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Ecosystem Services Research Program (ESRP) Albemarle-Pamlico Watershed and Estuary Study (APWES) Research Plan

Office of Research and Development
National Exposure Research Laboratory, Ecosystems Research Division, Athens, GA 30605

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ABSTRACT

The APWES is a place-based study for the U.S. EPA Ecosystem Services Research Program conducted through the collaboration across the EPA Office of Research and Development. The mission of the APWES is to develop ecosystem services science to inform watershed and coastal management decisions in the Albemarle-Pamlico watershed and estuary in North Carolina and Virginia. Over the next three years (2011 to 2014), the study will apply analysis of seven ecosystem services (clean air; clean water; climate resilience; flood and storm protection; food, fiber, and fuel; recreation; and biodiversity) to these management decisions. This study uses a systems approach to address the drivers, pressures, state, ecosystem services, and management decisions in the Albemarle-Pamlico watershed and estuary.

APWES research will be conducted according to three goals: 1) mapping and monitoring, 2) modeling, and 3) decision support. First, mapping and monitoring projects will develop methods to quantify ecosystem services, as well as drivers and pressures to the system. Results will lead to an assessment of ecosystem services, and support modeling efforts. Second, modeling will be used to relate changes in drivers and pressures to changes in ecosystem services. This research will include empirical and mechanistic modeling for the air, watershed, and estuary, informed by mapping and monitoring, and the linkage of models within modeling frameworks. Third, decision support tools will be developed to understand how management decisions alter services, so that quantified services can be used to inform watershed and estuary management decisions. For this goal, decision alternatives developed with stakeholder input and decision support tools, including an interactive web-based software application and Bayesian networks, will be developed and applied at multiple scales.

Ecosystem services will be used to inform decisions in the Albemarle-Pamlico watershed and estuary –the study will focus primarily on decisions related to EPA regulatory authority in air quality, wetlands, and water quality, and the related issue of water quantity. Tools developed for this work can also inform decisions related to reservoir management, species conservation, and climate adaptation. The APWES will examine tradeoffs or synergies among services under alternative management decisions, and seeks to understand how ecosystems can be managed sustainably for ecosystem protection and economic benefit. This study can also serve as a regional pilot for EPA Sustainable and Healthy Communities Research Program, to understand how the natural and built environments interact to affect community well-being and sustainability.

INTRODUCTION

EPA ESRP

Ecosystem services are the benefits that humans derive from ecosystems. Although these services, such as the provisioning of clean air and water, have traditionally been considered gifts of nature, recent advances in ecological and resource economics suggest that these services need to be included in economic analyses of costs and benefits (MEA 2005). An ecosystem services approach results in increased awareness of the environmental and economic costs of all goods and services and will help promote effective environmental policy and management strategies. The Ecosystem Services Research Program (ESRP) is a multi-year research initiative by the U.S. EPA to transform the way stakeholders understand and respond to environmental issues by making clear how our management choices affect the type, quality and magnitude of the services we receive from ecosystems (EPA 2008a). The program examines tradeoffs or synergies among services, and seeks to understand how we can manage ecosystems sustainably for ecosystem protection and economic benefit.

The Albemarle-Pamlico Watershed Study is one of five ESRP place-based studies. The place-based studies are designed to "…illustrate how regional and local managers can proactively use alternative future scenarios to conserve and enhance ecosystem goods and services" (U.S. EPA 2008a). The mission of the APWES is to use ecosystem services science to inform watershed decisions in the Albemarle-Pamlico watershed and estuary. Research will be conducted from 2011 to 2014 by multiple divisions of the EPA Office of Research and Development: the National Exposure Research Laboratory (NERL) Ecosystems Research Division (ERD) in Athens, GA; Environmental Sciences Division (ESD) in Las Vegas, NV and Research Triangle Park, NC; Ecological Exposure Research Division (EERD) in Cincinnati, OH; Atmospheric Modeling and Analysis Division (AMAD) in Research Triangle Park, NC, National Health and Ecological Effects Research Laboratory (NHEERL) Atlantic Ecology Division (AED) in Narragansett, RI; National Risk Management Research Laboratory (NRMRL) Air Pollution Prevention and Control Division (APPCD), Research Triangle Park, NC; and National Center for Environmental Assessment (NCEA) in Washington, DC with assistance from outside partners and collaborators.

The APWES is closely integrated with the ESRP Nitrogen and Wetlands Programs. The ESRP-Nitrogen program is focusing largely on national scale issues of nitrogen loading, removal, and impacts on ecosystems across the U.S. (Compton *et al.* 2009). APWES will develop nitrogen response relationships for ecosystem services provided by wetlands and waters, and produce high resolution maps of watershed-scale nitrogen loading and removal as well as predict estimates of probable changes in other ecosystem services affected by changes in nitrogen loading. In this framework, APWES data and information will be used to compare nitrogen response functions in a variety of geographic settings where sensitivity to nitrogen loading may vary, to inform more explicit national scale modeling efforts to examine scenarios associated with reactive nitrogen, and provide nitrogen input and output data for national data layers. Similarly, the ESRP Wetlands team is focused on national mapping efforts, and local-scale work done in APWES will inform this effort.

DESCRIPTION OF THE STUDY SITE

The Albemarle-Pamlico Watershed (APW) consists of about 80,000 km^2 of land and water in thirty-six counties in North Carolina and sixteen counties in Virginia (Figure 1). Six major freshwater river basins flow into the sounds– the Pasqotank, Roanoke, Chowan rivers flow into Albemarle Sound; the Tar-Pamlico and Neuse rivers flow into the Pamlico Sound; and the White Oak flows into Bogue Sound. Land cover in the watershed is predominantly forest (45 %), wetlands (14 %) and cultivated cropland and pasture (26 %); urban land cover accounts for less than 7 % (USEPA/USGS 2010). The region features a variety of habitat types, including pocosins (southeastern shrub bogs), pine savannahs, hardwood swamp forests, bald cypress swamps, salt marshes, brackish marshes, freshwater marshes and beds of submerged aquatic vegetation (SAV), and beaches. The Roanoke drainage is known for the most distinctive freshwater fish communities on the Atlantic Slope of the U.S. (Virginia DCR 2010). Significant ecological features of the Albemarle-Pamlico watershed and estuary are the numerous freshwater tidal wetland communities with rare species of vascular plants such as Coastal Plan Bottomland Hardwoods and Cypress-Gum Swamps that merge with vast, flat estuarine tidal marsh and forested wetlands on the estuary margins. The Albemarle-Pamlico estuarine system is the largest lagoonal estuarine system in the U.S. and second largest U.S. estuary. Annually, the system generates >$4 billion in fisheries, employment, and tourism (NC Div. of Marine Fisheries 1995, SELC 2009).

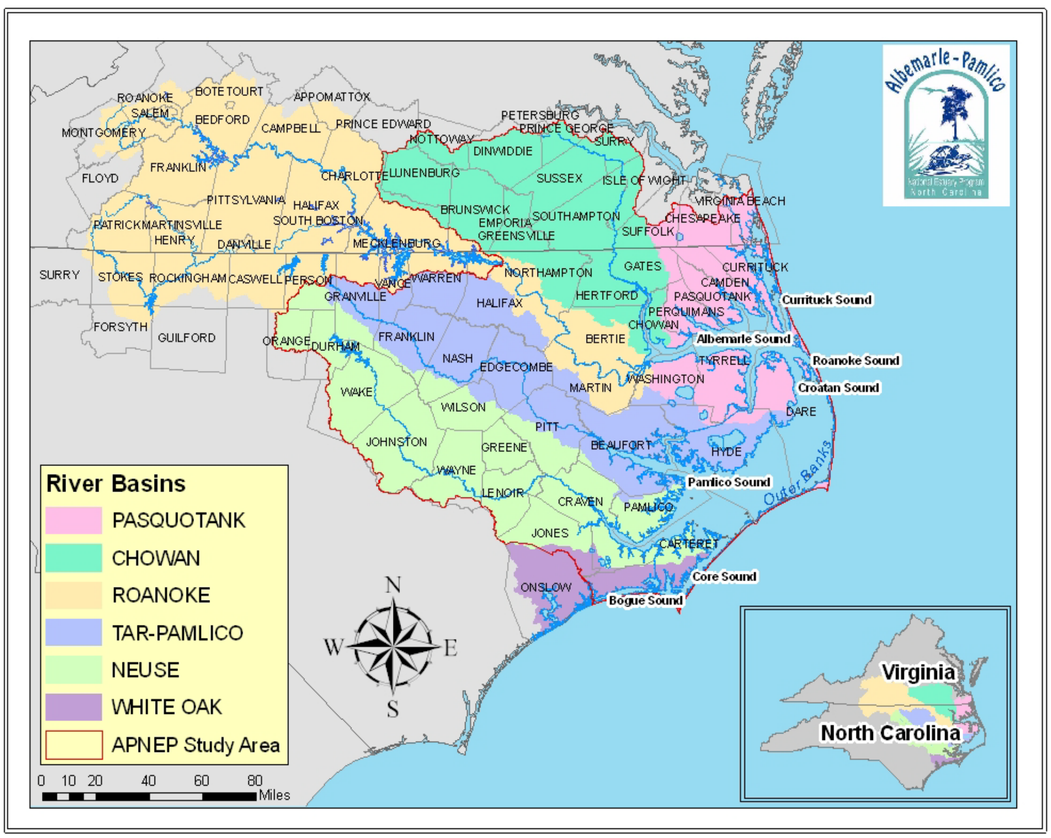

Figure 1. Albemarle-Pamlico watershed and estuary showing major river basins and county boundaries. Figure supplied by the APNEP (http://www.apnep.org).

More than three million people live in the APW, and many habitats and waters are affected by human activities. The most impaired river basins are the Neuse and Tar-Pamlico River basins, based on Aquatic Life Use Support, Recreation, and Fish Consumption (Deamer 2009). For more than thirty years, the Neuse River estuary has experienced harmful algal blooms, outbreaks of toxic microorganisms, and fish kills from nitrogen overload (Borsuk *et al.* 2001). Because of this impairment, the APWES can serve as a mesocosm for nutrient issues across the eastern U.S. Based on the substantial available body of science from past and current nutrient studies, the Albemarle-Pamlico watershed is a good study region to examine the effects of multiple pressures on high-value resources and services. Results of the APWES will be relevant to other Atlantic drainage systems to the north (*e.g.,* Chesapeake Bay) and south (*e.g.,* Savannah River Basin), where pressures and resources are similar.

ECOSYSTEM SERVICES IN THE ALEMARLE-PAMLICO WATERSHED & ESTUARY

Based on literature and discussions with stakeholders, we focus on seven main ecosystem services for the APWES (Table 1). To be consistent with the overall ESRP approach, we only consider final ecosystem services, which are biophysical indicators representing the last contribution of the ecosystem (Boyd and Banzhaf 2007). For example, for the service of recreation, the population size of sport fish is a final, measurable endpoint. These services are consistent with results from public hearings and surveys of stakeholders concerning the impairment of the Neuse River estuary, (Borsuk *et al.* 2001). Table 1 is also similar to the water quality use support ratings recognized by the NC Department Environment and Natural Resources (NCDENR 2007): aquatic life, including fishing and shellfishing; fish consumption (*i.e.,* “fishing” through sport and commercial methods); recreation, such as swimming, boating, and waterskiing; and biological integrity, the ecosystem capability to support and maintain a balanced community of organisms having structure and function similar to that of reference conditions. Important environmental services in the region, including energy generation, transportation, and mining can be incorporated in the future. The understanding of final services is a research question for ESRP (Ringold *et al.* 2009).

