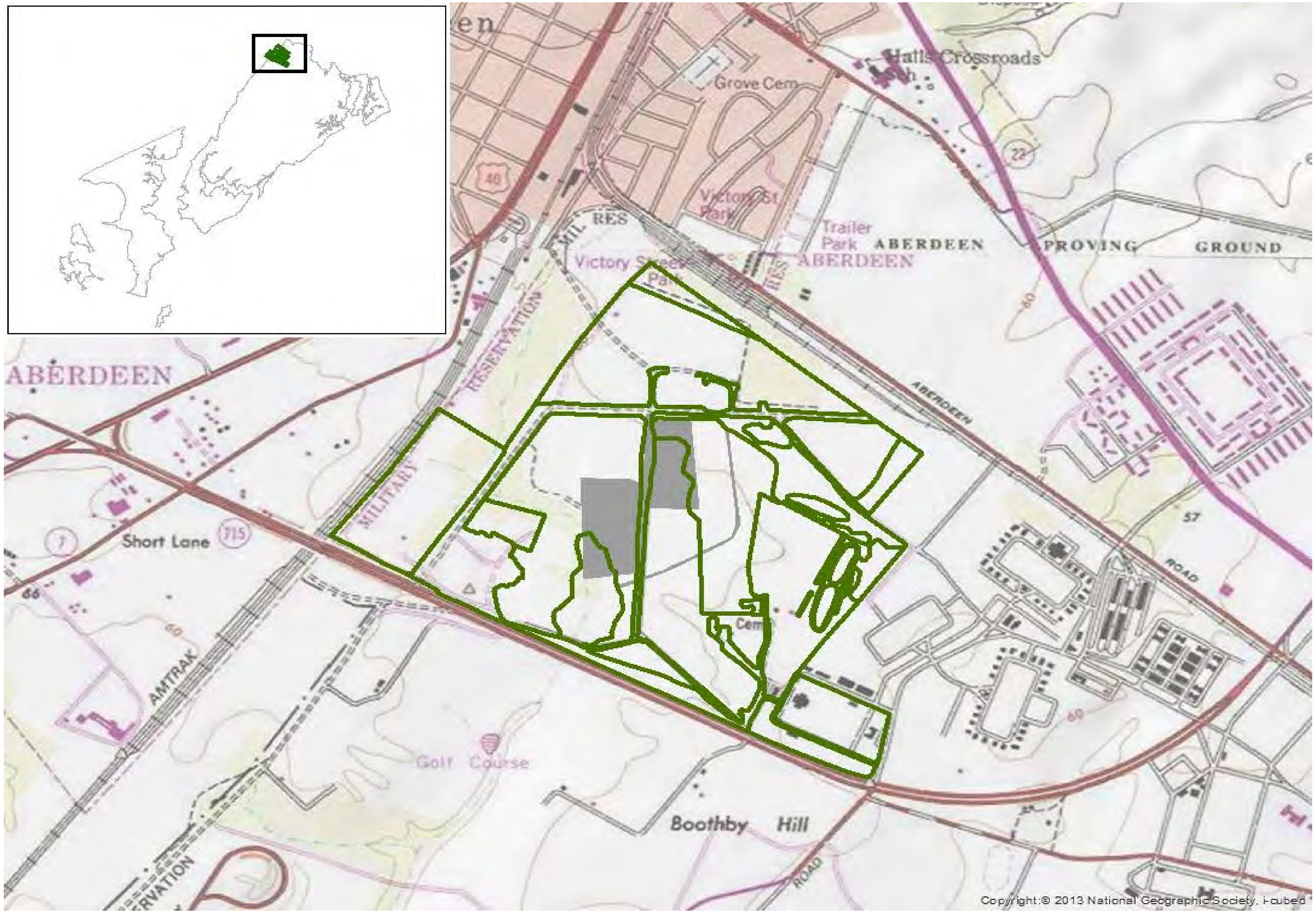
