TECHNICAL REPORT

Quantification of Nutrient and Suspended Solids Loading from Watersheds at Marine Corps Base Camp Lejeune, NC

SERDP Project RC-2245

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14. ABSTRACT
The Defense Coastal/Estuarine Research Program (DCERP) was a 10-year research and monitoring project designed to support ecosystem-based management on Marine Corps Base Camp Lejeune (MCBCL) in North Carolina, with the overarching objective to maintain MCBCL's natural resources and support the military training mission. This report addresses gaps in the understanding of the role that military lands play in the overall function of a watershed. To fill these gaps, we used a variety of approaches, including assessing tributary and tidal creek freshwater discharge; determining concentrations of nutrients, carbon, and sediments; and modeling watersheds and ecosystems. Our primary goal was to provide a realistic assessment of changes in estuarine water and habitat quality that are likely to result from representative changes in land use. To do this, we qualitatively and quantitatively assessed the export of nutrients and sediments from sub-watersheds with representative military land uses.

15. SUBJECT TERMS
Best management practices, carbon, land use, nitrogen, phosphorus, stormflow, stream, watershed, New River, Camp Lejeune

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Acronyms

DoD	U.S. Department of Defense
EPA	U.S. Environmental Protection Agency
g/ha	grams per hectare
ha	hectare
kg/ha	kilograms per hectare
m	meter
MCBCL	Marine Corps Base Camp Lejeune
NLCD	National Land Cover Dataset
NO_x	nitrate + nitrite
NRE	New River Estuary
ON	organic nitrogen
PO_4	phosphate
R^2	R squared
SERDP	Strategic Environmental Research and Development Program
TDN	total dissolved nitrogen
TSS	total suspended solids
WWTF	wastewater treatment facility

Introduction

Much of the U.S. population currently resides near the coast, and future coastal populations are projected to continue to increase in the future (NOAA, 2013). Therefore, estuaries are particularly susceptible to the impacts of anthropogenic activities in coastal watersheds. These impacts include increased nutrient loading from stormwater runoff and from both treated and untreated wastewater effluent, overharvesting of fish and shellfish, and habitat loss due to land development and reclamation. As a consequence of these pressures, many estuaries are currently listed as impaired or threatened under the U.S. Environmental Protection Agency's (EPA's) Clean Water Action Section 303(d) list.

Nutrient pollution from point sources (i.e., wastewater treatment facilities [WWTFs]) and non-point sources (i.e., runoff from agricultural lands) is responsible for excess primary production, known as eutrophication, in coastal waters. Eutrophication most often results from the development of algae blooms and is associated with subsequent low oxygen concentrations (hypoxia) in bottom waters that can result as the bloom organisms die, and then sink to the bottom where they are decomposed by bacteria. Hypoxic events can cause loss of habitat for fish and other estuarine bottom-dwelling organisms that require oxygen for respiration. Estuaries are particularly susceptible to hypoxia of bottom waters due to the natural vertical stratification caused by fresh, less dense river water flowing into an estuary over salty, denser ocean water. This stratification limits the mixing of oxygenated surface waters with low oxygen–containing bottom waters.

Changes in watersheds due to human development ultimately affect estuarine water quality through impacts on both the hydrology and the sources and composition of materials (e.g., nutrients, sediment, fecal material; Paul and Meyer, 2001; Sanger et al., 2013). The transition from a natural to a developed landscape results in increases in the amount of impervious cover and decreases in forested area, among other changes. Impervious surfaces include roads, walkways, and parking lots that do not allow rainfall to seep into the soil and recharge the groundwater, but create runoff of water into places where the water can drain and seep into the soil (U.S. EPA, 2017). These changes have two effects: (1) they decrease infiltration of rainfall into the soil where it can recharge the groundwater, and (2) they create short periods of increased peak surface stormflows (Leopold, 1968; Seaburn, 1969) with the potential for subsequent decreased baseflows (Barringer et al., 1994). The net effects are an overall increase in surface runoff volume, particularly in the stormflow component, and decreased groundwater recharge, which leads to reduced volume in the baseflow component (U.S. EPA, 2017).

Coastal streams are important conduits for both nutrients and contaminants in stormwater runoff to receiving waters (DiDonato et al., 2009; Mallin and Lewitus, 2004). Managing nutrient and sediment loading poses a challenge because sufficient quantities of each are necessary for proper aquatic ecosystem functioning, but an overabundance of either can be detrimental. Nutrients are necessary to support primary production, which supports higher trophic levels of the food chain. Ecologically valuable salt marshes that are downstream in many coastal creeks require sediment to maintain their elevation in the face of rising sea levels and wave-driven erosion. Sediment delivered in rivers and streams is thought to make an important contribution to salt marsh accretion (Morris et al., 2002); however, sediments and nutrients in excess concentrations can overwhelm ecosystem requirements and can degrade coastal habitats.

