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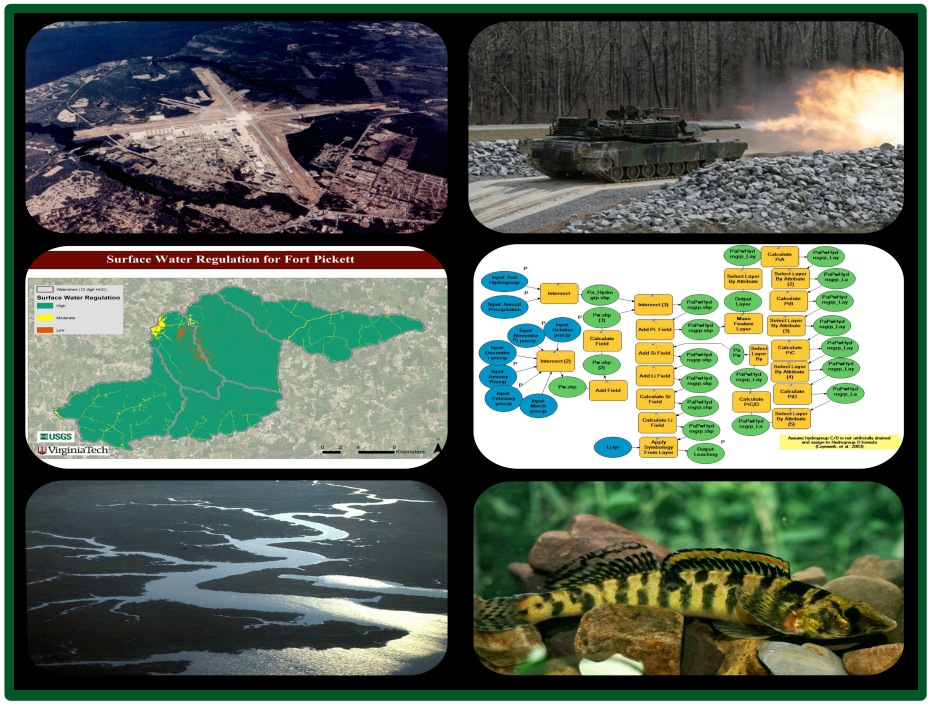

Regulating Services as Measures of Ecological Resilience on DoD Lands

November 2015

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14. ABSTRACT
Knowledge of ecosystem services can help DoD land managers enhance cost-effectiveness, minimize environmental damage, and maximize resources available for military missions. We demonstrated how to quantify and map regulating services (RS). Our objectives were to 1) estimate capacity and demand for selected RS, 2) examine effects of plausible future scenarios capacity and flow of these RS, and 3) project how changes in nearby lands might affect demand for RS. We incorporated data on land cover, soils, precipitation, and air temperature into GIS analyses to estimate capacity of sediment, nitrogen, and surface-water regulation. Surveys indicated that our approach was informative and easy to use.

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Regulating service, service capacity, service flow, service demand, sediment regulation, nitrogen regulation, surface water regulation, spatial analysis

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ACRONYMS AND ABBREVIATIONS

ACIL	annual contaminant input load
ANG-MTC	Army National Guard Maneuver Training Center
CRA	critical riparian area
DoD	U.S. Department of Defense
ES	ecosystem service
EUG	End-User-Guide
GIS	geographic information system
HU	hydrologic unit
INRMP	Integrated Natural Resources Management Plan
LULC	land use-land cover
m	meter(s)
m^2	square meter(s)
MACL	measured annual contaminant load
MCAS	Marine Corps Air Station
N	nitrogen
NLCD	National Land Cover Database
NRCS	Natural Resources Conservation Service
PO	performance objective
PRISM	Parameter-elevation Regressions on Independent Slopes Model
RS	regulating (ecosystem) service
RUSLE	Revised Universal Soil Loss Equation
SPARROW	Spatially Referenced Regressions On Watershed attributes
SSURGO	Soil Survey Geographic Database (USDA-NRCS)
USDA	U.S. Department of Agriculture

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EXECUTIVE SUMMARY

OBJECTIVES OF THE DEMONSTRATION

The project's overall objective was to provide the U.S. Department of Defense (DoD) with clearer insight into the current and future provision of freshwater ecosystem services (ESs) germane to many environmental concerns faced by the DoD, including threatened, endangered, and at-risk species, water quality compliance, and urban encroachment. The ecological resilience provided by regulating and supporting ecosystem services (RS) is important when planning land uses, whether for environmental stewardship or military training. Spatially explicit knowledge of RS capacity and flow can help DoD land managers make planning decisions that enhance cost-effectiveness, minimize environmental damage, and maximize the resources available for their military mission. Land-use choices by the DoD are made in the context of dynamic demographic, land-use, and climatic conditions on adjacent lands, which ultimately control RS capacity and flow. These dynamics can be depicted in future scenarios that enable land managers to envision tradeoffs and plan more effectively for environmental conflicts. Specific technical objectives were to (1) estimate current capacity of and demand for (i.e., ecological pressure on) selected RS within DoD lands, (2) examine the effects of future DoD land management (i.e., planned military and environmental operations) and climate changes on the capacity and flow of these RS, and (3) project how land use and climate changes in nearby lands might affect future demand for RS within DoD lands.

METHODOLOGY DESCRIPTION

The analytical framework that was demonstrated combines quantitative and spatial modeling to evaluate RS on and near DoD lands. Ecosystem service terminology varies widely among authors. Throughout this demonstration, the adopted terminology is derived from the current scientific literature. The approach, described below, incorporates widely accepted hydrologic models and equations, remote sensing, geographic information system (GIS) analysis, as well as stakeholder involvement. Although GISs are commonly used to assess RS via simple land cover proxies, this project's approach enables the project team to separately estimate the capacity and flow of RS by incorporating multiple layers of information, thereby increasing the resolution and accuracy of the analysis as well as its applicability to specific management questions.

Technical objectives were translated into 12 performance objectives (POs). The first four POs sought to improve production function details and spatial resolution of GIS-based analyses of the focal RS (i.e., surface water regulation, and sediment and nitrogen regulation). The next two POs sought to demonstrate transferability of the frameworks for measuring capacity of, demand on, demand for, and flow of RS. POs 7 and 8 sought to demonstrate how to rank ecological pressures on RS and measure flow of RS to beneficiaries. The next two POs sought to demonstrate how to minimize propagation errors in geospatial data and enhance RS-based decision support systems. POs 11 and 12 sought to demonstrate the utility of the framework for integrating RS into installation planning decisions and improve projections of RS to be used in that planning.

Baseline data required for the RS framework include land cover, land use, soil type and hydrologic characteristics, precipitation, and air temperature. These data are publicly available; however, site-specific data also were incorporated when the resolution was significantly better or when the data

were more up-to-date. The preceding data were integrated into several hydrological equations, including: (1) Surface Curve Number Method for estimating surface runoff based on land cover, soil type, and precipitation patterns; and (2) Revised Universal Soil Loss Equation, based on land cover, soil erodibility, slope, and management practices. These equations were used to estimate capacity of sediment, nitrogen (N), and surface water regulation. Nitrogen regulation capacity was assessed in two phases—leaching and riparian filtration, which together reduce the nitrogen loading into streams, rivers, and lakes. Nitrogen lost from surface water via infiltration was calculated using the New York Nitrogen Leaching Index. Nitrogen removed via filtration was calculated from published nitrogen-removal efficiencies associated with agricultural and riparian zone best management practices.

The innovative framework proposed here distinguishes RS capacity from RS flow by mapping the hydrologic flow of disservices and services from source to stream and beneficiaries, respectively. Ecological pressures (sometimes called disservices) were mapped using three methods (including field-collected data) and the results were compared to determine the most cost- and time-effective strategy for land-use planning. The three methods were established to reflect three levels of time and computer processing investment. Because the demand for RS depends largely on the magnitude and location of ecological pressures (e.g., sediment, nitrogen, and excessive surface water), the flow paths of known pressures were mapped as well as potentially unknown pressures from training areas. Finally, this project demonstrated a method to quantify the magnitude of RS generated on military installations by comparing water quality monitoring data to modeled estimates of upstream soil loss and ranking the watersheds based on their ecological pressure and ambient condition.

The geospatial analysis associated with this project was initially conducted within the ArcGIS environment—first in Economic and Social Research Institute version 9.3, and later adapted for ArcMap version 10.2 to correspond to updated systems used on military installations. Presentations of results and scenario planning meetings were conducted several times at two military installations (Army National Guard Maneuver Training Center [ANG-MTC] Fort Pickett and Marine Corps Air Station [MCAS] Cherry Point) throughout the demonstration, and a field validation of land cover data was conducted on both installations.

DEMONSTRATION RESULTS

This demonstration showed that many environmental issues (e.g., compliance with National Environmental Policy Act, Endangered Species Act, and Clean Water Act; suburban encroachment) facing military installations can be analyzed as tradeoffs among ESs. For example, this project's approach to ES analysis can inform planners regarding how dedicating a land parcel to training, housing, or stewardship will influence surface water quality or flooding. Capacities and flows of ES vary greatly across landscapes and are likely to vary as climate changes or development occurs. For example, climate change may increase nitrogen leaching if precipitation increases and off-installation development may impact on-installation water quality. The GIS maps developed via the approach herein are instructive in showing variation in ES capacities and flows. ES capacities often can be estimated via existing data but a need exists to validate data and recognize resolution limits; in some situations, new kinds of data are needed. For example, adequate data on ambient water quality were sometimes lacking and some land cover data were out of date. Analyses of ES capacity and flow are useful to managers and planners by helping them

identify and prioritize management targets. For example, flow-path analysis helps identify trouble spots to guide effective implementation of best management practices, and ES analysis can inform prioritization of compatible use buffers. Responses to the end-of-project surveys of installation staff likely to use this framework or tools indicated that the demonstrated approach was informative, useful, and easy to use in the context of installation environmental compliance and land-use planning. Because the analytical approach is new, much room for improvement remains. Refining the models and tools demonstrated herein will lead to better management choices and outcomes. The new tools that were developed are accessible to on-installation GIS analysts or hired consultants.

