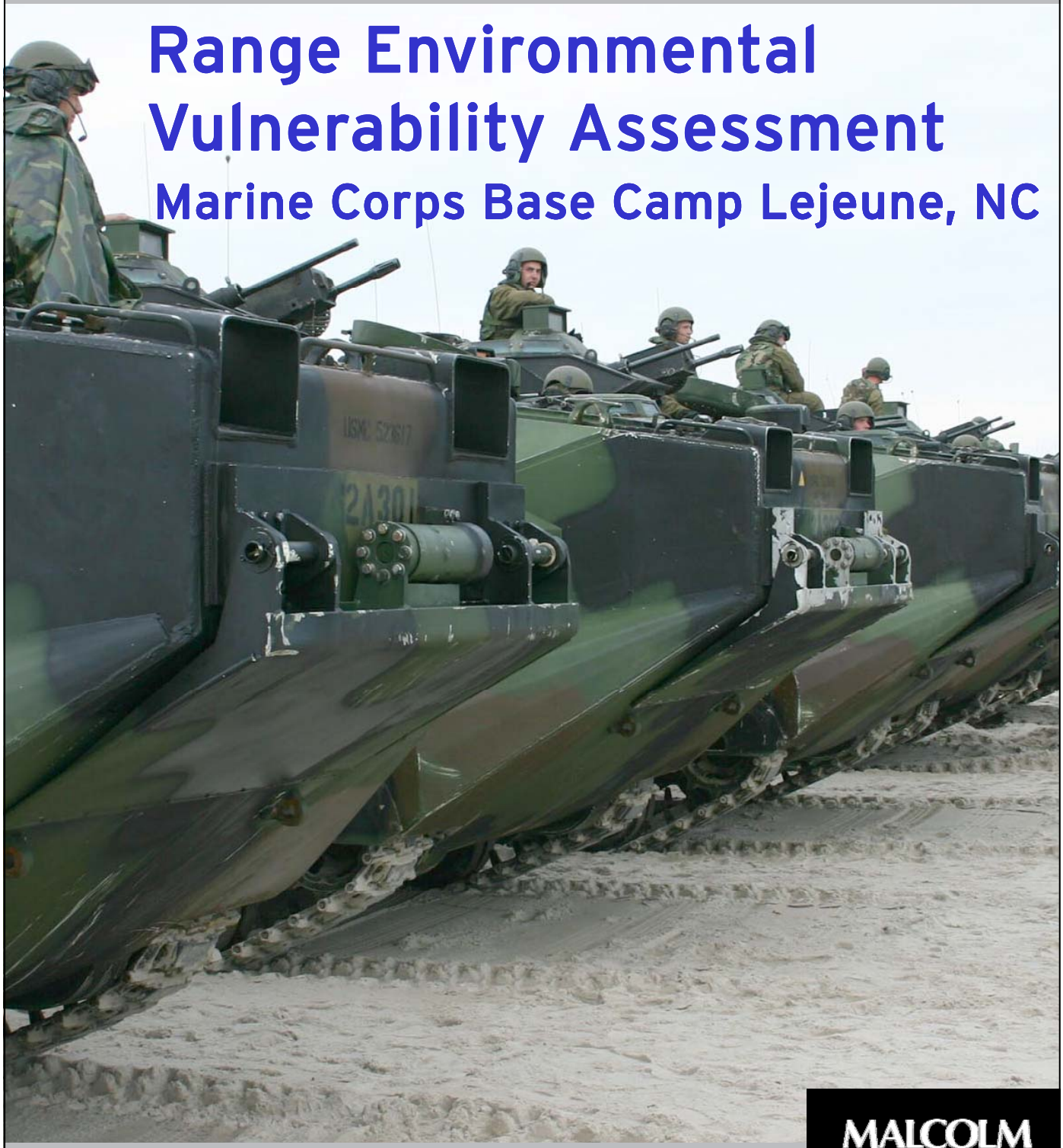
Headquarters Marine Corps

FINAL

Range Environmental Vulnerability Assessment

Marine Corps Base Camp Lejeune, NC



August 2009
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INDEPENDENT ENVIRONMENTAL ENGINEERS, SCIENTISTS AND CONSULTANTS

MALCOLM PIRNIE

Headquarters Marine Corps

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FINAL

Range Environmental Vulnerability Assessment

Marine Corps Base Camp Lejeune

August 2009

Report Prepared By:

Malcolm Pirnie, Inc.

101 South Washington Square
Suite 400
Lansing, Michigan 48933
(517) 337-0111

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Appendices

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B. Oak Grove
C. Small Arms Range Assessments
D. Final Field Sampling Report

ABBREVIATIONS AND ACRONYMS

ASR	Archive Search Report
bgs	Below Ground Surface
bmsl	Below Mean Sea Level
CSM	Conceptual Site Model
DoD	Department of Defense
DoDIC	Department of Defense Identification Code
EMD	Environmental Management Division
EOD	Explosive Ordnance Disposal
EPA	Environmental Protection Agency
ETA	Engineer Training Area
f_{oc}	Fraction of Organic Carbon
ft	Feet
ft^2	Square Feet
GIS	Geographic Information System
GP	General Purpose
gpd	Gallons Per Day
GSR	Greater Sandy Run
GSRA	Greater Sandy Run Area
HE	High Explosive
HMX	Cyclotetramethylene tetranitramine
in.	Inch
IRP	Installation Restoration Program
J	Estimated
°K	Degrees Kelvin
K	Soil Erodibility Factor
K_D	Sorption Coefficient
K_{OC}	Organic Carbon Partition Coefficient
K_{OW}	Octanol Water Partition Coefficient
kg	Kilogram

L	Liter
LDPW	Lejeune Department of Public Works
m	Meter
m^2	Square Meter
m^3	Cubic Meter
MAC	Military Operations in Urban Terrain Assault Courses
MC	Munitions Constituents
MCAS	Marine Corps Air Station
MCB	Marine Corps Base
MCRD	Marine Corps Recruit Depot
MDL	Method Detection Limit
mg	Milligram
mg/L	Milligram per Liter
MIDAS	Munitions Items Disposition Action System
mL	Milliliter
mm	Millimeter
MMRP	Military Munitions Response Program
mol	Moles
MOUT	Military Operations in Urban Terrain
mS	MilliSiemens
msl	Mean Sea Level
MS/MSD	Matrix Spike/Matrix Spike Duplicate
NA	Not Applicable
NC	North Carolina
ND	Analyte not detected above listed method detection limit
NDAA	National Defense Authorization Act
NREAO	Natural Resources and Environmental Affairs Office
NRCS	Natural Resources Conservation Service
NTUs	Nephelometric Turbidity Units
PETN	Pentaerythritol tetranitrate
PRA	Preliminary Range Assessment
QC	Quality Control

RDX	Cyclotrimethylene trinitramine
REVA	Range Environmental Vulnerability Assessment
RI	Remedial Investigation
RUSLE	Revised Universal Soil Loss Equation
SAP	Sampling and Analysis Plan
SAR	Small Arms Range
SARAP	Small Arms Range Assessment Protocol
SCS	Soil Conservation Service
SDZ	Surface Danger Zone
SOTG	Special Operations Training Group
ft^2	Square Feet
TACTS	Tactical Air Crew Combat Training System
T/E	Threatened and endangered
TNT	Trinitrotoluene
TRI	Toxics Release Inventory
µg	Micrograms
U	Analyte was not detected above listed method detection limit
U.S.	United States
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USGS	United States Geological Survey
USMC	United States Marine Corps
UXO	Unexploded Ordnance
WHPA	Wellhead Protection Area
WWII	World War II
ZOT	Zone of Transport

Executive Summary

The United States Marine Corps (Marine Corps) Range Environmental Vulnerability Assessment (REVA) program meets the requirements of the current Department of Defense (DoD) Directive 4715.11 *Environmental and Explosives Safety Management on Operational Ranges within the United States* and DoD Instruction 4715.14 *Operational Range Assessments*.

The purpose of REVA is to identify whether there has been a release or substantial threat of a release of munitions constituents (MC) from operational range or range complex areas to off-range areas. This is accomplished through a baseline assessment of operational range areas and the use of both conceptual and quantitative screening-level models of the fate and transport of REVA indicator MC based upon site-specific environmental conditions at the operational ranges and training areas. In addition, environmental sampling is performed, where applicable, to determine whether an actual release of MC has occurred. Indicator MC selected for the REVA program include trinitrotoluene (TNT), cyclotetramethylene tetranitramine (HMX), cyclotrimethylene trinitramine (RDX), and perchlorate.

This report presents the assessment results for the operational ranges and training areas at Marine Corps Base (MCB) Camp Lejeune and Marine Corps Air Station (MCAS) New River, North Carolina, collectively referred to as MCB Camp Lejeune throughout the remainder of this document. This assessment includes MCAS New River because it is a tenant of MCB Camp Lejeune. Currently there is only one operational range area, a small arms range, designated at MCAS New River. This report is the first comprehensive report on MC associated with the operational ranges at MCB Camp Lejeune and serves as the baseline of environmental conditions of the ranges. This report presents:

- Details on the installation's operational ranges and use of military munitions.
- Estimates of "loading rates" of MC at each range or training area based on records of munitions use.
- A prioritization of operational ranges and training areas for evaluation through the REVA process.
- A description of the Conceptual Site Model (CSM) for MCB Camp Lejeune that forms the basis of most assumptions for potential surface water and groundwater pathways for off-range migration of MC.
- Screening-level methods for analysis of surface water and groundwater pathways and the results of those analyses.
- A separate, qualitative assessment of Small Arms Ranges (SARs).

- Results of the REVA field sampling activities completed in 2008.

REVA is a voluntary, conservative, and tiered process. It applies readily-available information or conservative assumptions on munitions use, physical conditions at the installation to EPA-approved screening-level models to predict whether detectable concentrations of MC could migrate off the ranges to areas where human or ecological receptors could potentially be exposed to MC. If the screening-level models predict a detectable concentration, then further assessment, such as a field sampling effort, will be conducted. The results of the field sampling activities are compared to screening values identified by the Department of Defense (DoD, 2008) to evaluate the potential for detected concentrations to affect human health through drinking water or ecological receptors. The potential for off-range migration is assessed separately for SARs because the potential for lead migration and release is not reliably modeled without site-specific information, which was not obtained during the baseline assessment.

Military Munitions Training and Operations

MCB Camp Lejeune maintains operational ranges within the installation boundaries and on the waters of the nearby New River and Atlantic Ocean. The current, as well as historical, uses of these operational ranges were assessed under REVA. The Range Identification and Preliminary Range Assessment Report identifies 216 historical and operational range areas, which were cross-referenced with the 109 operational ranges and training areas identified within the 2003 National Defense Authorization Act (NDAA) Section 366 Report. The 109 operational ranges in the 2003 NDAA Section 366 Report included maneuver training areas, Impact Areas, and small arms ranges, each of which was evaluated for this REVA baseline assessment. Operational water range areas were also noted; however, since other operational ranges were determined to be of a greater potential concern, these water ranges are not further discussed in this report. The Military Munitions Response Program inventory identified 20 closed range areas and one transferred range area that are not within current operational range boundaries (as defined by the Section 366 Report),which also were not evaluated under this REVA baseline assessment.

The cross-reference of identified operational ranges and historical uses within operational range areas resulted in the identification of 33 REVA MC loading areas. These areas are the locations suspected to have been affected by potential MC resulting from primary military munitions training activities. These MC loading areas were prioritized to determine the most critical areas for modeling purposes, based on MC loading and groundwater and surface water characteristics. Based on the prioritization, 12 of the 33 identified MC loading areas were modeled. Due to overlapping uses over time, the MC loading areas were grouped into 10 MC loading areas and modeled as follows:

- G-10 Impact Area (operational)
- K-2 Impact Area (operational)
- F-5 (operational), F-2 Field Firing Range (historical use within operational area), and Musketry Range A (historical use within operational area)
- F-14 Field Firing Range (historical use within operational area)
- F-6 (operational)
- L-Impact Area (historical use within operational area)
- L-Ranges (operational)
- Combat Town (operational)
- M-10 Range (historical use within operational area)
- M-115 Range (historical use within operational area)

Operational small arms range areas were also identified and are qualitatively assessed in this report, including the following:

- A-1
- B-12
- D-29A and D-29B
- D-30
- F-11A and F-11B
- F-18
- I-1
- Military Operations in Urban Terrain Assault Course (MAC) 1 through 5
- SR-11
- Stone Bay Range Complex

The environmental conditions of the MC loading area operational ranges, along with the results of the groundwater and surface water screening-level analyses, were used to develop CSMs, which identify potential pathways and receptors.

Conceptual Site Model

Based on the procedures defined in the *REVA Reference Manual* (HQMC, 2006), the first step in the surface water and groundwater analyses is the development of a CSM of MC transport, including a description of the water flow system and identification of receptors. Even without additional modeling, the CSM provides a great deal of insight into the potential for MC to reach receptors. The CSM includes the identification of possible pathways (i.e., surface water and groundwater) for MC migration from the MC loading

area to potential receptors. Potential receptors include human population or threatened and endangered (T/E) species (ecological receptors) that use or are exposed to surface water and/or groundwater at MCB Camp Lejeune if a complete MC transport pathway existed. The concepts developed in the CSM are important to understanding potential transport mechanisms for MC and the possibility for receptors to be impacted at MCB Camp Lejeune.

Overview of CSM

MCB Camp Lejeune is situated within the Atlantic Coastal physiographic province and is located in the Lower Coastal Plain of North Carolina, the topography of which consists of flat terraces (also called surfaces) underlain by unconsolidated sediments. Elevations at MCB Camp Lejeune range from mean sea level (msl) to 72 feet (ft) above msl. The majority of the land area at MCB Camp Lejeune is covered by the Talbot surface at an elevation ranging from 24 to 42 ft above msl. Additionally, a thin narrow strip of land near the coast at MCB Camp Lejeune is covered by Pamlico surface at an elevation ranging from sea level to 24 ft above msl. Although the majority of the facility is relatively flat with slopes of less than 2%, steeper topography with slopes of 2% to 15% is present in the valleys of dendritic stream systems that dissect the terraces.

MCB Camp Lejeune is bounded to the southeast by Onslow Bay and the Atlantic Ocean and is bisected by the large New River embayment. The majority of MCB Camp Lejeune drains to the New River embayment and its tributaries. However, some southern areas of MCB Camp Lejeune drain directly to the Intracoastal Waterway, which parallels the coast near the southeast boundary. Much of the interior of MCB Camp Lejeune drains to intermittent and perennial streams that widen into tidal creeks in their downstream segments. Most perennial streams and tidal creeks occupy floodplains with extensive riparian wetlands. The flat terraces of the facility interior also contain regions that drain to low areas with no surface water outlets, including pocosins.

According to data obtained from MCB Camp Lejeune, 23 subwatershed areas have been delineated within the MCB Camp Lejeune installation boundary. These subwatershed areas mostly consist of perennial streams that drain to the New River embayment within the installation boundary. The subwatershed areas range in size from 2,760 to 31,746 acres.

Almost two-thirds (65%) of MCB Camp Lejeune is covered by forest, including pine forest, bottomland hardwood, and mixed pine-hardwood forest. About 22% of the facility area consists of pocosin. The installation area is about 5% developed, including base housing and operations buildings, and about 5% barren, most of which consists of military operations areas. The flat, upland regions of MCB Camp Lejeune are underlain by a variety of sandy and loamy soils of highly variable drainage characteristics.