This research addressed gaps in the understanding of the role that military lands play in the overall function of a watershed. To fill these gaps, we used a variety of approaches, including assessing tributary and tidal creek freshwater discharge; determining concentrations of nutrients, carbon, and sediments; and modeling watersheds and ecosystems. Our primary goal was to provide a realistic assessment of changes in estuarine water and habitat quality that are likely to result from representative changes in land use. To do this, we qualitatively and quantitatively assessed the export of nutrients and sediments from sub-watersheds with representative military land uses.

Methods

Sample Sites

Sample sites were located across Marine Corps Base Camp Lejeune (MCBCL) in North Carolina and encompassed a range of mean watershed imperviousness from 1.1% to 27.0% (**Figure 1 and Table 1**).

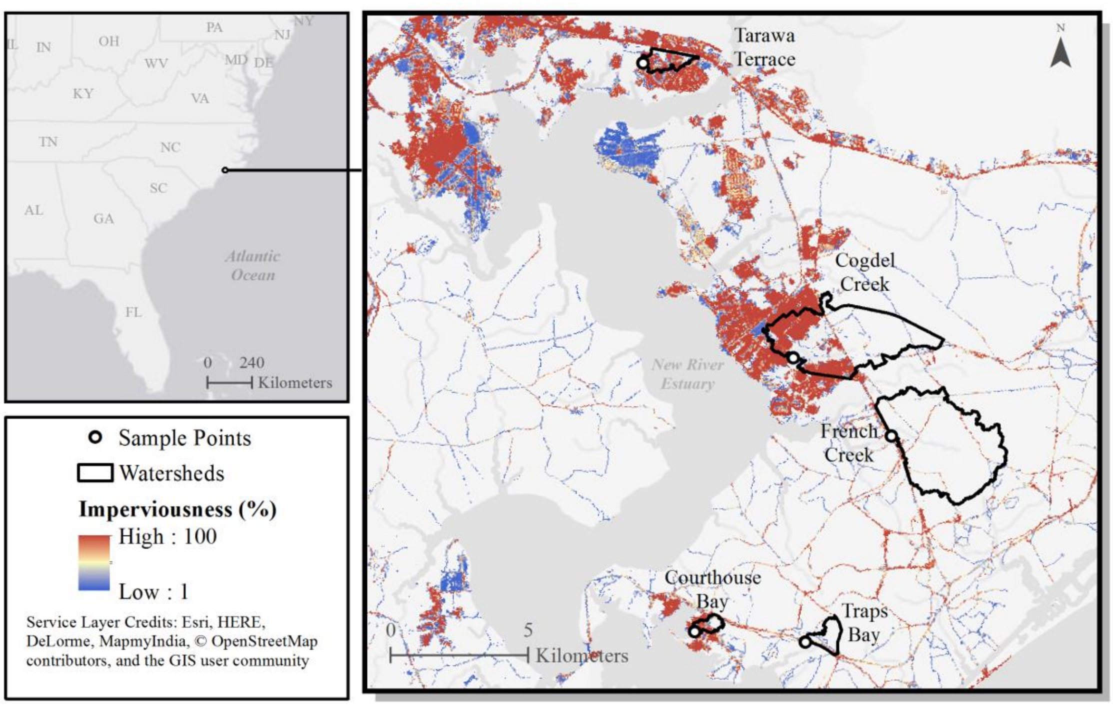

Figure 1. Sample points and watersheds were monitored for nutrient loadings from July 2008 through July 2015 using 2011 percent imperviousness data from the National Land Cover Dataset.

Table 1. Land Cover and Watershed Area (in ha and Percent Watershed) of Study Sites

Site	Forested Land	Impervious Surface	Developed Land	Total Watershed Area
Cogdels Creek	280.53 (33.6%)	115.25 (13.8%)	209.16 (25.0%)	835.83
French Creek	80.28 (9.9%)	8.56 (1.1%)	27.72 (3.4%)	807.30
Tarawa Terrace	24.48 (17.6%)	32.28 (23.2%)	63.90 (45.9%)	139.14
Courthouse Bay	3.06 (9.8%)	4.85 (15.5%)	19.62 (62.6%)	31.32
Traps Bay Creek	5.76 (11.3%)	2.11 (4.1%)	6.39 (12.5%)	51.03

Regression Equations

Mean watershed imperviousness was calculated by taking the mean of 2011 National Land Cover Dataset (NLCD) percent imperviousness data (Xian et al., 2011) within each watershed. Mean monthly nutrient loads for each water quality variable for each watershed were derived by calculating the mean of monthly nutrient loads between July 2008 and July 2015. A linear model was created for each water quality variable by using the mean monthly nutrient load as the dependent variable and percent watershed imperviousness as the independent variable. When necessary, outlier watersheds were removed from the linear model due to exceptionally high nutrient loads. The equations of these linear models for each water quality variable were used for extrapolating nutrient loading to the New River Estuary (NRE) from across MCBCL.