In general, a valuation approach is necessary for putting services in terms that can best inform decisions. Some services (*e.g.*, fisheries and forestry) already have monetary value; other services can be valued by employing different environmental economics valuation methods, including hedonic pricing, the travel cost method, and contingent valuation. Hedonic pricing, or revealed preference, is an indirect method that looks at the value individuals place on a particular ecosystem service through property values. For example, properties near a lake have higher values because of the environmental amenities the lake provides. Travel cost is also an indirect method where the value people place on ecosystem services is inferred by measuring the costs they incur in order to experience the services (Perman *et al.* 2003). This method is used to measure the value of recreational services. Contingent valuation is a direct method that involves asking a segment of the population about their willingness to pay for or willingness to accept a particular environmental change (*e.g.,* Weber and Stewart 2008). The APWES will also assess who receives the benefits and who pays the costs for various ecosystem service tradeoffs.

Table 1. APWES Ecosystems Services, Indicators, and Associated APWES Projects

Ecosystem Services	Definition	Service Indicators	APWES Mapping and Monitoring[1]	APWES Modeling[2]
Clean air	Air quality for human health, clear air for visibility and safety	• Air quality measurements	Aq	A
Clean water	Water quality and quantity used by humans for drinking, agricultural, and industrial uses	• Time series of flow and water quality measurement	Em, Fp	F, E, A
Climate resilience	Carbon sequestration capacity, N_2O emissions	• Amount sequestered/time by vegetation • Estimated emissions	Wa	W
Flood and storm protection	Avoidance of damages from flood and storms	• Areal extent of wetlands	Wa, Fp	W
Food, Fiber, and Fuel	Agricultural products, forest products, fish/shellfish consumed by humans	• Amount and quality of crops/livestock • Amount and health of target tree species • Fish and shellfish populations • Bacteria and chemical content	La	H , F, E
Recreation	Boating, swimming, birdwatching (fishing is considered under food)	• Water quantity • Bacterial concentrations in recognized swimming areas • Populations of watchable birds - Important bird habitats include gull/tern/skimmer colonies and colonial wading birds colonies as well as marsh bird nest areas.	Ts, Em	F, E, S
Biodiversity	Sustainability of iconic species for existence value	• Habitat suitability and population viability for selected species – fish, amphibians, shellfish	Ts, Fp	S

[1] Aq= Air quality monitoring (1.1); La = Landscape analysis (1.2.1, 1.2.2, 1.2.3); Ts = Mapping terrestrial species (1,2,4); Fp = Functional process zones (1.2.5); Wa = Wetland assessment (1.2.6, 1.2.7, 1.3.1, 1.3.2); Em = Estuarine monitoring – harmful algae blooms, hypoxia (1.3.3, 1.3.4, 1.3.5).

[2] A = CMAQ Air model (2.1); F = Freshwater quality and quality models (2.2.1, 2.2.2, 2,2,3); E = Estuarine hydrodynamic and water quality models (2.3.1, 2.3.2); S = Habitat and population models for terrestrial species (2.2.6), freshwater fish (2.2.5), and estuarine fish and shellfish (2.3.4); W = Wetlands models (2.2.4, 2.3.3). Production functions (2.3.5) will be used to relate ecosystem state to services.

ALBEMARLE-PAMLICO WATERSHED AND ESTUARY DECISIONS

Watershed and estuary decision-making occurs for many issues at multiple levels of governance. We consider classes of decisions in Table 2, developed from a literature review, public listening sessions, and discussions with stakeholders. The APWES will focus primarily on decisions related to water quality, water quantity, and wetlands. Although current decision-making occurs separately in these three areas, our vision is that these decisions are considered together in an ecosystem services context. Also, the EPA National Ambient Air Quality Standards NOx/SOx five-year review will occur in 2015, and will include nitrogen and services science supporting information. The Neuse River basin was a study area for the previous review, so it will likely be a focus in 2015 (U.S. EPA 2008b). We aim to meet short-term science needs for these decisions, and to provide a longer-term holistic services perspective. Additional decision categories could include agricultural policies, land management (*e.g.*, zoning, permit variances), and forest management.

One of the most important water quality issues in the Albemarle-Pamlico watershed and estuary is related to management of reactive nitrogen (Nr). Nr includes all biologically, chemically, and radiatively active nitrogen compounds in the atmosphere and biosphere: ammonia (NH_3) and ammonium (NH_4^+), nitric oxide (NO), nitrogen dioxide (NO_2), nitric acid (HNO_3), nitrous oxide (N_2O), and nitrate (NO_3^-), and organic compounds (urea, amines, and proteins). Past impacts associated with excessive nitrogen loading to the Albemarle-Pamlico estuary include high primary productivity and nuisance phytoplankton blooms that negatively impacted recreation and fisheries. As a result, in 1995, the North Carolina state legislature adopted a strategy to improve water quality in the Neuse River estuary through a 30 % reduction in the annual nitrogen loading from all sources based on 1995 levels. This reduction target (the "Neuse rules") took effect in 1998 and required point sources and selected nonpoint sources (agriculture and new development) to modify operations to reduce nitrogen inputs. Since full implementation of the nutrient reduction strategy, point source and agricultural loads have been reduced by 65 % and 45 %, respectively, but total nitrogen loading to the Neuse River estuary has remained essentially unchanged (Osmond 2009, Deamer 2009, Paerl *et al.* 2010). A similar situation exists for the Tar-Pamlico watershed. The APWES will combine monitoring, mapping, and modeling work on the airshed, watershed, and estuary to inform future nutrient management decisions. For example, ecosystem services may be used as indicators of benefits gained through alternative nonpoint source pollution control options.

STRATEGIC GOALS OF THE APWES

The APWES conceptual model (Figure 2) uses the DPSIR framework (GIWA 2001) to show how drivers of land use and climate change create pressures that alter the state of the system and the provisioning of ecosystem services. Management responses (decisions) affect drivers and pressures, alter services, however, these effects are often not considered when decisions are made (MEA 2005). Figure 2 shows how ecosystem services can inform the decisions, which feed back to the drivers and pressures in the form of adaptive management, which is consistent with Ecosystem Based Management (EBM) (Arkema *et al.* 2006). ESRP science is designed to quantify the links within the DPSIR framework to support improved decision-making.

Table 2. Watershed and Estuary Decisions to be supported by the APWES

Issue	Management responses (Decisions)	Decision maker	Science questions
Water quality			
	Develop standards	EPA Office of Water (OW)/NC , VA	What levels in streams are protective of estuary (Downstream Protection Values – DPVs) (*e.g.*, FL Dept Env Protection 2010)
	Develop Total Maximum Daily Loads (TMDLs)	NC DWQ, VA Dept. of Env. Quality (DEQ)	What are the spatial contributions of different areas (*e.g.*, Falls Lake) What are the relative contributions of different pressures?
	Implement BMPs, green infrastructure, land acquisition for protection, and trading to achieve TMDLs Revise riparian buffer rules (*e.g.,* for Neuse, Tar-Pamlico)	State: NC DWQ, NC Environmental Management Commission (EMC)	What are the missing sources of nitrogen (air, groundwater, storage in dams)? How is nitrogen removed in wetlands? How to optimize BMP efforts for the reduction of pollutants (and co-benefits)? (e.g., Chesapeake Bay)
Water quantity			
	Permit interbasin transfers of water	State: NC Division of Water Resources (DWR), VA DEQ	What are the effects of transfers on water quality and aquatic communities?
	Permit water withdrawals	NC DWR, NC Ecological Flows Science Advisory Board	What levels are needed instream (ecological flows)?
	Implement green infrastructure (related to EPA's Healthy Watersheds program in Virginia –VA DCR 2010)	EPA, Local communities	How to implement green infrastructure to best reduce stormwater and pollutants (and gain other benefits?)
	MS4 Stormwater regulation - Promulgate national standards for urban stormwater discharges including green infrastructure	EPA OW (also a water quality issue)	What are the stormwater retention benefits (and other benefits) associated with green infrastructure?
Wetlands			
	CWA 404 permitting for dredge and fill of waters, compensatory mitigation	Army Corps of Engineers (CoE), with EPA consultation	Are functions and services conserved through mitigation?
	Wetlands restoration to ameliorate local and coastal eutrophication	NC Ecosystem Enhancement Program (NCEEP)	Where to restore for the greatest improvement (and services benefit)?
	Significant nexus determination (assessment of connection or significant effect on physical/chemical/biological integrity of waters of U.S.) (Leibowitz *et al.*, 2008, Munoz *et al.*, 2009)	EPA Region 4	Do ephemeral streams and non-adjacent wetlands have significant nexus (*e.g.,* wetlands attenuating floods)?
Air quality			
	Next NOx/SOx five-year review - selecting an atmospheric concentration (or deposition rate) to protect public welfare	EPA Office of Air	Are functions and services altered or impaired by current ambient air levels of NOx and SOx?

Reservoir management			
	Dam removal	NCEEP	What are the costs and benefits of dam removal?
	Reservoir re-operation (*e.g.,* Sustainable Rivers Project on the John B. Kerr dam - Roanoke River www.nature.org/success/dams.html)	CoE, Nature Conservancy (TNC)	How do services change with different operation scenarios?
Coastal climate adaptation			
	Restoring oyster reefs and seagrass beds and building artificial reefs to buffer storm energy	NOAA, AP National Estuary Program (APNEP), TNC, NC Coastal Resources Commission	How to prioritize restoration projects?
	Protect land upslope for inland migration of marsh and species – land acquisition, rolling easements, living shorelines, planting bald cypress to aid forest transition		How to prioritize land for protection (Pearsall and Poulter 2005)?
	Planting marsh grasses to prevent mass wasting of the shore		What type and effort of restoration is needed for sustainability?
	Hydrologic restoration to control salt intrusion (management of ditches)		What are the benefits of this action under different sea level rise scenarios?
Species and habitat protection			
	Fishery regulations (limit season), close areas to fishing List species as Threatened/ Endangered or State Concern, identify and conserve critical habitat Evaluation of impacts on species (Endangered Species Act Section 7)	State: NC Div. of Marine Fisheries, U.S. Fish and Wildlife Service (USFWS), NOAA National Marine Fisheries Svcs (NMFS), Atlantic Coast Fisheries Commission	What factors lead to bacteria impairments in coastal waters? What are the habitat needs of species? How is connectivity threatened? How viable are populations under future scenarios? How do human activities affect species?
	Habitat Restoration – Coastal Habitat Protection Plan (CHPP), Virginia Healthy Waters program (Va Dept of Conservation and Recreation DCR 2010)	USFWS, NMFS, APNEP, NC Div. Of Coastal Mgmt, VA DCR	Where should habitat be protected and restored?
	Plan for climate change – protect areas for species range shifts (USFWS 2009)	USFWS Landscape Conservation Cooperatives	How will species ranges shift with climate change?