This demonstration included 12 POs—10 quantitative and 2 qualitative—that were initially designed to evaluate the success of the demonstration. Success was achieved on PO 1–4, 11, and 12, and partial success on performance objectives 5–7 and 9–10. Due to changes in the scope of the demonstration and data available during the demonstration, PO 8 was modified to better inform the impacts of regulating service capacity within installation boundaries and on lands in the corresponding encroachment buffer program. Limited success on POs was largely attributed to the lack of on-the-ground water quality monitoring data that would be needed to quantify the actual flow of regulating services occurring (e.g., surface water retention).

IMPLEMENTATION ISSUES

Few future issues, especially technological constraints, limit the implementation of the demonstrated framework for using RS to evaluate ecological resilience. The GIS tools that were developed can be used within the ArcGIS version 10.2 environment and require no further licenses beyond those already owned. End products, along with an End-User Guide, will enable GIS analysts to conduct the same analyses described in this report as well as adapt and update the underlying models as needed (through Python scripting or in ModelBuilder). The tools demonstrated in this project were developed to facilitate assessment of baseline and future changes to the landscapes of specific installations and surrounding areas. With such assessments, however, comes the need for (1) accurate information that drives the specification of model parameters, and (2) time for staff to conduct the analyses. On-installation personnel time was the most limited resource, followed by on-the-ground data from water quality monitoring; both limited the success of the demonstration and implications for future implementation. Implementation of the methodology herein may lead to re-assessments of installation tradeoffs in prioritizing their limited resources for environmental management. Even so, the work shows that implementing an RS-based assessment framework and methodology can provide insight into future land management on military installations, including decisions related to encroachment buffers, stewardship, and regulatory compliance.

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1.0 INTRODUCTION

1.1 BACKGROUND

U.S. Department of Defense (DoD) installations pursue missions within environmental constraints such as imperiled species, water quality, and encroachment. Ecosystem services (ESs) provide a framework for understanding environmental issues and can clarify spatial patterns, tradeoffs, and synergies of interest to stakeholders. Changes in land/water use in or near DoD lands may affect ES germane to military missions. Understanding sources and flows of ES and projecting shifts in delivery may help DoD land/water managers develop cost-effective environmental strategies. However, there is no readily available methodology for incorporating knowledge of ES into DoD decision-making (The Nature Conservancy, 2008). Regulating services (RS), benefits derived from ecological processes that regulate valued ecological features, are of particular interest to DoD managers because they strongly influence ecosystem resilience. Several biophysical factors determine a landscape's capacity to deliver RS, and many human actions decrease the capacity of RS while increasing demand for them (Carpenter et al., 2006).

Land-use choices by installations are made in the context of regional communities and land use and climate changes on adjacent lands, which ultimately control RS capacity, demand, and flow. The project team tested if an integrative approach to characterizing RS delivery, based on a suite of biophysical data layers, provides a better conceptualization and inventory of RS than prevailing approaches that simplistically rely on land cover proxies or ambient conditions. The team separately estimated and mapped capacity of and demand for select ESs that can be used to estimate and map ES flow. Estimated effects on RS flow were also induced by changes in climate or land/water use by recalculating RS capacity and demand under selected scenarios germane to base-specific issues. The findings will help planners determine which areas are best suited for different land uses and which areas will be most affected by region-wide land use or climate change.

1.2 OBJECTIVES OF THE DEMONSTRATION

This demonstration project addressed ten quantitative performance objectives (PO):

1. Improve production function details of geographic information system (GIS)-based analysis of Surface Water Regulation capacity;
2. Improve production function details of GIS-based analysis of Sediment and Nitrogen Regulation capacity;
3. Improve spatial resolution of GIS-based analysis of Surface Water Regulation capacity;
4. Improve spatial resolution of GIS-based analysis of Sediment and Nitrogen Regulation capacity;
5. Demonstrate transferability of Surface Water Regulation service-related frameworks for measuring capacity, demand on, demand for, and flow;
6. Demonstrate transferability of Sediment and Nitrogen Regulation service-related frameworks for measuring capacity, demand on, demand for, and flow;
7. Demonstrate framework to rank ecological pressure on RS;

8. Demonstrate how to measure flow of RS to beneficiaries;
9. Demonstrate minimal propagation errors in geospatial data; and
10. Enhance ES-based decision support systems.

POs 1–4 were fully met; POs 5–10 were partially met. Two qualitative POs were also addressed: PO 11 – Demonstrate utility of a framework for integrating RS into natural resource and mission planning decisions, and PO 12 – Improve projections of RS. The project team successfully met both of these POs. Figure 1 depicts relations between POs and demonstration tasks.

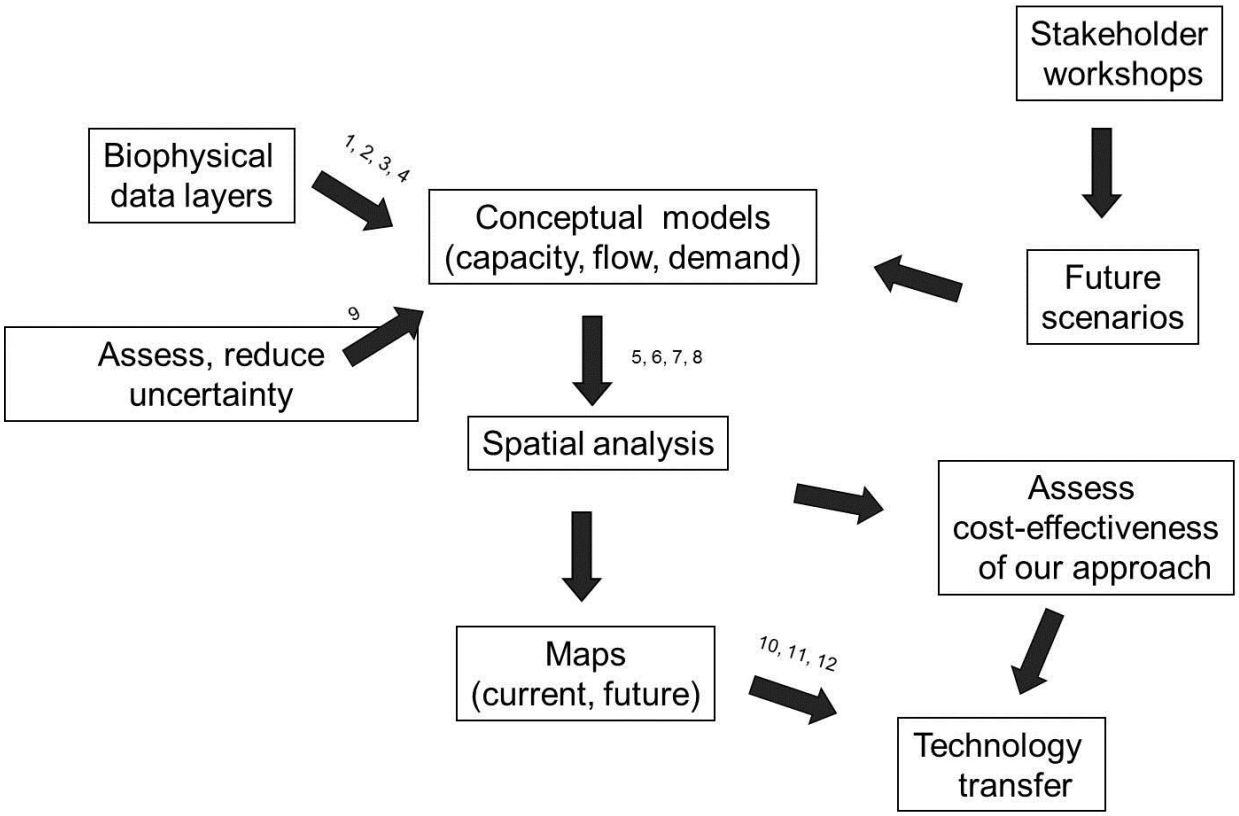

Figure 1. Flow Diagram Depicting the Main Demonstration Components and Associated POs.

Numbers near arrows refer to POs.

1.3 REGULATORY DRIVERS

At this time, there are no regulations or DoD directives articulating the need for this new methodology.

2.0 TECHNOLOGY

2.1 TECHNOLOGY/METHODOLOGY OVERVIEW

The project team used hydrologic models, remote sensing, GIS analysis (ArcGIS version 10.2), and stakeholder involvement to evaluate RS on and near DoD lands. The capacity and flow of RS were separately estimated by incorporating multiple layers of information. Data required for the framework include land cover, land use, soil type and hydrologic characteristics, precipitation, and air temperature, all of which are publicly available. These data were integrated into the Surface Curve Number Method (U.S. Department of Agriculture – Natural Resources Conservation Service [USDA-NRCS], 1972) for estimating surface runoff, and the Revised Universal Soil Loss Equation (USDA-NRCS, 2003). These equations were used to estimate capacities of sediment regulation and surface water regulation. Nitrogen-regulation capacity was treated as two linked processes—vertical infiltration and horizontal filtration—calculated from the New York Nitrogen Leaching Index (Czymmek et al., 2003) and published nitrogen-removal efficiencies, respectively.