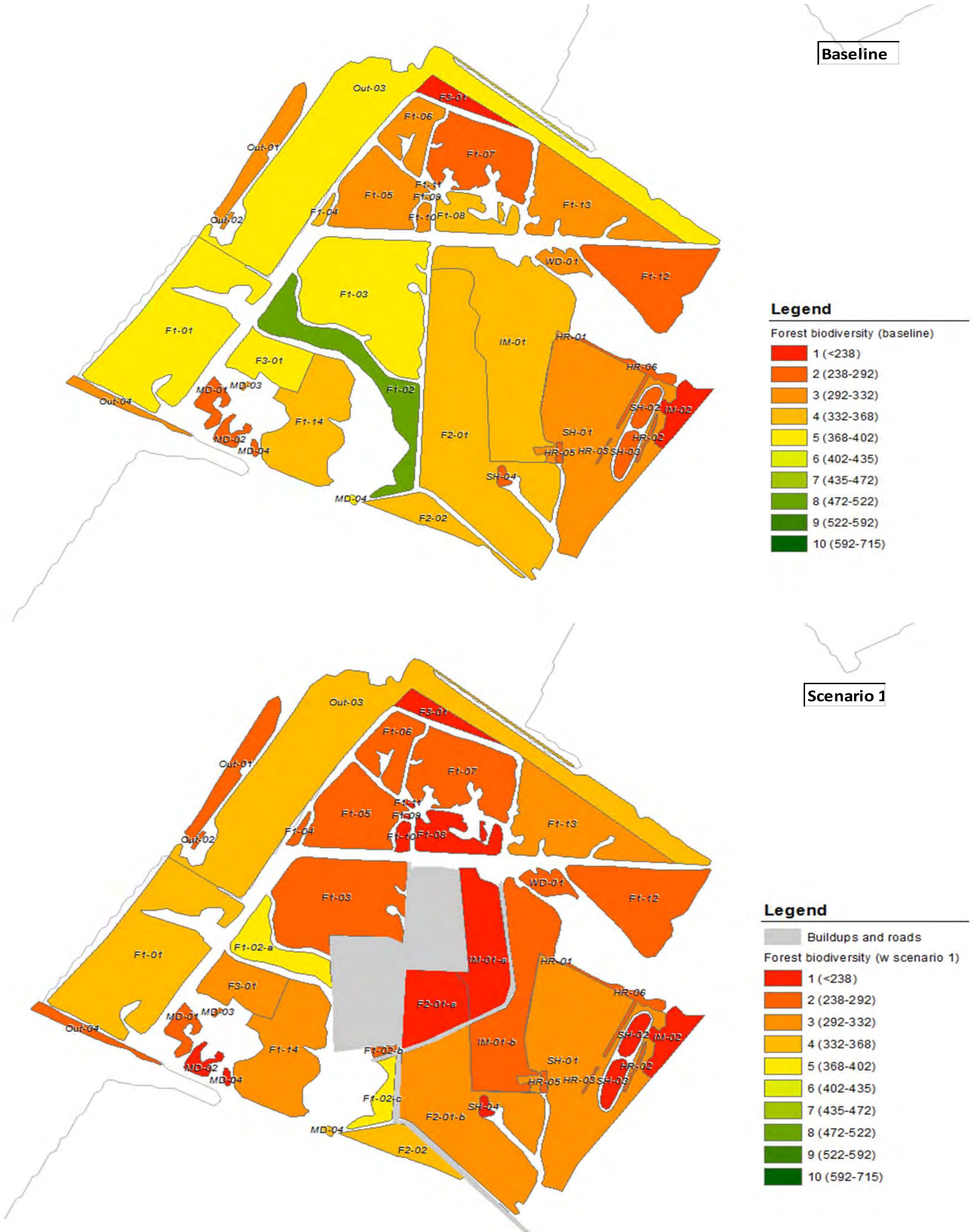