Below the surficial deposits of MCB Camp Lejeune are southeast-dipping marine sediments of Cretaceous to Miocene age with a total thickness of over 1,400 ft at Onslow Beach. These sediments have been divided into seven hydrostratigaphic units and commonly are divided into seven aquifer systems (aquifers and associated confining units). The aquifer systems from deepest to shallowest are Lower Cape Fear, Upper Cape Fear, Black Creek, Peedee, Beaufort, Castle Hayne, and Surficial aquifer systems. The Castle Hayne and Surficial aquifer systems were evaluated as part of REVA for MCB Camp Lejeune because the Castle Hayne aquifer is used for potable water at the base and the Surficial aquifer overlies the Castle Hayne aquifer and may act as a recharge source for the Castle Hayne aquifer. The Castle Hayne aquifer is overlain by the Castle Hayne confining unit.

After development of the CSM, quantitative analysis methods were used at selected ranges, in accordance with the approaches described in the *REVA Reference Manual* (HQMC, 2006). The quantitative methods used are considered screening-level models. They rely on multiple conservative assumptions, are more likely to overestimate than underestimate MC concentrations, and are used to determine whether or not particular ranges merit additional investigation.

Human and Ecological Receptors

Potential receptors include human populations or T/E species (ecological receptors) that use or are exposed to surface water and groundwater at MCB Camp Lejeune. These are possible receptors of potential MC migration if a complete transport pathway existed.

Camp Lejeune is home to federally listed T/E animals and plants. In addition, there are several species of endangered marine mammals and three species of endangered sea turtles that can frequent the adjacent waters. The following is a list of the protected animals, plants, and marine mammals identified:

- Red-cockaded woodpecker
- Sea turtles – Atlantic loggerhead turtle and green sea turtle
- Bald eagle (now removed from T/E species list)
- American alligator
- Endangered plants – rough-leaved loosestrife and seabeach amaranth

Other species of conservation significance include migratory shorebirds that receive federal protection. They use the southern section of Onslow Beach as a unique and important nesting habitat. The Venus flytrap is a state-listed species and is protected by North Carolina.

Surface Water Analysis Summary

Under REVA, the screening-level surface water analysis is used to estimate the MC concentrations potentially in surface water runoff at the edge of the MC loading areas. If this analysis predicts impacts at the edge of the loading area, then further calculations are performed to estimate the MC concentrations at a downstream receptor.

Average annual surface water concentrations of the indicator MC (TNT, RDX, HMX, and perchlorate) were estimated based on the average annual MC loading of each indicator MC to each MC loading area. The estimation of MC concentrations in surface water assumes that a portion of the MC may enter the surface water through several mechanisms: (1) erosion of particulate or adsorbed MC in soil; (2) direct dissolution of MC in surface water runoff; and (3) connectivity of groundwater and surface water. At MCB Camp Lejeune, it was assumed that MC primarily enters surface water through either erosion or dissolution into surface water runoff.

Results of the surface water screening-level analysis were compared to the REVA trigger values listed in Table ES-1 to evaluate the potential for MC releases to off-range receptors. The REVA trigger values are only used to compare modeling results to determine whether additional evaluations are necessary.

Table ES-1.
REVA Trigger Values for MC

MC	Trigger Value (µg/L)
RDX	0.16
TNT	0.08
HMX	0.08
Perchlorate	0.98

Note: µg/L – micrograms per liter

Groundwater Analysis Summary

The purpose of the groundwater screening-level analysis in the REVA program is to make best use of the available information to infer whether indicator MC can be transported in groundwater from loading areas to receptors. The groundwater analysis approach determines which sites show no potential for arrival of MC at the water table with concentrations above the REVA trigger values, and those are eliminated from further consideration. Those sites that do show the potential for MC to reach the water table at concentrations above the trigger values are further analyzed using a saturated zone groundwater model. For most other REVA sites, the saturated groundwater model used for this phase of the groundwater analysis is BIOCHLOR, a simplistic two-dimensional transport model that estimates contaminant transport in one-dimensional horizontal flow field with retardation (sorption) and first-order decay. This type of model

can only be used where the site groundwater conditions are well understood and are generally homogeneous and isotropic.

In the case of MCB Camp Lejeune, the one-dimensional groundwater modeling typically completed as part of the initial REVA baseline assessment was not conducted because the groundwater flow system that underlies the installation was potentially too complex and not well-enough defined for a one-dimensional analysis to be meaningful. These complexities include a two-aquifer flow system with an intervening aquitard of unknown characteristics and extent, limiting the ability to quantify the connection between aquifers, as well as the presence of multiple nearby pumping wells tapping the deeper aquifer. The two aquifers of potential concern at MCB Camp Lejeune are the Surficial aquifer and the Castle Hayne aquifer, separated by the Castle Hayne confining unit. There is evidence that these aquifers are interconnected at some locations on MCB Camp Lejeune (USGS, 2004); however, the degree of connectivity between the aquifers at the MC loading areas is unknown.

Based on these complexities, it was determined that the one-dimensional groundwater modeling may not yield results representative of actual site conditions and would not identify the potential for off-range migration. Therefore, two possible options were available for continuation of the groundwater analysis and the determination of the possibilities for MC migration off range. The first option was to utilize an advanced three-dimensional groundwater model, which would require significant data, time, and resources. The second option was to perform groundwater sampling at two of the larger and most highly used MC loading areas (G-10 and K-2 Impact Areas) to determine directly whether MC have potentially migrated from the operational ranges and conduct a hydraulic assessment test near the G-10 Impact Area (where monitoring wells are screened in the Surficial aquifer and water supply wells are screened in the Castle Hayne aquifer) to assess the degree of hydraulic connection between the two aquifers in this area. Groundwater sampling and the hydraulic assessment test was determined to be the best option. During the REVA process, the operational ranges were prioritized to determine which areas had the greatest potential for concern (i.e., G-10 and K-2). It was assumed that if these highest priority areas had potential MC migration, additional evaluation would be conducted of other areas; however, it was considered that if these areas showed minimal to no possible MC migration, additional evaluation would not be necessary at this time for lower priority sites.

Uncertainties regarding the interconnectivity and effects of the MCB Camp Lejeune water supply wells on the groundwater flow system led to the collection of additional field data. These field data were intended to help determine whether additional environmental sampling data and/or additional modeling were necessary. The additional field activities included the following:

- Collecting surface water samples along stream channels in streams adjacent to the K-2 and G-10 Impact Areas to further evaluate the potential for off-range MC release through surface water.
- Collecting groundwater samples from the Surficial aquifer obtained from monitoring wells surrounding the K-2 and G-10 Impact Areas and collecting groundwater samples from the Castle Hayne aquifer obtained from MCB Camp Lejeune water supply wells located around the G-10 Impact Area to further evaluate the potential for off-range MC release near the K-2 and G-10 Impact Areas.
- Assessing the hydraulic connection between the Surficial and Castle Hayne aquifers during a shutdown of selected MCB Camp Lejeune water supply wells and measuring the corresponding effect on the water levels in monitoring wells in the Surficial aquifer and water supply wells in the Castle Hayne aquifer near the G-10 Impact Area.

Screening-Level Modeling Results

Results of the vadose zone screening-level modeling and surface water screening-level modeling at MCB Camp Lejeune MC loading areas are provided below.

- G-10 Impact Area – Initial vadose zone modeling indicated that there is a potential for HMX, RDX, and TNT to reach the water table at detectable concentrations. Screening-level model results for surface water runoff indicated that the annual average edge-of-loading area HMX, RDX, and TNT concentrations could exceed the REVA trigger values. The annual average RDX and TNT concentrations in runoff entering the New River downstream of Town Creek and upstream of Stones Bay and the Intracoastal Waterway at the confluence point with Bear Creek were predicted to potentially exceed the REVA trigger values.
- K-2 Impact Area – Initial vadose zone modeling indicated that there is a potential for both RDX and TNT to reach the water table at detectable concentrations. Screening-level model results for surface water runoff indicated that the annual average edge-of-loading area MC concentrations for RDX and TNT could potentially exceed the REVA trigger values. The annual average RDX and TNT concentrations in runoff entering the New River downstream of Town Creek and upstream of Stones Bay and the New River at Stones Bay were predicted to potentially exceed the REVA trigger values.
- F-5, F-2 Field Firing Range, Musketry Range A – Initial vadose zone modeling indicated that there is a potential for RDX to reach the water table at a detectable concentration. Screening-level model results for surface water runoff indicated that the annual average edge-of-loading area MC concentration for RDX could exceed the REVA trigger value. The annual average MC concentrations in runoff entering the New River at its confluence point with Wallace Creek were predicted to be below the REVA trigger values.
- Historical Use F-14 Field Firing Range – Initial vadose zone modeling indicated no potential for the indicator MC to reach the water table at a detectable concentration

above the REVA trigger values. Screening-level model results for surface water runoff indicated that the annual average edge-of-loading area MC concentrations were predicted to be negligible.

- F-6 – Initial vadose zone modeling indicated that there is a potential for RDX, TNT, and perchlorate to reach the water table at detectable concentrations. Screening-level model results for surface water runoff indicated that the annual average edge-of-loading area MC concentrations for RDX, TNT, and perchlorate could exceed the REVA trigger values. However, the F-6 MC loading area was predicted to contribute small to negligible mass of MC into the New River between Town Creek and Stones Bay.
- Historical L-Impact Area – Initial vadose zone modeling indicated no potential for the indicator MC to reach the water table at a detectable concentration above the REVA trigger values. Screening-level model results for surface water runoff indicated that the annual average edge-of-loading area MC concentrations were predicted to be negligible.
- L-Ranges – Initial vadose zone modeling indicated that there is a potential for RDX to reach the water table at a detectable concentration. Screening-level model results for surface water runoff indicated that the annual average edge-of-loading area MC concentration for RDX could exceed the REVA trigger value. However, the L-Ranges MC loading area was predicted to contribute very little mass of MC in runoff (maximum of less than 5%) into the New River at Stones Bay.
- Combat Town – Initial vadose zone modeling indicated no potential for the indicator MC to reach the water table at a detectable concentration above the REVA trigger values. Screening-level model results for surface water runoff indicated that the annual average edge-of-loading area MC concentrations were predicted to be below the REVA trigger values.
- Historical Use M-10 Range – Initial vadose zone modeling indicated no potential for the indicator MC to reach the water table at a detectable concentration above the REVA trigger values. Screening-level model results for surface water runoff indicated that the annual average edge-of-loading area MC concentrations were predicted to be negligible.
- Historical Use M-115 Range – Initial vadose zone modeling indicated no potential for the indicator MC to reach the water table at a detectable concentration above the REVA trigger values. Screening-level model results for surface water runoff indicated that the annual average edge-of-loading area MC concentrations were predicted to be negligible.

Although the MC concentrations were predicted below levels of potential concern, the Marine Corps conducted field sampling activities at off-range surface water and groundwater locations at MCB Camp Lejeune. The field sampling was conducted to

determine whether actual MC migration had occurred as well as provide a general, although not direct, confirmation of the modeling results.

SAR Assessments

The small arms ranges were qualitatively assessed using the Small Arms Range Assessment Protocol (SARAP) (HQMC, 2006). This protocol evaluates each range using factors such as range design and layout, physical and chemical characteristics of range area, range use, maintenance practices, and potential pathways and receptors. The results of the assessments are provided in Table ES-2.

Table ES-2
Small Arms Range Assessments

Range Name	Surface Water Environmental Concern	Groundwater Environmental Concern
A-1	Moderate	Moderate
B-12	Moderate	Moderate
D-29A and B	Moderate	Moderate
D-30	High [a]	High
F-11A and F-11B	Moderate	Moderate
F-18	Moderate	High
I-1	Minimal	Moderate
MAC 1 – 5	Moderate	Moderate
SR-11	Minimal	Moderate
Stone Bay Complex Range		
o Dodge City	High [a]	Moderate
o Multipurpose Range	Moderate	Moderate
o Mechanical Range	Moderate	Moderate
o Non-Mechanical Range	Moderate	Moderate
o Alpha Range	High [a]	Moderate
o Bravo Range	High [a]	Moderate
o Charlie Range	High [a]	Moderate
o Hathcock Range	High [a]	Moderate

[a] Ranking increased based on professional judgment

Professional judgment was used to increase some of the surface water environmental concern rankings because wetlands or surface water bodies are located in the surface danger zone.

The University of South Carolina-Beaufort is currently conducting a study concerning the fate of lead in the environment at Marine Corps bases, including MCB Camp Lejeune. This data, when available, may be used to refine the small arms range assessments.

Field Sampling Activities

The initial assessment of the screening-level surface water and groundwater modeling predicted low levels of explosives potentially present within the surface water. In addition, the further groundwater assessment was necessary due to unknown subsurface aquifer connections. As a result, groundwater and surface water sampling was recommended. Sampling events were conducted between November 2007 and April 2008. The *Final Field Sampling Report* contains additional details from the sampling events (Appendix D).

Field activities included sampling of off-range surface water and groundwater.

- Seven surface water locations, downgradient of operational ranges
- Raw ground water from nine operational drinking water supply wells, screened in the Castle Hayne aquifer
- Groundwater from 16 monitoring wells, screened in the Surficial aquifer
- Surface water at one background location, upgradient of operational ranges near K-2 Impact Area

Sample locations were selected based on modeling results for high explosives (HE) at mixed use ranges, not on the results of the SARAP.

All samples were analyzed for the full suite of explosives, including perchlorate, and total and dissolved lead. Groundwater samples were also analyzed for inorganic ions to determine its chemical characteristics. The sampling included more constituents than were modeled during the REVA process.

Lead was included in the field sampling as a proactive measure at locations already selected on the basis of predicted HE concentrations. Lead is also known to be a consistent of HE munitions; therefore, its inclusion was expected to provide an indicator of possible heavy metal constituents.

Field Sampling/Activities Results

The analytical results were compared to DoD Range and Munitions Use (RMUS) Subcommittee screening values, which were developed from existing USEPA or state guidelines to promote consistency across the services' operational range assessment programs. The results were also compared the North Carolina NCAC 2L surface water and groundwater standards.

Surface Water Sampling

None of the surface water samples had detectable concentrations of explosives. Two samples had perchlorate detected at concentrations above the method detection limit (MDL) but below the laboratory reporting limit (0.016 and 0.014 µg/L, respectively).

However, the perchlorate concentrations detected were well below the RMUS surface water screening value of 9,300 µg/L. Total lead was detected in six samples at concentrations above the MDL but below the laboratory reporting limit. The dissolved lead concentrations were all nondetectable. The RMUS surface water screening value for lead is 2.5 µg/L, but is only applicable to dissolved lead. All the analytical results for both total and dissolved lead were below this screening value.

Groundwater Sampling

None of the groundwater samples had detectable concentrations of explosives. Perchlorate was detected above the laboratory reporting limit in four samples at concentrations between 0.14 and 0.31 µg/L. All the perchlorate concentrations detected were well below the established RMUS human drinking water screening value of 15 µg/L. Total lead was detected in two samples at concentrations of 5.7 and 100 µg/L, respectively. The 100 µg/L value was abnormally high and was suspected to be erroneous. A second sample collected from the well by MCB Camp Lejeune personnel on January 9, 2008, had less than 3 µg/L of total lead and less than 3 µg/L of dissolved lead, which are below the RMUS human drinking water screening value of 15 µg/L. Both wells were resampled during the April 2008 sampling event and had concentrations of total lead of 1.5 and 0.49 J, respectively (J – estimated value, the analyte was positively identified, the quantization is an estimation).All total and dissolved lead concentrations were below the RMUS human drinking water screening value of 15 µg/L.

Hydraulic Test

A hydraulic test was conducted in the area surrounding the G-10 Impact Area. The hydraulic test was performed by shutting down selected MCB Camp Lejeune water supply wells and measuring the corresponding effect in water levels in the monitoring wells in the Surficial aquifer and water supply wells in the Castle Hayne aquifer. In addition to the hydraulic test, groundwater samples collected were also analyzed for inorganic ions to determine the chemical makeup of the groundwater at sampled locations. These geochemical analytical results and the hydraulic test helped to assess the hydraulic connection between the Surficial aquifer and the Castle Hayne aquifer.