RS capacity was distinguished from RS flow by incorporating estimates of the demand for RS. Demand for a given RS is equivalent to the amount of water, sediment, or nitrogen that society wants regulated to achieve a specific objective. RS demand was calculated by subtracting the pre-established water goal from the inputs (amount of water, sediment, or nitrogen entering the study area) estimated via models. The water, sediment, or nitrogen exported from DoD lands represent inputs to downstream communities. RS flow was calculated by subtracting the quantity or concentration of water, sediment, or nitrogen measured in surface waters from the modeled input estimates. All analytical procedures were documented so they can be replicated beyond our demonstration. In sum, an objective approach was provided for measuring and mapping RS. Such information can help DoD managers connect planned activities with appropriate, cost-effective locations.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY/ METHODOLOGY

Current ES assessments are often based simply on land-cover and ambient environmental condition. However, ES delivery is complex, depending on other physical factors (e.g., soil, slope, precipitation) and social contexts. In addition, ES assessments rarely distinguish the potential supply (capacity) of an RS from its flow (actual benefits derived), and ambient conditions alone do not accurately reflect RS capacity or flow. Demand on an RS (a precursor to RS flow estimation) reflects the amount of ecosystem "work" required to achieve a predetermined societal goal. Thus, demand for water purification can be measured as the quantity of contaminant that must be excluded or removed to meet a management goal. This can be calculated by subtracting the goal quantity from total inputs. Environmental degradation occurs when demand on RS (e.g., contaminant loading) exceeds RS capacity. Assessments that base RS flow on ambient conditions alone misrepresent capacity if they fail to account for differences in demand on RS. Estimates of RS flow should reflect the actual work by the system (Peterson et al., 2010), which is the difference between measured ambient condition and stressor inputs.

Application of the methodology is limited by the accuracy and availability of existing spatial data that can be translated into a GIS. Data quality and reliability are crucial, so the project team field-

validated spatial data and used these studies to incorporate uncertainty into the results. The methodology can also be limited by non-involvement of installation stakeholders, whose engagement is crucial in developing landscape scenarios for ES analysis.

3.0 PERFORMANCE OBJECTIVES

Table 1 outlines the quantitative and qualitative POs, metrics, data requirements, and success criteria for the demonstrations at Fort Picket and Marine Corps Air Station (MCAS) Cherry Point. Throughout the table and report, "resolution" of raster (gridded) data refers to the cell size (e.g., 30 meters [m]), while "resolution" of vector (polygon) data refers to the size of the smallest feature that can be detected. Because finer-resolution data typically provide better information for decision-making, this demonstration sought to increase the spatial resolution of ES inventories and the resolution of data inputs into production functions (i.e., ES capacity equations). The latter resolution is referred to as *production function detail*. Production functions are derived from conceptual models for capacity of focal ES.

Table 1. POs for Demonstrations at Fort Pickett and MCAS Cherry Point.

POs	Metrics	Data Requirements	Success Criteria	Results
Quantitative				
1. Improve *production function details* of GIS-based analysis of Surface Water Regulation capacity	Percent of *calculation factors* from conceptual model that are included in spatial analysis of ES capacity	Geospatial data including: land cover, soil, elevation, precipitation	• ≤33.3% of calculation factors are absent when there are ≤3 calculation factors noted in the Surface Water Regulation capacity conceptual model. • ≤50% of calculation factors are absent when there are >3 calculation factors noted in the Surface Water Regulation capacity conceptual model.	Surface Water Regulation capacity: 100% (3/3) of factors were available at the regional and national scale for Fort Pickett and 100% of the factors were available at the national and local (on installation) scale for Cherry Point.
2. Improve *production function details* of GIS-based analysis of Sediment and Nitrogen Regulation capacity	Percent of *calculation factors* from conceptual model (Figure 11; green boxes) that are included in spatial analysis of ES capacity	Same as PO#1	• ≤33.3% of calculation factors are absent when there are ≤3 calculation factors noted in the Sediment and Nitrogen Regulation capacity conceptual model. • ≤50% calculation factors are absent when there are >3 calculation factors noted in the Sediment and Nitrogen Regulation capacity conceptual model.	Sediment and Nitrogen Regulation capacity: 100% (3/3) of factors were available at the regional and national scale for Fort Pickett and 100% of the factors were available at the national and local (installation) scale for Cherry Point.

Table 1. Performance Objectives for Demonstrations at Fort Pickett and MCAS Cherry Point (continued).

POs	Metrics	Data Requirements	Success Criteria	Results
Quantitative (continued)				
3. Improve *spatial resolution* of GIS-based analysis of Surface Water Regulation capacity	Resolution of final GIS layer	Same as PO #1	Area of the smallest parcel of land representing intersecting capacity factors is smaller than LULC resolution (30 m).	The smallest parcel of land representing intersecting capacity factors was <1 square meters (m^2) in Fort Pickett and in Cherry Point.
4. Improve *spatial resolution* of GIS-based analysis of Sediment and Nitrogen Regulation capacity	Resolution of final GIS layer	Same as PO #1	Area of the smallest parcel of land representing intersecting capacity factors is smaller than LULC resolution (30 m = 900 m^2)	**Vertical Retention –** The smallest parcel of land representing intersecting capacity factors was <900 m^2 in Fort Pickett and in Cherry Point (see text for more detail). **Horizontal Retention –** The smallest parcel of land representing intersecting capacity factors was 100 m^2 in Fort Pickett and in Cherry Point. **Riparian filtration –** The smallest parcel of land representing intersecting capacity factors was <300 m^2 in Fort Pickett and in Cherry Point (see text for more detail).
5. Demonstrate transferability of Surface Water Regulation service-related frameworks for measuring capacity, demand on, demand for, and flow	Availability of data inputs from conceptual model available at functional resolution for Fort Pickett, Cherry Point, and the 8-digit hydrologic units (HUs) containing Fort Pickett and Cherry Point	Geospatial data same as PO #1 for: a) Fort Pickett, b) 8-digit HUs containing Fort Pickett, c) Cherry Point, d) 8-digit HUs containing Cherry Point	a) No more than one dataset is absent for the within-installation or HU analyses b) no more than two datasets are of lower resolution than within-installation data inputs	All datasets for capacity were present at low resolution, and all but one dataset was available at the installation level (precipitation). In some cases, the national dataset was the highest resolution (e.g., SSURGO). The LULC data set was not available at the installation level, but multiple datasets were synthesized to create it. Ambient condition data (for ecological pressure assessment) was not available from the installations and the precipitation data for Fort Pickett came from >30 miles away.

Table 1. Performance Objectives for Demonstrations at Fort Pickett and MCAS Cherry Point (continued).

POs	Metrics	Data Requirements	Success Criteria	Results
Quantitative (continued)				
6. Demonstrate transferability of Sediment and Nitrogen Regulation service-related frameworks for measuring capacity, demand on, demand for, and flow	Availability of data inputs from conceptual model available at functional resolution for areas within the same 8-digit HUs and available for both demonstration installations	Same as PO #5	a) No more than one dataset is absent for within-installation or HU analyses b) no more than two datasets are of lower resolution than within-installation data inputs	All datasets for capacity were present at low resolution, and all but one dataset was available at the installation level (precipitation). In some cases, the national dataset was the highest resolution (e.g., SSURGO). The LULC data set was not available at the installation level, but multiple datasets were synthesized to create it. Ambient condition data was not available from Cherry Point and the precipitation data for Fort Pickett came from >30 miles away.
7. Demonstrate framework to rank ecological pressure on RS	Percent congruency between ecological pressure estimates using our approach and those based on full-scale hydrologic modeling	Data inputs required for SWAT or SPARROW model, RUSLE	Estimated ecological demand is within 10% of modeled ecological pressure (i.e., 90% or more of classifications measured by area are shared between approaches)	Maps were produced illustrating the overlap (percent congruency) among ecological pressure indicators based on three levels of data processing and time investment for Sediment and Nitrogen Regulation and Surface Water Regulation. Nitrogen monitoring data were not available.
8. Demonstrate how to measure flow of RS to beneficiaries	Spatially-explicit statistical similarity (tested with chi-square) between expected and observed values of RS capacity, demand on RS, ambient condition, and measured flow	Geospatial layers for: a) two focal services capacity, b) ecological pressure on RS, c) ambient condition, and d) estimates of RS flow	*Modified*^: ≥1 map/installation illustrates the flow of services and pressures from on-installation training areas and table that prioritizes compatible buffer land parcels impacted by on-installation land use and RS	Two maps were produced for each installation showing the flow of ecological pressures (erosion/sediment loading, surface water runoff) and buffer lands were ranked based on their contribution to installation ES and their ability to mitigate ecological pressures

Table 1. Performance Objectives for Demonstrations at Fort Pickett and MCAS Cherry Point (continued).

Performance Objectives	Metrics	Data Requirements	Success Criteria	Results
Quantitative (continued)				
9. Demonstrate minimal propagation errors in geospatial data	Estimates of post-field-validated capacity based on reclassified land cover and capacity range estimates based on producer/user accuracy estimates for land cover data	NLCD 2006 data, installation land cover data	Capacity estimates based on post-field-validation and reclassified data fall within confidence intervals produced from data-source accuracy assessments.	Land cover data were largely out of date on both installations. Trends of inaccuracy were noted that reflected primary succession (barren to forest) and construction (forest to grassland) (see text for more detail).
10. Enhance ES-based decision support systems	Number of ArcTools or scripts created to facilitate ES inventory process	ArcGIS ModelBuilder and geospatial data	At least one tool/script for each ES analyzed	Four ArcTools were developed for Sediment and Nitrogen Regulation and two ArcTools were developed for Surface Water Regulation.
Qualitative				
11. Demonstrate utility of a framework for integrating RS into natural resource and mission planning decisions	a) Survey response by GIS Analysts and Natural Resource Managers to evaluate ease of use	a) Feedback from GIS Analysts and Natural Resources Managers at Fort Pickett and Cherry Point	a) Mean survey response from analysts and natural resource managers >1.5 using scorecard approach, indicating that the framework and GIS tools provided are helpful and user-friendly.	Mean survey response was 3.0 for Cherry Point and 2.5 for Fort Pickett. Results indicate that framework and tools are easy to use.
	b) Survey response by decision-makers and planners to evaluate the utility of products from the framework demonstrated	b) Feedback from decision-makers and planners at Fort Pickett and Cherry Point	b) Mean survey response from decision-makers and planners >1.5 using scorecard approach, indicating that the analytical framework demonstrated can help with environmental compliance and land-use planning.	Mean survey response was 3.0 for Cherry Point and 2.6 for Fort Pickett. Results indicate that framework and tools are useful in the context of installation compliance and planning.

Table 1. Performance Objectives for Demonstrations at Fort Pickett and MCAS Cherry Point (continued).