Loading of Nitrogen, Phosphorus, and Suspended Solids from MCBCL Watersheds

To understand the contribution of loading sources originating on MCBCL to the NRE, headwater streams were gauged during baseflow and storm events. Flow was measured continuously, and samples were analyzed for nutrient and total suspended solids (TSS) concentrations. Concentration measurements for each water quality variable were combined with freshwater discharge measurements to calculate monthly loads.

To estimate the mean monthly nutrient and sediment loadings from MCBCL watersheds to the NRE, mean watershed imperviousness of watersheds draining to the NRE from MCBCL were calculated, and regression equations were used to calculate predicted nutrient and sediment loadings. We used ESRI ArcMap and aerial imagery to select 225 points around the NRE at the mouth of streams that flow into the estuary. The watershed for each of these points was delineated by using 1-m resolution elevation data. Mean watershed imperviousness was calculated for all 225 watersheds by using the same methodology previously described in the Regression Equations section of this report (**Figure 1**). Monthly loads for each variable from the stream water quality data were averaged, and a regression between the mean monthly load and mean watershed imperviousness was developed. The regression equations were then used to calculate an estimated mean monthly load of each water quality variable for all 225 watersheds. Maps of estimated mean monthly nutrient and sediment loads were created from stream water quality data collected between 2008 and 2015 on five watersheds across MCBCL.

Load Partitioning

To understand the contribution of all MCBCL watersheds to total dissolved nitrogen (TDN) loading in the NRE versus sources off Base, the sources of TDN were partitioned and were calculated by scaling loading terms from stream and river measurements, measurements from WWTFs, and estimates of atmospheric deposition and loading from Onslow Bay to the NRE.

Results

Regression Equations

Our research encompassed a range of watershed development (**Table 1**). The value of these data is enhanced through the development of regression equations relating development (as represented by imperviousness) to the loading of nitrogen, phosphorus, and TSS (**Table 2**). These equations can be used to predict changes in loads that may result from future changes in imperviousness. Also, the data used to calculate these regression equations are presented in **Table 3** to better illustrate the magnitude of the measured loads.

The relationship between imperviousness and nitrate + nitrite (NO_x), phosphate (PO_4), and TSS were the strongest, with R^2 values greater than 0.75. Notably, the relationships between imperviousness and organic nitrogen (ON), as well as imperviousness and TDN, were much weaker than the other relationships. There was not a large difference in ON loads between watersheds, resulting in a relatively flat regression equation and a low R^2 value. The magnitude of ON loads was much larger than inorganic nitrogen loads, causing TDN loads to exhibit a similar relationship to that of ON loads. The strong relationships between imperviousness and NO_x, PO_4, and TSS indicate that future development on MCBCL will increase the loading of these water quality variables that could negatively impact the NRE.

Table 2. Descriptions of Data and Equations Used to Create Maps of Estimated Monthly Loads for Various Water Quality Variables

Variable	Regression Equation	R^2	Number of Watersheds
NO_x	NO_x (g/ha)=0.7934×mean imperviousness	0.7811	4
ON	ON (g/ha)=−1.2462×mean imperviousness+103.99	0.2094	4
PO_4	PO_4 (g/ha)=0.0608×mean imperviousness+1.6268	0.8648	4
TDN	TDN (g/ha)=−0.2949×mean imperviousness+108.74	0.0139	4
TSS	TSS (kg/ha)=1.2461×mean imperviousness	0.7492	5

Note: The date range for all variables was July 2008 through July 2015.

Table 3. Mean Nutrient and Sediment Loads (in g/ha) with Standard Errors in Parentheses for the Entire Sampling Period

Site	NO_x	ON	TDN	PO_4	TSS
Courthouse Bay	**89.19 (11.18)**[a]	**696.29 (66.91)**[a]	**1,044.92 (85.38)**[a]	**14.54 (1.62)**[a]	30.54 (5.64)
Cogdels Creek	6.78 (0.72)	94.33 (7.31)	106.98 (8.10)	2.32 (0.19)	6.87 (0.80)
French Creek	2.06 (0.38)	67.01 (5.51)	71.89 (5.80)	1.81 (0.17)	0.93 (0.15)
Tarawa Terrace	26.64 (2.15)	58.97 (4.64)	95.40 (6.92)	3.55 (0.29)	42.11 (8.97)
Traps Bay Creek	2.58 (0.35)	133.74 (16.89)	146.04 (18.05)	1.85 (0.20)	4.37 (0.54)

[a] Bolded values were outliers that were not used in the regression equations.

Loading of Nitrogen, Phosphorus, and Suspended Solids from MCBCL Watersheds

Coastal streams are both the receiving waters and transport conduits for land-derived materials (e.g., nutrients, sediment). This high level of connectivity to the surrounding watershed makes headwater coastal streams sentinels or indicators of impacts that may occur due to changing land uses. Determining the impacts of land use and rainfall patterns on material delivery by streams is necessary for quantifying and reducing degradation resulting from watershed development. Results indicated that in more developed watersheds with a higher percentage of impervious surfaces (e.g., roofs, paved roads, parking lots), loading of most constituents increased when compared with less developed watersheds with lower percentages of impervious surfaces (**Table 1**). Regression modeling determined the relationship between development (i.e., impervious area) and loading. These relationships were used to map loads (mass per hectare) from watersheds to the NRE (**Table 2 and Figures 2 through 6**).