The APWES mission is to use ecosystem services science to inform watershed decisions in the Albemarle-Pamlico watershed and estuary. ORD and others have worked extensively in the past on assessing and forecasting drivers, stressors (pressures), and ecosystem condition (state) for airsheds, watersheds, and estuaries. The work proposed here will advance this science, as well as expand our research to explicitly link to ecosystem services and management decisions. We identified three goals to accomplish our mission:

1. MAPPING AND MONITORING. Develop methods to quantify ecosystem services, as well as drivers and pressures

- Develop indicators for ecosystem services, and identify and map the provisioning of key ecosystem services from different ecosystem types
- Assess the condition of ecosystem services provided by rivers, wetlands and coastal waters, at a variety of spatial and temporal scales.

2. MODELING. Relate changes in drivers and pressures to changes in ecosystem state and services

- Provide the scientific basis and response functions needed to evaluate changes in ecosystem services provided by watersheds under future scenarios
- Quantify and account for the combined and cumulative effects of point and non-point pollution sources to the airshed, watershed, and estuary

3. DECISION SUPPORT. Understand how management decisions alter all services, and use this understanding to inform watershed management decisions

- Examine tradeoffs or synergies among ecosystem services
- Forecast economic and societal costs and benefits of management actions and seek to manage sustainably for ecosystem protection and economic benefit.

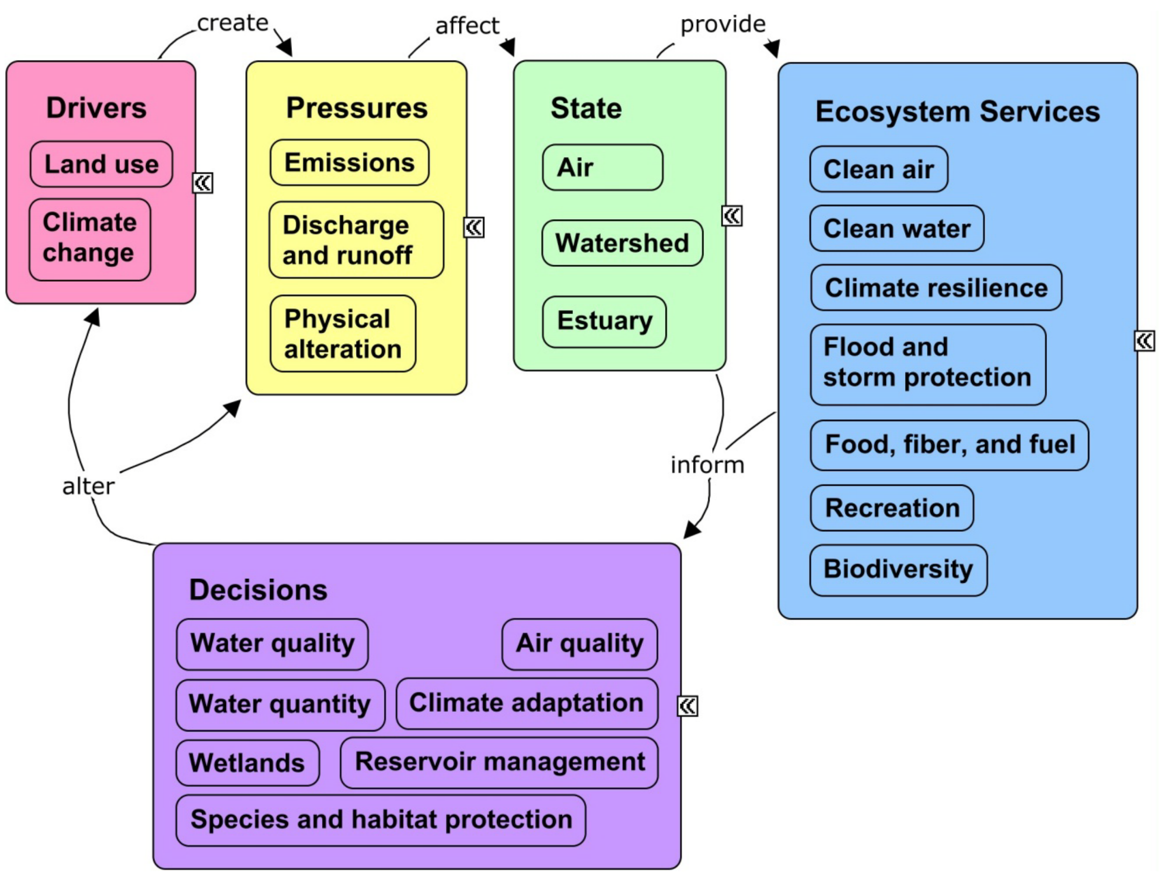

Figure 2. APWES conceptual model, where drivers are socioeconomic and natural forces influencing the ecosystem; pressures are stresses that human activities place on the ecosystem; the state is the condition of the ecosystem; services are benefits that ecosystems provide to humans (Table 1); and decisions are the management responses by society to the environment (Table 2).

RESEARCH APPROACH

The APWES Research Plan is framed through the goals of mapping and monitoring, modeling, and decision support, which will be conducted at the same time. While each goal will directly provide results that inform decisions, there will also be a flow of information between these efforts: monitoring and mapping will provide input for modeling; modeling will create functions that are built into decision support tools; and decision analysis will identify future needs for monitoring, mapping, and modeling. Research products, including publications, maps, modeling and decision support tools, will be delivered to stakeholders for informing decisions (Appendix 1).

1. MAPPING AND MONITORING

Mapping and monitoring will be used to establish a current baseline against which future management scenarios will be compared to inform decisions. Mapping and monitoring research will also supply information for the modeling (Goal 2) and decision support (Goal 3) aspects of the APWES. Mapping and monitoring help identify where services are and define their baseline condition. APWES mapping and monitoring will be conducted in the context of the ESRP National Atlas, where data for eight ecosystem services (Clean water for recreation and aquatic habitat; Adequate water supply; Food, fuel and fiber; Recreation, cultural and aesthetic amenities; Climate regulation; Protection from hazardous weather; Habitat and the maintenance of biodiversity; Clean air) are summarized by the 83,000 U.S. watersheds (12-digit hydrologic unit codes - HUCs). APWES efforts seek to improve on the Atlas approach, with a focus on the drivers, pressures, and services most significant to the Albemarle-Pamlico watershed and estuary for the airshed, watershed, and estuary. Primary assessment activities for air include characterization of the current state of nutrient drivers and pressures and the improvement of monitoring of atmospheric and terrestrial nutrients. Watershed mapping and monitoring will be conducted to characterize land cover change and agricultural systems, map terrestrial species, identify functional process zones in rivers, and characterize processes in isolated and tidal wetlands. For the estuary, research includes mapping of coastal wetlands, monitoring of wetlands below-ground biomass, and monitoring of water quality, algae, and hypoxia in water.

We acknowledge that these efforts are limited by time, money, and personnel Research gaps include the characterization of organic nitrogen and measurements of air deposition over urban and wetland land use classes. Additional work could also be conducted on phosphorus, and in particular, understanding the role of the Aurora Phosphate Mine in the Tar-Pamlico watershed, and the interaction of sea level rise and phosphate in Miocene sediments. If possible, we would add to our sensor suite for other chemical species. Research is needed on characterizing the diffuse exchange of water and associated chemicals (*e.g.,* nitrogen) between shallow aquifers and the estuary in the tidewater region of the Neuse. Characterization would benefit from focused field studies, such as the flow path studies (wells in transect), combination with seepage meters and remote sensing technology. A better understanding of the impact of engineered systems (artificial drainage, etc), is needed for wetlands and watersheds. While data efforts are strongest in the Neuse River basin, additional data collection in other parts of the watershed would support model transfer and validation.

1.1. Air Mapping and Monitoring

Atmospherically deposited nitrogen reaches coastal areas via direct deposition, or through deposition in the watershed and transport to the coast. It can play a major role in coastal nitrogen budgets and may also contribute to eutrophication and other coastal biological and chemical changes. Nitrates (NO_3^-) {wet and dry}, nitric acid (HNO_3) {dry}, ammonia (NH_3) {dry}, and ammonium (NH_4^+) {wet and dry} are the principle components of atmospherically deposited nitrogen, however new emphasis is being placed in understanding the role of other compounds such as N20 and organic compounds. APWES research efforts will include characterizing the ecosystem state with respect to these compounds and quantifying pollutant sources and sinks.

1.1.1. Ammonia

- *Ambient Concentrations*

Although NH_3 may contribute to as much as 30 % of the total atmospheric deposited nitrogen, very little long term data of ammonia concentrations is available in the U.S. In 2007 the Ammonia Monitoring Network (AMoN) monitoring program was initiated by the National Atmospheric Deposition Program (NADP, nadp.sws.uiuc.edu/). The aim of this initiative was to study the feasibility of establishing a nationwide network of passive ammonia monitors. In 2009 a study was initiated between EPA's NERL, Office of Air and Radiation (OAR), Clean Air Markets Division (CAMD); and the Office of Air Quality Planning and Standards (OAQPS) to deploy different monitoring techniques for NH_3 at a small number of CASTNET (Clean Air Status and Trends Network, epa.gov/castnet/) sites co-located with NADP AMoN sites to determine NH_3 levels and to evaluate existing ammonia measurement technology.

For APWES, atmospheric ammonia measurements from the CASTNET site (BFT142) near Beaufort, North Carolina (www.epa.gov/CASTNET/sites/bft142.html) are being enhanced to provide a more complete depiction of the total atmospheric nitrogen budget. These measurements will be collected for one week every five weeks for 9 sampling periods over one year. The suite of standard CASTNET constituents: NH_3, nitric acid, nitrates, and ammonia ion will be collected. Also, a weekly annular denuder system (ADS) and a weekly standard CASTNET three-stage filter pack and a filter pack with an additional phosphorus acid impregnated filter used to capture NH_3 will run during the measurement week. This data will then be available for use in model evaluation. *(Lead – Baumgardner, EPA/NERL/ESD)*

The spatial and temporal variability of atmospheric NH_3 concentrations is being investigated in the Neuse and Cape Fear River basins, where animal and crop production and subsequent NH_3 emissions is widespread. Since 2008, EPA's APPCD has been monitoring NH_3 concentrations using passive sampling technology at 20 – 25 sites within these watersheds to characterize the magnitude and seasonal variability of atmospheric NH_3 concentrations across a range of local emission densities. These ground-based measurements are used to develop concentration fields for high spatial resolution NH_3 dry deposition modeling, evaluation of regional air quality models, and, most recently, validation of NH_3 measurements from the tropospheric emission spectrometer on board the AURA satellite. *(Leads - Walker, EPA/NRMRL/APPCD; Pinder, EPA/NERL/AMAD; Bash, EPA/NERL/AMAD)*

- *Concentrated Animal Feeding Operations (CAFOs)*

Concentrated Animal Feeding Operations (CAFOs) are concentrated sources of multiple pressures: reactive nitrogen (ammonia, nitrates), methane, phosphorous, fecal matter, bacteria, pharmaceuticals, pesticides, salts and metals. CAFOs emit gases directly into the atmosphere with consequent nitrogen deposition onto the landscape and open water, and cause human respiratory and other health effects downwind. CAFO effluent leaked from ponds and sprayed on surrounding agricultural fields may pollute surface and groundwater, degrading water quality in wells and contributing to fish kills, hypoxia and algal blooms downstream. Accurate knowledge of the location and landscape attributes surrounding the thousands of CAFOs in the Albemarle-Pamlico watershed is essential to predicting their impacts. However, the geographic coordinates of CAFOs in existing databases may be inaccurate (*e.g.,* the CAFO is reported to be at a business address in a town; other errors may misplace CAFOs up to 1000m from their true locations). This research addresses this geospatial information gap by explicitly mapping locations of swine and poultry CAFOs in the landscape.