Figure D-1. Base map showing Scenario 1 location.



Forest Habitat Provisioning for Biodiversity

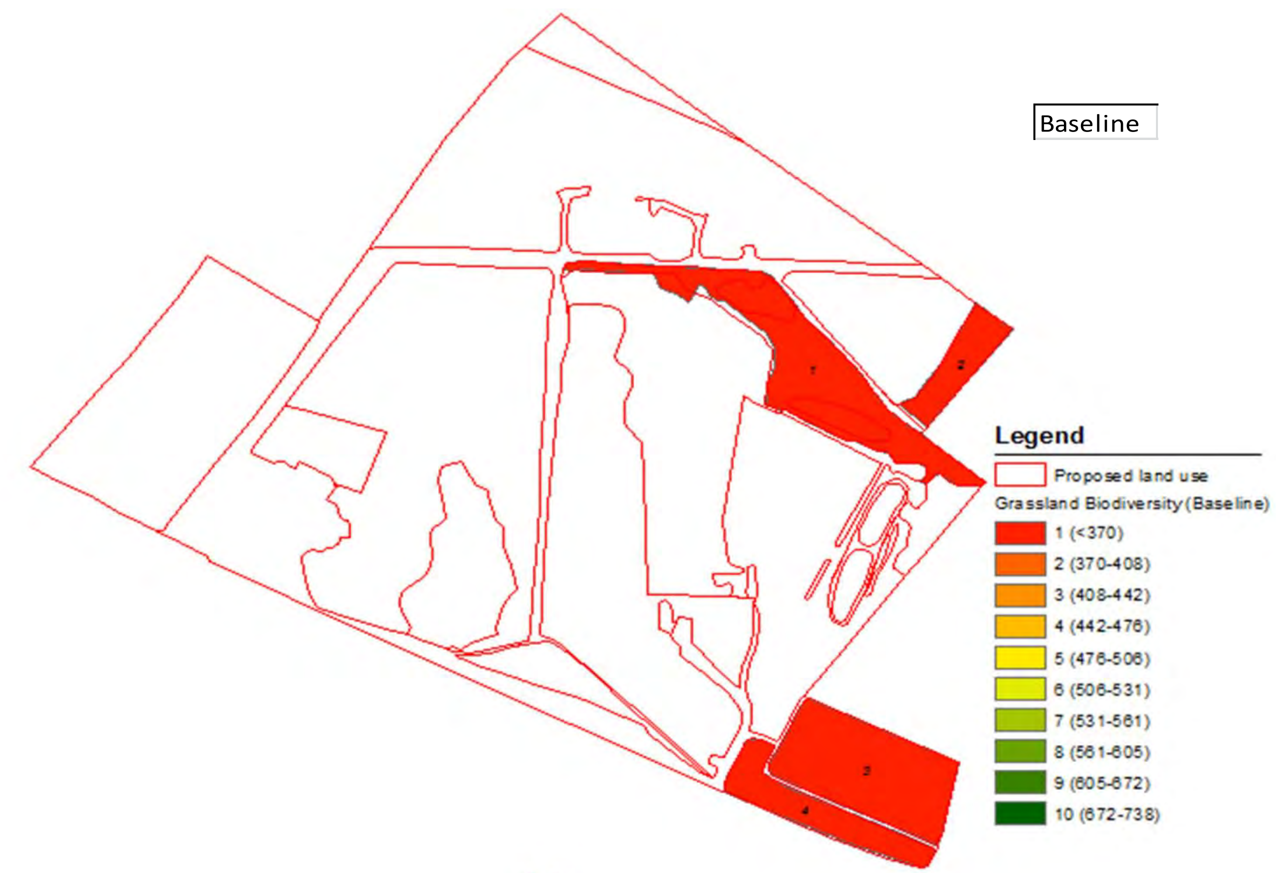
Baseline	overall	overall_r	Scenario 1	overall	overall_r
F1-01	388	5	F1-01	342	4
F1-02	478	8	F1-02-a	382	5
			F1-02-b	282	2
			F1-02-c	378	5
F1-03	382	5	F1-03	238	2
F1-04	365	4	F1-04	260	2
F1-05	318	3	F1-05	242	2
F1-06	305	3	F1-06	275	2
F1-07	270	2	F1-07	270	2
F1-08	338	4	F1-08	232	1
F1-09	310	3	F1-09	205	1
F1-10	315	3	F1-10	165	1
F1-11	328	3	F1-11	222	1
F1-12	280	2	F1-12	265	2
F1-13	300	3	F1-13	300	3
F1-14	360	4	F1-14	325	3
F2-01	362	4	F2-01-a	205	1
F2-02	358	4	F2-01-b	310	3
F2-02	358	4	F2-02	342	4
F3-01	235	1	F3-01	235	1
F3-01	378	5	F3-01	322	3
HR-01	250	2	HR-01	220	1
HR-02	285	2	HR-02	285	2
HR-03	242	2	HR-03	242	2
HR-05	238	2	HR-05	238	2
HR-06	250	2	HR-06	250	2
IM-01	335	4	IM-01-a	205	1
			IM-01-b	268	2
IM-02	235	1	IM-02	235	1
MD-01	285	2	MD-01	250	2
MD-02	278	2	MD-02	208	1
MD-03	315	3	MD-03	240	2
MD-04	275	2	MD-04	215	1
MD-04	400	5	MD-04	340	4
Out-01	318	3	Out-01	288	2
Out-02	295	3	Out-02	250	2
Out-03	380	5	Out-03	350	4
Out-04	308	3	Out-04	262	2
SH-01	308	3	SH-01	308	3
SH-02	240	2	SH-02	225	1
SH-03	242	2	SH-03	228	1
SH-04	268	2	SH-04	232	1
WD-01	320	3	WD-01	275	2

Figure D-2. Screen shots for model outputs under baseline and Scenario1 conditions--Biodiversity/Forest

Wetland Habitat Provisioning for Biodiversity

Baseline	overall	overall_r	Scenario 1	overall	overall_r
F1-1	291	3	F1-1	231	2
F1-10	276	2	F1-10	246	2
F1-2	299	3	F1-2	344	4
F1-3	292	3	F1-3	292	3
F1-4	355	5	F1-4	344	4
F1-5	309	3	F1-5	294	3
F1-6	306	3	F1-6	231	2
F1-7	370	5	F1-7	190	1
F1-8	436	7	F1-8	230	2
F1-9	390	5	F1-9	330	4
F2-1	311	4	F2-1	221	1
F2-2	324	4			
F2-3	242	4	F2-3	242	2
F2-4	249	2	F2-4	234	2
F2-5	248	4	F2-5	248	2
F2-6	290	3	F2-6	245	2
IM-1	385	5			
IM-2	305	3	IM-2	275	3
MD-1	419	6	MD-1	269	3
WA-1	532	8	WA-1	349	4
WD-1	382	5	WD-1	356	5

Figure D-3. Screen shots for model outputs under baseline and Scenario1 conditions--Biodiversity/Wetland