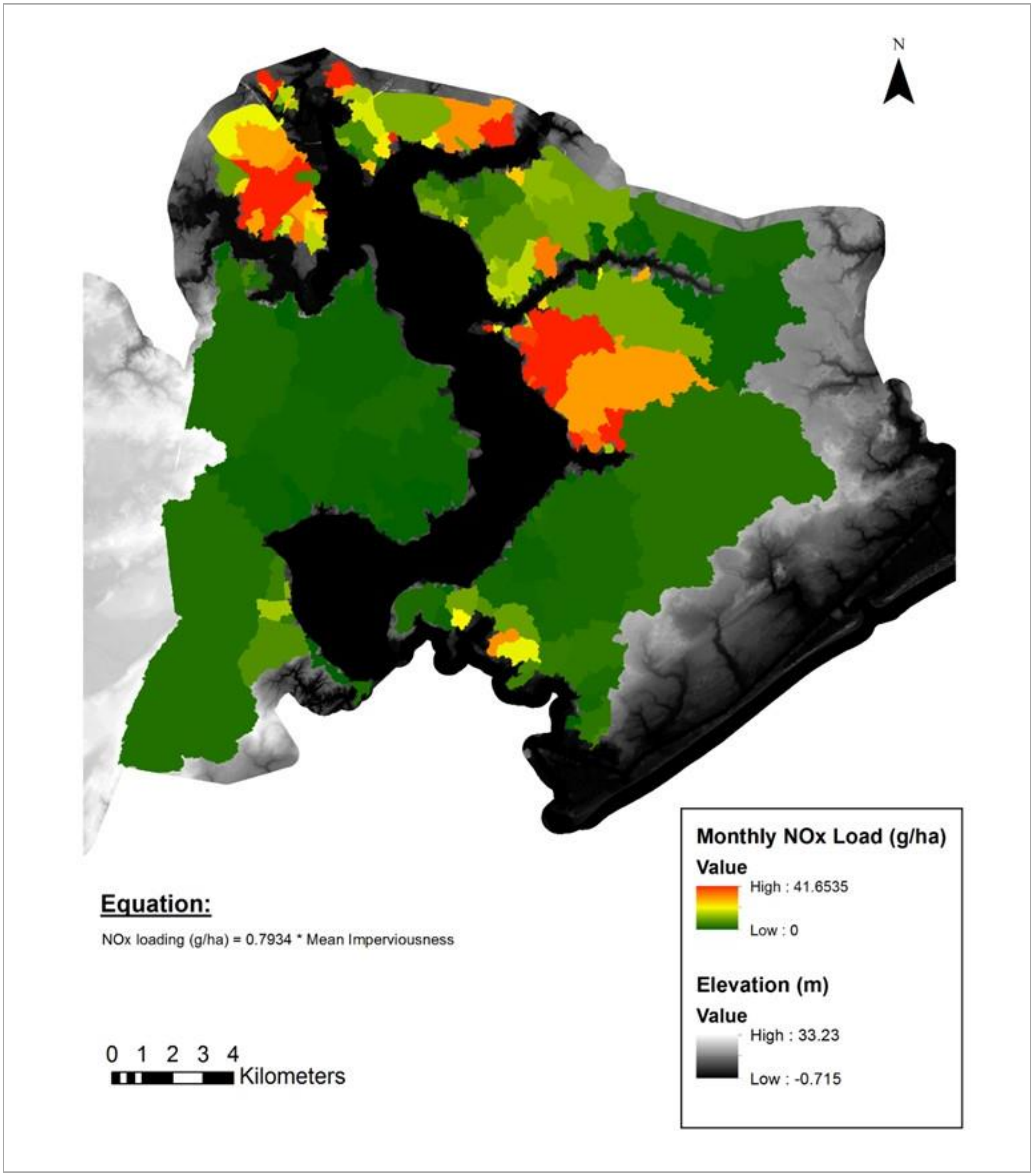

Figure 2. Estimated monthly nitrate+nitrite (NOx) load (in g/ha) from Marine Corps Base Camp Lejeune to the New River Estuary from 2008 through 2015.

Warm values represent higher loads and are extrapolated based on the observed relationship between imperviousness and nitrate loading.