Based on the hydraulic test results and the geochemical difference between the groundwater from the Surficial and Castle Hayne aquifers, there does not appear to be a significant hydraulic connection between the Surficial and Castle Hayne aquifers near the G-10 MC loading area. There are no wells screened in the Castle Hayne aquifer near the K-2 MC loading area. The results of the hydraulic test indicate that there is a minimal possibility of MC migration from the Surficial aquifer to the Castle Hayne aquifer near the G-10 Impact Area.

Monitoring Well Installation

During August 4-11, 2008, a deep monitoring well was installed at the request of the installation and HQMC in order to evaluate the groundwater in the Castle Hayne aquifer in the northeast side of the G-10 Impact Area. The monitoring well was sampled for the full explosive suite, perchlorate, lead, and inorganic ions on October 9, 2008. There were no detections of explosives, perchlorate, or lead.

Conclusions and Further Actions

The REVA field sampling results for MCB Camp Lejeune indicate that perchlorate and lead were detected more frequently than explosives at the locations sampled. No detections of MC, lead, or perchlorate exceeded DoD RMUS screening values for the identified receptors. The hydraulic test conducted indicated that there does not appear to be a significant hydraulic connection between the Surficial and Castle Hayne aquifers near G-10.

The field sampling effort was a continuation of the baseline assessment but was not intended to be a direct confirmation of the modeling results. Nevertheless, this REVA sampling provides a general confirmation of modeling results, which were based on conservative assumptions. Sampling results may be considered a conservative snapshot of off-range MC migration at the time they were collected.

Trace concentrations of MC were detected below screening values identified by DoD to assess impact to human health and environment. Nevertheless, to ensure the sustainability of MCB Camp Lejeune operational ranges, options for further management and assessment are being considered for high priority ranges identified through this REVA baseline assessment. In addition, subsequent vulnerability assessments will be conducted on operational ranges at MCB Camp Lejeune on a five-year cycle or when significant changes are made to existing operational ranges that potentially affect the determinations made during this baseline assessment, as described in the *REVA Reference Manual* (HQMC, 2006).

Based on the assessment results presented in this report, no immediate environmental concern of MC migration to off-range areas was identified; however, further actions may be evaluated to continue to mitigate the possibility of MC migration from operational ranges at MCB Camp Lejeune to ensure future range sustainability.

1. Introduction

1.1. Purpose

The United States (U.S.) Marine Corps (Marine Corps) Range Environmental Vulnerability Assessment (REVA) program meets the requirements of the current Department of Defense (DoD) Directive 4715.11 *Environmental and Explosives Safety Management on Operational* Ranges within the United States and DoD Instruction 4715.14 *Operational Range Assessments*.

The REVA program is a proactive and comprehensive program designed to support the Marine Corp's environmental range sustainment initiative. Operational ranges across the Marine Corps are being assessed to identify areas and activities that are subject to possible impacts from external influences, as well as to determine whether a release or substantial threat of a release of munitions constituents (MC) from operational range or range complex areas to off-range areas creates an unacceptable risk to human health and/or the environment. This is accomplished through a baseline assessment of operational range areas and, where applicable, the use of both conceptual and quantitative screening-level fate and transport models of indicator MC based upon site-specific environmental conditions at the operational ranges and training areas.

In recent years, the DoD and the Marine Corps have experienced a dramatic increase in encroachment pressures associated with operational range activities. In some instances, encroachment issues have impacted training. The early identification of encroachment issues will allow the Marine Corps installation to minimize external pressures, thereby minimizing potential impacts to training. Operational ranges and maneuver areas are essential to Marine Corps training; therefore, sustaining these areas for use is critical to mission readiness.

REVA is a component of the Marine Corps Range Sustainment Program. The operational range assessments conducted through REVA enhance the Marine Corps' ability to prevent or respond to a release or substantial threat of a release of MC of concern from an operational range or range complex to off-range areas. The assessments also provide information to support operational range sustainment.

This report presents the assessment results for the operational ranges and training areas at Marine Corps Base (MCB) Camp Lejeune and Marine Corps Air Station (MCAS) New River, North Carolina (NC), collectively referred to as MCB Camp Lejeune throughout the remainder of this document (Figure 1-1). This report is the first comprehensive report

of MC associated with the operational ranges at MCB Camp Lejeune and, as such, serves as the baseline of environmental conditions of the ranges.

1.2. Scope and Applicability

The scope of the REVA program includes Marine Corps operational ranges located within the United States and overseas. Operational ranges (as defined in 10 United States Code 101(e)(3)) include, but are not limited to, fixed ranges, live-fire maneuver areas, small arms ranges (SARs), buffer areas, and training areas where military munitions are known or suspected to be used currently or to have been used historically. The presence of other than operational ranges is noted where applicable, but such ranges are not assessed under the REVA program. These other than operational ranges are being addressed under the Marine Corps' Munitions Response Program.

Site-specific environmental conditions and MC loading rates are used to develop conceptual site models (CSMs) to assess whether the potential exists for a release or substantial threat of a release of MC from an operational range or range complex area to an off-range area. Where applicable, screening-level fate and transport models are also used to conservatively estimate the concentrations of MC potentially migrating to off-range exposure points. Exposure pathways considered in the REVA process include consumption of surface water and groundwater for off-range human and threatened and endangered (T/E) ecological receptors, as described in the *REVA Reference Manual* (HQMC, 2006). Other off-range exposures scenarios (e.g., soil ingestion, incidental dermal contact, bioaccumulation, and food chain exposure) currently are not considered in the REVA process.

The MC evaluated in the REVA program include trinitrotoluene (TNT), cyclotetramethylene tetranitramine (HMX), cyclotrimethylene trinitramine (RDX), and perchlorate. TNT, HMX, and RDX are considered to be indicator MC. Studies have shown that they are detected in a high percentage of samples containing MC due to their chemical stability within the environment. They are common high explosives used in a wide variety of military munitions. Perchlorate is a component of the solid propellants used in some military munitions. Perchlorate is also considered an indicator MC, as its high solubility, low sorption potential, and low natural degradation rate make the compound highly mobile in the environment. Additional information pertaining to the physical and chemical characteristics of the REVA indicator compounds is provided in the *REVA Reference Manual* (HQMC, 2006).

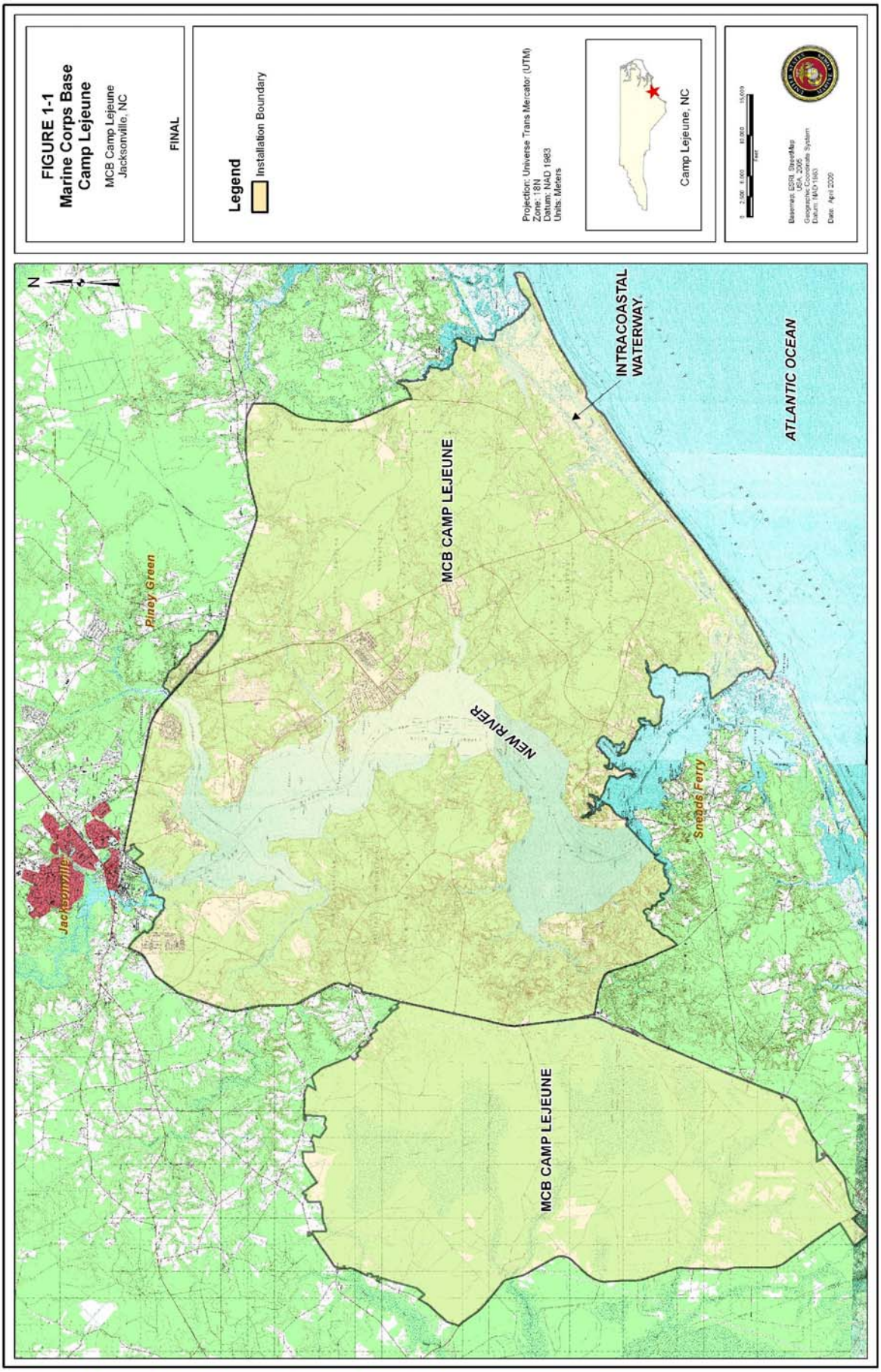


FIGURE 1-1
Marine Corps Base
Camp Lejeune
MCB Camp Lejeune
Jacksonville, NC
FINAL
Legend
Installation Boundary
Projection: Universe Trans Mercator (UTM)
Zone: 18N
Datum: NAD 1983
Units: Meters
Camp Lejeune, NC
Basemap: ESRI, StreetMap USA, 2006
Geographic Coordinate System
Datum: NAD 1983
Date: April 2020
N
Jacksonville
Piney Green
MCB CAMP LEJEUNE
NEW RIVER
INTRACOASTAL WATERWAY
ATLANTIC OCEAN
Sneads Ferry
MCB CAMP LEJEUNE

The primary MC of concern at SARs is lead because it is the most prevalent (by weight) potentially hazardous constituent associated with small arms ammunition. The mobility of lead in the environment is highly variable depending on site-specific conditions; modeling of lead would require site-specific geochemical data that generally are unavailable during a baseline assessment. Therefore, instead of modeling lead transport, active SARs at the installation are qualitatively reviewed and assessed to identify factors that influence the potential for lead migration. These factors include a range's design and layout, the physical and environmental conditions of the area, and current and past operation and maintenance practices. The amount of lead that has been loaded to the operational ranges has also been determined.

The processes and assumptions used in estimating the potential MC deposited onto the identified MC loading areas within the operational ranges are included in Section 3. The analysis methods and assumptions for each medium (surface water and groundwater) are discussed in Sections 5 and 6, respectively.

This report addresses the data collection efforts, the CSM, the results of screening-level fate and transport modeling, and results of the field sampling effort, which was also conducted as part of the assessment. The assessment process is outlined in the *REVA Reference Manual*, which includes a detailed description of the fate and transport models selected for the baseline environmental operational range assessments, the data needed to run those models, and recommended sources for data. In addition, the *REVA Reference Manual* provides a detailed description of the REVA MC Loading Rate Calculator (HQMC, 2006).

This baseline environmental range assessment report presents the conditions of the operational ranges at the time the assessment was conducted. The baseline environmental range assessment was performed using available data and personnel interviews and is supplemented with information from external sources, including reports and documentation.

1.3. Report Organization

This REVA baseline environmental range assessment report for MCB Camp Lejeune is organized into the following sections:

Section 1 – Introduction

Section 2 – Summary of Data Collection Effort

Section 3 – Munitions Constituents Loading Rates and Assumptions

Section 4 – Conceptual Site Model

Section 5 – Surface Water Analysis Methods and Assumptions

Section 6 – Groundwater Analysis Methods and Assumptions

Section 7 – Operational Range Training Areas

Section 8 – Small Arms Range Assessments

Section 9 – Field Data Collection Results

Section 10 – References

2. Summary of Data Collections Effort

Data required for the operational range assessments were obtained from Headquarters Marine Corps, the installation during a site visit by the REVA assessment team, and external data sources. External data sources include reports and online information from organizations such as the U.S. Geological Survey (USGS) and the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service. Data obtained from Headquarters Marine Corps and the installation included various documents and reports conducted for the installation (e.g., master plans, Archive Search Report [ASR], Preliminary Range Assessment [PRA] and Installation Restoration Program [IRP] reports).

The REVA assessment team conducted a site visit from July 26 through 29, 2006. The site visit team reviewed various data repositories and conducted interviews with installation personnel from the offices listed below.

- Natural Resources and Environmental Affairs Office
- Tactical Air Crew Combat Training System (range management and central scheduling)
- Range Operations and Control
- Explosive Ordnance Disposal (EOD)
- SAR
- Facilities
- Geographic Information System (GIS)
- Community Planning and Liaison
- Air Traffic Control

The REVA assessment team was accompanied by Headquarters Marine Corps and Training and Education Command personnel during the site visit. The REVA team also conducted several field sampling efforts, including groundwater and surface water sampling during November 10-11, 2007, additional groundwater sampling during April 27-30, 2008, a hydraulic assessment test during December 10-13, 2007, and the installation of a monitoring well during August 4-11, 2008.

3. Munitions Constituents Loading Rates and Assumptions

Fate and transport screening analysis and modeling requires an estimation of the amount of indicator MC deposited on operational ranges over time in order to determine if there is a release or substantial threat of a release of MC. Within REVA, this deposition is referred to as MC loading. Operational range usage, boundaries, and other characteristics typically change over time; therefore, an analysis of their history must be performed to map the affected areas over time and to calculate the historical and current MC loading.

Operational ranges are often subdivided into one or more MC loading areas. MC loading areas can include current and historical munitions use areas within the operational ranges, such as bomb targets, firing points, and training and maneuver areas. The MC loading for the operational ranges is then estimated separately for each MC loading area within that operational range and for each REVA indicator MC. For the purposes of REVA, the MC loading estimate is the average mass deposited annually in the defined MC loading area for the duration of the period that the operational range activities generating the MC loading were conducted.

Assumptions are made throughout the MC loading analysis process to estimate the spatial distribution of the MC on individual MC loading areas. In areas that do not have fixed or known targets (e.g., training and maneuver areas where military munitions such as pyrotechnics are being or have been used sporadically throughout the area), the MC loading is assumed to be evenly distributed across the area. In other cases, the MC loading is assumed to be concentrated into smaller discrete MC loading areas within the operational range (such as individual targets). Section 3.5 includes figures that depict the MC loading areas for MCB Camp Lejeune and also describes the assumptions that were made for each operational range that was assessed.

3.1. MC Loading Process

The MC loading was estimated based on mass-loading principles. Studies have shown that MC are deposited on the operational range through low- and high-order detonations and can leach from corroded unexploded ordnance (UXO). These processes are presented in the equation below:

Total MC loading = MC (low-order) + MC (high-order) + MC (UXO)

Where: MC (low-order) is the amount of MC deposited as a result of low-order detonations.

MC (high-order) is the amount of MC deposited as a result of high-order detonations.

MC (UXO) is the amount of MC deposited as a result of breached UXO.