Performance Objectives	Metrics	Data Requirements	Success Criteria	Results
Qualitative (continued)				
12. Improve projections of RS	Survey response from scenario-workshop participants	Feedback from workshop participants at Fort Pickett and Cherry Point	Mean survey response from workshop participants >1.5 using scorecard approach, indicating that the scenario-generating process and the analyses produced from the workshop-developed scenarios are useful to decision-making.	Mean survey response was 3.0 for Cherry Point and 2.3 for Fort Pickett. Results indicate that scenarios and resulting analyses are useful in the context of installation compliance and planning.

^ Modified due to the lack of installation-level ambient condition data and installation interest in identifying where impacts from installation are experienced.

LULC = Land use-land cover
NLCD = National Land Cover Database
RUSLE = Revised Universal Soil Loss Equation
SSURGO = Soil Survey Geographic Database
SPARROW = Spatially Referenced Regressions On Watershed attributes
SWAT = Soil and Water Assessment Tool

3.1 PO #1: IMPROVE PRODUCTION FUNCTION DETAILS OF GIS-BASED ANALYSIS OF SURFACE WATER REGULATION CAPACITY

Create mappable production functions of Surface Water Regulation capacity. It was presumed that land cover alone is an unreliable predictor of spatial variation in RS and that production functions would be improved if they incorporate data layers in addition to land cover. Improvements in production function detail were assessed by the percentage of calculation factors (from the conceptual model) actually included in the spatial analysis. All three factors were successful in that the conceptual model was available at national and regional scales.

3.2 PO #2: IMPROVE PRODUCTION FUNCTION DETAILS OF GIS-BASED ANALYSIS OF SEDIMENT AND NITROGEN REGULATION CAPACITY

Create mappable production functions of Sediment and Nitrogen Regulation capacity. This PO is analogous to PO #1. All three calculation factors were successful in that the conceptual model was available at the national and regional scales.

3.3 PO #3: IMPROVE SPATIAL RESOLUTION OF GIS-BASED ANALYSIS OF SURFACE WATER REGULATION CAPACITY

Create geospatial layers of Surface Water Regulation capacity that provide greater detail than land cover data. The project team sought to provide the greatest resolution possible to GIS analysts, natural resource managers, and decision-makers. The team aimed to produce final data layers for RS capacity in which the area of the smallest parcel of land representing intersecting capacity factors is <900 square meters (m^2). By including multiple data layers to estimate ES capacity, the project accounted for greater landscape heterogeneity than land cover alone. This was evident when the resulting RS capacity layers were analyzed and the smallest feature was <1 m^2.

3.4 PO #4: IMPROVE SPATIAL RESOLUTION OF GIS-BASED ANALYSIS OF SEDIMENT AND NITROGEN REGULATION CAPACITY

Create geospatial layers of Sediment and Nitrogen Regulation capacity that provide greater detail than land cover data. This PO is analogous to PO #3 and refers to output from three related capacity models: vertical nitrogen retention, horizontal soil retention, and riparian filtration (of nitrogen and sediment). The spatial resolution of capacity data for two of the three focal RS (soil retention and riparian filtration) was increased.

3.5 PO #5: DEMONSTRATE TRANSFERABILITY OF SURFACE WATER REGULATION SERVICE-RELATED FRAMEWORKS FOR MEASURING CAPACITY, ECOLOGICAL PRESSURE, DEMAND FOR, AND FLOW

Develop easily mapped RS production functions based on widely available data. To enhance broad applicability, the team aimed to produce production functions that accommodate widely available data as well as finer-resolution local data. The transferability of the approach was demonstrated by applying production functions to the entire 8-digit hydrologic units (HUs) containing Fort Pickett and Cherry Point. Success was assessed by the number of outside datasets that were unavailable for analysis or had lower resolution than within-installation datasets. Data was acquired for all Surface Water Regulation analyses, both inside installation boundaries and in neighboring areas. Thus, the framework was transferrable across installation boundaries.

3.6 PO #6: DEMONSTRATE TRANSFERABILITY OF SEDIMENT AND NITROGEN REGULATION SERVICE-RELATED FRAMEWORKS FOR MEASURING CAPACITY, ECOLOGICAL PRESSURE, DEMAND FOR, AND FLOW

Develop easily mapped RS production functions based on widely available data. This PO is analogous to PO #5. Data was acquired for all Sediment and Nitrogen Regulation analyses, both inside installation boundaries and in neighboring areas. Thus, the framework was transferrable across installation boundaries.

3.7 PO #7: DEMONSTRATE FRAMEWORK TO RANK ECOLOGICAL PRESSURE ON RS

Measure the relative difference between estimates from the approach and results from full-scale hydrologic modeling approaches. While ecological pressure (i.e., nutrient, sediment, contaminant loading) can be measured in the field or estimated from sophisticated hydrologic models, the project team aimed to demonstrate a much less data- and time-intensive approach that produces relative values of ecological pressure. Success was assessed by the congruency (in areal extent) between results from the approach and results from hydrologic models. Overlap (percent congruency) was mapped among ecological pressure indicators for Sediment Regulation and Surface Flooding. A 68–82% overlap was observed between predicted and observed erosion at Fort Pickett, but 100% overlap between predicted and observed flooding at Cherry Point.

3.8 PO #8: DEMONSTRATE HOW TO MEASURE FLOW OF RS TO BENEFICIARIES

Create a mappable function that defines RS flow as ecological work. Land cover or ambient condition are often used to represent RS flow but neither accurately reflects regulatory processes of ecosystems. Ambient condition depends on ecological capacity and demand (Figure 2). The project team aimed to compare observed versus expected relationships among RS capacity, ecological demand, ambient condition, and measured RS flow. The team was unable to fully meet this PO because the installations had little data on ambient conditions. The approach was adapted to focus on the flow of riparian filtration services by comparing upland estimates of soil loss to instream measures of turbidity and total suspended solids at Fort Pickett.

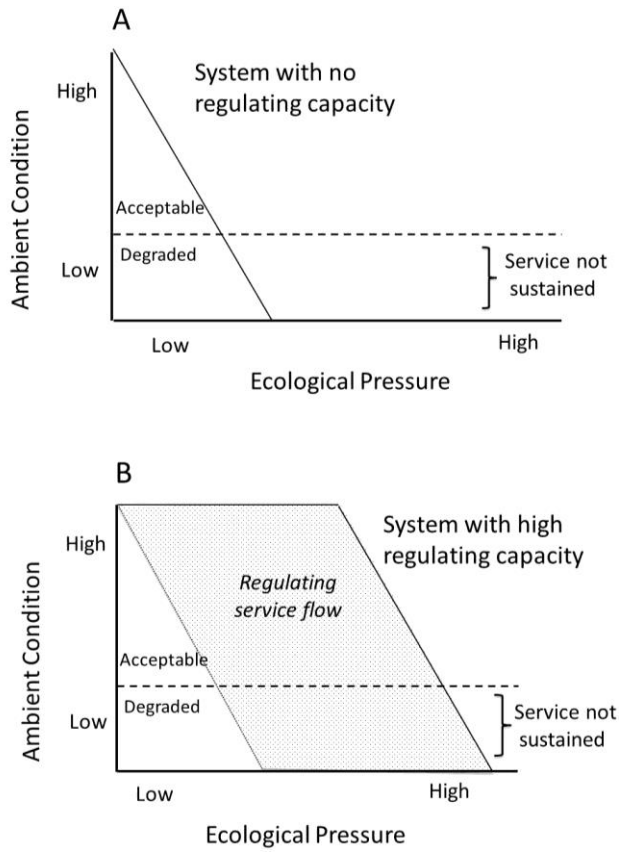

Figure 2. Relations among Ecosystem Stress, Ambient Condition, and RS Capacity.

In a system with no RS capacity, (1) condition degrades quickly with increasing stress and may be acceptable under only low stress. In a system with low RS capacity, (2) the ecosystem can do some "work" to maintain condition despite increasing stress but is overwhelmed if stress reaches moderate levels. In a system with high RS capacity, (3) conditions become unacceptable only at very high levels of stress. Ecosystem work represents RS flow. As shown here, ambient condition is a function of RS capacity and the stress (or demand) on the regulating processes.

3.9 PO #9: DEMONSTRATE MINIMAL PROPAGATION ERRORS IN GEOSPATIAL DATA

Incorporate geospatial data-producer accuracy assessments into capacity estimates to decrease data propagation error. To reduce errors in geospatial inputs, measures of producer accuracy were incorporated into our capacity calculations. Land cover data was field-validated, reclassified as needed, and the RS capacity was recalculated. This objective was partially met.

3.10 PO #10: ENHANCE ES-BASED DECISION SUPPORT SYSTEMS

Produce and demonstrate ArcGIS-based tools to facilitate the assessment and mapping of RS. Availability of decision-support tools for RS analysis is limited. Success was assessed by the number of tools or ArcScripts produced. The team developed 1–3 ArcGIS tools for each focal RS, as well as tools to help synthesize land cover data and create land-use change scenarios.

3.11 PO #11: DEMONSTRATE UTILITY OF A FRAMEWORK FOR INTEGRATING RS INTO NATURAL RESOURCE AND MISSION PLANNING DECISIONS

1. *Assess ease-of-use by GIS Analysts or Natural Resource Managers.* Ease-of-use was assessed via surveys in which installation staff answered questions regarding the usefulness and user-friendliness of the framework and GIS tools. Responses were scaled from 1 to 3 as follows: 1 – framework and GIS tools are inadequate and difficult to use; 2 – framework and GIS tools are generally helpful, but could be more user-friendly; 3 – framework and GIS tools are adequate, helpful, and user-friendly. This PO was met successfully with mean scores >2.2.
2. *Assess utility of framework for integrating RS into natural resource and mission planning.* The project team assessed utility of the RS framework and end-user tools via surveys in which installation staff answered questions regarding the utility the framework. Responses were scaled from 1 to 3 as follows: 1 – framework is inadequate and not worth implementing; 2 – framework is adequate and may be helpful; 3 – framework exceeds expectations, and will definitely help environmental compliance and ecosystem-level planning. This PO was met successfully with mean scores >2.2.