The method uses high resolution aerial photography and satellite imagery, and advanced remote sensing feature extraction techniques. CAFO barns where animals (swine, poultry) are housed are typically long, rectangular, light-colored buildings situated in otherwise primarily agricultural and vegetated landscapes. This presents a favorable combination of target and background for mapping by remote sensing. The method uses automated feature extraction software to search for long, bright, rectangular targets in a background of vegetation and agricultural fields. The output is a map and vector overlay of potential CAFO barns, ready for export to GIS for further analysis. Lidar data may enhance the analysis, and can provide additional information about local topography and vegetation buffers surrounding CAFOs. (Note that the analyst examines the output to correct false positives and false negatives (undetected CAFOs)). This research will create spatially explicit maps of CAFO locations to support development of emissions inventories of nitrogen compounds. Advances in the emissions inventory are expected to improve CMAQ model estimates of concentration and deposition. *(Lead: Pilant, EPA/NERL/ESD).*

1.1.2. Nitrous Oxide

The measurement of the production of nitrous oxide from both denitrification and nitrification processes will aid our understanding of the magnitude and variability of these two processes under a gradient of soil moisture and nitrogen input regimes within a coastal wetland complex. Trace gas detectors using either quantum cascade lasers or laser diode systems with cavity ring-down technologies have the sensitivity for measuring and discriminating these nitrogen isotopes (Kroon *et al.* 2007, Waechter *et al.* 2008, Hendriks *et al.* 2008). Our research includes deploying these sensors at the ground-level as well as via aerial platforms. The stable isotopes of N_2O are ^{14}N and ^{15}N, and ^{16}O and ^{18}O. Nitrifying microbes tend to fractionate N_2O in favor of the lighter isotope, so the N_2O produced will generally be depleted in ^{15}N and ^{18}O. The microbes involved in denitrification do not show the same degree of fractionation (Baggs 2008). This complex relationship means that it may be possible to more accurately determine the reactive nitrogen removed by denitrification by subtracting the N_2O produced by nitrification (Perez *et al.* 2006, Sutka *et al.* 2006, Bouwman *et al.* 2010). This information is needed to quantify determine wetland ecosystem services for reactive nitrogen removal and better describe the Nr removal efficiencies of various wetland types found in coastal N.C. *(Lead – Williams, EPA/NERL/ESD)*

N_20, which can be emitted from agricultural operations and from soil microbial processes, is another Nr source that should be considered. Characterization of N_2O emissions from the soil and water is a current gap in characterization of the Nr budget. Groundbased and airborne measurements of N_2O emissions from agricultural and wetlands soils will be used to determine the sources and source strengths of N_2O in the atmosphere. Stable isotope techniques using laser based trace gas spectrometers can help estimate the source contribution from soil nitrification or denitrification processes to the atmospheric concentration of N_2O in the study region. Additionally, water samples are being collected at 25 sites in the Neuse River Estuary and Pamlico Sound approximately biweekly, both at the surface and at depths within the water column. Dissolved nitrous oxide concentrations, atmospheric nitrous oxide concentrations, and meteorological data (wind speed) will be combined to quantify the emission of N2O into the atmosphere from the water surface. Correlations between dissolved N_2O, oxygen, temperature, salinity, and nutrient concentrations will be examined to investigate potential N_2O production mechanisms. These field data can be used to improved estimation and modeling of N_2O emission by CMAQ. *(Leads – Williams, EPA/NERL/ESD and Cooter, EPA/NERL/AMAD)*

1.1.3. Nitrogen dioxide, Nitrogen Oxides

APWES research will build upon recent advances in the space-time modeling of fused spatial information to provide: 1) a methodology for the routine development of seasonal and annual spatial patterns of total sulfur and nitrogen deposition across the eastern U.S.; and 2) State/regional estimates of total sulfur and nitrogen loadings. While it is currently possible to construct a spatial wet deposition surface from National Atmospheric Deposition Network (NADP) data, EPA is limited to reporting total loadings (wet plus dry) only at the CASTNET dry deposition monitoring sites. To provide better spatial information on total deposition, we will combine long-term wet and dry weekly monitoring data with gridded numerical model deposition output from the Community Multi-Scale Air Quality (CMAQ) model. These spatial surfaces can be used to calculate (through numerical integration) the total sulfur or nitrogen loadings and associated uncertainty for any ecological, air quality, or programmatic region of interest. Also, we propose to use statistical fusion techniques to provide predictions of atmospheric nitrogen species, (*e.g.*, NO_2, NOx) in coastal North Carolina. These techniques have never been applied to nitrogen species before, and these data will address issues associated with the extremely limited deposition monitoring and sparse monitoring for the atmospheric pollutants NO_2, NOx in this region. This effort combines air monitoring data and CMAQ output to produce temporal and spatial deposition patterns to support watershed and estuary models *(Lead – Holland, EPA/NERL/ESD)*

1.1.4 Regional scale atmospheric deposition

Deposition estimates from the CMAQ model are being made available for 2002-2006 and provide more complete information about the atmospheric nitrogen budget than current national monitoring studies. The data will be available at the 36 km grid resolution for the entire U.S. and the 12 km scale for the eastern U.S. Additional data will include wet deposition estimates for 2002 that have been adjusted for bias in precipitation. Deposition data from CMAQ will be used in the National Atlas. *(Lead-Dennis, EPA/NERL/AMAD)*

1.2. Watershed Mapping/Monitoring

1.2.1. APWES Land Cover Characterization

Data from multiple Earth Observation System sensor systems will be incorporated into a multi-temporal based approach to provide the modeling inputs required to assess dentrification rates (*i.e.*, temperature, redox potential, evapotranspiration) and other Nr-flux measurements. Vegetation composition, structure, and other bio-physical parameters will be derived using remotely sensed data from NASA's prototype L-Band Polarmetric Synthetic Aperture Radar data, operational MODIS (Moderate Resolution Imaging Spectroradiometer) data, available LIDAR (LIght Detection and Ranging) data, and hyperspectral imagery from the Environmental Mapping Visible Imaging Spectrometer (EMVIS), a visible and near-infrared (VISNIR) hyperspectral imager with 240 contiguous spectral bands spanning 400 nm- 900 nm. These metrics can be useful parameters for nitrogen cycling and landscape biodiversity. *(Lead – Lunetta, EPA/NERL/ESD)*

1.2.2. Land Cover Change

APWES will build upon existing methods of detecting landscape change within the watershed, which has focused on the development and implementation of automated procedures to monitor landscape change across the system in near-real time using NASA's Moderate Resolution imaging Spectrometer (MODIS) instrument. The goal of this research is to monitor and map the locations of change events across the landscape and identify the outcome of the change event to provide an updated classification reflecting the new landscape condition. Proposed research includes the implementation of: 1) a new more robust change detection alarm capability that will provide greater accuracy; 2) procedures developed in the Great Lakes Basin to map the major crop types will be implemented across the Albemarle-Pamlico watershed on an annual time-step and will track changes in crop rotational patterns; and 3) a new annual land-cover classification map products for the APWES. This information is particularly useful to support Nr modeling efforts related to fertilizer application rates (source allocations), and potential de-nitrification processes associated with specific landscape cover types (*e.g.*, wetlands and riparian buffers). The phenology data used to create the above landscape products can also be used to derive phenology-based metrics. Data products currently available for the watershed include phenology data and annual LC change alarm products beginning in year 2002–present. Both data sets can be accessed for data visualization and downloads at maps6.epa.gov/viewer.htm. Phenology metrics can be generated as needed to support future modeling efforts (*i.e.*, onset of greenness, growing season duration, peak greenness, and senescence). Correct characterization of the phenology is important to estimating dry deposition, as vegetation has a significant role in deposition. *(Lead – Lunetta, EPA/NERL/ESD)*

1.2.3. Remote sensing of agricultural systems

The APWES will use advanced remote sensing systems to accurately characterize important components of the agriculturally-influenced Nr cycle. In agricultural systems, applied nitrogen can be (1) incorporated by crop biomass, (2) incorporated by microbial biomass, (3) lost to the atmosphere through nitrification and denitrification processes, or(4) leached thru the soil profile to the groundwater. Field instrumentation will measure crop response to Nr applications to understand (1) using imaging spectrometers and synthetic aperture radar. Trace gas spectrometery will measure nitrous oxide emissions from fertilizer applications to understand (3) in agricultural and wetland systems. University and other cooperators will assist in (2) and (4) using measurement and modeling. Aggregation and analysis of this information will allow for a mass balance of reactive nitrogen in agricultural systems.

This work is based in the use of field and airborne (for large-scale mapping) imaging spectroscopy methods that detect plant biochemical response to nutrient uptake. Remote sensing methods that can such as color infrared photography and multispectral imaging such as commercial satellite imaging are not sensitive enough to detect subtle differences in plant pigments or phytochromes that indicate nutrient status and environmental stress. Imaging spectroscopic methods can characterize spectral absorptions associated with leaf biochemistry and can be used to determine plant nutrient utilization throughout the growing season. These methods are based on reflectance spectroscopy absorption band-depth analysis (Clark and Roush 1984, Kokaly and Clark 1999). This work will further these methods by applying them to precision agriculture management for determining crop nitrogen status and needs.

This project is a cooperative venture between EPA/NERL and NC State University (Soil Science, Crop Science, Biological and Agricultural Engineering Departments and Open Grounds Farm). We will use data and information fusion techniques to integrate remote sensing data from sensors that measure biophysical or chemical vegetation characteristics to characterize crop growth and response to nutrients over time. This information will be integrated with other ancillary data including nitrogen application rates to develop a method to predict crop response. These results support precise and realistic nutrient management recommendations for applying nutrients at optimal times based on site specific conditions, to reduce the amount of reactive nitrogen loaded to receiving waters *(Lead – Williams, EPA/NERL/ESD)*

1.2.4. Mapping terrestrial populations and biodiversity services

This project will use land cover data, land stewardship data, and deductive habitat models for terrestrial vertebrate species from the U.S. Geological Survey Gap Analysis Program to map metrics reflecting ecosystem services or biodiversity aspects valued by humans over large areas. Metrics will be derived from species-of-greatest-conservation-need, threatened and endangered species, harvestable species (upland game, migratory birds, and big game), total species richness, and taxon richness. We will evaluate additional indices for application to provide a broad biodiversity perspective. The project will be conducted at multiple scales: a focused study in the Albemarle-Pamlico watershed, and a more general study for the Southeast U.S. (9 states) *(Implemented through interagency agreement with USGS National Gap Analysis Program, with Ken Boykin at New Mexico State University)*

1.2.5. Riverine Functional Process Zones

The Neuse River basin will be mapped according to Functional Process Zones (FPZs), riverine hydromorphic patches organized longitudinally at various spatial scales (Thorp *et al.* 2006, Thorp *et al.* 2010). The FPZs are repeatable and only partially predictable in position (less so among ecoregions). Because they differ substantially in hydrogeomorphic characteristics, FPZs are also likely to vary significantly in community structure, ecosystem function, ecosystem services, and response to nutrient loadings, and thus will respond differently to efforts at river rehabilitation. For this project, the FPZs will be delineated for the entire Neuse River basin to explain more of the natural variation that exists among different types of river sections. This information will also be useful for the characterization of ecosystem services basin-wide. *(Lead – Flotemersch, EPA/NERL/EERD, in collaboration with Kansas University).*