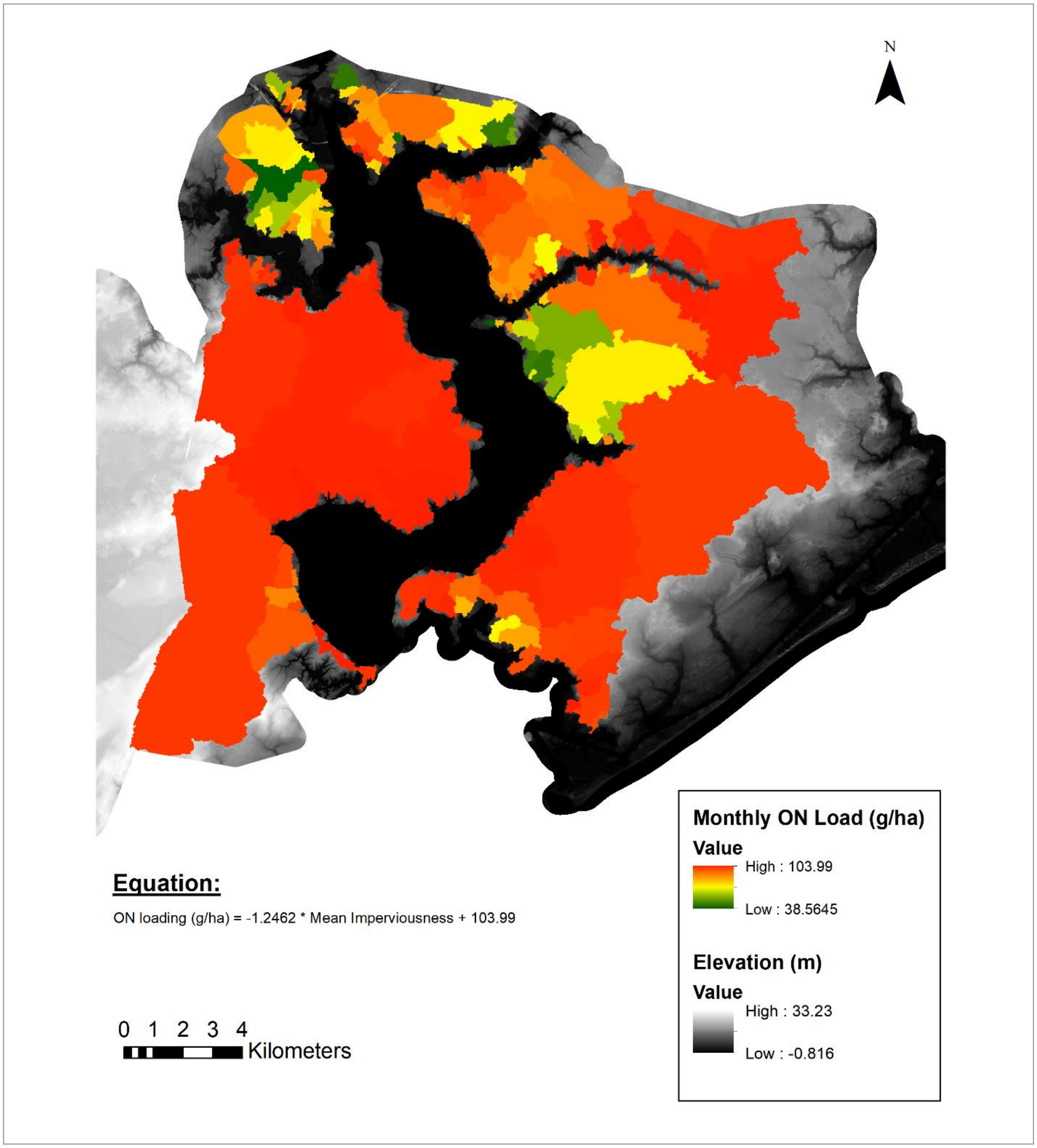

Figure 3. Estimated monthly organic nitrogen (ON) load (in g/ha) from Marine Corps Base Camp Lejeune to the New River Estuary from 2008 through 2015.