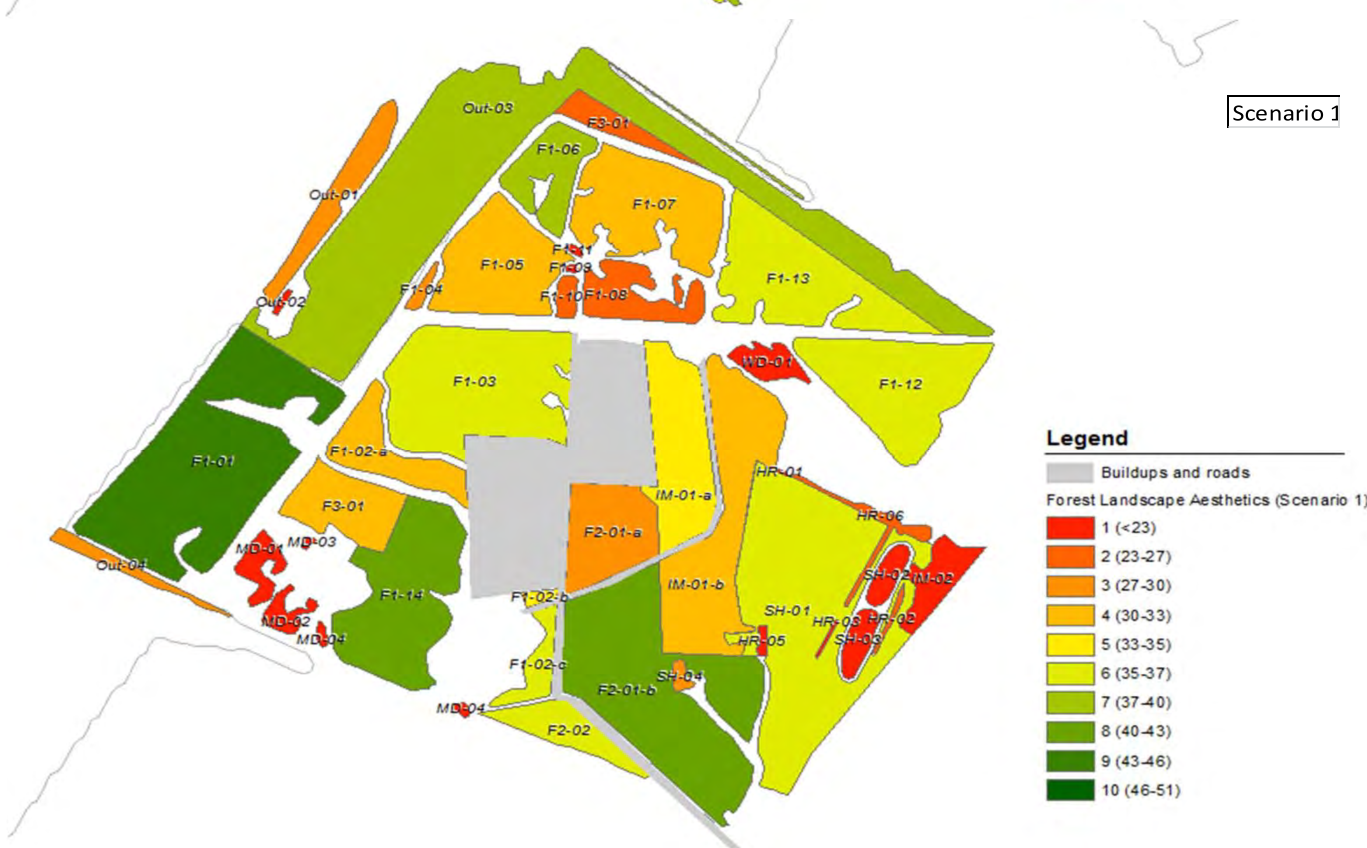


Grassland Habitat Provisioning for Biodiversity

Baseline	overall	overall_r	Scenario1	overall	overall_r
1	361	1	1	336	1
2	351	1	2	351	1
3	255	1	3	255	1
4	278	1	4	292	1

Figure D-4. Screen shots for model outputs under baseline and Scenario 1 conditions--Biodiversity/Grassland