3.12 PO #12: IMPROVE PROJECTIONS OF RS

Develop projections of RS capacity based on future scenario workshops. The future scenario workshops were evaluated via surveys in which workshop participants answered questions regarding the usefulness of the workshop and products. Reponses were scaled from 1 to 3 as follows: 1 – workshop and products are inadequate and not worth the investment; 2 – workshop and products are adequate and may be helpful; 3 – workshop and products exceed expectations, and will definitely help achieve and maintain environmental compliance and ecosystem-level planning. This objective was considered to be met if the mean score of the workshop participants was >1.5, indicating that participants agree that the scenario-generating process and analyses produced from the workshop-developed scenarios were useful in planning and decision-making. This PO was met with a mean score of 2.3 and 3.0 at Fort Pickett and Cherry Point, respectively.

4.0 SITE DESCRIPTION

Below, the salient features of the Army National Guard Maneuver Training Center (ANG-MTC) Fort Pickett and MCAS Cherry Point are described.

4.1 SITE LOCATION AND HISTORY

ANG-MTC Fort Pickett is in southeastern Virginia, approximately 3 miles east of Blackstone, Virginia, and within the Piedmont physiographic province. Fort Pickett now provides an assortment of training facilities as well as interspersed buffer zones for various live-fire exercises.

MCAS Cherry Point, comprising ~19,200 acres on the coast of North Carolina, is the primary airfield for Marine Corps aviation in the eastern United States. It maintains, operates, and provides support for the operations of the 2nd Marine Aircraft Wing.

Fort Pickett and Cherry Point were selected as demonstration sites because they: (1) are large DoD properties within the geographic focus of concurrent ES research, (2) face significant current land-use and climate changes, (3) rely on sediment and nitrogen regulation and surface water regulation services to pursue their missions, (4) support imperiled species that will likely be affected by changes in RS capacity, (5) interact with stakeholders to manage surface water quality and quantity, and (6) have relevant existing spatial data. Both installations face encroachment issues that threaten their military operations.

4.2 SITE CHARACTERISTICS

Topography within Fort Pickett is gently rolling; elevation ranges from 61 m to 137 m above sea level. Most of Fort Pickett is within the Nottoway River basin, which ultimately drains into the Albemarle Sound. The Nottaway River mostly meets standards of the U.S. Clean Water Act, but some segments crossing Fort Pickett are impaired (Fort Pickett Integrated Natural Resources Management Plan [INRMP]). Most upland soils on Fort Pickett have slow to moderate infiltration rates; loams and sandy loams are most common. Four wetland soils are present, which have slow infiltration rates (Fort Pickett INRMP).

Elevation at Cherry Point ranges from near sea level to 33 feet. Cherry Point is entirely within the Neuse River basin and contains approximately 1,600 acres of wetlands. There are 21 soils represented, mostly poorly drained loamy sand. Neuse River, Slocum Creek, and Hancock Creek are subject to tidal fluctuations, largely wind driven. Land cover within Cherry Point includes pine, mixed hardwood, swamp, and coastal forests, and freshwater marshes. Loblolly Pine stands dominate forested areas and are burned every 3–5 years.

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5.0 TEST DESIGN

5.1 CONCEPTUAL TEST DESIGN

The demonstration analyzed high-resolution spatial data to inform decision-makers concerning potential effects of land management on RS and installation objectives.

5.2 BASELINE CHARACTERIZATION AND PREPARATION

Existing data was used to integrate into baseline maps of RS capacity; sources included National Land Cover Database (NLCD) land cover, Soil Survey Geographic Database (SSURGO) soil, Parameter-elevation Regressions on Independent Slopes Model (PRISM) precipitation, and U.S. Geological Survey (USGS) precipitation data.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY AND METHODOLOGY COMPONENTS

RS was analyzed at both sites concurrently but timing for all POs was not synchronized. The methodology and results were presented to personnel at both installations three times. During the first site visit, the project team provided an overview of concepts, data needs, and applications. On-site personnel provided the team with relevant points of contact and databases. During the second meeting, preliminary results from the analyses were presented and led to discussions regarding potential uses of the geospatial tools. During this time, the project team realized how RS analyses could be used to help prioritize land parcels to build encroachment buffers, which became a new analytical focus.

5.4 FIELD TESTING

The field testing occurred via the on-installation presentations described in the preceding section.

Table 2. Timelines for Major Demonstration Tasks.

Tasks	Start	End
Develop decision-making framework	March 2013	August 2014
Introduction to ES assessment on site	March 2012	March 2012
Conduct baseline assessments (capacity, ecological pressure, and flow)	March 2012	June 2014
Develop ArcTools for baseline analysis	May 2012	August 2014
Field data collection	March 2013	September 2014
LULC accuracy assessment	March 2013	September 2014
Present baseline results	March 2013	September 2014
Conduct hydrologic modeling (NRCS Curve Number method and GIS-adapted RUSLE)	May 2012	July 2014
Compare methods for ecological pressure mapping	April 2014	August 2014
Scenario development workshop (Fort Pickett)	March 2013	March 2013
Scenario development workshop (Cherry Point)	August 2013	August 2013
Parameterize, model, and interpret scenarios	March 2013	June 2014
Present scenario analysis, land use accuracy, and ArcTools	July 2014	October 2014
Evaluate decision-maker and GIS analyst utility and tool ease of use	July 2014	October 2014

5.5 SAMPLING PROTOCOL

The project team compiled accuracy estimates for the land cover classes and conducted field validations to estimate user accuracy and producer accuracy. For all datasets, at least five observations per major land-cover type were sampled. Confusion matrices were developed to quantify the uncertainty associated with installation-specific data and to compare this to the producer and user accuracy of the NLCD dataset. For wetlands, the team found moderate producer accuracy (53%–69%) and low user accuracy (29%–39%).

5.6 SAMPLING RESULTS

Field sampling was a component of PO #9. See discussion in section 6.9.

6.0 PERFORMANCE ASSESSMENT

6.1 PO #1: IMPROVE PRODUCTION FUNCTION DETAILS OF GIS-BASED ANALYSIS OF SURFACE WATER REGULATION CAPACITY

Improvements in production function details were measured by the percentage of calculation factors incorporated into capacity analysis and mapping. Data for all calculation factors were available. Precipitation was locally monitored only at Cherry Point, but rain-gage data was used from a site 30 miles from Fort Pickett to serve as a high-resolution dataset (Figure 3).

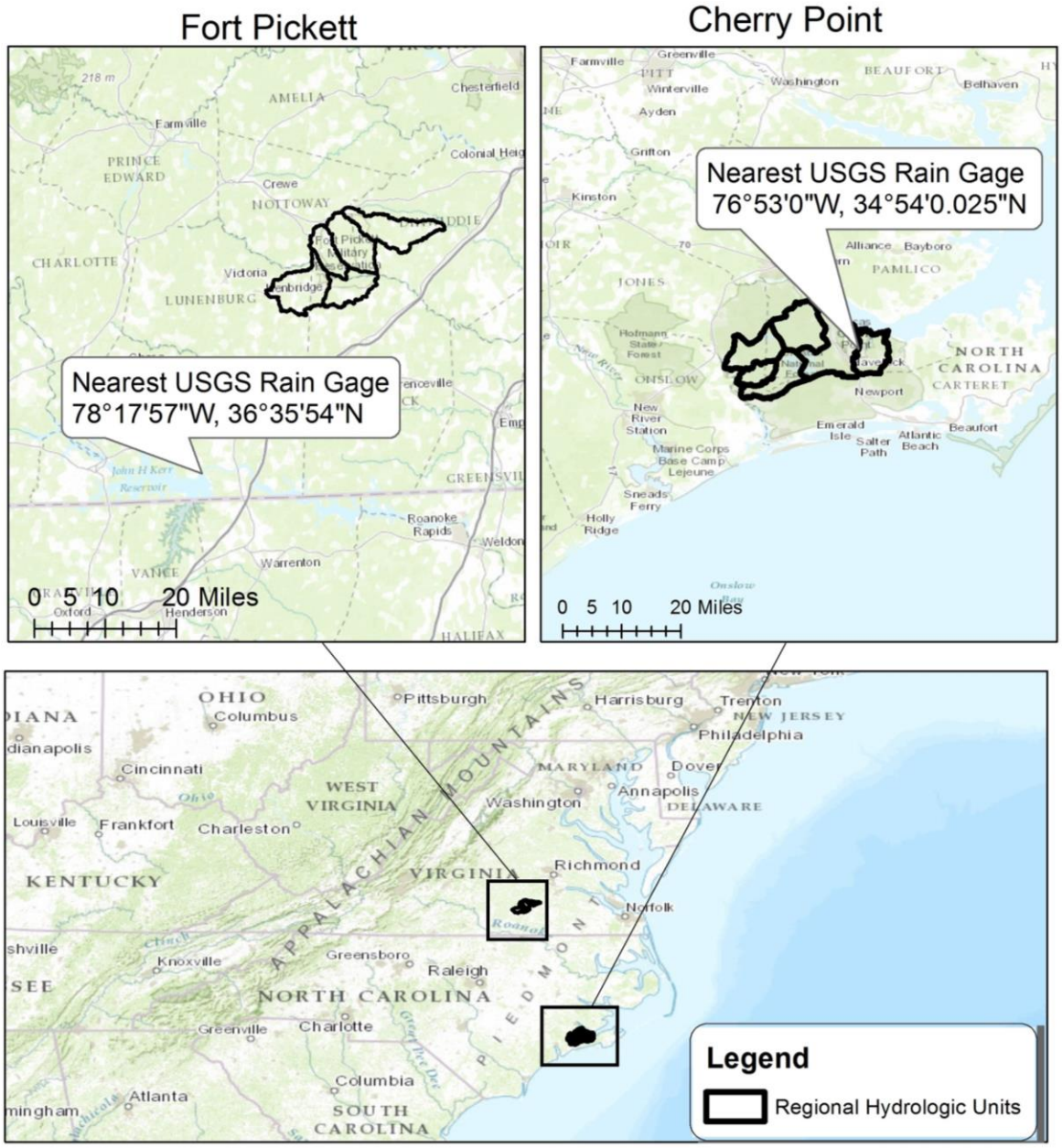

Figure 3. Maps Illustrating Locations of "Installation-Level" Precipitation Gages for Cherry Point (right) and Fort Pickett (left).