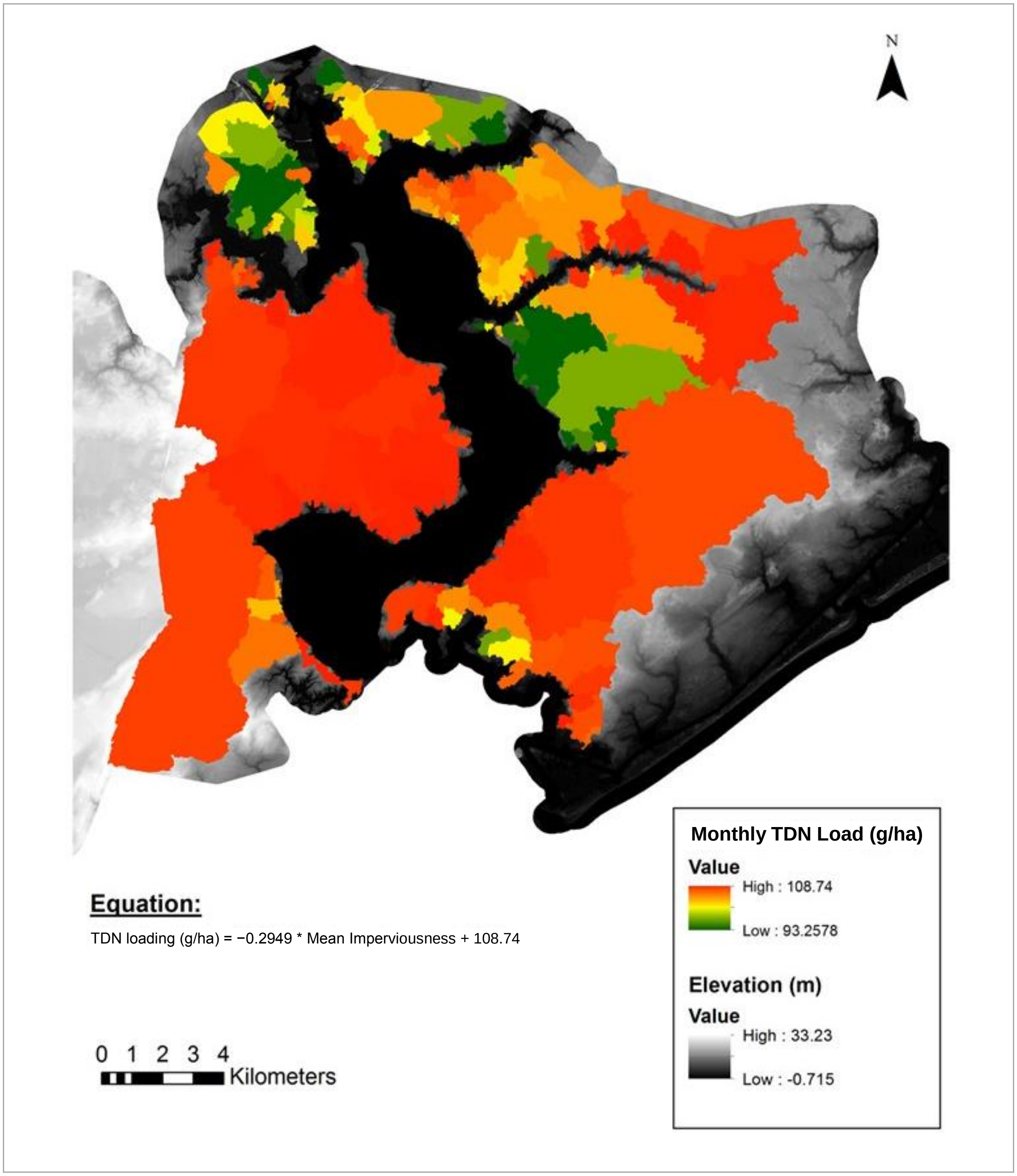

Figure 4. Estimated monthly total dissolved nitrogen (TDN) load (in g/ha) from Marine Corps Base Camp Lejeune to the New River Estuary from 2008 through 2015.