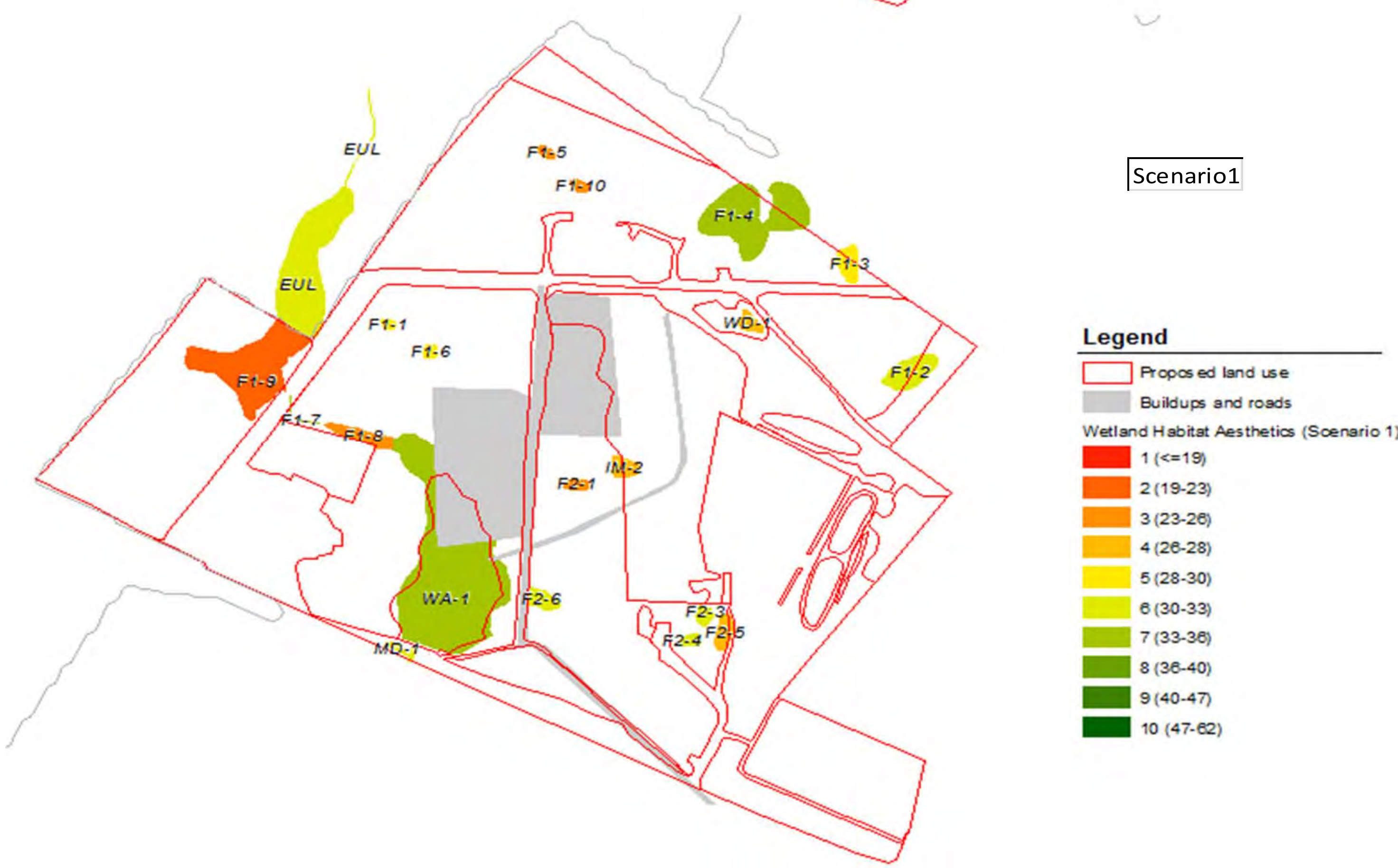
p_r
6



Forest Landscape Aesthetics

Baseline	overall	rank	Scenario 1	overall	rank
F1-01	45	9	F1-01	44	9
F1-02	44	9	F1-02-a	32	4
			F1-02-b	35	5
			F1-02-c	36	6
F1-03	31	4	F1-03	37	6
F1-04	30	3	F1-04	30	3
F1-05	30	3	F1-05	33	4
F1-06	38	7	F1-06	38	7
F1-07	36	6	F1-07	33	4
F1-08	29	3	F1-08	26	2
F1-09	19	1	F1-09	19	1
F1-10	25	2	F1-10	25	2
F1-11	23	1	F1-11	23	1
F1-12	36	6	F1-12	36	6
F1-13	36	6	F1-13	36	6
F1-14	39	7	F1-14	41	8
F2-01	40	7	F2-01-a	30	3
F2-02	37	6	F2-01-b	42	8
F2-02	37	6	F2-02	37	6
F3-01	30	3	F3-01	25	2
F3-01	31	4	F3-01	31	4
HR-01	16	1	HR-01	20	1
HR-02	17	1	HR-02	25	2
HR-03	19	1	HR-03	19	1
HR-05	20	1	HR-05	19	1
HR-06	25	2	HR-06	25	2
IM-01	38	7	IM-01-a	35	5
			IM-01-b	33	4
IM-02	23	1	IM-02	23	1
MD-01	17	1	MD-01	17	1
MD-02	18	1	MD-02	18	1
MD-03	11	1	MD-03	11	1
MD-04	13	1	MD-04	13	1
MD-04	20	1	MD-04	15	1
Out-01	30	3	Out-01	30	3
Out-02	18	1	Out-02	18	1
Out-03	41	8	Out-03	39	7
Out-04	26	2	Out-04	29	3
SH-01	37	6	SH-01	37	6
SH-02	14	1	SH-02	14	1
SH-03	11	1	SH-03	11	1
SH-04	34	5	SH-04	30	3
WD-01	18	1	WD-01	18	1