6.2 PO #2: IMPROVE PRODUCTION FUNCTION DETAILS OF GIS-BASED ANALYSIS OF SEDIMENT AND NITROGEN REGULATION CAPACITY

All calculation factors in the conceptual model were available at high and low resolution, except precipitation, for which no installation data were available at Fort Pickett (see PO #1 and Figure 3). The source of precipitation data had a notable effect on the outputs for vertical nitrogen retention, which was lower when the team used 30-year averages as inputs. Also, rain-induced runoff was higher than the 30-year averages that were input into the surface water retention models. The team suggests the preference for data source depends on management objectives. If the management objective is to look at long-term regional patterns, the PRISM data is preferable; if the objective is to estimate short-term impacts to the delivery of RS, the rain gage is preferable.

6.3 PO #3: IMPROVE SPATIAL RESOLUTION OF GIS-BASED ANALYSIS OF SURFACE WATER REGULATION CAPACITY

Geospatial models run faster on low-resolution data. The two models for which computing time may be long are those for surface water regulation and sediment retention. Land cover variation is important to capture in these models but high-resolution elevation data (10 m or finer) may not be necessary. Installation-specific datasets were developed on land cover by integrating several vector datasets into a raster dataset.

6.4 PO #4: IMPROVE SPATIAL RESOLUTION OF GIS-BASED ANALYSIS OF SEDIMENT AND NITROGEN REGULATION CAPACITY

A sensitivity analysis was performed of the slope-length and steepness (LS) factors to determine if inputs of 10-m elevation data produced different results than inputs of 30-m elevation data. The results suggest that using the highest resolution data available is the most cost-effective option.

6.5 PO #5: DEMONSTRATE TRANSFERABILITY OF SURFACE WATER REGULATION SERVICE-RELATED FRAMEWORKS FOR MEASURING CAPACITY, ECOLOGICAL PRESSURE, DEMAND FOR, AND FLOW

The project team used the models to map RS capacity and ecological pressures within the four 12-digit HUs that intersected each installation. By creating seamless layers of land cover, a single model for each installation was run within the context of its surrounding areas. However, differences between estimates of rainfall based on PRISM data versus observed local data were large enough to affect model results, as reported in sections 6.1 and 6.2. Mapping RS flow as a function of ecological pressure and ambient condition was the greatest challenge because neither installation had extensive datasets on water quality or stream flow. This shortfall prevented the team from quantifying the flow of RS in terms of sediment and nitrogen loading. Therefore, the team concluded that the framework for quantifying the flow of RS depends on ambient condition monitoring and suggest that this aspect of the demonstration be revisited when monitoring data become available.

6.6 PO #6: DEMONSTRATE TRANSFERABILITY OF SEDIMENT AND NITROGEN REGULATION SERVICE-RELATED FRAMEWORKS FOR MEASURING CAPACITY, DEMAND ON, DEMAND FOR, AND FLOW

The analysis for this PO was analogous to that for PO #5. Again, the lack of ambient condition monitoring was the greatest hurdle, which limits transferability of the methodology.

6.7 PO #7: DEMONSTRATE FRAMEWORK TO RANK ECOLOGICAL PRESSURE ON RS

Three methods for mapping ecological pressures that vary in terms of field and computer processing intensity were compared. The team was able to compare all three methods only for sediment loading and surface water, as the data needed for other RS were not available. Observed erosion locations were derived from a 2005 dataset and observed flooding areas were mapped via Cherry Point personnel. The relative differences among methods were measured by quantifying the overlap observed among respective maps (Table 3). The land use-land cover (LULC)-based approach, the easiest and least costly, used simple LULC classifications to define a "source" of ecological pressure. GIS-based models were also developed that require less data than a full hydrologic model but more data than LULC alone. For sediment retention, a spatially explicit model was developed to predict erosion, based on the Revised Universal Soil Loss Equation (RUSLE) and Lim et al. (2005). Based on these results, it was concluded that the model-based maps of ecological pressure were more efficient if all model inputs are up-to-date. If geospatial data are out of date, field assessments will be more accurate.

Table 3. Investment Comparison of Methodologies for Identifying Three Sources of Ecological Pressure (Nitrogen, Sediment, and Surface Floods).

Nitrogen (N) pressure was not included in the comparisons because water quality monitoring that could identify areas of high N loading does not occur at Cherry Point and N loading is not considered an issue at Fort Pickett. Data and model needs for three methods are shown.

Methods	Data and Model Indicators of Regulating Services		
	Nitrogen Regulation	Sediment Regulation	Surface Water Regulation
Least time and data intensive	Upland and Riparian LULC	Upland LULC	Upland LULC and soil types
Field and time intensive	Water quality data (Cherry Point)	Observed erosion points (Fort Pickett)	Observed flooded areas (Cherry Point)
Processing and time intensive	SPARROW model	RUSLE model	NRCS Curve Number Run-off

6.8 PO #8: DEMONSTRATE HOW TO MEASURE FLOW OF RS TO BENEFICIARIES

For the focal RS, ecological work is interpreted as the volume of water processed without causing a flood (or drought) and the amount of sediment and nitrogen prevented from entering waterways. The project team focused on sediment loading at Fort Pickett, where upland soil loss is the main

ecological pressure driving the flow of riparian filtration. This approach provides a watershed-scale snapshot of RS flow, quantified as a function of ecological pressure and ambient condition.

The contributing area of each water-quality monitoring point was delineated and the upland erosion was estimated as the ecological pressure metric. Expected soil loss (annual contaminant input load [ACIL] in Figure 4) and two indicators of sediment condition, turbidity, and total suspended solids (measured annual contaminant load [MACL] in Figure 4) were standardized to range from 0 to 1. Because the project team expected these metrics of ecological pressure and ambient condition to be positively correlated, the team could examine indirectly the flow of riparian filtration services. Spatial patterns of calculated RS flow were calculated in Figure 5. A caveat is that the team conducted this analysis with two disparate sets of field-collected water quality data, which precluded an integrative interpretation. Despite the data shortcomings, the relative measures of ecological pressure and ambient condition demonstrated the process and analytical outputs whereby RS flow and ecological work can be quantified and mapped. To fully quantify RS flow, the team suggests: (1) monitoring bank erosion and in-stream sediment concentrations for an entire year, which would provide a more accurate MACL; and (2) evaluating upland soil loss and filtration capacity along the flow path of eroded soil on route to streams.

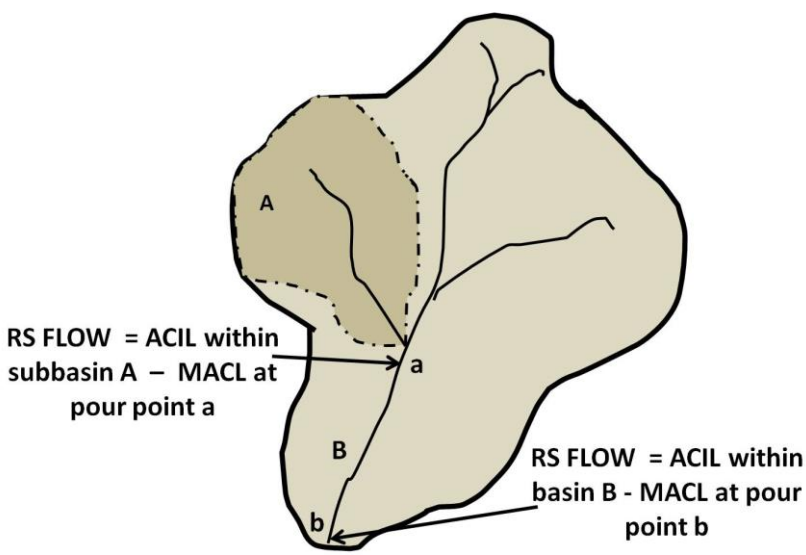

Figure 4. Watershed Approach to Estimating RS Flows Based on Ecological Pressure Measured by ACIL and Ambient Condition Derived from MACL at the Pour Point.