1.2.6. Isolated wetland below-ground denitrification characterization

ESRP researchers will be collecting multiple soil samples from six isolated wetlands in the Croatan National Forest. Samples will be analyzed for ambient and potential denitrification, and assessments for within-site and between-site determinants of denitrification conducted. Isotopic analyses (Pb210 and Cs137) and down-core measures of total phosphorus, total nitrogen, and total carbon will be conducted to quantify historic rates of nutrient and carbon sequestration. N_2O is also being measured. These analyses are also being measured at isolated wetlands in northeast Ohio and north central Florida to provide a multi-ecoregion assessment of nutrient assimilation by wetlands. Coupled with other ESRP research on nitrogen removal in Pacific Northwest emergent marshes and aquatic bed wetlands, Gulf of Mexico marshes and mangroves, and upper Midwest fens and bogs, this data will inform models of wetland denitrification. *(Lead - Lane, EPA/NERL/EERD)*

1.2.7. Tidal wetland reactive nitrogen flux characterization

APWES research will link ground-water and surface water modeling elements to better understand and model nonpoint (diffuse) subsurface nitrogen source loadings to coastal wetlands. The uncertainty associated with the nutrient processing function provided by wetlands will be addressed using a step-wise and progressive modeling approach. We will evaluate the utility of advanced remote sensing technologies, specifically trace gas detectors, optical hyperspectral airborne imaging systems and synthetic aperture radar for determining, in part, the mass flux of reactive nitrogen in wetland and agricultural ecosystems. This information is needed to quantify nitrogen removal by accounting for production and losses of important nitrogen species such as N_2O from agricultural and wetland sources. Two tidal wetland complexes with current research monitoring of nutrient flux and hydrologic flow that are multi-agency wetland creation/restoration projects have been selected as study sites. Both wetlands (400-1000 acres) abut large active agricultural lands. Research at the Carteret County site is led by NCSU in cooperation with the North Carolina Coastal Federation. The Tyrrell County site research is lead by Duke University under a Department of Energy Grant. *(Lead – Iiames, EPA/NERL/ESD)*

1.3. Estuary Mapping/Monitoring

1.3.1. Extent and Quality of Tidal Wetlands in the APWES

To determine the potential functions and services that tidal wetlands provide, with regard to storm surge protection and other services, it is necessary to first identify and quantify the extent of tidal wetlands and their relative quality. To measure extent, we propose using Landsat satellite data, multispectral airborne data, analogue remote sensing data (*e.g.*, aerial photography), and geographic information systems data (*e.g.*, C-CAP,and/or National Wetlands Inventory data) to identify tidal wetlands and monotypic stands of dominant wetland vegetation in tidal wetlands of the staged study area. A hybrid image analysis approach similar to those techniques piloted by Lopez *et al.* (2004) will be used to delineate relevant coastal-zone wetlands, utilizing the above-described remote sensing and GIS data. The resulting gains and losses of wetlands across that time period can be combined with coefficients of storm surge reductions with wetland acreage to provide relative levels of vulnerability for coastal regions during the different decades. Probabilities of storm activity vary widely along the Atlantic coast and would also be incorporated into the level of vulnerability. Wetland condition will be determined using the best available and practicable field-assessment protocol(s), such as a floristic quality index or a (rapid) qualitative habitat assessment, which is robust enough to apply to a representative sample of wetlands across a biophysical gradient relevant to wetland quality. Where possible, this work will be integrated with the EPA National Wetlands Condition Assessment. This work can inform decisions about which land should be acquired for coastal wetland restoration and whether permits should be granted for development in coastal areas. *(Lead – Lopez, EPA/NERL/ESD)*

1.3.2. Measurement of belowground structure in coastal wetlands

APWES research will also support the measurement of belowground structure in coastal wetlands. Computed tomography (CT) imaging, for the first time, is being used to successfully quantify wet mass of coarse roots, rhizomes, and peat in cores collected from organic-rich (Jamaica Bay, NY) and mineral (North Inlet, SC) soils. In addition, image analysis software was coupled with the CT images to measure abundance and diameter of the coarse roots and rhizomes in marsh soils. CT imaging can discern the roots, rhizomes, and peat based on their varying particle densities. Calibration rods composed of materials with standard densities (*i.e.*, air, water, colloidal silica, and glass) were used to operationally define the specific x-ray attenuations of the coarse roots, rhizomes, and peat in the marsh cores. Using CT imaging, significant positive nitrogen fertilization effects on the wet masses of the coarse roots, rhizomes, and peat, and the abundance and diameter of rhizomes were measured in the mineral soils. CT imaging successfully assessed and quantified coarse roots, rhizomes, peat, and soil particle densities in coastal salt marshes, and is a practical and effective approach to monitor belowground structure in coastal wetlands (Wigand 2008). Because the belowground structure in coastal wetlands is critical to the provision of key ecosystem services such as flood abatement and carbon sequestration, the monitoring of belowground structure should be part of wetland management, conservation, and restoration plans. *(Lead – Wigand, EPA/NHEERL/AED)*

1.3.3. Estuarine Chlorophyll a, Salinity, and Turbidity

Chlorophyll a (a standard measure of phytoplankton biomass), salinity and turbidity will be mapped at a nominal spatial resolution of 300 m (7.5 ha) and at multiple temporal scales across the Albemarle-Pamlico estuary system using data from the European Space Agency (ESA) MEdium Resolution Imaging Spectrometer (MERIS), flown on the ENVI-1 satellite, and a hyperspectral radiometer system, flown on a NASA aircraft (EPA/NASA Interagency Agreement). These data will be integrated with in situ measurement data from the MODMON and the automated system onboard NC State ferries that cross the Pamlico Sound as part of the UNC/Duke/NC Dept of Natural Resources/NC Dept of Transportation Ferry Monitoring (FERRYMON), to derive, calibrate and validate empirical chlorophyll and turbidity bio-optical models to better understand the spatial and temporal variability of phytoplankton production, distribution, and suspended sediment flux rates across the study area. A salinity algorithm will be derived from the satellite data to provide data for estimating freshwater residence times on a regional scale for the Albemarle-Pamlico system. These datasets will also be used to estimate nitrogen dynamics simulated by the Estuary Nitrogen Model and the RMA2 and RMA4, two-dimensional hydrodynamic and transport models. *(Lead – Keith, EPA/NHEERL/AED)*

1.3.4. Estuarine Harmful Algal Blooms (HAB)

Studies on the transport and fate of nitrogen delivered to the Neuse estuary (Christian *et al.* 1991, Paerl *et al.* 1998) indicated that during high winter and spring rainfall events nonpoint source reactive nitrogen is introduced through direct atmospheric deposition and stormwater runoff into the freshwater upper reaches of the estuary. During these events, much of the reactive nitrogen that enters the Neuse estuary is in the form of nitrate (NO_3-) which is rapidly removed in the oligo-mesohaline segments of the upper estuary to promote elevated phytoplankton growth rates that result in extensive winter-spring blooms of dinoflagellates and crytomonads (Pinkney et. al. 1997). During relatively dry summer and fall months the broad lower reaches of the Neuse estuary vertically stratifies in a “lake-like” fashion (Paerl 1987, Showers *et al.* 1990) due to weak circulation. Because of these hydrodynamics, NH_4 may be nitrified to nitrite and nitrate by aerobic microbial processes which consumes dissolve oxygen and may contribute to hypoxia (Christian and Thomas 2003). Also during these months, nuisance cyanobacterial (*Microcystic aeruginosa*) blooms develop and proliferate in the freshwater portions of the Neuse River. Research will create an early warning framework for detecting HAB. This hierarchical framework would use daily MODIS satellite imagery of the Albemarle-Pamlico estuary to monitor regional scale change in chlorophyll concentrations. Aircraft and in situ hyperspectral data allow estimation of pigment concentrations and identification of phytoplankton groups, based on their unique spectral signatures. Cyanobacterial biomass will be quantified based on algorithms to retrieve the biomarker pigment C-phycocyanin (C-PC) and chlorophyll concentrations from Section 1.3.2. (Hunter *et al.* 2010). Results will be compared with data collected from FERRYMON. Research will investigate if cyanobacteria are also characteristic of other waters in the estuarine system and whether there is a link between their presence in coastal stormwater ponds and lagoons associated with CAFOs. *(Lead – Keith, EPA/NHEERL/AED).*

1.3.5 Estuarine Hypoxia

Molybdenum (Mo), which has been used as a geochemical marker of hypoxic bottom water conditions (Boothman and Coiro 2009), will be applied in Albemarle-Pamlico sounds to rapidly assess the duration/frequency of hypoxia in these waters. This research, which includes studies in laboratory microcosms and the field, relates the accumulation rate and concentration of molybdenum in estuarine sediments to the total number of days that dissolved oxygen concentrations occur below a threshold value. Concentrations of Mo in sediment will be used to assess interactions between sediment diagenesis and water column dynamics and to examine their relationship to foodweb dynamics in Pamlico Sound. *(Lead – Boothman, EPA/NHEERL/AED, EPA Region 4)*

2. MODELING

Modeling research in the APWES will improve the capability to relate changes in drivers -> pressures -> ecosystem state -> ecosystem services (Figure 2), and forecast how changes in drivers and pressures alter the provisioning of services. Mapping and monitoring efforts (Goal 1) are critical for characterizing model inputs and supporting model development. Model output will be translated to service measures that can be used directly to inform management decisions; model output and relationships will also be used in decision support efforts (Goal 3). APWES modeling research will focus on model development, application, and uncertainty analysis for air, watershed, and estuary. Efforts are also underway to link models in frameworks – research on the FRAMES model framework is underway at NERL/ERD for several of the models included in the APWES. The interrelated models for the APWES are shown in Figure 3. Not shown in Figure 3 are additional data (*e.g.*, USGS gaged flow, measured nutrient data, measured population numbers) needed for calibration and validation. The relation of models to services is also noted in Table 1.

While the APWES modeling approach is fairly comprehensive, research gaps include models for plant and soil dynamics in agriculture and forest systems, modeling future distributions of terrestrial species, and representing wetlands within watershed models. Additionally, models of geomorphological changes in the river channel would better support habitat and species models. We also need a better representation of interactions between shallow aquifers and the estuary in the tidewater regions. This would require expanded computational modeling tools such as the emerging state-of-the-art full physics-based numerical models linking ground water and surface water (beyond the current generation of semi-process based watershed models). As time allows, we will also develop additional modeling capabilities for representing toxics, including mercury, pesticides, and emerging contaminants in the estuary. We hope to interface with modeling efforts for pesticides underway in ORD (U.S. EPA ORD 2010). Also, more detailed modeling of shoreline/tidal wetland changes under future sea level rise scenarios is needed (Hopkinson *et al.* 2008). Integrating models in frameworks requires the development of standards for model input, output, and uncertainty analysis. Also, model validation in new sites is needed, and this will require the support of continued, comprehensive monitoring.