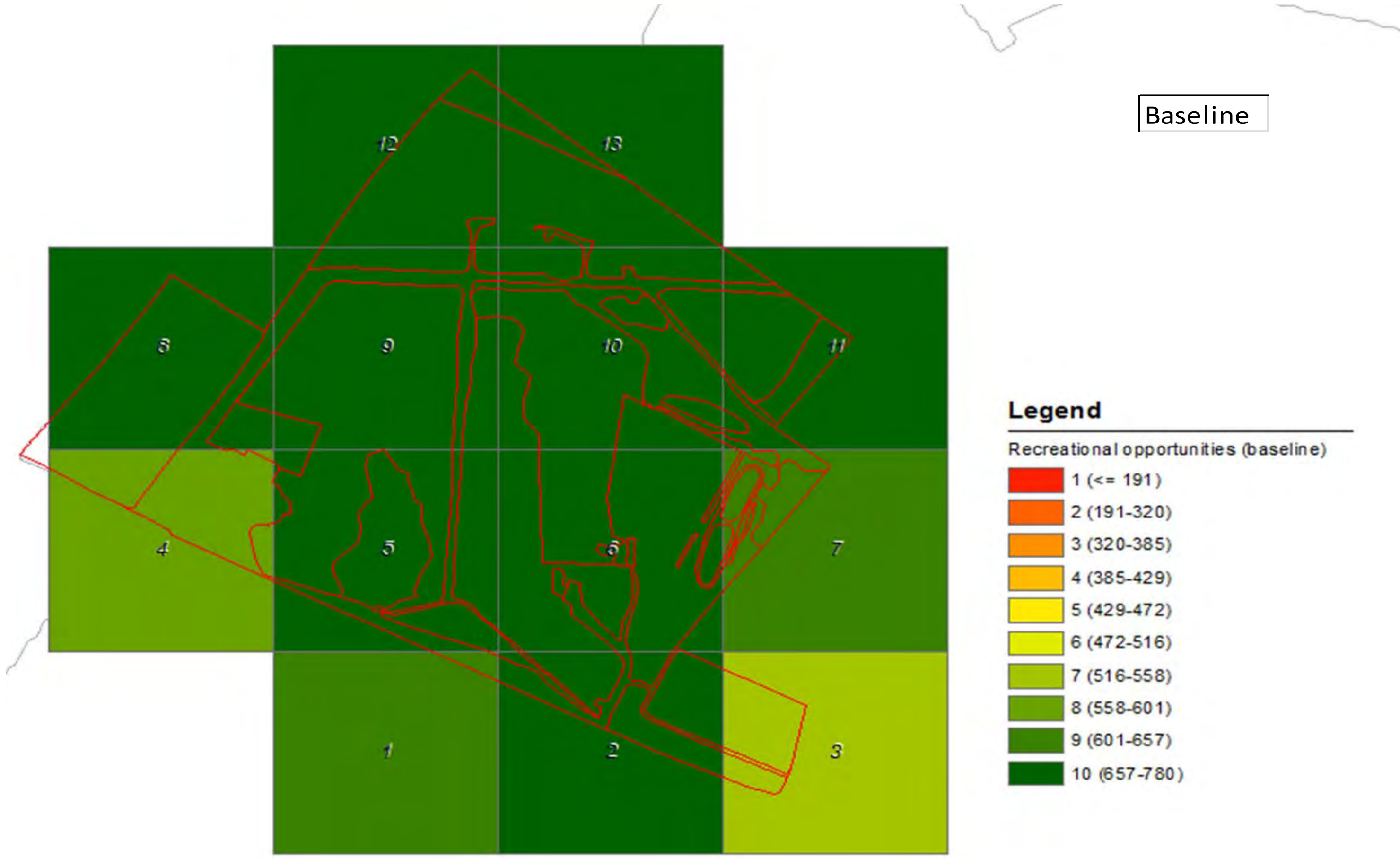
Figure D-5. Screen shots for model outputs under baseline and Scenario 1 conditions--Landscape Aesthetics/Forest



Wetland Landscape Aesthetics

Baseline	overall	Rank	Scenario1	overall	Rank
F1-1	23	2	F1-1	29	5
F1-10	28	4	F1-10	26	3
F1-2	30	5	F1-2	32	6
F1-3	27	4	F1-3	30	5
F1-4	34	7	F1-4	34	7
F1-5	21	2	F1-5	25	3
F1-6	27	4	F1-6	30	5
F1-7	29	5	F1-7	34	7
F1-8	30	5	F1-8	25	3
F1-9	23	2	F1-9	23	2
F2-1	24	3	F2-1	26	3
F2-2	29	5			
F2-3	28	4	F2-3	31	6
F2-4	27	4	F2-4	31	6
F2-5	25	3	F2-5	27	4
F2-6	27	4	F2-6	32	6
IM-1	25	3			
IM-2	23	2	IM-2	28	4
MD-1	35	7	MD-1	32	6
WA-1	39	8	WA-1	34	7
WD-1	26	3	WD-1	28	4

Figure D-6. Screen shots for model outputs under baseline and Scenario 1 conditions--Landscape Aesthetics/Wetland



Recreational opportunities

Baseline	Overall	Rank	Scenario 1	Overall	Rank
1	651	9	1	651	9
2	763	10	2	781	10
3	551	7	3	551	7
4	587	8	4	596	8
5	753	10	5	781	10
6	712	10	6	730	10
7	623	9	7	623	9
8	694	10	8	738	10
9	677	10	9	747	10
10	720	10	10	713	10
11	724	10	11	724	10
12	678	10	12	722	10
13	729	10	13	730	10

Figure D-7. Screen shots for model outputs under baseline and Scenario 1 conditions--Recreational Opportunities

Baseline	TN reductic	Rank	Scenario 1	TN reductic	Rank
F1-1	1.77	1	F1-1	1.77	1
F1-10	2.34	1	F1-10	2.34	1
F1-2	17.32	1	F1-2	17.32	1
F1-3	9.01	1	F1-3	9.01	1
F1-4	72.4	4	F1-4	72.4	4
F1-5	2.22	1	F1-5	2.22	1
F1-6	2.26	1	F1-6	2.26	1
F1-9	163.51	6	F1-9	163.51	6
F2-1	3.44	1	F2-1	3.44	1
F2-2	3.9	1			1
F2-3	11.32	2	F2-3	11.32	2
F2-4	9.38	2	F2-4	9.38	2
F2-5	20.5	2	F2-5	20.5	2
F2-6	6.84	1	F2-6	6.84	1
IM-1	0.6	1			1
IM-2	6.88	1	IM-2	6.88	1
WA	256.75	7	WA	203.54	6
WD-1	4.9	1	WD-1	4.9	1