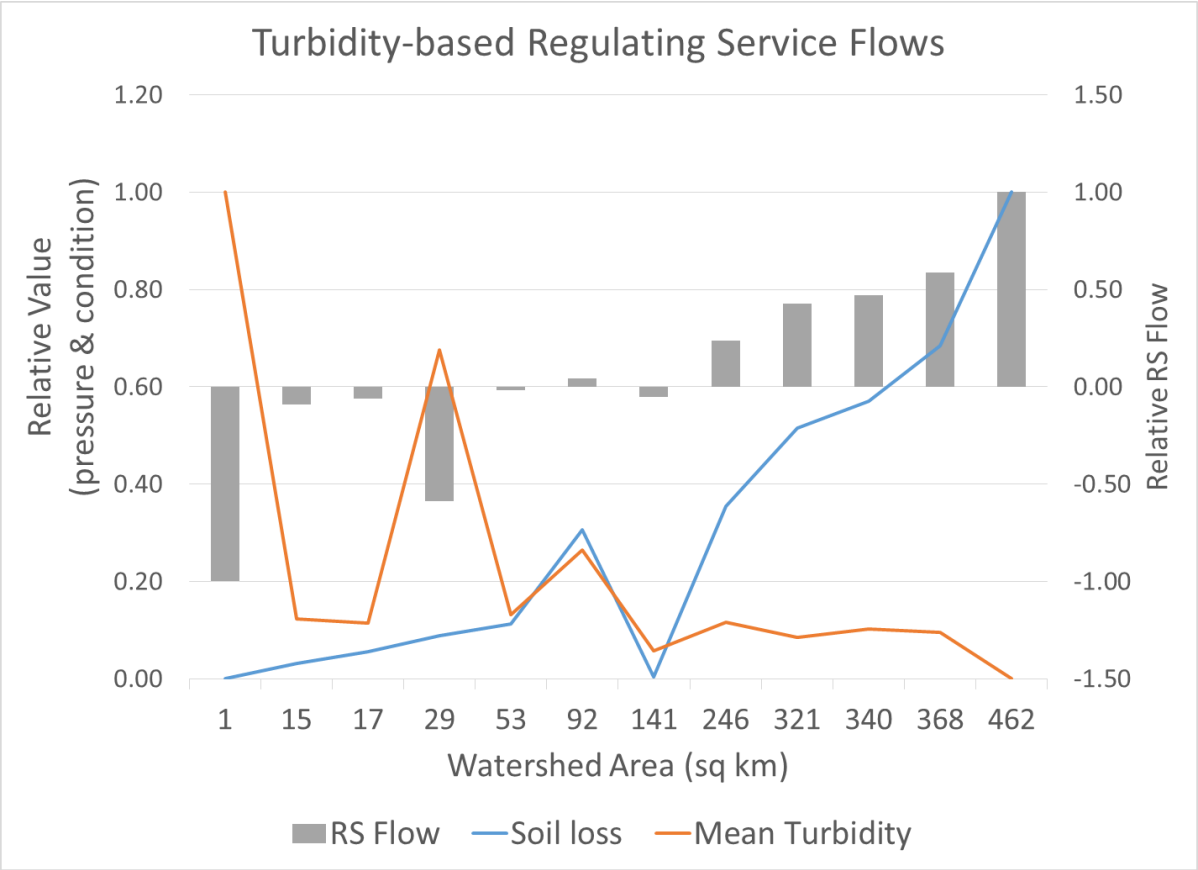

Figure 5. Relative Values of Total Soil Loss (Ecological Pressure) and In-Stream Turbidity (Ambient Condition) Are Plotted for 12 Nottoway River and Fort Pickett Water Quality Monitoring Sites.

Riparian filtration service (RS) flow is graphed on the secondary y-axis (on right) as the relative difference between soil loss and turbidity (i.e., ecological work).

Given the difficulty in mapping RS flow in terms of ecological work, a component was added to this PO (Figure 6) to describe areas of service benefit and disservice. The team identified areas likely to contribute sediment to streams and mapped potential transport paths. The specific area where sediment could enter a stream is the critical riparian area (CRA). Reference maps were created for each installation that highlight sources of ecological pressure and their hydrologic-based flows.

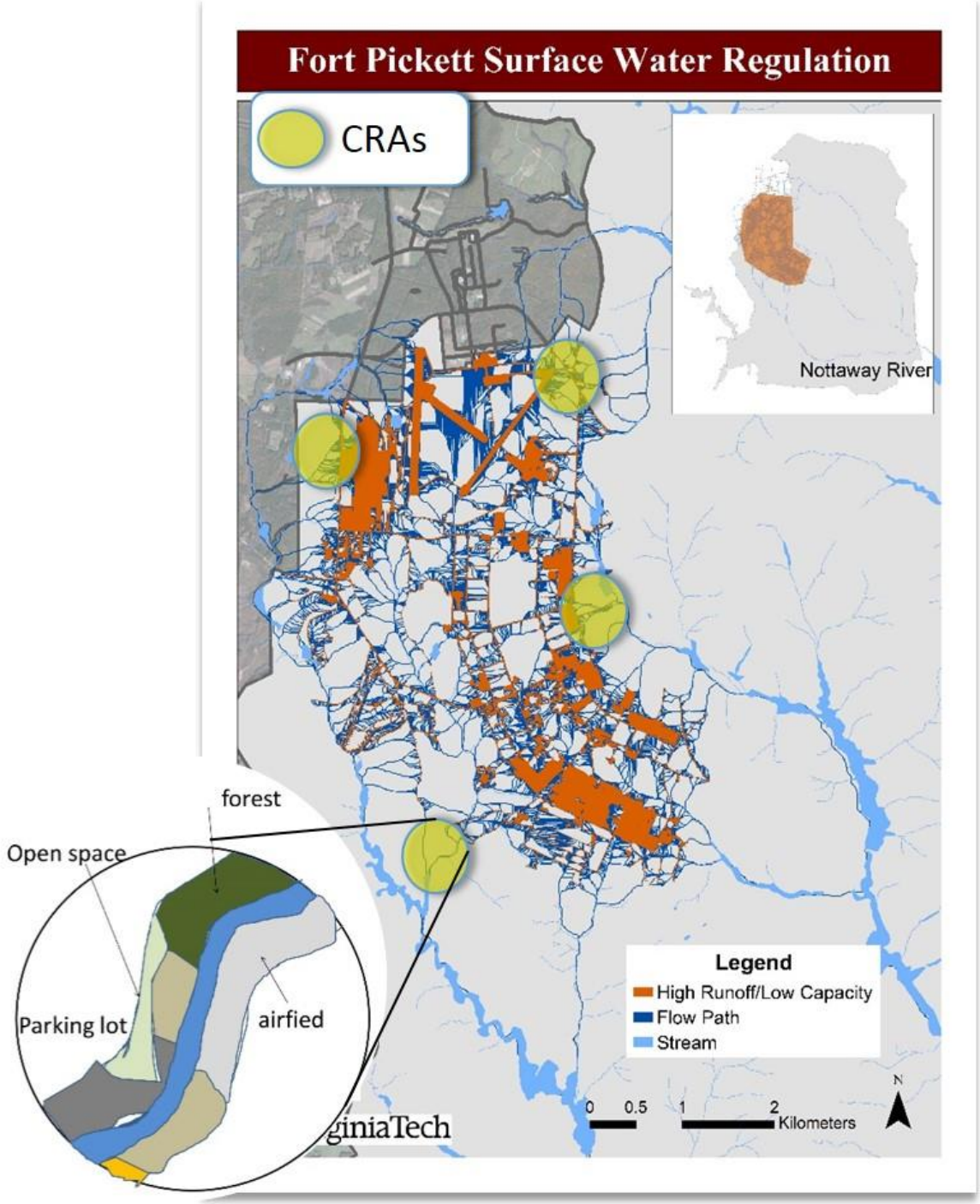

Figure 6. Map of CRAs Based on Water Flow (Along Flow-Paths) from Areas of High Surface Runoff Potential.

6.9 PO #9: DEMONSTRATE MINIMAL PROPAGATION ERROR IN GEOSPATIAL DATA

Errors in geospatial data can occur due to spatial inaccuracy, misclassification, or undocumented changes over time. LULC data are particularly dynamic over time. The project team used a

stratified, random selection technique to identify field validation sites where the current LULC class was recorded. The field validations suggested that the geospatial data used was out of date, which resulted in low user accuracy largely attributable to ecological succession. Given the direction of the most common misclassifications, the team suggests that the estimates of RS capacity are underestimates. Forest, shrub, and wetland support higher capacities of riparian filtration, surface water regulation, and sediment regulation; the N leaching model is not affected by land cover, so groundwater protection is not impacted by inaccuracies in land cover. This experience suggests that installations and regional GIS working groups might consider taking an adaptive approach to data management and updating to ensure that important data users have access to up-to-date data.

6.10 PO #10: ENHANCE ES-BASED DECISION SUPPORT SYSTEMS

The team was highly successful at developing GIS tools and ArcScripts to quantify the capacity of RS. Tools were designed so that GIS beginners could operate them and GIS experts can modify them as needed. An End-User-Guide (EUG) was also designed to help future users.

6.11 PO #11: DEMONSTRATE UTILITY OF A FRAMEWORK FOR INTEGRATING RS INTO NATURAL RESOURCE AND MISSION PLANNING DECISIONS

The project team used questionnaires distributed to installation staff to assess success in this objective. Questionnaires were distributed immediately after the end-of-project presentations. To assess ease-of-use of the methodology, two survey questions were developed, each with a 3-level score (3 is best; 1 is worst). Survey results indicate that the demonstrated framework and GIS tools were generally adequate and easy to use. To assess utility of the methodology, six questions were developed, each with a 3-level score (3 is best; 1 is worst). Survey results indicate that the demonstrated framework can be useful in environmental compliance and land use planning. The effectiveness in advancing installation staff's knowledge of RS delivery was also assessed in the end-of-project survey by developing five questions, each with a 3-level score (3 is best; 1 is worst). Survey results indicate that staff likely to use the framework or tools adequately understand the conceptual basis for analyzing RS delivery related to their installation.

6.12 PO #12: IMPROVE PROJECTIONS OF RS

The team held workshops to meet with key players in environmental management and mission operations. Important issues were discussed and the types of information needed to make planning decisions were listed. The project team discussed the RS that installations provided and compared those to potential disservices or ecological pressures attributable to installations. An analysis was designed to prioritize future buffer-land acquisition to maximize RS capacity associated with installations and to minimize the disservices conveyed from installations to neighboring communities. Then a prioritization framework was developed that (1) evaluated the capacity of focal RS within each land parcel proposed for the buffer programs, (2) determined if the land parcel would contribute services/disservices to the installation or be a recipient of services/disservices, and (3) (for Fort Pickett) determined whether the potential parcel could reduce surface water runoff and help reduce sediment loading into Nottoway River. These metrics were calculated on a relative scale (0–1) for all potential land parcels and summed to determine a final rank.

Usefulness of workshops was assessed by surveying participants. Four questions were developed, each with a 3-level score (3 is best; 1 is worst). Survey results indicate that the workshops and analytical products are generally helpful in environmental compliance and land use planning.

6.13 RANGE SITING COMPARISON

In collaboration with the RC-201113 team, an ESTCP effort led by Dr. Gretchen Daily at Stanford University, the project team (RC-201114) conducted a post-hoc analysis of ES capacity change expected with the development of new training ranges on Fort Pickett. The RC-201113 team assessed biodiversity, carbon storage, and sediment export impacts from the development of new training ranges (Figure 7, middle). Potential impacts to riparian filtration, erosion control, and surface water regulation were assessed (Figure 7, top). Given the lack of overlap in the teams' approaches to mapping services, little insight into which analytical approach is more credible or cost-effective can be provided. The project team suggests that the more compartmentalized approach is better suited to informing on-the-ground management decisions about preventing upland erosion or stabilizing sediment along riparian corridors and stream banks.