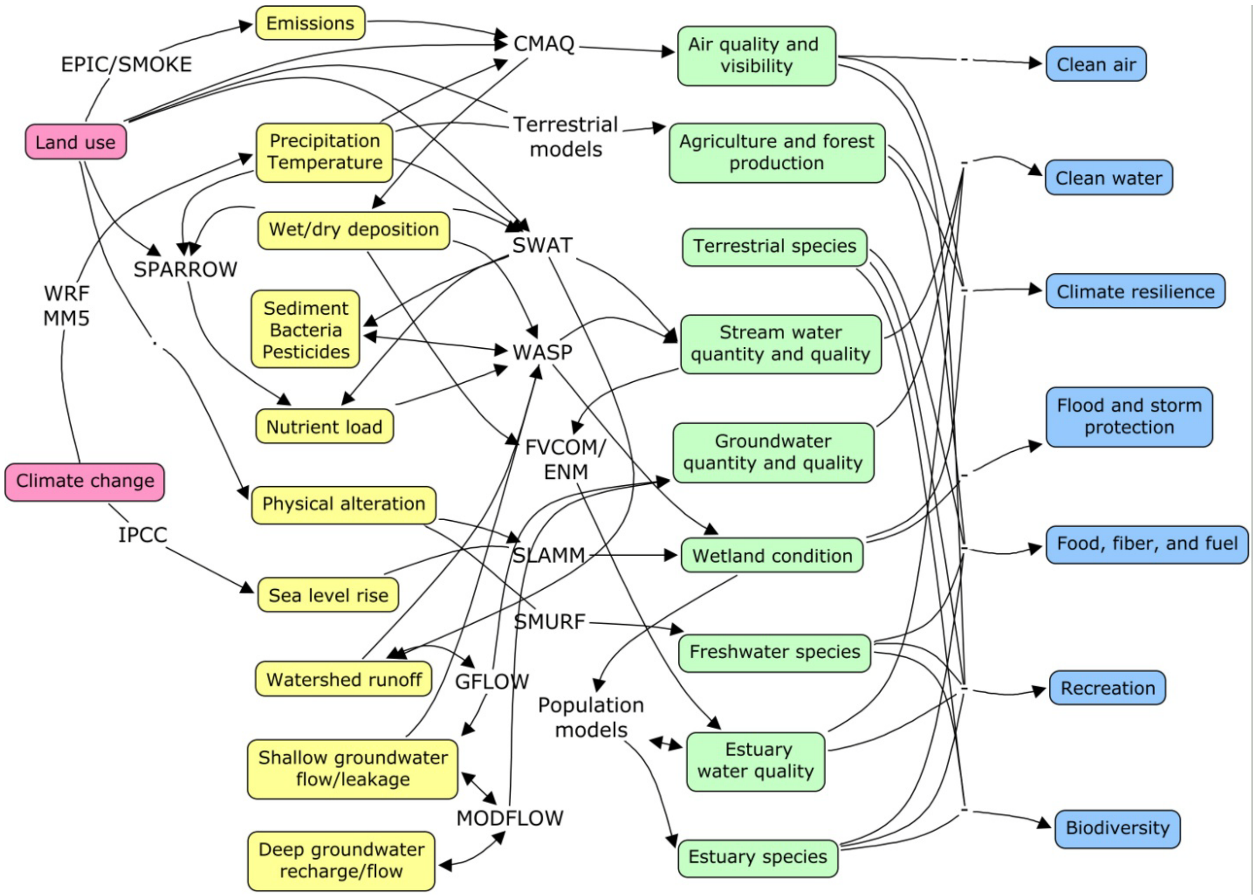

Figure 3. Relation of APWES modeling components to drivers (red), pressures (yellow), ecosystem state (green) and services (blue) (analogous to top four boxes in Fig. 2):

- Meteorological models (WRF or MM5) provide inputs (precipitation, temperature, etc) for CMAQ
- Environmental Policy Integrated Climate (EPIC) model predicts effects of crop management on movement of soil, water, nutrients and pesticides and their impact on crop productivity and water quality; the Sparse Matrix Operator Kernel Emissions (SMOKE) Modeling System processes emissions inventories to convert them to resolution needed by CMAQ
- Air modeling relies on the Community Multiscale Air Quality (CMAQ) model, an Eulerian model that ingests emissions (EPIC model) and meteorological data and provides atmospheric concentrations and deposition across a gridded domain
- Watershed models (SWAT, WASP) interface with the shallow groundwater models (GFLOW, which interacts with MODFLOW for deep groundwater) to simulate flow, temperature, sediment, and nutrients (and possibly bacteria and toxics, including mercury and pesticides).
- SPARROW, an empirical model for nutrient loading, will inform SWAT calibration.
- Estuary models (FVCOM, ENM) rely on atmospheric, watershed, and groundwater inputs to predict estuarine water quality
- Ecological models (SMURF, Population models) take inputs from watershed/estuary models to forecast changes in species populations
- The SLAMM sea level rise model forecasts wetland condition based on IPCC sea level rise predictions
- Additional model inputs are not shown here (*e.g.*, data for soils, elevation, wind, emissions data, CAFOs, species population parameters)

2.1. Air Modeling

2.1.1. Improved CMAQ model input - Land surface characterization

- **Land cover** – Land cover is a dynamic element and deposition estimates vary greatly by underlying surface. CMAQ will be updated (*e.g.*, modifying surface exchange parameters) to use the NLCD 2001 and more detailed land cover data sets developed using remote sensing techniques (Section 1.2), and model sensitivity to these differences will be tested *(Lead – Schwede, EPA/NERL/AMAD)*
- **Crop type** – Specification of the crop type in an area is critical to estimating fertilizer usage as it greatly affects land management practices. Crop data bases currently being used for CMAQ, including the USDA National Agricultural Statistics Service Cropland data layer, Farm Service Agency/FAPRI CRP assessment, Conservation Effects Assessment Project, and RCA analytical database, are static and represent a snapshot in time. Procedures developed in the Great Lakes basin to map the major crop types will be implemented across the Albemarle-Pamlico watershed on an annual time-step and will track changes in crop rotational patterns. The crop maps can be used as an alternative to the standard CMAQ data sets to investigate the sensitivity of the predicted surface exchange to the crop specification. *(Leads – Lunetta, EPA/NERL/ESD and Cooter, EPA/NERL/AMAD)*
- **Phenology** – While remote sensing of phenological data (Section 1.2.2) provides useful information and model inputs, use of the data will be restricted to retrospective and current studies. Therefore, models of phenology must also be explored. The FErtilizer Scenario Tool for CMAQ (FEST-C) will be used to generate phenological data. For current conditions, output from FEST-C will be compared with remote sensing and ground based measurements to establish comparability between the methods and provide uncertainty estimates. *(Leads – Cooter, EPA/NERL/AMAD and Iiames, EPA/NERL/ESD)*
- **Soil** – Characterization of the soil type and condition is critical to improved estimates of NH_3 bidirectional exchange in CMAQ. Work with the FEST-C will provide estimates of soil condition, nitrogen loss, and nitrogen transformation. Outputs from FEST-C will be compared with remote sensing information. (*Leads – Cooter, EPA/NERL/AMAD and Williams, EPA/NERL/ESD)*

2.1.2. Improved CMAQ model input - Nitrogen Emissions characterization

While sources of oxidized nitrogen tend to be well characterized in the National Emissions Inventory, sources of reduced nitrogen (primarily NH_3) are not. Agricultural sources of reduced nitrogen, which represent about 75 % of total NH_3 emissions, include animal feeding operations (CAFOs), animal waste, and fertilizer application. Currently, soil NH_3 emissions from chemical fertilizers are estimated using emission factors based on fertilizer sales. Using the new bidirectional algorithm in CMAQ, NH_3 emissions due to chemical fertilizer application will be removed from the input and will be modeled with CMAQ using inputs on fertilizer application timing, method and rates from FEST-C. *(Lead – Bash, EPA/NERL/AMAD)*

Remote sensing data from sensors that measure different biophysical or chemical characteristics of vegetation at locations in the Albemarle-Pamlico watershed will be used to characterize crop response to nitrogen and growth over time. This information will be integrated with other ancillary data including nitrogen application rates to predict crop response. These results to will be used to assist in making precise and realistic nutrient management recommendations and will be available for comparisons against the scenario representations in FEST-C. *(Leads – Williams, EPA/NERL/ESD and Cooter, EPA/NERL/AMAD)*

2.1.3. Improve CMAQ process modeling

Several key process areas have been targeted for CMAQ development including modeling the bidirectional exchange of pollutants such as NH_3, mercury, and pesticides and developing the CMAQ adjoint model for inverse modeling of net NH_3 fluxes in bi-directional exchange version of CMAQ. Missing pathways of air-surface exchange such as lightning NOx production, cloud deposition, and emissions and deposition of base cations have been identified in the model and will be addressed. For many ecological assessments, deposition estimates for specific land use types are needed rather than the grid-based value. CMAQ is being modified to allow output of land use-specific deposition estimates as well as estimates due to stomatal flux only. *(Leads – Bash, Dennis, Schwede – EPA/NERL/AMAD)*

2.1.4. CMAQ model evaluation and sensitivity

Estimates of uncertainty and variability are important aspects of any assessment. Numerous CMAQ evaluations have been completed for concentration and wet deposition as data for these studies is readily available from U.S. monitoring networks. Evaluation of dry deposition estimates remains a challenge due to the limited data availability. NH_3 concentrations and deposition present a special situation due to the bidirectional exchange of this pollutant. Standard monitoring networks do not provide the spatial detail needed to evaluate model processes and special studies are needed. We will assess the sensitivity of CMAQ depositions estimates of deposition to land use and climate change scenarios, which can affect emissions, concentration, and deposition. *(Lead - Schwede, NERL/AMAD)*

2.2. Watershed Modeling

2.2.1. Future climate, land use, and flow

Future land use and climate will be developed in a study focused on 20 U.S. watersheds, including the Albemarle-Pamlico. Monthly climate data for 30-year future periods will be taken from dynamically downscaled future climate change scenarios via a partnership with the North American Regional Climate Change Assessment Program. Future land use will be provided by the ICLUS tool, an ArcGIS application to derive land use change projections for housing density and impervious cover consistent with the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios storylines (U.S. EPA 2009). This project will use the future land use and climate to model of streamflow, sediment, and nutrients at the 8-digit HUC scale using the SWAT watershed model (Neitsch *et al.* 2005); inputs will also be used for the finer-scale modeling in 2.2.2 *(Lead – Johnson/Weaver, EPA/NCEA).*

2.2.2. *Upland hydrologic modeling*

Upstream watershed (surface and sub-surface) processes may result in impaired downstream water quality, which necessitates a holistic approach incorporating atmospheric, watershed and water quality models to represent variations in spatial and temporal processes. A set of watershed models will be applied at multiple (spatial and temporal) scales in the Albermarle-Pamlico watershed. A multi-scale approach will allow for assessment and forecasting of land use and climate change impacts on a variety of ecosystem services, for which data resolution and lag times may widely differ. This work moves forward from an initial analyses assessing how various spatially-explicit sources of precipitation data affect linkages between air quality and watershed modeling. The performance of various watershed models (*e.g.*, SWAT) will be investigated in simulating water and nutrient budgets. In order to determine the best source of precipitation data for watershed modeling, multiple precipitation data sources are being tested using SWAT at four different watershed scales within the Neuse basin. Improved representation of bi-directional flow of nutrients will be developed with NERL/AMAD by linking the CMAQ modeling system with watershed models. We will use the results of the USGS SPARROW and MODFLOW models for improving our calibrations on watershed flow and nutrient response (Figure 3). The SPARROW model has been applied at the RF1 resolution (1:250,000) in the Southeast (Hoos and McMahon 2009), and is now being applied using the NHD Plus catchments (1:100,000) (USEPA/USGS 2010). A Neuse River basin groundwater model GFLOW (Haitiema 1995) in combination with the USGS MODFLOW model (Campbell and Coes 2010) of the Coastal Carolinas will be used to represent recharge and leakage and constrain the Neuse River SWAT model calibrations on flow. The groundwater model will also be used to delineate subsurface flow paths from nitrogen sources to stream riparian zone, Instream water and nutrient cycling processes will be represented with the WASP model (Wool *et al.* 2003). This set of models will produce time series output at the Neuse River watershed pour point of instream flow and depth and total suspended sediment, dissolved oxygen, nutrient, and mercury concentrations. *(Lead – Kraemer, EPA/NERL/ERD)*