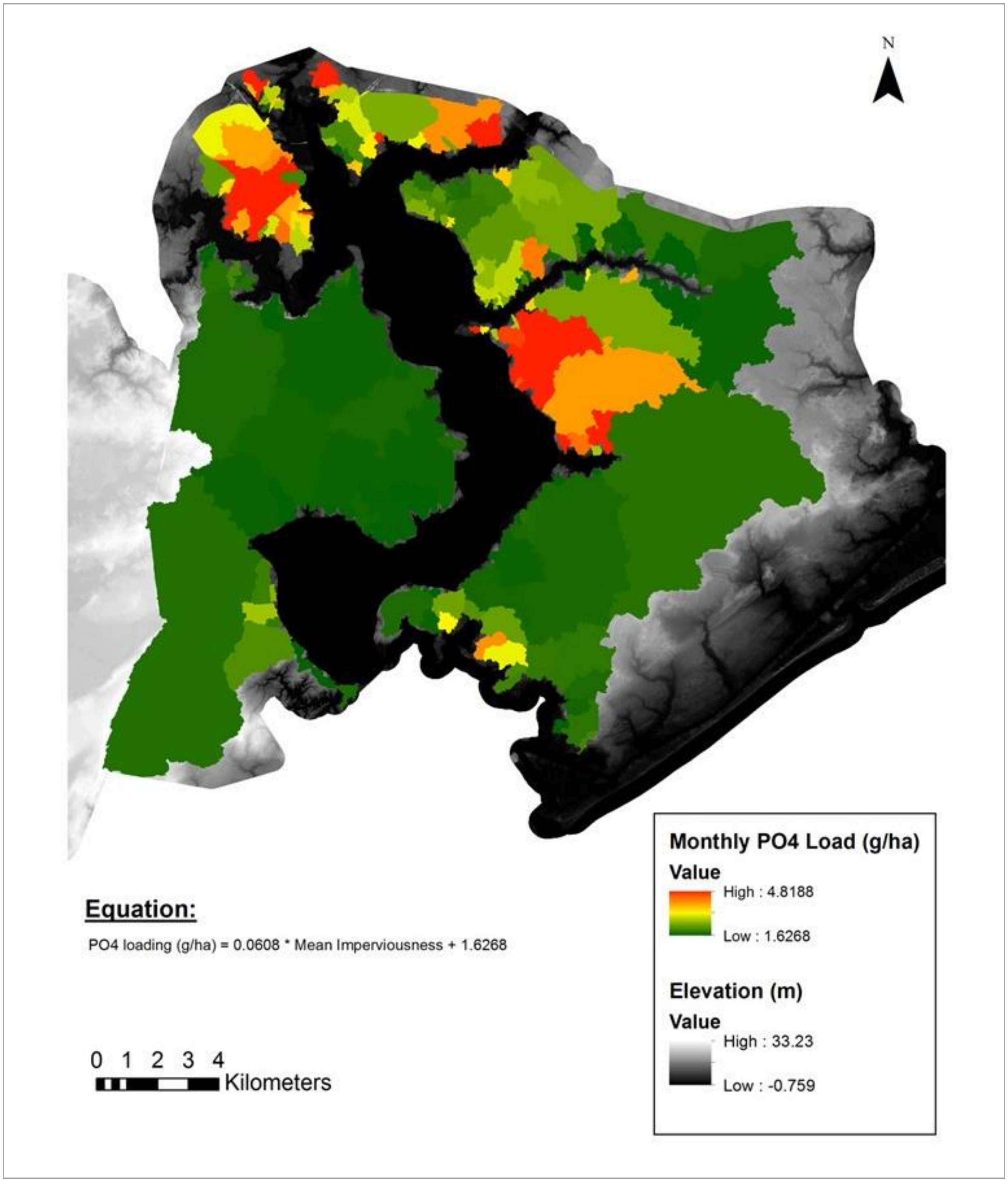

Figure 5. Estimated monthly phosphate (PO_4) load (in g/ha) from Marine Corps Base Camp Lejeune to the New River Estuary from 2008 through 2015.

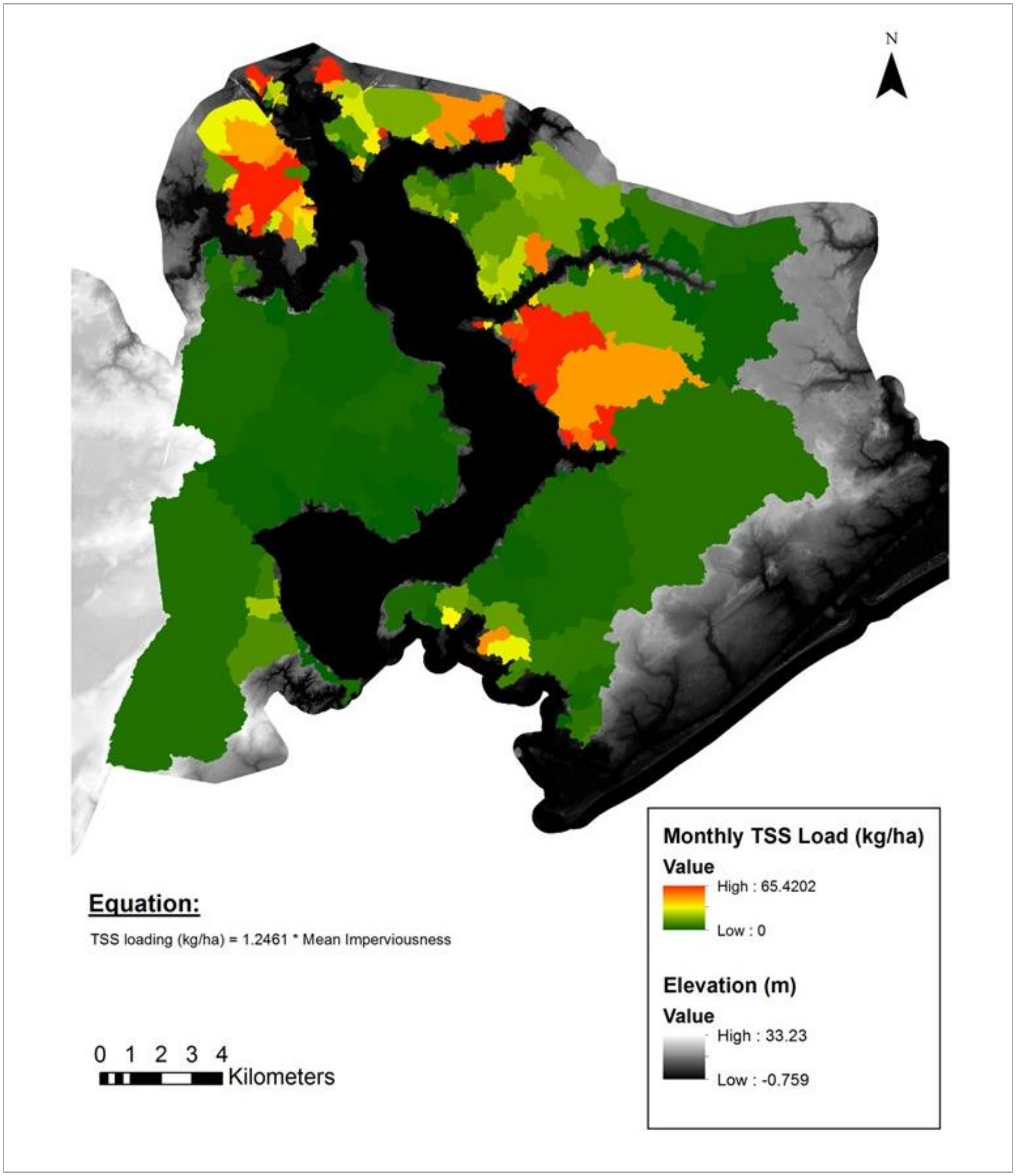

Figure 6. Estimated monthly total suspended solids (TSS) load (in g/ha) from Marine Corps Base Camp Lejeune to the New River Estuary from 2008 through 2015.