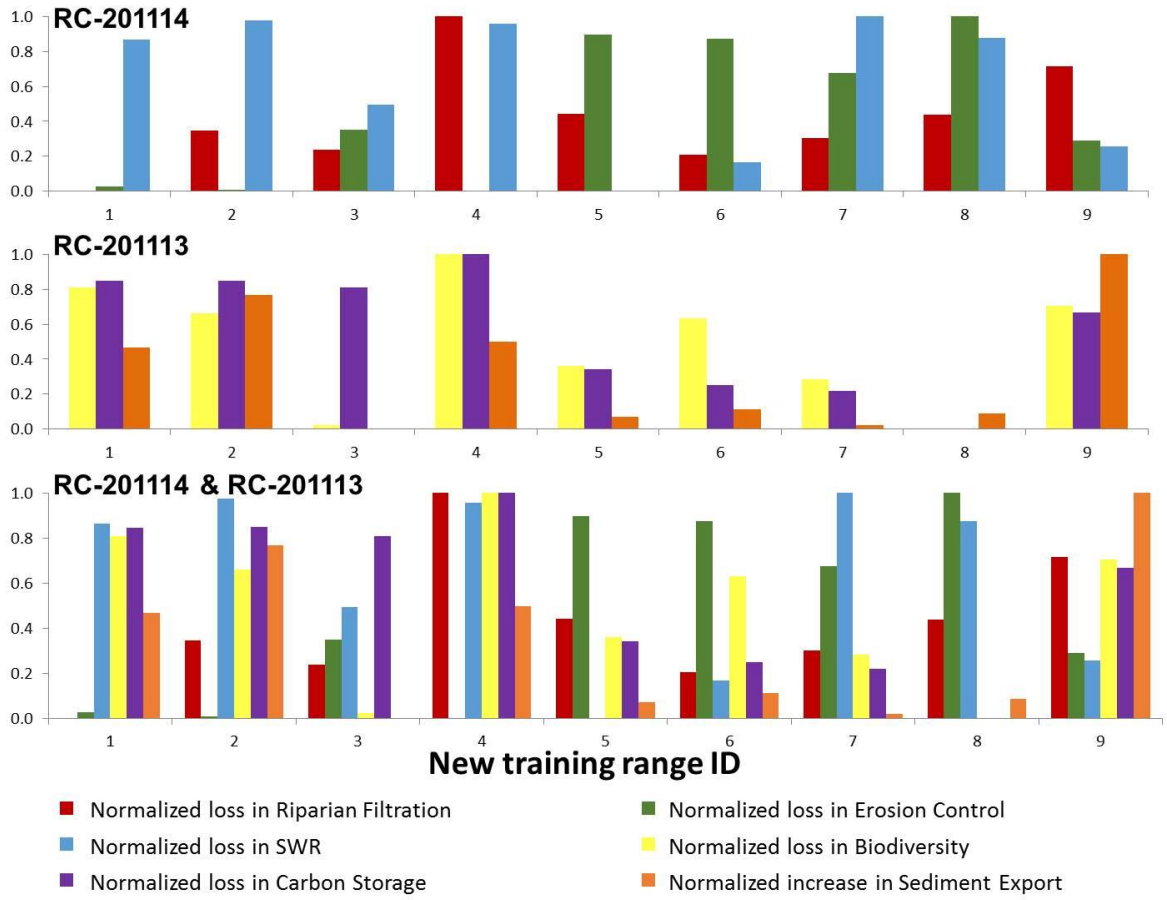

Figure 7. Normalized Losses of ES Capacity from the Development of New Training Ranges (1–9) on Fort Pickett.

Top: Riparian filtration, erosion control, and surface water regulation (SWR) results from the RC-201114 team. Middle: Biodiversity, carbon storage, and sediment export results from the RC-201113 team. Bottom: Summary (two upper panels combined) of losses associated with developing new training ranges.

7.0 COST ASSESSMENT

7.1 COST MODEL

Costs of this demonstration included labor, equipment, data storage, software licenses, and geospatial and non-spatial data. Each is described in Table 4.

Table 4. Cost Model for ES Assessment Methodology.

Cost Element	Data Tracked during Demonstration	Estimated Costs
Computer workstation	Estimates based on the optimal computer processor for reducing processing time and maximizing memory and mapping resolution	$1,400–$1,600
ArcGIS license	Estimates based on the cost to installations and term of license	Cost already paid
Geospatial data inputs	Estimates based on the costs of data compilation from data repositories	$0
Field data collection	Estimates based on time needed to conduct field validation for each geospatial data input and mean labor cost	$600–$1,200, depending on the sampling protocol
Analyst effort	Estimates based on time needed to gather, prepare, and process data inputs in ArcGIS by GIS analyst	$500 (at $25/hr for 1 week) per capacity tool analysis

- ***Computer workstation:*** A computer is needed to collate, prepare, and process data and to map RS. The cost of an optimal desktop computer was estimated for the analyses.
- ***ArcGIS license:*** ArcGIS is a one-time cost already paid for by all DoD installations.
- ***Geospatial data inputs:*** There was no cost for the data required to assess RS.
- ***Field data collection:*** Data validation costs are ordinarily distributed across other uses of spatial data. To minimize field costs, the labor costs were tracked for the field data collection.
- ***Analyst effort:*** The effort was estimated as the time it takes an experienced analyst to collate, prepare, and process data and to map RS, given the availability of ArcTools or ArcScripts.

7.2 COST DRIVERS

The main costs that impact the use of our methodology include: (1) purchase cost of a computer with suitable rapid access memory (RAM) and disk space, and (2) analyst salary. Computer costs continue to decrease. The cost of an in-house GIS analyst is typically shared across multiple mission objectives.

7.3 COST ANALYSIS AND COMPARISON

Hiring a regional GIS Analyst to use the models and tools might increase efficiency and consistency among installations. It could also reduce the person-hours needed to learn and adapt

models, and the purchase and maintenance costs of computer hardware. This structure could promote consistency in data and analysis across installations, promote partnerships outside installations, and enhance economies of scale for remote sensing. This arrangement could reduce the costs associated with losing access to an installation GIS analyst, as occurred at Fort Pickett during the demonstration. Three components of the demonstration—the framework for prioritizing buffer lands, the critical riparian area analysis, and the training area scenario analyses—have potential to significantly reduce costs of land use planning and compliance for DoD installations.

8.0 IMPLEMENTATION ISSUES

To facilitate implementation of the methods, a suite of geodatabases that contain input data, toolboxes, and ArcMap documents was developed. The methods for mapping and quantifying RS are provided in a model-based form in which all inputs, intermediate products, and processes are editable, and an ArcTool form in which the interface simply prompts data inputs and the naming of model products. The project team incorporated feedback from installation staff into the final preparation of data and prepared an EUG that (1) explains objectives of each tool/model, (2) describes inputs and outputs, and (3) contains screenshots of the models.

The team knows of no regulations that would limit the use of the methods. Installations could review data security protocols to see if the transfer of spatial data could be made more expedient.

Maintenance of, and access to, adequate GIS and ES expertise is another potential implementation issue. If ES assessment frameworks are adopted by installations, it may be helpful to review protocols related to attracting, retaining, and refilling GIS expertise. Potential solutions might include taking short courses or consulting with off-installation experts. A related factor to consider is whether it is more cost-effective to distribute the needed GIS expertise at each installation versus at centralized locations.

Analytical hurdles were encountered related to scarcity of data from on-installation environmental monitoring tied to compliance issues such as storm water and erosion control. Such data on ambient conditions are critical for validating RS models, providing accurate model inputs, and ultimately documenting progress toward management goals. Possible mitigating actions include: (1) reviewing the priorities assigned to environmental monitoring, (2) establishing partnerships with agencies or stakeholders to share costs and data for monitoring, and (3) conducting analyses similar to those presented herein on installations that have more appropriate monitoring data.

The busy schedules of installation staff could become an implementation issue. A related potential issue is how to engage staff with ES experts so that staff can recognize opportunities to use ES analyses to address environmental concerns. In this context, it may be helpful to reach out to regional ES experts to seek guidance on how to frame environmental concerns in ways amenable to ES analyses. The team saw clear links between RS and installation issues but the interactions with staff seemed too brief and disjointed to make those links clear so that the work was relevant or timely. An alternative approach might have been to focus the demonstrations on a specific environmental issue (e.g., suburban encroachment) by applying an ES-based approach, but without first laying out ES concepts for staff, then asking them to come up with ways such an approach can be useful. To save staff time, communication and meetings were limited to those in which multiple objectives could be met. In retrospect, this strategy did not allow ample time to explore the potential applications that arose after the project team presented the demonstration results.

In summary, the team foresees few future issues limiting the implementation of the demonstrated framework. The GIS tools that were developed can be used within the ArcGIS version 10.2 environment and require no further licenses beyond those already owned. The end products and EUG will enable GIS analysts to conduct the same analyses described in this report, as well as

adapt and update the underlying models. However, the team found that on-installation personnel time was the most limiting resource, followed by on-installation environmental monitoring data.

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APPENDIX A. POINTS OF CONTACT

Point of Contact	Title and Organization	Contact Information	Role(s) In Project
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Colin Johnson	GIS Analyst/Manager, Fort Pickett, Blackstone, VA	(no longer at Fort Pickett)	GIS analyst and temporary manager of Army Compatible Use Buffer program
Carmen Lombardo	Natural/Cultural Resources Manager, MCAS Cherry Point, NC	252-466-5870 carmen.lombardo@usmc.mil	Project development and input for scenario analysis
Jessica Guilianelli	National Environmental Policy Act Compliance Specialist, MCAS Cherry Point, NC	jessica.guilianelli@usmc.mil	Installation liaison who assisted with meeting organization and initial data transfer

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