2.2.3. Improved rainfall-runoff relationships

Derivation of a practical rainfall-infiltration-runoff relationship eventually to replace the curve number and other simplified rainfall-runoff relationships for assessing ecosystem services provided by green infrastructure is targeted for the next decade. Simplified rainfall-runoff relationships are widely used in hydrology to estimate stream flow. Best suited to urban landscapes, these simplified methods many times do not realistically represent (and value) forest runoff, and ignore the infiltration, flow paths, and source areas upon which several ecosystem services depend. Research within the APWES will (1) pilot test curve number selection processes for use in formulating the hydrologic component of the ESRP National Atlas if these tests can be coordinated with evaluations of other hydrologic modeling approaches and (2) eventually (beyond 2014) develop and demonstrate infiltration-based runoff forecasts for green infrastructure and major land uses. The proposed rainfall-infiltration-runoff relationship will utilize advances in remote sensing, including radiometry and spectrometry for soil moisture, digital elevation models and LiDAR for slope and other watershed characteristics, and integration of NEXRAD, satellite, and other remote sensing for rainfall distribution. Geographic information systems (GIS) will be used with revised soil moisture retention databases and other remote sensing databases to dynamically forecast runoff at different scales of analysis and quantify the uncertainty. Extensive rainfall-runoff data from over 450 watershed studies worldwide, along with U.S. Geological Survey stream flow data and National Weather Service rainfall data for many larger U.S. watersheds, can be used to test estimates from the curve number method and the proposed methods, and quantify the intrinsic uncertainty. The new rainfall-infiltration-runoff relationship will be proposed by 2020 to upgrade critical hydrologic models, including SWAT, used by ESRP to quantify ecosystem services involving stream flow, soil moisture, and ground water after a comprehensive review of ecohydrologic modeling to guide the derivation of a new simplified relationship. *(Lead – McCutcheon, EPA/NERL/ERD)*

2.2.4. Representation of riparian buffers in the watershed

Riparian buffer areas, especially if forested, attenuate nutrients and provide water quality and biodiversity services and thus are an important best management practice encouraged by state and federal incentive programs. In the Coastal Plain of the APW, flows often include a significant sub-surface component which can influence riparian buffer effectiveness. Artificial drainage also reduces nitrogen attenuation by effectively bypassing existing buffers. In addition, spatial variation in nutrient loads influences the relative degree of water quality service provided by riparian buffers. We have developed a simple GIS-based watershed riparian model that connects various agricultural nitrogen sources with natural buffers via surface and sub-surface flows. The model broadly assesses the relative nitrogen attenuation for buffers. To better account for sub-surface flows in the model, we include GIS-derived data layers of landform and baseflow. In addition, we use existing stream networks, digital elevation models, soils, and landcover data to estimate the influence of artificial drainage layer on relative nitrogen attenuation. When combined in the GIS riparian model, these additional data layers produce maps that highlight the relative nitrogen attenuation by riparian buffers in the APW. Such maps can then be used to inform watershed-scale nutrient management as well as to most effectively target watersheds for conservation or restoration. Validation of this relative nitrogen attenuation riparian model will be combined with other monitoring/modeling work being planned for the Albemarle-Pamlico watershed. *(Lead – Christensen, EPA/NERL/ESD)*

2.2.5. Modeling freshwater populations

Freshwater fish provide multiple ecosystem services, including food and biodiversity. To map these services, empirical habitat suitability models will be developed for selected species. To simulate the response of these services to pressures, we will use SMURF, a spatially explicit metacommunity model for river networks (Rashleigh 2009). These will be linked to dynamic watershed inputs (flow, sediment, temperature) in an integrated modeling system to forecast the change in the populations of valued species under future scenarios *(Lead – Rashleigh, EPA/NERL/ERD)*.

2.3. Estuary Modeling

2.3.1. Estuarine hydrodynamic models

Data on reactive nitrogen transport derived from riverine loads based on U.S. Geological Survey SPARROW models, and supplementary data from atmospheric loading and direct discharges will be input into the RMA2 and RMA4 models, 2-dimensional hydrodynamic and transport models developed by the U.S. Army Corps of Engineers. Model results will be used to forecast nitrogen distribution in response to circulation patterns and water residence time within the Albemarle-Pamlico estuarine system. RMA 2-D predictions will be refined for use with the water quality, sediment transport and biological modules of the 3-dimensional Finite Volume Coastal Ocean Model (FVCOM), developed by UMASS-Dartmouth and Woods Hole Oceanographic Institution. This model will simulate the effects of atmospheric (wind stress, heat flux, precipitation), hydrodynamic (river discharge and groundwater flux), tidal forcings and bathymetry on the distribution of reactive nitrogen concentrations in the Albemarle-Pamlico estuary and its impact on dissolved oxygen, chlorophyll and dissolved organic matter. *(Lead – Abdelrhman, EPA/NHEERL/AED)*

2.3.2. Estuarine nutrient modeling

The Estuary Nitrogen Model (ENM) will be used to estimate average nitrogen concentrations in estuaries using riverine loads based on USGS SPARROW models, and supplementary data for atmospheric loading and direct discharges. The ENM is a mass balance model that assumes that nitrogen loss within estuaries can be formulated as a first-order process for which the rate is proportional to system nitrogen content. The model has been used to calculate: the fraction of watershed- and atmospherically-derived nitrogen that flows through the estuary to the sea (throughput), estimate the fraction of nitrogen from the watershed and atmosphere that is lost within the estuary to denitrification, the mean annual concentration of total nitrogen in an estuary, compare the fractions of total nitrogen in the estuary that derive from land-side loading and input from the sea, and estimate the sensitivity of estuarine total nitrogen concentrations to loading changes (Dettmann *et al.* 2005). The ENM has been used to demonstrate the dependence of throughput, denitrification losses and concentrations of total nitrogen in estuaries on flushing time. *(Lead – Dettmann, EPA/NHEERL/AED)*

2.3.3 Sea level rise modeling

Significant sea level rise may affect the APW, leading to changing shorelines and loss of barrier islands and wetlands (Pearsall and Poulter 2005). Research in the APWES seeks to address some of these potential consequences, using the Sea Level Affecting Marshes Model (SLAMM), which simulates the dominant processes involved in wetland conversions and shoreline modifications and provides maps of wetlands distribution during long-term sea level rise (Craft *et al.* 2009). In the ESRP, SLAMM modeling is being conducted on several coastal wetlands around the country, focusing on one coastal marsh in CA and one in N.C. – the Harkers Island region near Morehead City. Additional efforts will relate urban/agricultural change and sea level rise to potential changes in ecosystem services for these coastal wetlands, and develop less computationally complex models for sea level rise, which may be more practicable at broad scales, and comparing these models to SLAMM. Modeling efforts will be coordinated with ongoing NOAA work in this area (ADCIRC model) *(Lead – Erickson, EPA/NERL/ESD in collaboration with NOAA CSC, Charleston, SC)*

2.3.4. Modeling estuarine populations

Population modeling of high value resources (oysters, blue crabs, mussels, finfish, shrimp) will be conducted to investigate relationships between multiple, interacting pressures to the provisioning services provided by these species. This modeling will build on strong understanding of the estuary that already exists (*e.g.*, Christian *et al.* 2009). These population models will be linked with data on reactive nitrogen transport derived from coastal/estuarine hydrodynamic and nitrogen residence time models to develop ecological production functions which relate the removal of excess nitrogen from direct and indirect sources by shellfish and shellfish reefs by water filtration (ecological function) to enhance provisioning and recreation services (response) in estuaries and coastal waters. Both primary and secondary nursery areas will be considered. *(Lead – Thursby, EPA/NHEERL/AED with NOAA-Beaufort)*

2.3.5 Production functions for ecological response endpoints and ecosystem services.

Most of the modeling projects presented in this section are designed to increase our ability to predict how changes in pressures will affect biophysical processes. Although this information is critical for understanding of the dynamics of the system, these biophysical measures will need to be translated into endpoints (ecosystem services) that policy makers and the general public can readily understand. To bridge the gap between mapping and modeling to decision support ecological production functions need to be developed. Ecological production functions are models that relate changes in ecosystem state or condition to changes in the provisioning of ecosystem services. For example, we can model how changes in reactive nitrogen loads to the estuaries affect the occurrence probabilities of hypoxic events. To make the leap to ecosystem services we also need to be able to translate model predictions into real world effects on services such as commercial shellfish harvests or user recreation days. This project will work with the modeling groups to develop the ecological production functions necessary to translate model endpoints in indicators of ecological services. (*Lead - Milstead/ Keith, EPA/NHEERL/AED)*

3. DECISION SUPPORT

As the quality and quantity of ecosystem services are jointly determined by ecological production and direct or indirect human consumption or enjoyment, a coupled economic-ecological model is required for evaluating ecosystem service stocks and flows. The strategy is to create economic-ecological decision support tools within which decisions are represented explicitly, and baseline estimates can be updated as new data become available and changes in ecosystem services can be estimated repeatedly for different situations and in different decision making contexts. In terms of the DPSIR framework (Fig. 2), this will complete the loop from ecosystem services -> decisions -> drivers and pressures. Decision support research will use information from Mapping/Monitoring (Goal 1) and Modeling (Goal 2). Specifically, results from the set of models described in Goal 2 will be summarized in production functions (relating drivers and pressures -> ecosystem services) that are used in decision support tools. APWES decision support research will involve improvement and development of existing tools. Three different approaches are being used (DASEES, EDT, and MIMES), since they approach decisions in different ways, and through our research, we will evaluate and compare these different approaches. These tools fall at different levels of complexity, so it is not a matter of selecting one, rather, we seek to understand which types of approaches work best for which stakeholders, decisions, and scales.

Linking decisions to drivers and pressures requires a detailed understanding of the decision-makers and the decision context. We recognize that ongoing interactions with stakeholders are necessary for successful, useful products to inform decisions in the Albemarle-Pamlico watershed and estuary (Table 2), We created a partnership with the Albemarle-Pamlico National Estuary Program (APNEP) to support the delivery of the products to decision-makers through the APNEP Policy Board and Management Advisory Committee. The APNEP is one of six EPA National Estuary Program Climate Ready Estuaries, so it is a particular focus for climate decisions. We are also in collaboration with economists at CDC and economists and social scientists serving as ESRP Special Government Employees for assistance on valuation.

Research gaps for decision support include: 1) how to translate decision alternatives into scenarios for model input; 2) how information from process-based models (Goal 2) are captured as production functions that can be used in decision tools (building on 2.3.5); 3) how valuation approaches can be integrated with services and decision support (Fisher *et al.* 2008), and 4) how decision support tools should be delivered to stakeholders (*e.g.*, what type of computer interface, what type of training and technology transfer are needed). Within decision support research, we hope to gain a better understanding of how to evaluate trade-offs across space and time (Rodriguez *et al.* 2006).