Studies conducted by the DoD have shown that the MC remaining from high-order detonations are much less significant than the amount of MC deposited from low-order detonations. Corrosion studies conducted by the U.S. Army have shown that it can take a long time for UXO to corrode. Although MC remaining from low-order detonations is the most significant contributor to the MC loading estimates, REVA accounts for MC contributed by all three of these potential sources.

MC loading estimates for low-order detonations, high-order detonations, and UXO for the MC loading areas associated with each operational range are estimated using the equations below:

MC (low-order) = (quantity of military munitions expended) x (low-order rate) x (amount of residual remaining from a low-order detonation)

MC (high-order) = (quantity of military munitions expended) x (high-order rate) x (amount of residual remaining from a high-order detonation)

MC (UXO) = (quantity of military munitions expended) x (dud rate) x (amount of residual exposed as a result of damage to UXO casings)

Dud rate and low-order rate data for REVA were estimated based upon the July 2000 study performed by the U.S. Army Technical Center for Explosives, *Safety Report of Finding for Study of Ammunition Dud and Low-order Detonation Rates*. Dud and low-order rates for military munitions in this report were presented and made available according to the military munitions DoD Identification Code (DoDIC). For the DoDICs with no available dud or low-order rate, the default values listed in the referenced report of 3.45% (dud rate) and 0.028% (low-order rate) were used. In addition, for the purposes of REVA, it was assumed that the amounts of residual energetics (MC) remaining after a low-order detonation and a high-order detonation were 50% and 0.1%, respectively. These numbers are consistent with those used in the U.S. Navy's Range Sustainability Environmental Program Assessment.

The primary source used to provide the types and amounts of energetic fillers associated with the military munitions was the Defense Ammunition Center's Munitions Items Disposition Action System (MIDAS)[1] Web site. In addition to MIDAS, other sources used for MC data include the ORDDATA II software (Enhanced International Definer's

[1] Data are retrieved from MIDAS by performing a search for the MC, which produces a list of military munitions with their respective amounts of MC. The list of military munitions is then evaluated, as more than one matching National Stock Number is often listed for a named item, and the highest and lowest MC quantities are captured and averaged for REVA MC loading estimate calculations.

Guide to UXO Identification, Recovery and Disposal; Version 1.0, 1999) and various ordnance technical manuals. In cases where specific military munitions use data were unavailable, the military munitions types were selected on the basis of common military munitions used during the periods of use of the operational range.

3.2. Expenditure Data

Range Control maintains military munitions expenditure data for the operational ranges managed by the installation. Current military munitions expenditures were obtained from Range Control in hard copy format for the period from 1991 through 2005. However, the format, organization, and volume of material made it difficult to perform effective evaluation and analysis of the data. Range Control confirmed that these data are the same as those provided to the Environmental Affairs Division each year for Toxics Release Inventory (TRI) reporting requirements. Therefore, based on the availability and electronic format of the TRI data, the 2001-2004 operational range expenditure-based TRI data were selected as the basis for the military munitions expenditure analysis. Historical expenditure data were estimated back to 1976 based on extrapolation of the 2001-2004 electronic expenditure data. For operational ranges and historical use areas within operational ranges that were used prior to 1976, discussions with Range Control determined that the military munitions used should reflect those military munitions indicated within MCB Camp Lejeune's ASR and PRA[2]. Although the military munitions types for the periods of operation prior to 1976 were obtained from the ASR and PRA, the quantification of these items was based on quantities of similar items or groups of items (i.e., mortars, projectiles, or bombs) in the 2001-2004 expenditure data. Therefore, all military munitions expenditures used in this assessment are based on the quantities extracted from the 2001-2004 data and adjusted for changes in types of military munitions used.

3.3. REVA MC Loading Rate Calculator

The REVA MC Loading Rate Calculator provides an automated method to calculate the overall loading of the operational range based upon the military munitions expenditure estimating methods discussed above. The MC Loading Rate Calculator estimates an average expenditure rate that is applied to each year that the operational range is known or suspected to have been operational where expenditure data are missing or incomplete.

The MC Loading Rate Calculator also applies values for the data discussed earlier (dud rate, low-order rate, high-order rate, and residual amount of MC remaining) and physical size of the MC loading area (square meters [m^2]) so that the estimated MC concentrations are presented in the units required for the fate and transport analysis (kilograms per square meter [kg/m^2]). Additionally, the calculator applies a Training Factor to account

[2] ASR and PRA were conducted by the U.S. Army Corps of Engineers to support the Military Munitions Response Program (MMRP).

for fluctuations in training due to world events, such as conflicts and wars, during which there was an increase or decrease in training. The Training Factor is discussed in more detail below.

In the event that the documented military munitions expenditure data do not result in an MC loading to a primary MC loading area or range training area then the mass of that particular MC is considered zero. This is presented in the MC loading tables as not applicable (NA).

3.4. Training Factor

Historically, military training operations have been affected by conflicts and wars over time. This effect usually resulted in an increase in training prior to a conflict or war, with a tapering off of training during the event, followed by an increase in training again toward the end of the event, with a subsequent decrease again to a nonevent level. REVA attempted to account for this training effect by developing a training timeline of significant military conflicts and wars from 1914 through present day. This timeline accounts for the following:

- World War I
- World War II (WWII)
- The Cold War
- The Korean War
- The Vietnam War
- The Persian Gulf War
- Afghanistan
- Iraq

Subject matter experts within the Marine Corps were queried to establish time periods of increased training throughout history. The training analysis resulted in the development of a baseline level of training, as well as four periods that increase the MC loading rate for that period by a Training Factor. The periods identified and their associated Training Factors follow:

- Period A: 1914-1924 (baseline + 40%)
- Period B: 1925-1937 (baseline)
- Period C: 1938-1976 (baseline + 50%)
- Period D: 1977-1988 (baseline + 20%)
- Period E: 1989-present (baseline + 50%)

The baseline expenditure rate is applied to each year the operational range was in use. The MC Loading Rate Calculator automatically applies the Training Factor adjustments according to time period to estimate the MC loading rates for each year the operational range is known or suspected to have been in use. The REVA MC Loading Rate Calculator and its Training Factor are explained in more detail in the *REVA Reference Manual* (HQMC, 2006).

3.5. MC Loading at MCB Camp Lejeune

The PRA for MCB Camp Lejeune identified 216 historical and operational range areas which were cross-referenced[3] with the 109 operational ranges and training areas identified within the 2003 National Defense Authorization Act (NDAA) Section 366 Report for operational ranges. The 109 operational ranges in the 2003 NDAA Section 366 Report include maneuver training areas, impact areas, and SARs, each of which was evaluated for this REVA baseline assessment. Operational water range areas were also noted; however, since other operational range areas were determined to be of greater potential of concern, these water ranges are not further discussed in this report. The MMRP inventory identified 20 closed range areas and one transferred range area that are not within current operational range boundaries (as defined by the Section 366 Report), which also were not evaluated under this REVA baseline assessment. The 109 operational ranges are identified in Table 3-1.

[3] Cross-reference was based on range name only since NDAA Section 366 Report maps were unavailable. Those ranges whose names were the same or similar were assumed to be the same. Therefore, the completeness of this cross-reference is limited.

Table 3-1: Section 366 Report Operational Ranges and REVA MC Loading Area Cross-Reference

NDAA Section 366 Report Range		Corresponding REVA MC Loading Area							Notes
Name	Size (Acres)	Name	Status	Size (Acres)	Begin Use	End Use	Overall Priority	Description of Use	
Artillery Range	85	Not applicable (NA)	NA	NA	NA	NA	NA	NA	Not modeled; unidentified location
Bear Island, Brown's Island Bombing Target	980	Brown's Island[a]	Operational	1038	1945	Present	Low	Artillery impact area	Not modeled[b]
		Rocket Range 2	Historical	14	1945	1947	Low	Air-to-ground rocketry	Not modeled[b]
N-1/BT-3 Impact Area and Danger Zone	33580	Brown's Island	Historical	1038	1945	1976	Low	Artillery impact area	Not modeled[b]
G-10 Impact Area	4967	G-10 Impact Area	Operational	1349	1953	Present	High	Multi-use impact area	Modeled; see Section 7.1.
GSR Impact Area SA	1249	NA	Operational	NA	NA	NA	NA	Training, maneuver, and impact area	NA
GSR Impact Area SB	1129	NA	Operational	NA	NA	NA	NA	Training, maneuver, and impact area	NA
GSR Impact Area SC	1202	NA	Operational	NA	NA	NA	NA	Training, maneuver, and impact area	NA
GSR Impact Area SD	1456	NA	Operational	NA	NA	NA	NA	Training, maneuver, and impact area	NA
		NA	Operational	NA	NA	NA	NA	Training, maneuver, and impact area	NA
GSR Impact Area SE	1686	NA	Operational	NA	NA	NA	NA	Training, maneuver, and impact area	NA
GSR Impact Area SF	4102	NA	Operational	NA	NA	NA	NA	Training, maneuver, and impact area	NA
GSR Impact Area SG	1743	NA	Operational	NA	NA	NA	NA	Training, maneuver, and impact area	NA
GSR Impact Area SH	1077	NA	Operational	NA	NA	NA	NA	Training, maneuver, and impact area	NA
GSR Impact Area SI	3294	NA	Operational	NA	NA	NA	NA	Training, maneuver, and impact area	NA
GSR Impact Area SJ	2368	NA	Operational	NA	NA	NA	NA	Training, maneuver, and impact area	NA
		NA	Operational	NA	NA	NA	NA	Training, maneuver, and impact area	NA
GSR Impact Area SK	2563	NA	Operational	NA	NA	NA	NA	Training, maneuver, and impact area	NA
GSR Impact Area SL	5312	NA	Operational	NA	NA	NA	NA	Training, maneuver, and impact area	NA
GSR Impact Area SM	1107	NA	Operational	NA	NA	NA	NA	Training, maneuver, and impact area	NA
GSR Impact Area SN	1584	NA	Operational	NA	NA	NA	NA	Training, maneuver, and impact area	NA
GSR Impact Area SO	1658	NA	Operational	NA	NA	NA	NA	Training, maneuver, and impact area	NA
		NA	Operational	NA	NA	NA	NA	Training, maneuver, and impact area	NA
GSR Impact Area SP	982	NA	Operational	NA	NA	NA	NA	Training, maneuver, and impact area	NA
GSR Impact Area SQ	560	NA	Operational	NA	NA	NA	NA	Training, maneuver, and impact area	NA
GSR Impact Area SR	990	NA	Operational	NA	NA	NA	NA	Training, maneuver, and impact area	NA
GSR Impact Area ST	2422	NA	Operational	NA	NA	NA	NA	Training, maneuver, and impact area	NA
GSR Impact Area SU	1447	NA	Operational	NA	NA	NA	NA	Training, maneuver, and impact area	NA
GSR Impact Area SV	2459	NA	Operational	NA	NA	NA	NA	Training, maneuver, and impact area	NA
GSR Impact Area SW	3250	NA	Operational	NA	NA	NA	NA	Training, maneuver, and impact area	NA
K-2 Impact Area	3237	K-2 Impact Area	Operational	870	1950	Present	Medium	Multiuse impact area	Modeled; see Section 7.2.
Maneuver Training Area AA	209	NA	NA	NA	NA	NA	NA	NA	Not modeled[c]
Maneuver Training Area AB	536	NA	NA	NA	NA	NA	NA	NA	Not modeled[c]
Maneuver Training Area AC	618	NA	NA	NA	NA	NA	NA	NA	Not modeled[c]
		A-1	Operational	NA	NA	NA	NA	Small arms training	Not modeled[c]; small arms military munitions use only
Maneuver Training Area AD	313	NA	NA	NA	NA	NA	NA	NA	Not modeled[c]
New River Live Ammo Indoctrination Course	12	NA	NA	NA	NA	NA	NA	NA	Not modeled; unidentified location
New River Water Range Areas	2500	NA	NA	NA	NA	NA	NA	NA	Not modeled; unidentified location
Range D-29A	2	D-29	Operational	NA	NA	NA	NA	Small arms training	Not modeled[c]; small arms military munitions use only

NDAA Section 366 Report Range		Corresponding REVA MC Loading Area							Notes
Name	Size (Acres)	Name	Status	Size (Acres)	Begin Use	End Use	Overall Priority	Description of Use	
Range D-30	2	D-30	Operational	NA	NA	NA	NA	Small arms training	Not modeled[c]; small arms military munitions use only
Tactical Maneuver Training Area BC	536	NA	NA	NA	NA	NA	NA	NA	Not modeled[c]
		B-12	Operational	NA	NA	NA	NA	Small arms training	Not modeled[c]; small arms military munitions use only
Tactical Maneuver Training Area BD	394	NA	NA	NA	NA	NA	NA	NA	Not modeled[c]
Tactical Maneuver Training Area CA	874	NA	NA	NA	NA	NA	NA	NA	Not modeled[c]
Tactical Maneuver Training Area CB	821	NA	NA	NA	NA	NA	NA	NA	Not modeled[c]
Tactical Maneuver Training Area DA	483	NA	NA	NA	NA	NA	NA	NA	Not modeled[c]
Tactical Maneuver Training Area DB	389	NA	NA	NA	NA	NA	NA	NA	Not modeled[c]
Tactical Maneuver Training Area DC	357	NA	NA	NA	NA	NA	NA	NA	Not modeled[c]
Tactical Maneuver Training Area DD	265	NA	NA	NA	NA	NA	NA	NA	Not modeled[c]
Tactical Maneuver Training Area DE	295	NA	NA	NA	NA	NA	NA	NA	Not modeled[c]
Tactical Maneuver Training Area DF	478	NA	NA	NA	NA	NA	NA	NA	Not modeled[c]
Tactical Maneuver Training Area E	852	NA	NA	NA	NA	NA	NA	NA	Not modeled[c]
Tactical Maneuver Training Area FA	1081	Maneuver Training Areas - F, L, Q, and R	Operational	19036	1941	Present	Low	Maneuver training area	Not modeled[b]
		F-5	Operational	19	1972	Present	High		Modeled; see Section 7.3.
		F-2	Operational	19	1972	Present	Low	NA	Not modeled[b]
		F-2 Field Firing Range	Historical	19	1950	1976	High		Modeled; see Section 7.3.
		Musketry Range A	Historical	19	1942	1947	High		Modeled; see Section 7.3.
Tactical Maneuver Training Area FB	922	Maneuver Training Areas - F, L, Q, and R	Operational	19036	1941	Present	Low	Maneuver training area	Not modeled[b]
		F-4	Operational	NA	NA	NA	Low	Small arms training with pyrotechnic use	Not modeled[b]; small arms military munitions use only
		F-1 Field Firing Range	Historical	48	1950	1961	Medium		Not modeled[b]
		F-14 Field Firing Range	Historical	63	1950	1961	High		Modeled; see Section 7.4.
Tactical Maneuver Training Area FC	1982	Maneuver Training Areas - F, L, Q, and R	Operational	19036	1941	Present	Low	Maneuver training area	Not modeled[b]
		Military Operations in Urban Terrain (MOUT) Assault Course (MAC) 1-5	Operational	NA	NA	NA	NA	Small arms training	Not modeled[b]; small arms military munitions use only
		MOUT	Operational	NA	NA	NA	Low	Urban assault training	Not modeled[b]
Tactical Maneuver Training Area FD	1065	Maneuver Training Areas - F, L, Q, and R	Operational	19036	1941	Present	Low	Maneuver training area	Not modeled[b]
		F-6	Operational	39	1972	Present	High		Modeled; see Section 7.5.
Tactical Maneuver Training Area FE	922	Maneuver Training Areas - F, L, Q, and R	Operational	19036	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area FF	1021	Maneuver Training Areas - F, L, Q, and R	Operational	19036	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area FG	2169	Maneuver Training Areas - F, L, Q, and R	Operational	19036	1941	Present	Low	Maneuver training area	Not modeled[b]
		F-11 (A and B)	Operational	NA	NA	NA	Low	Small arms training with pyrotechnic use	Not modeled[b]; small arms military munitions use only
		F-1850CAL	Operational	NA	NA	NA	Medium		Not modeled[b]
		Engineer Training Area-3	Operational	0.2	1994	Present	Low	ETA	Not modeled[d]
		F-12 Field Firing Range	Historical	44	1950	1985	High		Recommended for modeling[e]
Tactical Maneuver Training Area GA	767	Maneuver Training Areas - G and I	Operational	13565	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area GB	536	Maneuver Training Areas - G and I	Operational	13565	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area GC	623	Maneuver Training Areas - G and I	Operational	13565	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area GD	1102	Maneuver Training Areas - G and I	Operational	13565	1941	Present	Low	Maneuver training area	Not modeled[b]
		EOD-1	Operational	0.2	1994	Present	Low	EOD training area	Not modeled[d]
Tactical Maneuver Training Area GE	507	Maneuver Training Areas - G and I	Operational	13565	1941	Present	Low	Maneuver training area	Not modeled[b]