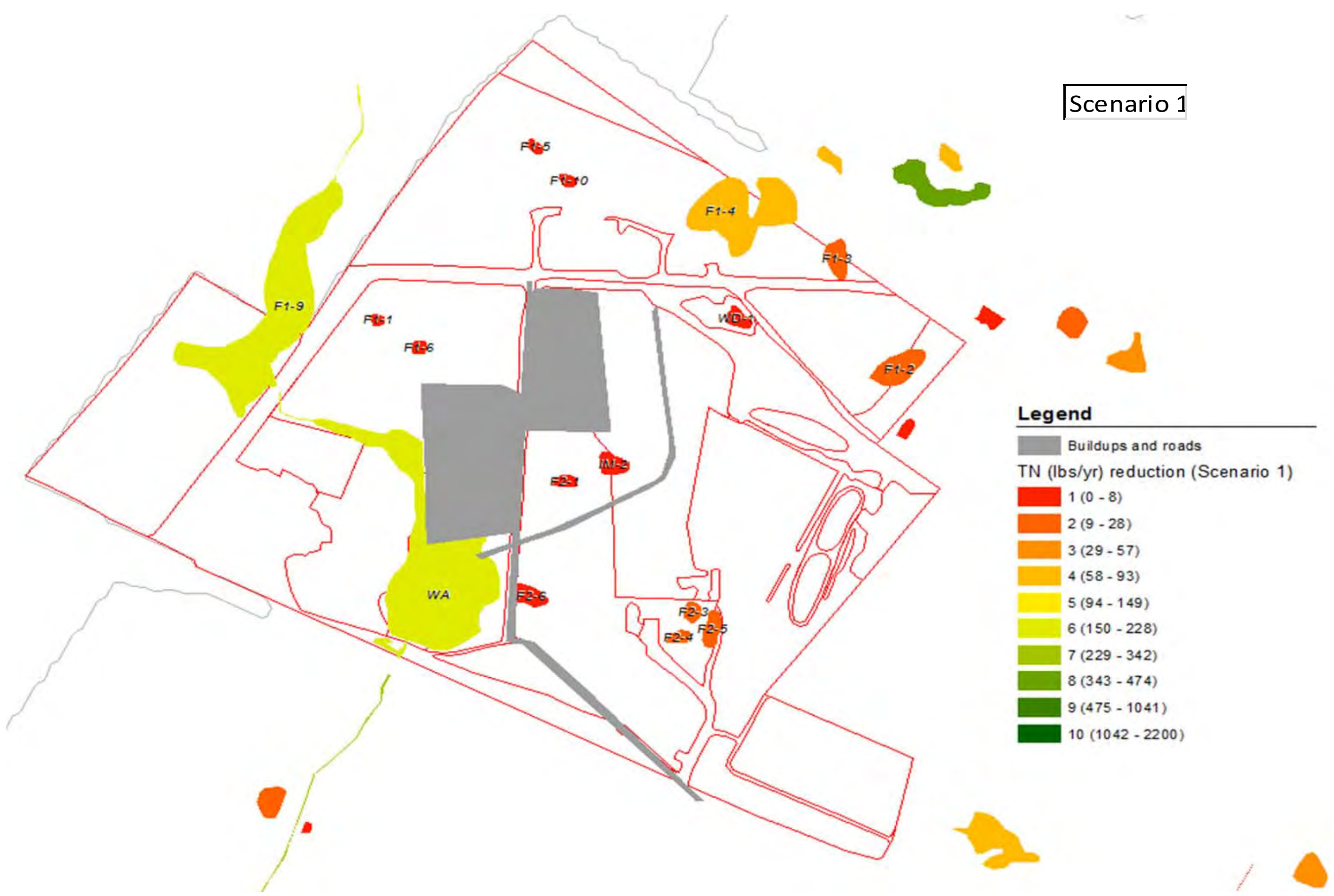


Figure D-8. Screen shots for model outputs under baseline and Scenario1 conditions--Nutrient (N) Sequestration