Load Partitioning

The dominant source of nitrogen to the NRE is from the off-Base lands in the upper watershed (**Figure 7**). We found that on an annual basis, off-Base watersheds (i.e., New River and Southwest Creek) contributed 64% of the external nitrogen load to the NRE, whereas MCBCL watersheds and the Base's WWTF contributed a combined 15% of the load (**Figure 7**). Onslow Bay (i.e., the Atlantic Ocean) and atmospheric deposition accounted for 15% and 7% of the external nitrogen load, respectively. When only watershed sources are considered (i.e., excluding direct atmospheric deposition and the input from Onslow Bay), 75% of the nitrogen load was calculated to originate from the off-Base watershed.

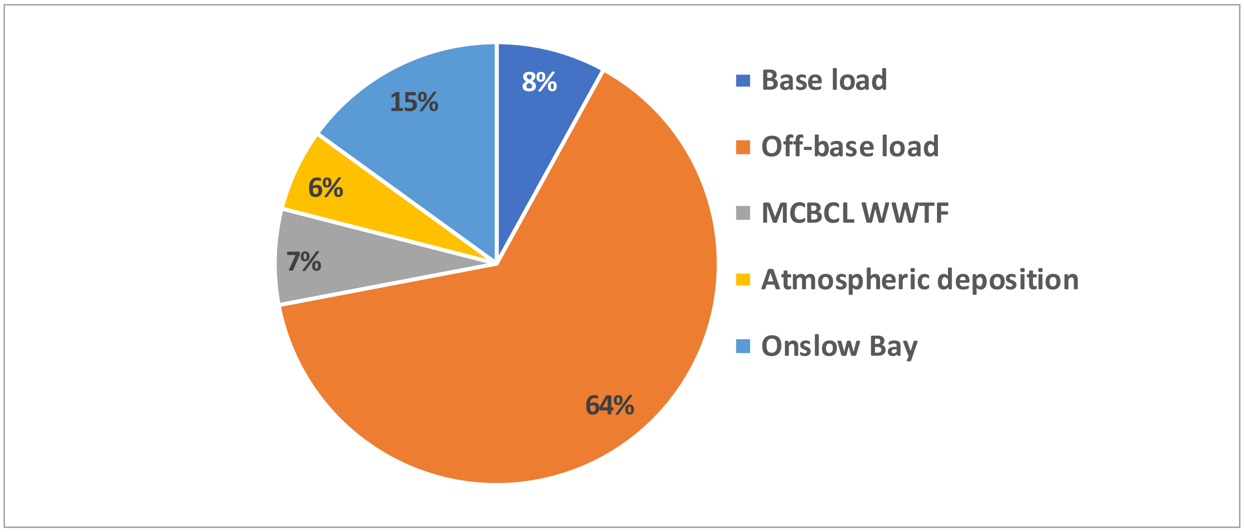

Figure 7. Sources of annual allochthonous total nitrogen loading to the NRE based on empirical scaling of measured loads.

Conclusions

The NRE is a shallow, semi-lagoonal estuarine system. Shallow estuaries are particularly vulnerable to disturbances, including excessive inputs of nutrients (e.g., nitrogen, phosphorus) and sediments. We determined the relative importance of off-Base versus on-Base sources of nutrients and sediment to the NRE and compared loads within the NRE. Other DCERP research demonstrated that nitrogen was the primary nutrient driving eutrophication in the NRE (RTI, 2017).

Although the current status of nutrient sources points heavily toward management of nutrients in the NRE watershed upstream of MCBCL, increasing infrastructure development and military training needs are rapidly modifying land uses on MCBCL that could impact the future delivery of nutrients and sediment to the NRE. Projections of the potential for changes in MCBCL's contributions can be calculated with the regression models that we provided in this report.

Determining the impacts of land use and rainfall patterns on material delivery by streams is necessary for quantifying and reducing water quality degradation resulting from watershed development. This determination will become increasingly important as population increases and corresponding land-use changes in Onslow County and across MCBCL occur with the addition of changes in the hydrologic cycle anticipated as a result of future climate change. Results indicated that in more developed watersheds with higher percentages of impervious surfaces (e.g., roofs, paved roads, parking lots), loadings of most constituents increased when compared with less developed watersheds with lower percentages of impervious surfaces.

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