NDAA Section 366 Report Range		Corresponding REVA MC Loading Area							Notes
Name	Size (Acres)	Name	Status	Size (Acres)	Begin Use	End Use	Overall Priority	Description of Use	
Tactical Maneuver Training Area GF	644	Maneuver Training Areas - G and I	Operational	13565	1941	Present	Low	Maneuver training area	Not modeled[b]
		ETA-4	Operational	0.2	1994	Present	Low	ETA	Not modeled[d]
Tactical Maneuver Training Area GG	1746	Maneuver Training Areas - G and I	Operational	13565	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area GH	931	Maneuver Training Areas - G and I	Operational	13565	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area GI	596	Maneuver Training Areas - G and I	Operational	13565	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area HA	910	Maneuver Training Areas - H, K and M	Operational	18381	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area HB	1542	Maneuver Training Areas - H, K and M	Operational	18381	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area HC	860	Maneuver Training Areas - H, K and M	Operational	18381	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area HD	938	Maneuver Training Areas - H, K and M	Operational	18381	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area HE	633	Maneuver Training Areas - H, K and M	Operational	18381	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area HF	1067	Maneuver Training Areas - H, K and M	Operational	18381	1941	Present	Low	Maneuver training area	Not modeled[b]
		Combat Town	Operational	6	1976	Present	Medium	Urban combat training	Modeled as indicator of Medium sites; see Section 7.8.
Tactical Maneuver Training Area HG	567	Maneuver Training Areas - H, K and M	Operational	18381	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area HH	744	Maneuver Training Areas - H, K and M	Operational	18381	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area IA	1067	Maneuver Training Areas - G and I	Operational	13565	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area IB	871	Maneuver Training Areas - G and I	Operational	13565	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area IC	911	Maneuver Training Areas - G and I	Operational	13565	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area ID	1124	Maneuver Training Areas - G and I	Operational	13565	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area IE	1438	Maneuver Training Areas - G and I	Operational	13565	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area IF	1445	Maneuver Training Areas - G and I	Operational	13565	1941	Present	Low	Maneuver training area	Not modeled[b]
		ETA-2	Operational	0.2	1994	Present	Low	ETA	Not modeled[d]
Tactical Maneuver Training Area IG	543	Maneuver Training Areas - G and I	Operational	13565	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area JA	329	NA	NA	NA	NA	NA	NA	NA	Not modeled[c]
Tactical Maneuver Training Area JB	268	NA	NA	NA	NA	NA	NA	NA	Not modeled[c]
Tactical Maneuver Training Area JC	274	NA	NA	NA	NA	NA	NA	NA	Not modeled[c]
Tactical Maneuver Training Area JD	246	NA	NA	NA	NA	NA	NA	NA	Not modeled[c]
Tactical Maneuver Training Area KA	634	Maneuver Training Areas - H, K and M	Operational	18381	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area KB	1103	Maneuver Training Areas - H, K and M	Operational	18381	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area KC	1010	Maneuver Training Areas - H, K and M	Operational	18381	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area KD	432	Maneuver Training Areas - H, K and M	Operational	18381	1941	Present	Low	Maneuver training area	Not modeled[b]
		EOD-2	Operational	0.2	1970	Present	Low	EOD training area	Not modeled[d]
		ETA-5	Operational	0.2	1994	Present	Low	ETA	Not modeled[d]
Tactical Maneuver Training Area L (Rifle Range)	665	Maneuver Training Areas - F, L, Q, and R	Operational	19036	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area LA	1443	Maneuver Training Areas - F, L, Q, and R	Operational	19036	1941	Present	Low	Maneuver training area	Not modeled[b]
		L-Ranges	Operational	706	1957	Present	High		Modeled; see Section 7.7.
Tactical Maneuver Training Area LB	732	Maneuver Training Areas - F, L, Q, and R	Operational	19036	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area LC	1256	Maneuver Training Areas - F, L, Q, and R	Operational	19036	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area LD	348	Maneuver Training Areas - F, L, Q, and R	Operational	19036	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area LE	818	Maneuver Training Areas - F, L, Q, and R	Operational	19036	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area LF	1608	Maneuver Training Areas - F, L, Q, and R	Operational	19036	1941	Present	Low	Maneuver training area	Not modeled[b]
		L-Impact Area	Historical	66	1951	1962	High	Artillery impact area	Modeled; see Section 7.6.

NDAA Section 366 Report Range		Corresponding REVA MC Loading Area							Notes
Name	Size (Acres)	Name	Status	Size (Acres)	Begin Use	End Use	Overall Priority	Description of Use	
Tactical Maneuver Training Area LG	229	Maneuver Training Areas - F, L, Q, and R	Operational	19036	1941	Present	Low	Maneuver training area	Not modeled[b]
		Special Operations Training Group (SOTG) North	Operational	3	1985	Present	Low	Special operations training	Not modeled[b]
		SOTG South	Operational	4	1985	Present	Low	Special operations training	Not modeled[b]
Tactical Maneuver Training Area MA	980	Maneuver Training Areas - H, K and M	Operational	18381	1941	Present	Low	Maneuver training area	Not modeled[b]
		M-8 Assault of a Fortified Position Range	Historical	0.3	1958	1961	High		Not modeled; M-10 Range modeled as nearby indicator site.
		M-10 Hand Grenade Range	Historical	0.3	1958	1961	High	Grenade impact area	Modeled; see Section 7.9.
		M-113 Hand Grenade Range	Historical	0.3	1970	1977	High	Grenade impact area	Not modeled; M-115 Range modeled as nearby indicator site.
		M-115 Hand Grenade Range	Historical	0.3	1970	1977	High	Grenade impact area	Modeled; see Section 7.10.
Tactical Maneuver Training Area MB	1238	Maneuver Training Areas – H, K, and M	Operational	18381	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area MC	1312	Maneuver Training Areas – H, K, and M	Operational	18381	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area MD	1335	Maneuver Training Areas – H, K, and M	Operational	18381	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area ME	1726	Maneuver Training Areas – H, K, and M	Operational	18381	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area MF	1413	Maneuver Training Areas – H, K, and M	Operational	18381	1941	Present	Low	Maneuver training area	Not modeled[b]
		M-Impact Area	Historical	135	1941	1945	Medium	Artillery impact area	Not modeled
Tactical Maneuver Training Area QA	1166	Maneuver Training Areas – F, L, Q, and R	Operational	19036	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area QB	512	Maneuver Training Areas – F, L, Q, and R	Operational	19036	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area RA	1043	Maneuver Training Areas – F, L, Q, and R	Operational	19036	1941	Present	Low	Maneuver training area	Not modeled[b]
Tactical Maneuver Training Area RB	780	Maneuver Training Areas – F, L, Q, and R	Operational	19036	1941	Present	Low	Maneuver training area	Not modeled[b]
NA	NA	I Area	Operational	NA	NA	NA	NA	Small arms training	Not modeled; small arms only range located at Courthouse Bay
NA	NA	ETA-1	Operational	0.2	1994	Present	Low	ETA	Not modeled[d]
NA	NA	Stone Bay	Operational	NA	NA	NA	NA	Small arms training	Not modeled; small arms military munitions use only
NA	NA	UXO Area	Historical	NA	NA	NA	Low	UXO contamination	Not modeled; no basis for quantifying MC loading rate
Marine Corps Outlying Fields – Oak Grove	956	Marine Corps Outlying Fields – Oak Grove	Operational	NA	1943	Present	Low	Marine Corps Outlying Fields	Modeled as part of MCAS Cherry Point; see Appendix C

Note:
Limited military munitions use (i.e., pyrotechnics and blanks) was noted in the multiple landing zones located on MCB Camp Lejeune; however, these areas were not designated as separate MC loading areas since the surrounding maneuver training areas are already evaluated at a higher MC loading rate for the same military munitions and the landing zones are not designated as separate operational ranges from these maneuver training areas.

[a] MC loading area acreage for Brown's Island is greater than that shown in the NDAA Section 366 Report due to the inability to cross-reference the exact area mapped for that report. The MC loading area was defined from aerial photographs and discussions with Range Control that indicated which areas were most affected by military munitions.
[b] Modeling assumptions were to model only high overall priority MC loading areas as installation indicators; however, due to the preliminary modeling results, some medium priority sites were modeled as well.
[c] Maneuver Training Areas assumed to receive no MC loading include Maneuver Training Areas A, B, C, D, E, and J.
[d] Training activities within ETA and EOD training areas are assumed to be less likely to create low-order and dud contamination and, therefore, are lower priority sites. In addition, these areas are assumed to be regularly maintained to enable their continued use.
[e] F-12 was later determined to contain no REVA indicator MC and was withdrawn from the modeling process.
NA – Not Applicable
EOD – Explosive Ordnance Disposal
ETA – Engineer Training Area
UXO – Unexploded Ordnance

MC loading areas associated with current operational range activities, as well as historical uses within operational range boundaries, were delineated. These operational ranges were screened for the potential presence of REVA indicator MC (as indicated by the REVA MC Loading Rate Calculator) according to the types of military munitions expended within their boundaries. Operational ranges that were determined to contain no REVA indicator MC were withdrawn from the REVA modeling, including:

- Greater Sandy Run (GSR) Impact Area SA
- GSR Impact Area SB
- GSR Impact Area SC
- GSR Impact Area SD
- GSR Impact Area SE
- GSR Impact Area SF
- GSR Impact Area SG
- GSR Impact Area SH
- GSR Impact Area SI
- GSR Impact Area SJ
- GSR Impact Area SK
- GSR Impact Area SL
- GSR Impact Area SM
- GSR Impact Area SN
- GSR Impact Area SO
- GSR Impact Area SP
- GSR Impact Area SQ
- GSR Impact Area SR
- GSR Impact Area SS
- GSR Impact Area ST
- GSR Impact Area SU
- GSR Impact Area SV
- GSR Impact Area SW

In addition, some maneuver training areas were identified as being more frequently used than others. Lesser-used training areas tend to be infrequently used due to the wet characteristics of the areas. The lesser-used maneuver training areas do have REVA MC associated with training activities; however, due to their limited use the REVA team

determined that the more frequently used maneuver training areas would provide a representation of these lesser used areas. The following maneuver training areas considered to be the infrequently used areas, as identified by Range Control, were not modeled under REVA:

- Maneuver Training Area AA
- Maneuver Training Area AB
- Maneuver Training Area AC
- Maneuver Training Area AD
- Tactical Maneuver Training Area BC
- Tactical Maneuver Training Area BD
- Tactical Maneuver Training Area CA
- Tactical Maneuver Training Area CB
- Tactical Maneuver Training Area DA
- Tactical Maneuver Training Area DB
- Tactical Maneuver Training Area DC
- Tactical Maneuver Training Area DD
- Tactical Maneuver Training Area DE
- Tactical Maneuver Training Area DF
- Tactical Maneuver Training Area E
- Tactical Maneuver Training Area JA
- Tactical Maneuver Training Area JB
- Tactical Maneuver Training Area JC
- Tactical Maneuver Training Area JD

The remaining maneuver training areas were grouped into three clusters, based on their levels of use:

- Maneuver Training Areas F, L, Q, and R
- Maneuver Training Areas G and I
- Maneuver Training Areas H, K, and M

The maneuver training areas are shown in Figure 3-1. The MC loading areas identified within the MCB Camp Lejeune complex are shown in Figure 3-2.

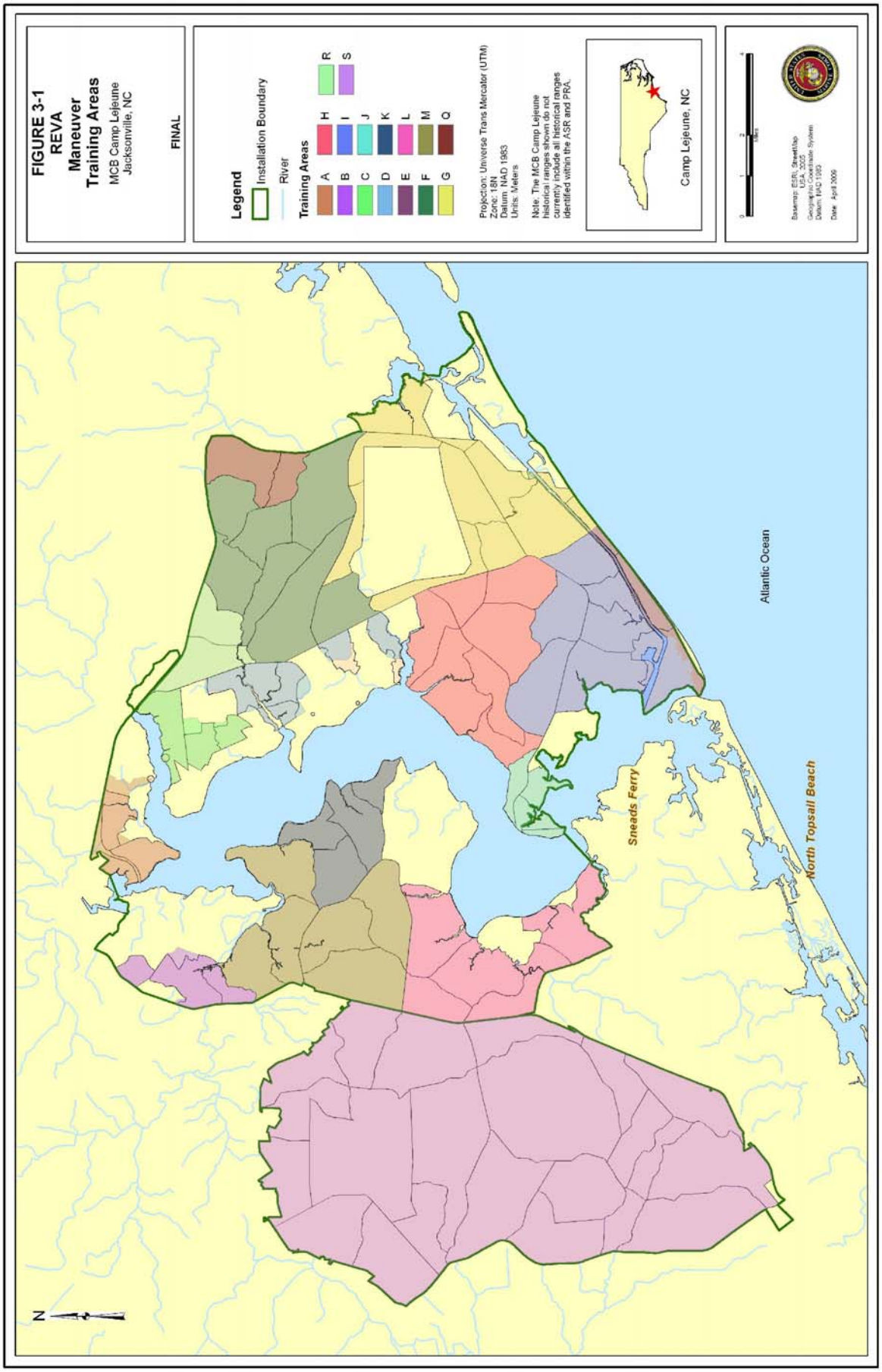


FIGURE 3-1
REVA
Maneuver
Training Areas
MCB Camp Lejeune
Jacksonville, NC
FINAL
Legend
Installation Boundary
River
Training Areas
A
B
C
D
E
F
G
H
I
J
K
L
M
Q
R
S
Projection: Universe Trans Mercator (UTM)
Zone: 18N
Datum: NAD 1983
Units: Meters
Note: The MCB Camp Lejeune historical ranges shown do not currently include all historical ranges identified within the ASR and PRA.
Camp Lejeune, NC
Basemap: ESRI, StreetMap USA 2005
Geographic Coordinate System
Datum: NAD 1983
Date: April 2006
Atlantic Ocean
Sneads Ferry
North Topsail Beach
N