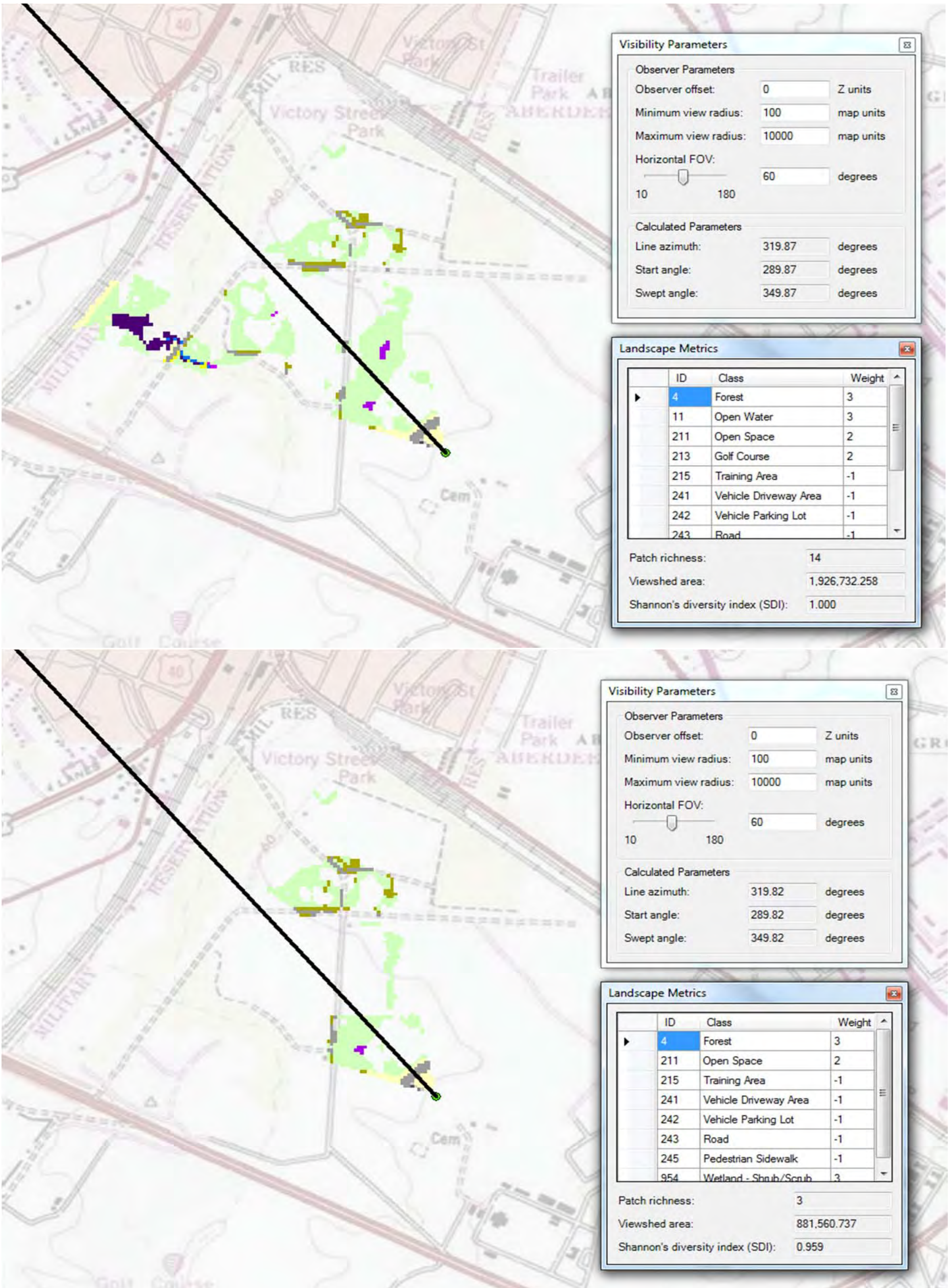


Figure D-9. Screen shots for model outputs under baseline and Scenario 1 conditions--Vista Aesthetics

Appendix E

Statistical Testing Results Used to Determine Significant Differences between Baseline and Scenario 1

Biodiversity: Forest

	FrstSize	edge_sdi	DistRd	DistBlg	ProxWtr	close	DistEdge	EgCmplx	soil	slope	overall
V.stat	10	264	321	773	6	151	336	5	6	6	465
p.value	0.100348	0.189343	0.343026	6.91E-11	0.855132	0.223718	0.737042	0.422678	0.181449	0.855132	1.77E-06
sig.diff	no	No	no	yes	no	no	no	no	no	no	yes

Biodiversity: Grassland

	FrstSize	edge	DistRd	DistBlg	close	ProxWtr	dist_fores	EgCmplx	n_soil	overall
V.stat	0	3	3	7	0	0	0	0	0	3
p.value	NaN	1	1	0.625	NaN	NaN	0.125	NaN	NaN	1
sig.diff	no	no	no	no	no	no	no	no	no	no

Biodiversity: Wetland

	WtldSize	heter	dist_road	dist_build	dist_close	dist_edge	shp_cmplx	n_soil	overall
V.stat	66	130	244	208	4	276	5	3	265
p.value	0.029617	0.360333	0.000639	0.00013	0.789268	2.38E-07	0.422678	0.371093	0.000119
sig.diff	yes	no	yes	yes	no	yes	no	no	yes

Landscape Aesthetics: Forest

	lndDiff	EgCmplx	strLCctr	surLCdiv	FrstSize	VegInsp	age_r	FrsDen	overall
V.stat	56	5	7.5	26	10	16	3	5	183
p.value	0.484642	0.422678	0.589774	0.287636	0.100348	0.821098	0.345779	1	0.018729
sig.diff	no	no	no	no	no	no	no	no	yes

Landscape Aesthetics: Forest

	lndDiff	EdgeCmplx	Water	surWater	strLCctr	surLCdiv	WtldSize	VegInsp	overall
V.stat	106	5	9	3.5	7	7	6	17	193
p.value	0.985101	0.422678	0.78353	0.343028	0.577469	0.577469	0.181449	0.000649	0.000502
sig.diff	no	no	no	no	no	no	no	yes	yes

Nutrient Sequestration

	TN_reduction
V.stat	6
p.value	0.181449
sig.diff	no

Recreational Opportunities

	dist_build	dist_road	aesthetics	slope	bio_div	trail_len	trail_inte	trail_loop	dist_boat	overall1
V.stat	84	70	4	0	21	0	0	9	0	2
p.value	0.004639	0.094238	0.77283	NaN	0.031033	0.005962	0.005962	0.095335	NaN	0.017617
sig.diff	yes	no	no	no	yes	yes	yes	no	no	yes