3.1. Decision Analysis for a Sustainable Environment, Economy and Society (DASEES)

The DASEES decision support tool supports multiple steps. First, it supports an understanding of the context of a decision, though social network analysis and a "build-your-own DPSIR" tool (and associated training module) that can be used by decision-makers. Second, it develops an approach for identifying objectives, and includes a "value of information for conflict resolution" tool to facilitate discussions among stakeholders on costs and benefits of management actions. Third, DASEES supports developing management options, with a database of "sustainable" options for land and resource use decisions. Fourth, DASEES supports evaluating management options with a Bayesian modeling tool that builds an influence diagram representing the relationships within DPSIR, and the associated uncertainties. This tool allows users to visualize the impacts of the various management options, including a breakdown of the Impacts on the relevant ecosystem services and a comparison of the impacts on ecosystem, economic, and social services. The APWES worked with the ESRP Decision Support team to hold one stakeholder workshop in the basin (Sept. 2010), to build a stakeholder community associated with the project. *(Lead – Ten Brink/Vega, EPA/NRMRL in collaboration with Neptune, Inc.)*

3.2. Environmental Decision Toolkit (EDT)

The EPA environmental decision toolkit (EDT) is an interactive web-based software application designed according to client input regarding key assessment questions, issues, and management needs within a region. The EDT integrates available spatial data and model outputs in different combinations, allowing users to explore environmental conditions and vulnerabilities from a number of perspectives, *e.g.*, economic development, conservation planning, water quality protection. The toolkit can be used to prioritize areas for management, identify watersheds for additional monitoring or research, compare alternative future scenarios (once completed), and complete an integrated assessment of conditions and vulnerabilities across an entire region or basin. The toolkit provides both regional overview and zoom-in capabilities to individual watersheds. The EDT is being developed for application across ESRP, with targeted development for the Albemarle-Pamlico watershed *(Lead – Smith, EPA/NERL/ESD)*

3.3. Multiscale Integrated Models of Ecosystem Services (MIMES)

The MIMES system is a suite of five submodels - Atmosphere, Lithosphere, Hydrosphere, Biosphere and Anthroposphere – that are synthesized and interrelated. MIMES enables understanding of the contributions of ecosystem services by quantifying the effects of varying environmental conditions derived from land use change (Boumans and Costanza 2007). MIMES evaluates effects of land use changes and management decisions on ecosystem services, and how these in turn affect natural, human and built capital. A benefit of the MIMES approach is that changes in the ecosystem feed back to influence changes in the human system. *(Lead – Roel Boumans, EPA Special Govt. Employee)*

SYNTHESIS AND FUTURE DIRECTIONS

The APWES mission is using ecosystem services science for informing watershed decisions (Figure 2). Each of the three study goals provide direct input to services and decision: assessments from Goal 1 can be used to support prioritization of management actions, such as land acquisition, protection, and restoration. Model forecasts (Goal 2) will be used to relate future land use and climate scenarios to changes in services; and decision support tools (Goal 3) can be used directly by decision-makers to run alternative management scenarios that explicitly relate decisions to services. Projects goals are linked to one another: mapping/monitoring (Goal 1) supports modeling (Goal 2), and both provide input for decision support (Goal 3). An example of this model-data input connection is seen in the linkage of reactive nitrogen flux measurements within APWES tidal wetlands, a current project within the EPA/NERL/LCB (Figure 4). This theoretical schematic (Figure 4) helps to identify the data gaps as wetland nitrogen flux is modeled from fine spatial scale/high model complexity (*i.e.* process-based models) at the wetland level to medium spatial scale/medium model complexity (spatially-distributed models) at the 6-digit HUC level (*i.e.*, Neuse River basin), and ultimately to the entire Albemarle-Pamlico watershed.

The work described will focus mainly on informing decisions most closely related to the mission of EPA: water quality, water quantity, and wetlands. To inform these decisions, we will focus mainly on state-level decision-makers, and work with EPA Region 4 to facilitate connections with the states. While our outreach to North Carolina has been extensive, additional efforts are needed for Virginia. We plan to bring science on both the ecosystem state and services to inform decisions (Figure 2). For example, decisions on implementation of nitrogen TMDLs (and nutrient management strategies) in the Neuse and Tar-Pamlico basins require a better understanding on the state of the system (*e.g.*, lag times, air and groundwater contributions) and well as the services (how to optimize restoration efforts?) (Table 1). Similarly, wetlands management requires knowledge of the state of the system to understand the role of wetlands in the landscape and to establish significant nexus, as well as understanding how functions and services are best conserved in compensatory mitigation. Banzhaf (2010) emphasized the need to communicate the results of environmental economic analyses to policy makers to help inform their decisions. We will employ economic analysis for services, through incorporation of existing work (*e.g.*, drinking water analysis in the Neuse River basin, Elsin *et al.* 2010), or through the development of simple approaches. Our vision is that in the future, watershed decisions will be made more holistically, where multiple decisions and their impacts are considered together as integrated watershed management. For example in the estuary, oyster reef restoration is typically considered for improvement of harvest and reduction of public health risks, but also has benefits for climate adaptation (Coen and Luckenbach 2000). We hope that the APWES can lead to better watershed decision-making in the Albemarle-Pamlico watershed and estuary, and ultimately benefit human and ecological well-being.

This project is designed to be compatible with the new direction in EPA's Office of Research and Development, the Sustainable and Healthy Communities Research Program (SHCRP). The SHCRP integrates the three key elements of sustainability—economics, environment, and social (human health and social justice). The Albemarle-Pamlico watershed and estuary can serve as a potential pilot site for the sustainable regional communities component of the SHCRP, due to our existing research, as well as other sustainability research in the region (Popp *et al.* 2001; "Sustainable Raleigh"; sustainable Roanoke - sustainableroanoke.org/). In particular, we envision partnering with the Albemarle-Pamlico Conservation and Communities Collaborative (AP3C), where several conservation and community groups are working together to protect the region's natural resources while providing economic opportunities (Adams 2010). The Albemarle-Pamlico watershed and estuary is characterized by multiple pressures, landscape diversity, and upland-to-estuary linkage; possible urban (*e.g.*, Raleigh, where studies are already underway) and rural (*e.g.*, Goldsboro, Elizabeth City) communities are available as pilot sites across mountain, piedmont, and coastal ecoregions. Because the watershed and estuary system is representative of other Atlantic slope systems, the APWES will develop transferrable products and outcomes for other regions. The decision science and analysis developed though this project is comprehensive and flexible enough to explore new SCHRP directions, including new technologies and environmental justice. In the future, our vision in that the research outlined here can support EPA's effort s to understand how the natural and built environments interact to affect community well-being and sustainability.

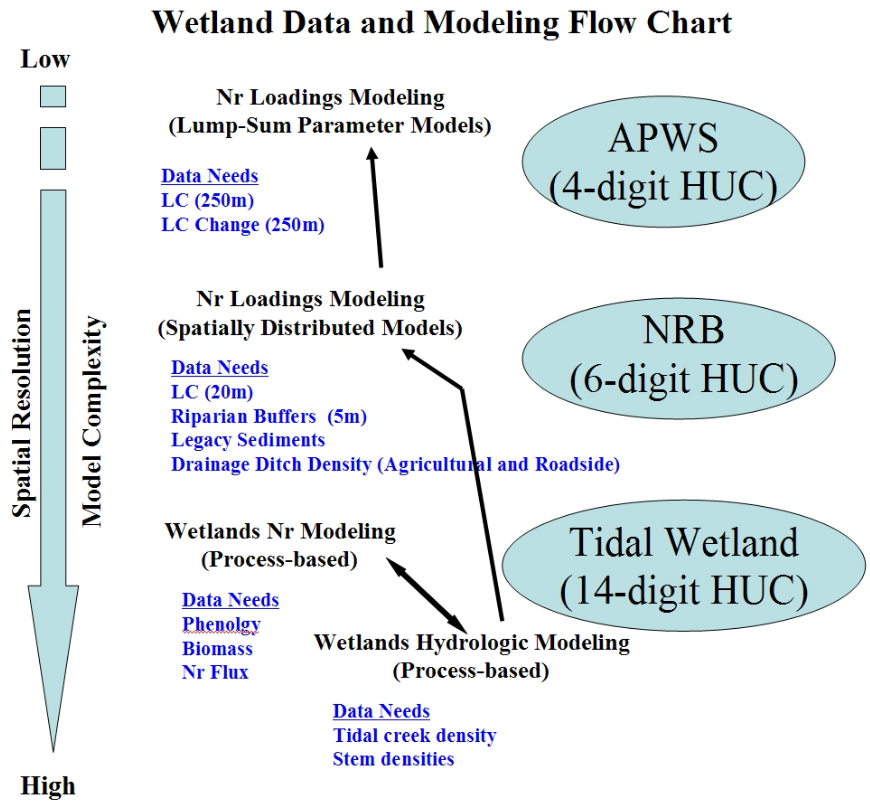

Figure 4. Example data/model flow chart for reactive nitrogen in wetland showing interaction of mapping, monitoring and modeling at multiple scales.

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APPENDIX 1. Expected APWES Products 2011-2014 (to be updated yearly)

Mapping and Monitoring Products	Year	Section	Notes
• *Estimates of atmospheric deposited nitrogen load in the coastal environment*	2013	1.1	Schwede, Cooter, Dennis (NERL)
• *Mapping Biodiversity Metrics Representing Ecological Services at the U.S. National , Regional, and Watershed Scales. EPA report*	2014	1.2.4	Kepner, Neale Bradford (NERL)
• *FPZ coverage for the Neuse River basin*	2012	1.2.5	Flotemersch (NERL)
• *Maps of extent and quality of coastal wetlands; relative levels of vulnerability for coastal regions during the different decades.*	2013	1.3.1	Lopez (NERL)
• *Detailed maps of water quality and provisioning ecosystem services in the Albemarle-Pamlico estuary*	2013	1.3.4, 1.3.5	Keith (NHEERL)
Modeling Products			
• *Air deposition predictions*	2011	2.1	Schwede, Cooter, Dennis (NERL)
• *30-year future climate predictions (monthly delta at weather stations) to support modeling*	2011	2.2.1	Johnson, Weaver (NCEA)
• *Review Article: Limitations of the curve number relationship between rainfall and runoff (APM)*	2011	2.2.3	McCutcheon (NERL)
• *Maps of Sea level rise inundation for Morehead City area, NC*		2.3.3	Erickson (NERL)
• *An evaluation of currently available models for estuarine species of interest.*	2011	2.3.4	Thursby, Ayvasian, Nye (NHEERL)
• *Population models for selected high value resources*	2012	2.3.4	Thursby, Ayvasian, Nye (NHEERL)
• *Ecological productions functions that empirically model relationships between ecological response endpoints and ecosystem services using biophysical data*	2012	2.3.5	Milstead (NHEERL)
Decision Support Products			
• *DASEES system for the Neuse River basin*	2012	3.1	Vega, Dyson , Tenbrink (NRMRL)
• *Prototype EDT for APW*	2011	3.2	Smith (NERL)
• *MIMES model for the APW, including the estuary*	2011	3.3	Boumans

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