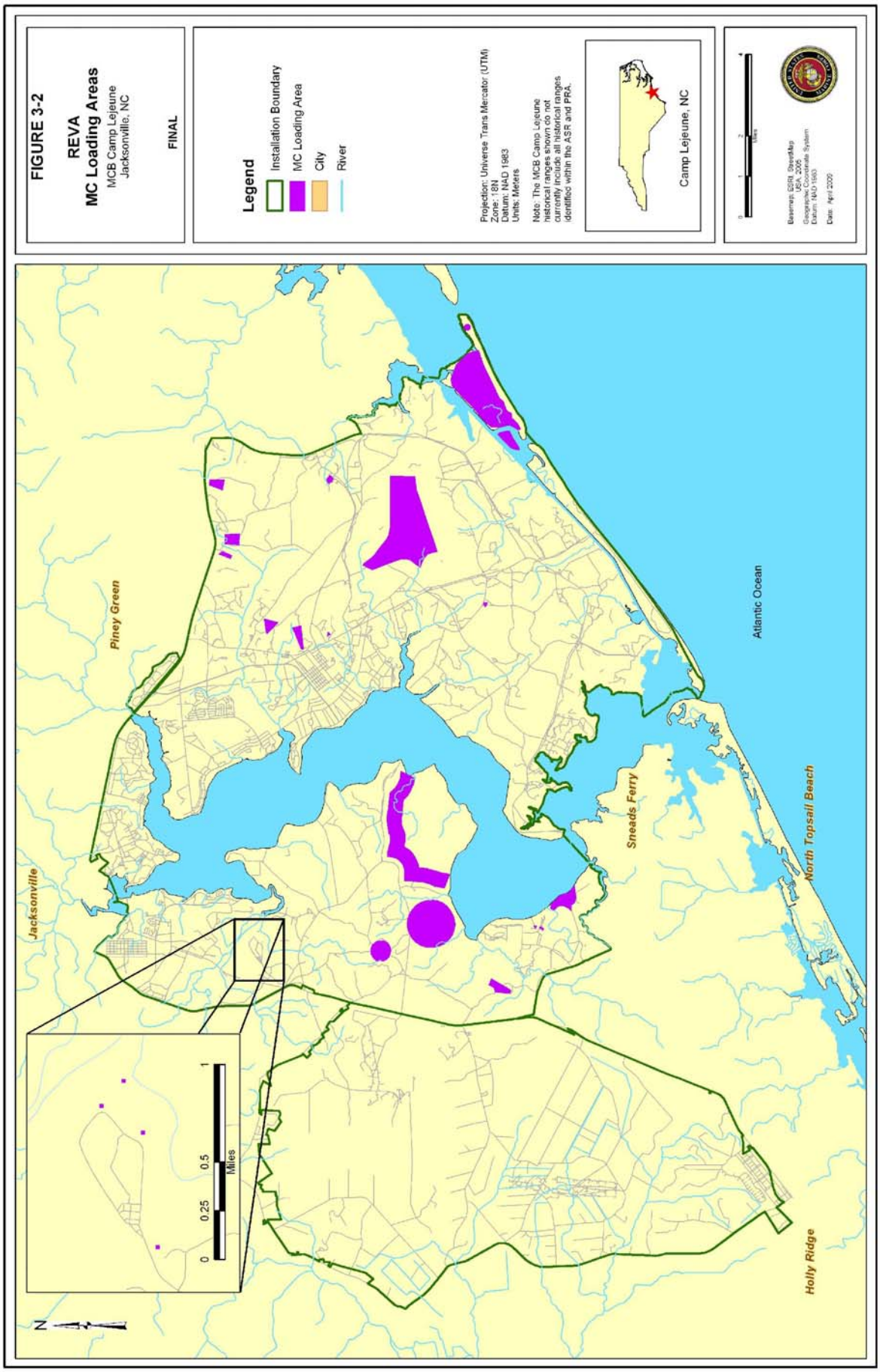


FIGURE 3-2
REVA
MC Loading Areas
MCB Camp Lejeune
Jacksonville, NC
FINAL
Legend
Installation Boundary
MC Loading Area
City
River
Projection: Universe Trans Mercator (UTM)
Zone: 18N
Datum: NAD 1983
Units: Meters
Note: The MCB Camp Lejeune historical ranges shown do not currently include all historical ranges identified within the ASR and PRA.
Camp Lejeune, NC
Miles
Basemap: ESRI, StreetMap USA, 2005
Geographic Coordinate System
Datum: NAD 1983
Date: April 2009
Piney Green
Jacksonville
Sneads Ferry
North Topsail Beach
Holly Ridge
Atlantic Ocean
N
0
0.25
0.5
1
Miles

Due to the comprehensive use of MCB Camp Lejeune for training purposes over time, the delineation resulted in 33 REVA MC loading areas. Subsequently, the REVA assessment team identified the need to prioritize these MC loading areas for modeling purposes, based on MC loading and groundwater and surface water characteristics. As presented in the next section, this prioritization resulted in the modeling of 12 of the 33 identified MC loading areas.

3.5.1. MC Loading Area Prioritization

The identified MC loading areas were rated qualitatively prior to modeling, based on MC and groundwater and surface water characteristics. These ratings subsequently were used to assign three category-specific priorities (MC, surface water, and groundwater), as well as an overall priority, to the MC loading areas to determine which sites were of the greatest potential concern for screening-level modeling purposes. The overall priority includes an evaluation of each of the factors.

The MC prioritization was determined by evaluating the level of use, duration of MC loading, expected presence of REVA indicator MC, size, and current status for each MC loading area.

The level of use analysis accounts for the intensity of training activities conducted at all operational ranges and historical use areas within operational ranges that are associated with the MC loading area. Level of use was rated as high, medium, or low, based on expenditure data, input from Range Control, and professional judgment of the REVA assessment team. The more intense (frequent) the level of use, the higher the priority of the area.

The duration of MC loading accounted for the period of use of all operational ranges and historical use areas within operational areas that were associated with the MC loading area. Duration was rated as low (< 5 years), medium (5 to 15 years), or high (> 15 years). The longer the duration, the more adverse the expected affect on the environment and, therefore, the higher the priority.

The expected REVA indicator MC evaluation identified how many of the REVA indicator MC (HMX, RDX, TNT, and perchlorate[4]) were present at the MC loading area. The types of military munitions were rated based on the actual number of different MC present (i.e., one through four). Those sites containing one REVA indicator MC were rated low; those with two REVA indicator MC were rated medium; those with three or four indicator MC were rated high. Therefore, the greater the number of REVA indicator MC present, the higher the priority of the site. During the identification of the MC

[4] Since lead is being evaluated qualitatively within REVA and not being modeled, it is not included in this analysis.

loading areas, sites that did not contain REVA indicator MC were removed from further analysis.

The size of the MC loading area was evaluated to account for the distribution of MC loading over larger sites. Size of the MC loading areas was prioritized as high (< 5 acres), medium (5 to 25 acres), or low (> 25 acres); therefore, the smaller the size of the MC loading area, the higher the priority.

The current status of the ranges associated with the MC loading areas was simply an indicator of whether MC loading currently continues at the site. Current status of an MC loading area was indicated as operational or historical use. In most instances, operational MC loading areas will be the higher priority; however, there may be historical use MC loading areas within operational range boundaries that are rated as high priorities as well.

Ten MC loading areas were identified as having high overall priority for screening-level modeling at MCB Camp Lejeune (Table 3-2). Following the prioritization of these identified MC loading areas, they were regionalized based on geological characteristics. MC loading areas determined to be representative of the worst-case scenarios within each region were then selected for modeling. The MC loading areas representing the varying geological conditions of MCB Camp Lejeune were as follows:

- G-10 Impact Area (operational)
- K-2 Impact Area (operational)
- F-14 Field Firing Range (historical use within an operational area)
- F-6 (operational)
- F-12 Field Firing Range (historical use within operational area)[5]
- L-Impact Area (historical use within operational area)
- L-Ranges (operational)
- M-10 Range (historical use within operational area)

During the modeling process, the REVA assessment team identified the need to model three more of the prioritized MC loading areas based on the initial modeling results of the above eight MC loading areas, which indicated the potential for MC to reach the shallow groundwater. These included the following:

- F-5 (operational), F-2 Field Firing Range (historical use on within an operational area), and Musketry Range A (historical use within an operational area) (all same location)
- Combat Town (operational)

[5] F-12 was later determined to contain no REVA indicator MC and was withdrawn from the modeling process.

- M-115 Range (historical use within operational area)

Details on these modeling areas are provided in Sections 7.1 through 7.10.

Table 3-2.
MC Loading Prioritization of Modeled REVA MC Loading Areas

MC Loading Area	Expected MC Loading Rate			Size (acres)	Current Status	REVA Indicator MC Priority	Overall MC Priority
	Level of Use	Duration	REVA MC				
G-10 Impact Area	High	High	High	Low	Operational	High	High
K-2 Impact Area	High	High	High	Low	Operational	High	High
F-5	Medium	High	Medium	Medium	Operational	Medium	Medium
F-2 Field Firing Range	Medium	High	Medium	Medium	Historical	Medium	High
Musketry Range A	Medium	Medium	Medium	Medium	Historical	Medium	Medium
F-14 Field Firing Range	Medium	High	Medium	Low	Historical	Medium	High
F-6	Medium	High	Medium	High	Operational	High	High
F-12 Field Firing Range	Medium	High	Medium	Low	Historical	Medium	High
L-Impact Area	High	High	High	Low	Historical	High	High
L-Ranges	High	High	Medium	Low	Operational	High	High
Combat Town	High	High	Medium	Medium	Operational	Low	Medium
M-10 Range	High	High	Medium	High	Historical	High	High
M-115 Range	High	High	Medium	High	Historical	High	High

4. Conceptual Site Model

CSMs were developed for the operational ranges at MCB Camp Lejeune and MCAS New River. A CSM is a summary of the conditions of an operational range, including the environmental setting, MC loading estimates, and a discussion of potential pathways and receptors. Development of a CSM is a key component of the groundwater and surface water analyses and provides insight into the potential for MC transport to receptors. The CSM also helps determine which ranges may require more quantitative assessment methods. The general CSM for MCB Camp Lejeune (Figure 4-1) is presented in this section with specific CSMs for individual ranges and training areas discussed in Section 7. For REVA, the CSM for each operational range addresses the following:

- MC loading estimates (detailed in Section 3)
- Geography, topography, and climate
- Surface water features
- Soil characteristics and land cover
- Erosion potential
- Hydrogeology and groundwater characteristics
- Potential surface water and groundwater pathways
- Potential receptors

Key information sources used in the development of the operational range CSMs included the following:

- Military munitions expenditure data
- GIS
- IRP site data
- USGS topographic maps and regional groundwater resources report
- USDA soil survey data
- Precipitation data
- Marine Corps ASR
- Marine Corps PRA report

Where detailed information of site-specific characteristics and information did not exist, available regional information was used to estimate local characteristics.

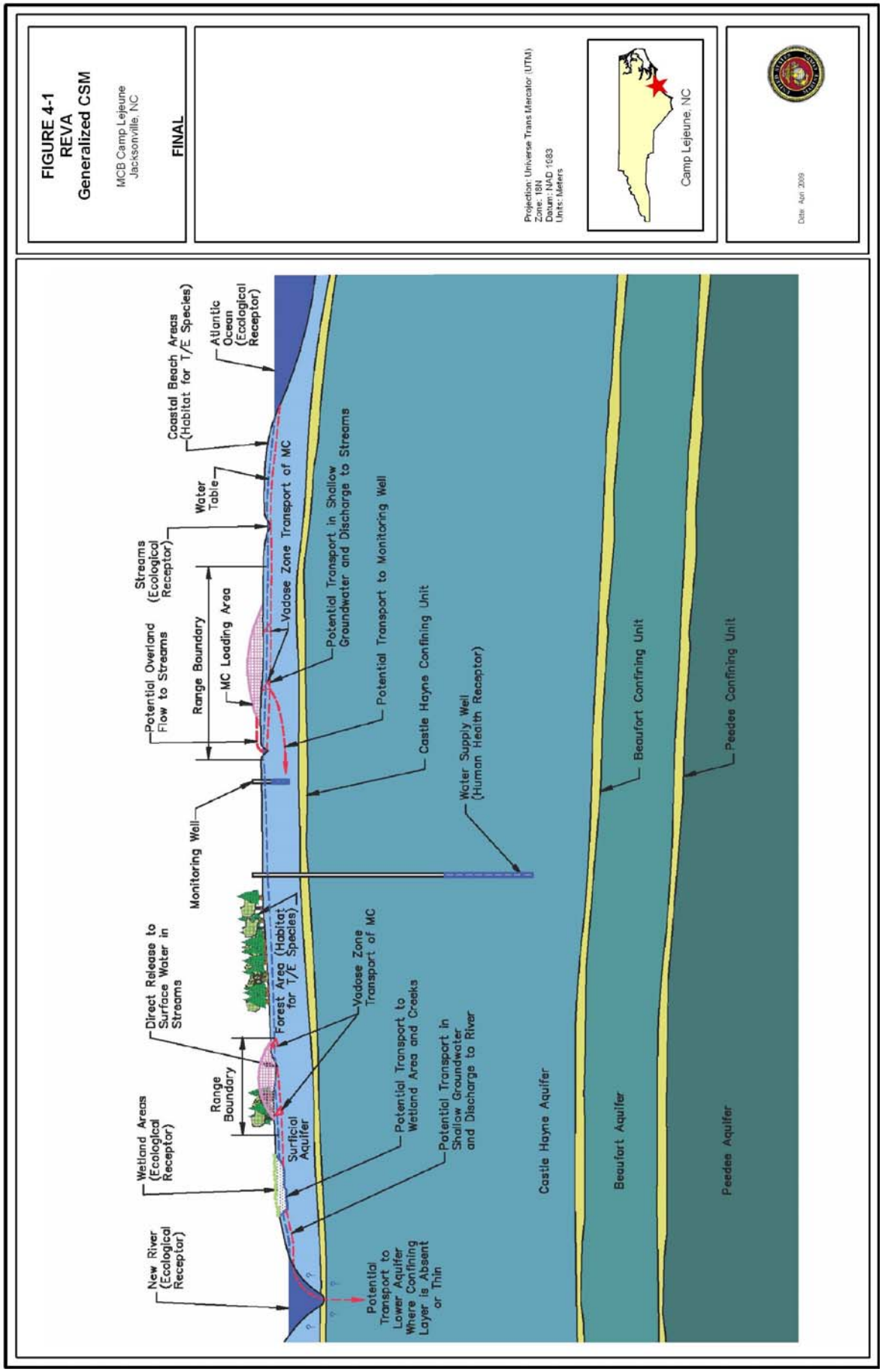


FIGURE 4-1
REVA
Generalized CSM
MCB Camp Lejeune
Jacksonville, NC
FINAL
Projection: Universe Trans Mercator (UTM)
Zone: 18N
Datum: NAD 1983
Units: Meters
Camp Lejeune, NC
Date: April 2009
Coastal Beach Areas (Habitat for T/E Species)
Atlantic Ocean (Ecological Receptor)
Water Table
Streams (Ecological Receptor)
Potential Overland Flow to Streams
Range Boundary
MC Loading Area
Vadose Zone Transport of MC
Potential Transport in Shallow Groundwater and Discharge to Streams
Potential Transport to Monitoring Well
Castle Hayne Confining Unit
Water Supply Well (Human Health Receptor)
Beaufort Confining Unit
Peedee Confining Unit
Monitoring Well
Direct Release to Surface Water in Streams
Forest Area (Habitat for T/E Species)
Vadose Zone Transport of MC
Potential Transport to Wetland Area and Creeks
Potential Transport in Shallow Groundwater and Discharge to River
Range Boundary
Wetland Areas (Ecological Receptor)
Surficial Aquifer
New River (Ecological Receptor)
Potential Transport to Lower Aquifer Where Confining Layer is Absent or Thin
Castle Hayne Aquifer
Beaufort Aquifer
Peedee Aquifer

4.1.1. Installation Description

MCB Camp Lejeune, known as the world's most complete amphibious training base, is located on the coastal plain in Onslow County, NC. The military installation currently covers approximately 246 square miles (153,439 acres) and is bisected by the New River, which flows in a southeasterly direction and forms a large estuary before entering the Atlantic Ocean. The Atlantic Ocean forms the southeastern boundary of the facility, which contains approximately 14 miles of beachfront. The city of Jacksonville, NC, is located immediately northwest of the cantonment area.

4.1.2. Background

In 1940, the Marine Corps surveys of the southeastern coast of the United States resulted in the recommendation of the New River area of Onslow County, NC, for a new Marine Corps base (MCB Camp Lejeune). By April 1941, construction began at New River, and late in September 1941, the installation received its first Marine trainees, the First Marine Division. On December 20, 1941, the New River Marine Barracks was renamed Camp Lejeune, in honor of the late Lieutenant General John A. Lejeune. The Training Center was formally organized at Camp Lejeune by the end of 1941. This center consisted of a school battalion, quartermaster battalion, engineer battalion, artillery battalion, infantry battalion, barrage balloon group, parachute battalion, and replacement battalions—virtually every phase of modern warfare except an air arm, which was provided by the nearby Marine Air Base at Cherry Point. Toward the end of WWII, the camp was designated as a home base for the Second Marine Division, which began to arrive home from Japan in July 1946. During WWII and continuing during the Korean War and Vietnam War, MCB Camp Lejeune functioned as the major East Coast training facility to prepare Marines for combat (USACE, 2000b).

In the early 1970s (Vietnam era), the military reservation covered approximately 170 square miles (110,000 acres) primarily in five distinct geographical locations under the jurisdiction of the Base Command. They included Camp Geiger (Infantry Training School), Montford Point (Service Support Schools-Field Medical Service), Mainside, Courthouse Bay, the Rifle Range area, and MCAS New River. The three major commands at MCB Camp Lejeune were Marine Corps Base, the Second Marine Division, and Force Troops Fleet Marine Force, Atlantic. Other historical installation commands and facilities included the First Marines, Headquarters and Service Company, a complete Naval Hospital, specialized schools to provide training in engineering and supply, and basic military training areas. In the late 1980s and early 1990s, investigations were conducted into ways of alleviating deficiencies in operational land training areas and available operational firing ranges at MCB Camp Lejeune. In 1992, the federal government purchased 44,000 acres of land adjacent to the southwestern portion of the base, known as the Greater Sandy Run Area (GSRA).

4.1.3. Geomorphology and Climate

MCB Camp Lejeune is situated within the Atlantic Coastal physiographic province and is located in the Lower Coastal Plain of North Carolina, the topography of which consists of flat terraces (also called surfaces) underlain by unconsolidated sediments. Elevations at MCB Camp Lejeune range from mean sea level (msl) to 72 feet (ft) above msl. The majority of the land area at MCB Camp Lejeune is covered by the Talbot surface at an elevation ranging from 24 to 42 ft above msl (USDA SCS, 1992). Additionally, a thin narrow strip of land near the coast at MCB Camp Lejeune is covered by Pamlico surface at an elevation ranging from sea level to 24 ft above msl. Although the majority of the facility is relatively flat with slopes of less than 2%, steeper topography with slopes of 2% to 15% is present in the valleys of dendritic stream systems that dissect the terraces. The southeast coast of MCB Camp Lejeune consists of a barrier island complex that trends northeast to southwest. A northeast-southwest trending scarp, approximately 30 ft in elevation, parallels the modern coastline and follows the general trend of NC State Route 172. The scarp separates low-lying, wet, swampy areas in the southeast from drier upland terrace regions to the west. Some local depressions within the terrace region east of the New River have been interpreted as early karst topography (Geophex, 1993a, b).

MCB Camp Lejeune is bounded to the southeast by Onslow Bay and the Atlantic Ocean and is bisected by the large New River embayment. The majority of the surface drainage at MCB Camp Lejeune is to the New River. The New River is a broad, meandering microtidal estuary (Triangle, 1999). Upstream of MCB Camp Lejeune, the river is confined to a relatively narrow channel. Some southern areas of MCB Camp Lejeune drain directly to the Intracoastal Waterway, which parallels the coast near the southeast boundary. Much of the interior of MCB Camp Lejeune drains to intermittent and perennial streams that widen into tidal creeks in their downstream segments. Most perennial streams and tidal creeks occupy floodplains with extensive riparian wetlands. The flat terraces of the facility interior also contain regions that drain to low areas with no surface water outlets, including pocosins (shrub wetland). The scarp noted above is the drainage divide between the two drainage systems. The salinities of the New River and back barrier lagoons are brackish to marine. The salinities of the smaller streams and tributaries are fresh in the upper portions, but become progressively brackish in their lower portions as they approach the main water bodies (Triangle, 1999).

Onslow County, NC, has a warm, temperate climate. Winter is cool with occasional brief cold spells. Annual precipitation data were obtained from a weather station in Jacksonville, NC, for the period 1996-2005 and a weather station in New Bern, NC, for 1970-2005. The average annual precipitation calculated from these data was 72.5 inches per year. Average snowfall is about 3 inches per year. In addition to the climate information used as part of each operational range CSM, it should be noted that hurricanes are not unusual to the area. Hurricanes have caused severe flooding and damage in low-lying areas near the ocean, sounds, bays, rivers, and creeks. According to

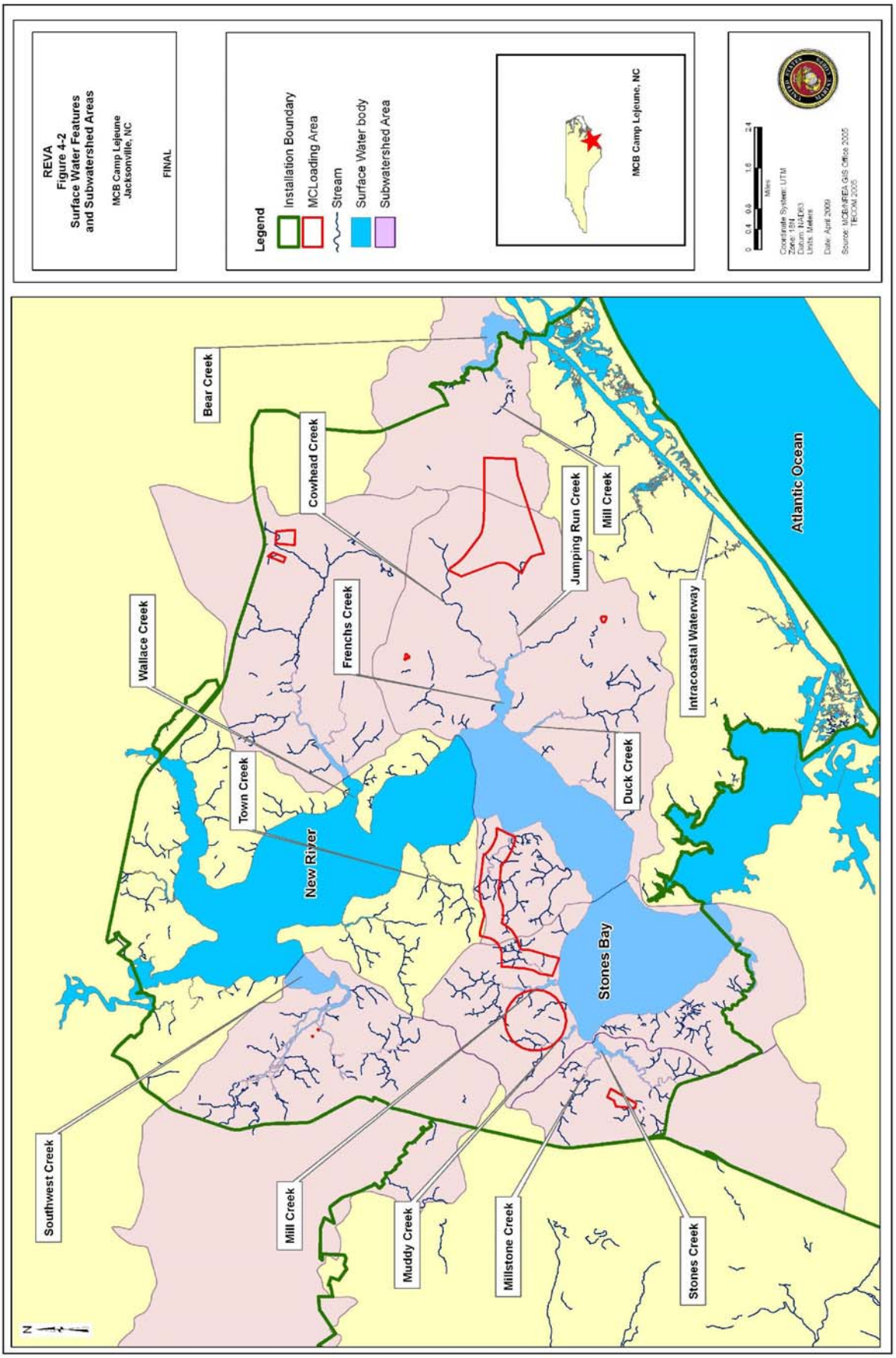
USDA SCS (1992), 56 hurricanes passed across or close by the North Carolina coast between 1900 and 1986.

4.1.4. Surface Water

MCB Camp Lejeune is bounded to the southeast by Onslow Bay and the Atlantic Ocean, and is bisected by the large New River embayment. The majority of MCB Camp Lejeune drains to the New River embayment and its tributaries. However, some southern areas of MCB Camp Lejeune drain directly to the Intracoastal Waterway, which parallels the coast near the southeast boundary. Much of the interior of MCB Camp Lejeune drains to intermittent and perennial streams that widen into tidal creeks in their downstream segments. Most perennial streams and tidal creeks occupy floodplains with extensive riparian wetlands. The flat terraces of the facility interior also contain regions that drain to low areas with no surface water outlets, including pocosins. Figure 4-2 shows the surface water features and subwatershed areas on MCB Camp Lejeune.

According to data obtained from MCB Camp Lejeune (GIS data, 2005), 23 subwatershed areas have been delineated within the MCB Camp Lejeune installation boundary. These subwatershed areas mostly consist of perennial streams that drain to the New River embayment within the installation boundary. The subwatershed areas range in size from 2,760 to 31,746 acres. A majority of these subwatershed areas extend beyond the MCB Camp Lejeune installation boundary; only five out of the 23 subwatersheds are entirely located within the installation boundary. High priority MC loading areas are located in six of the existing 23 subwatersheds within MCB Camp Lejeune's installation boundary. These include subwatersheds of the different segments of the New River and the various tributary streams of the New River.

The subwatershed of Southwest Creek upstream of its confluence with the New River has the largest drainage area of the subwatersheds consisting of high priority MC loading areas. This 28, 830 acres subwatershed is located on the northwest part of MCB Camp Lejeune. It consists of Southwest Creek and its tributaries. Southwest Creek originates northwest of the New River embayment, it flows perennial for approximately 5 miles before it widens into a tidal Creek and ultimately discharges into the New River. Riparian wetlands exist though out the entire stream segment. Tributaries of Southwest Creek include Harris Creek, Haws Run, Hicks Run, Mill Run, and Tank Creek. Federal threatened and endangered (T/E) species including the red-cockaded woodpecker and the American alligator have been documented to exist within this subwatershed (MCB Camp Lejeune INRMP, 2001). This subwatershed drains the M-10 and M-115 MC loading areas.


REVA
Figure 4-2
Surface Water Features
and Subwatershed Areas
MCB Camp Lejeune
Jacksonville, NC
FINAL
Legend
Installation Boundary
MCLoading Area
Stream
Surface Water body
Subwatershed Area
MCB Camp Lejeune, NC
0 0.4 0.8 1.6 2.4
Miles
Coordinate System: UTM
Zone: 18N
Datum: NAD83
Units: Meters
Date: April 2009
Source: MCB/NREA GIS Office 2005
TECOM 2005
Bear Creek
Cowhead Creek
Wallace Creek
Frenchs Creek
Town Creek
Jumping Run Creek
Mill Creek
Intracoastal Waterway
Duck Creek
Atlantic Ocean
New River
Stones Bay
Southwest Creek
Mill Creek
Muddy Creek
Millstone Creek
Stones Creek
N

The subwatershed of the New River between Town Creek and Stones Bay is located in the central part of MCB Camp Lejeune. It is entirely located within the boundaries of MCB Camp Lejeune. This 21,123 acres subwatershed consists of streams that drain westward, northwestward, southwestward, eastward, and southeastward and ultimately discharge into the New River. These streams include Whitehurst Creek and an unnamed stream that drain eastward and southeastward into the New River and Cowhead Creek, Jumping Run, Frenchs Creek, Duck Creek, Goose Creek, Two Pole Branch and Cogdels Creek that drain westward, northwestward and southward into the New River. Almost all of the streams within this subwatershed drain through riparian wetland areas. Federal T/E species, including the red-cockaded woodpecker, rough-leaved loosestrife, and the American alligator, have been documented to exist within this subwatershed (MCB Camp Lejeune INRMP, 2001). This subwatershed drains large portions of the G-10 and K-2 Impact Areas and all of F-6 and Combat Town MC loading areas.

The subwatershed of Wallace Creek upstream of its confluence with the New River is located in the east part of MCB Camp Lejeune. A small portion of this subwatershed extends beyond the installation boundary. This 12,868 acres subwatershed consists of Wallace Creek and its tributaries. Wallace Creek originates approximately 4.6 miles east of the New River and flows perennial through riparian wetland areas and widens into a tidal Creek before discharging into the New River. Some of the tributaries of Wallace Creek include Bearhead Creek and Beaverdam Creek. Federal T/E species including the red-cockaded woodpecker and the American alligator have been documented to exist within this subwatershed (MCB Camp Lejeune INRMP, 2001). This subwatershed drains the F-5 and F-14 MC loading areas.

The subwatershed of the New River at Stones Bay is located in the south central part of MCB Camp Lejeune. A small southern portion of this subwatershed extends beyond the installation boundary. This 12,294 acres subwatershed includes streams that drain southward and northeastward and discharge into Stones Bay. Some of these streams include Everett Creek, Mill Creek, and Muddy Creek. The federal T/E red-cockaded woodpecker species have been documented to exist within this subwatershed (MCB Camp Lejeune INRMP, 2001). This subwatershed drains the entire L-Range MC loading area and approximately 40% of the K-2 Impact Area MC loading area.

The subwatershed of Stones Creek upstream of its confluence with Stones Bay is located in the south part of MCB Camp Lejeune. Almost half the area of this subwatershed extends beyond the installation boundary. This 7,585 acres subwatershed includes Stone Creek and its tributary Millstone Creek. Stones Creek originates as a perennial stream approximately 5 miles southwest of Stones Bay and widens into a tidal creek before discharging into Stones Bay. Both Stones Creek and Millstone Creek flow through riparian wetland areas. Red-cockaded woodpecker species that are federally threatened and endangered have been documented to exist within this subwatershed (MCB Camp Lejeune INRMP, 2001). This subwatershed drains L-impact MC loading area.

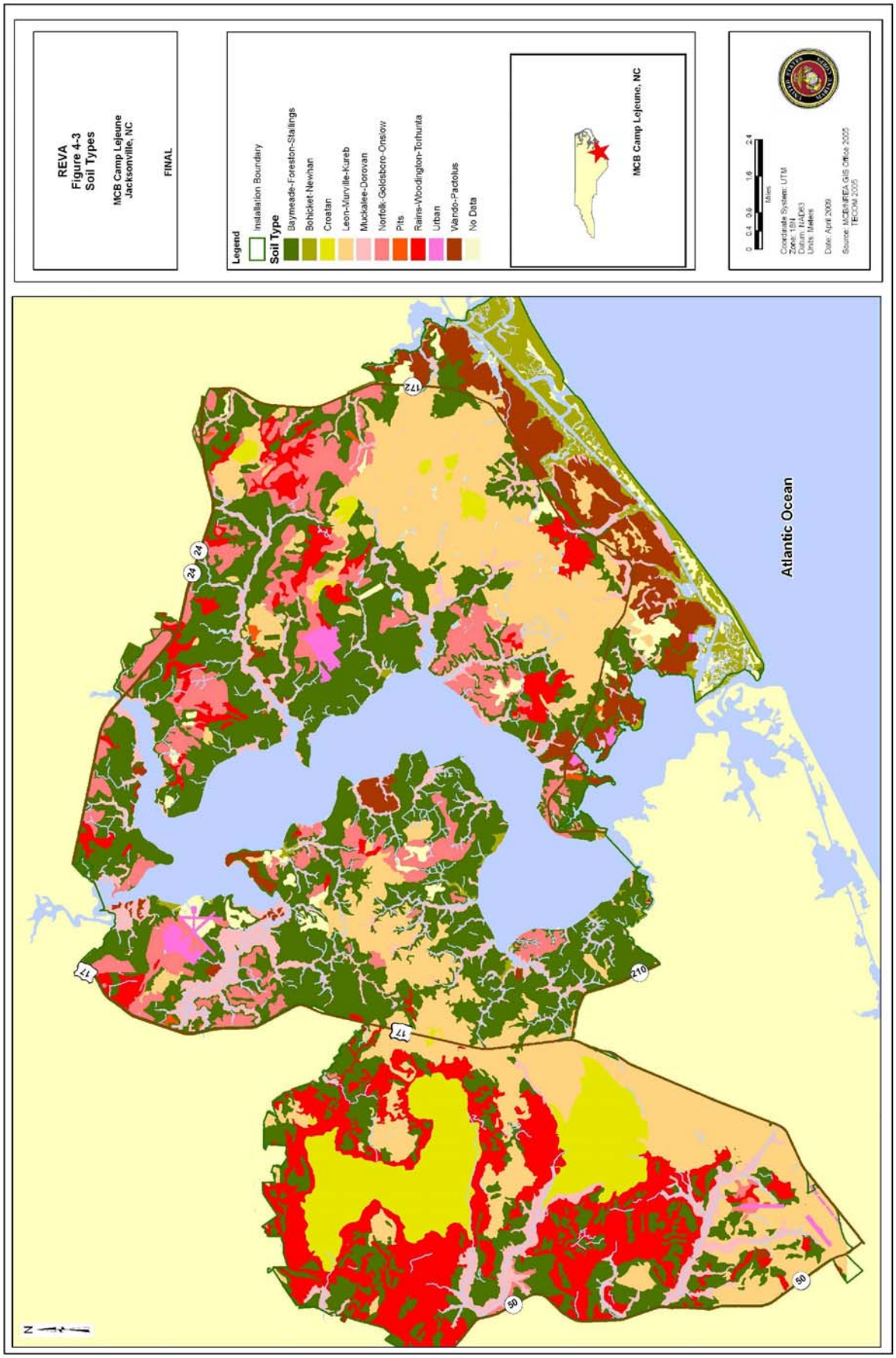
The subwatershed of Bear Creek upstream of its confluence with the Intracoastal Waterway is located in the southeastern part of MCB Camp Lejeune. Some portions of this subwatershed extend beyond the installation boundary. This 6,886 acres subwatershed include Bear Creek and its tributary Mill Creek. Bear Creek originates approximately 3.8 miles north of the Intracoastal Waterway and widens into a tidal creek before discharging into the Intracoastal Waterway. Bear Creek drains through riparian wetland areas. Federal T/E species including the red-cockaded woodpecker and rough-leaved loosestrife are located within this subwatershed (MCB Camp Lejeune INRMP, 2001). The subwatershed drains some portion of G-10 impact MC loading area.

4.1.5. Soil Characteristics and Land Cover

The flat, upland regions of MCB Camp Lejeune are underlain by a variety of sandy and loamy soils of highly variable drainage characteristics (USDA SCS, 1992). Figure 4-3 presents the soil types identified on MCB Camp Lejeune. Most upland areas that are designated as MC loading areas at MCB Camp Lejeune are underlain by the loamy Baymeade-Foreston-Stallings association or the sandy Leon-Murville-Kureb association. These soils have an organic content of 0.5% to 2%. The floodplains and riparian wetlands of MCB Camp Lejeune are underlain by soils of the Muckalee-Dorovan association, which consist of loam, sandy loam, and muck. The barrier island complex on the coast is underlain by tidal marsh and dune soils of the Bohick-Newhan association. Low-lying pocosin areas at MCB Camp Lejeune are underlain by poorly drained, mucky soils of the Croatan series that have a very high organic content (25%-60%).

Almost two-thirds (65%) of MCB Camp Lejeune is covered by forest, including pine forest, bottomland hardwood, and mixed pine-hardwood forest. About 22% of the facility area consists of pocosin. The installation area is about 5% developed, including base housing and operations buildings, and about 5% barren, most of which consists of military operations areas.

Soil erodibility factors (K) of the predominant soil series at MCB Camp Lejeune are low to moderate (0.1 to 0.3 tons/acre) (USDA SCS, 1992). Most of the loamy sands that underlie the flat, upland portions of the facility have low erodibility factors of 0.1 to 0.15 tons/acre. Even in areas of higher slope, such as stream valleys, the high vegetative cover causes the natural erosion potential to be slight. Undisturbed upland forest, forested bottomlands, and pocosins will have very low rates of erosion. The coastal barrier island complex is subject to erosion from wave action – particularly during storm surges – but serves to protect landward areas from such effects. Areas with a moderate potential for erosion are those where the vegetation and soil have been disturbed by military operations.


REVA
Figure 4-3
Soil Types
MCB Camp Lejeune
Jacksonville, NC
FINAL
Legend
Installation Boundary
Soil Type
Baymeade-Foreston-Stallings
Bohicket-Newhan
Croatan
Leon-Murville-Kureb
Muckalee-Dorovan
Norfolk-Goldsboro-Onslow
Pits
Rains-Woodington-Tofhunta
Urban
Wando-Pactolus
No Data
MCB Camp Lejeune, NC
0 0.4 0.8 1.6 2.4
Miles
Coordinate System: UTM
Zone: 18N
Datum: NAD83
Units: Meters
Date: April 2009
Source: MCB/NREA GIS Office 2005
TECOM 2005
Atlantic Ocean
172
24
24
17
17
210
50
50

4.1.6. Geology

Below the surficial deposits of MCB Camp Lejeune are southeast-dipping marine sediments of Cretaceous to Miocene age with a total thickness of over 1,400 ft at Onslow Beach. These sediments have been divided into seven hydrostratigaphic units and commonly are divided into seven aquifer systems (aquifers and associated confining units). The aquifer systems from deepest to shallowest are Lower Cape Fear, Upper Cape Fear, Black Creek, Peedee, Beaufort, Castle Hayne, and Surficial aquifer systems. The Castle Hayne and Surficial aquifer systems were evaluated as part of REVA for MCB Camp Lejeune because the Castle Hayne aquifer is used for potable water at the base and the Surficial aquifer overlies the Castle Hayne aquifer and may act as a recharge source for the Castle Hayne aquifer. However, based on hydraulic test results and the chemical difference in the groundwater between the Surficial and Castle Hayne aquifers, there does not appear to be a significant hydraulic connection between the Surficial and Castle Hayne aquifers in the vicinity of the G-10 MC loading area (see Section 9). Figure 4-4 illustrates a hydrogeologic section across MCB Camp Lejeune passing between the G-10 and K-2 impact areas. A more detailed discussion of the hydrogeologic setting at MCB Camp Lejeune is presented in reports by Harned and others (1989), Harden and others (2004), and Cardinell and others (1993).

4.1.6.1. Surficial Aquifer

The Surficial aquifer at MCB Camp Lejeune is composed of Pleistocene deposits and recent deposits of sand and silts and the upper portion of the Miocene Belgrade Formation. This aquifer ranges in thickness from 0 ft in the channel of the New River and its tributaries to 75 ft in the southeastern portion of MCB Camp Lejeune (Harned et al., 1989). This aquifer is not used as a potable water supply; therefore, there are no water supply wells in this aquifer at MCB Camp Lejeune.

The following limit the potential future use of the surficial aquifer as a source of potable water:

- Relatively low yield
- Requirements for additional water quality monitoring and treatment of groundwater supplies under the direct influence of surface water
- Susceptibility to groundwater contamination as evidence by over 120 IRP and underground storage tank investigations and over 15 investigations that have existing and/or proposed active treatment systems for contaminated groundwater in the surficial aquifer (Baker, 1997a)
- Salinity or potential saltwater intrusion

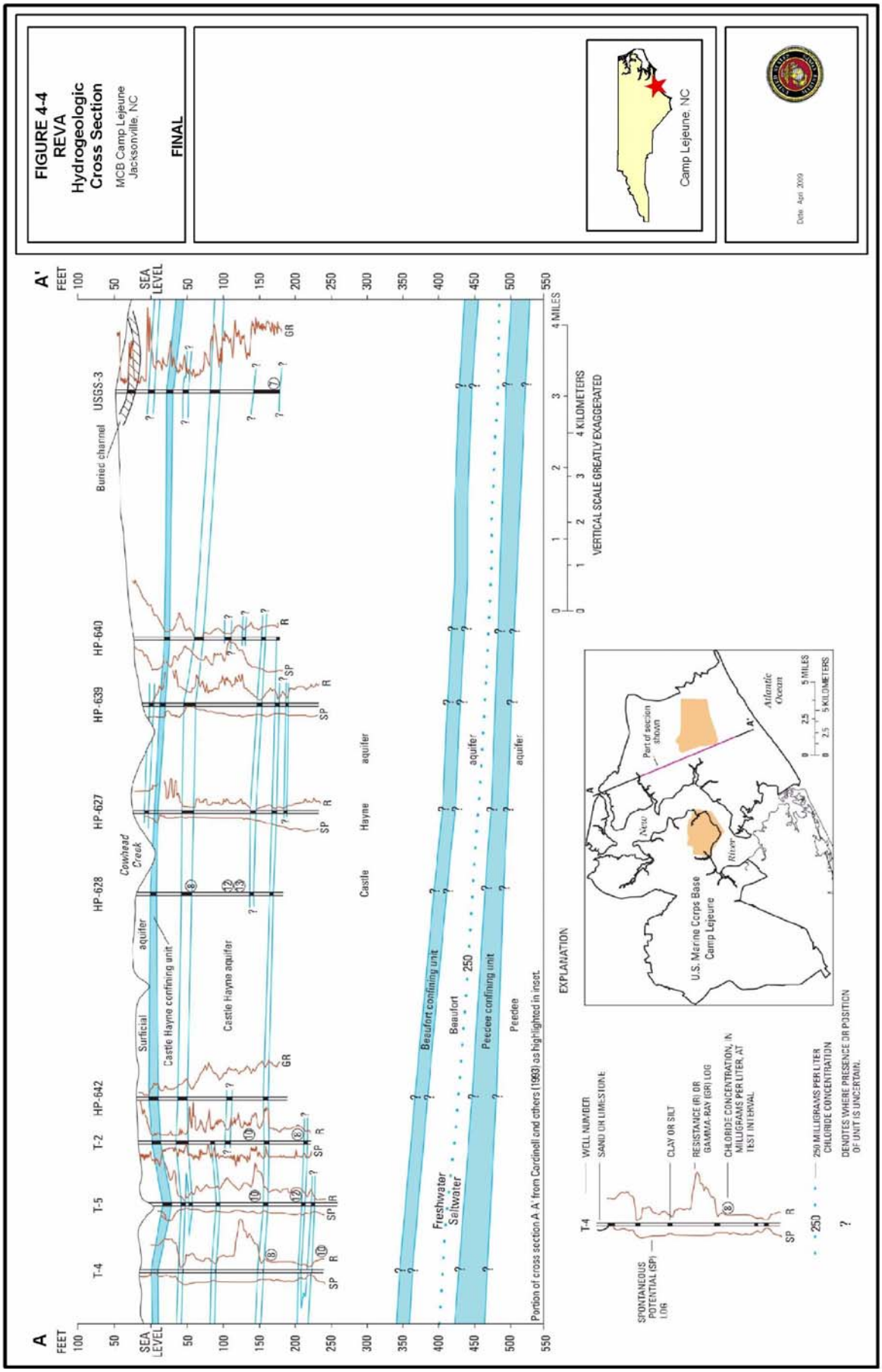


FIGURE 4-4
REVA
Hydrogeologic
Cross Section
MCB Camp Lejeune
Jacksonville, NC
FINAL
Camp Lejeune, NC
Date: April 2009
A
A'
FEET
SEA LEVEL
T-4
T-5
T-2
HP-642
HP-628
HP-627
HP-639
HP-640
USGS-3
Buried channel
Cowhead Creek
Surficial aquifer
Castle Hayne confining unit
Castle Hayne aquifer
Castle Hayne aquifer
Beaufort confining unit
Beaufort aquifer
Peedee confining unit
Peedee aquifer
Freshwater
Saltwater
250
GR
SP
R
4 MILES
4 KILOMETERS
VERTICAL SCALE GREATLY EXAGGERATED
Portion of cross section A-A' from Cardinell and others (1993) as highlighted in inset.
EXPLANATION
U.S. Marine Corps Base
Camp Lejeune
New
River
Atlantic Ocean
Part of section shown
5 MILES
5 KILOMETERS
WELL NUMBER
SAND OR LIMESTONE
CLAY OR SILT
RESISTANCE (R) OR GAMMA-RAY (GR) LOG
CHLORIDE CONCENTRATION, IN MILLIGRAMS PER LITER, AT TEST INTERVAL
SPONTANEOUS POTENTIAL (SP) LOG
250 MILLIGRAMS PER LITER CHLORIDE CONCENTRATION
DENOTES WHERE PRESENCE OR POSITION OF UNIT IS UNCERTAIN.

4.1.6.2. Castle Hayne Confining Unit

The Castle Hayne confining unit separates the Surficial aquifer from the underlying Castle Hayne aquifer. The Castle Hayne confining unit is a thin, discontinuous unit composed of clay, clayey sands, and silts. The confining unit is composed of one or more of the following units:

- Lower portion of Belgrade Formation
- River Bend Formation
- Castle Hayne Formation

The confining unit is generally less than 10 ft thick and has an estimated vertical hydraulic conductivity ranging from 0.0014 to 0.41 ft/day. It is not present in the area of the New River or other localized areas containing buried paleochannel deposits (Geophex, 1994). Because of the limited thickness and the discontinuous nature of the confining unit, the Castle Hayne aquifer is best characterized as a semiconfined aquifer.

4.1.6.3. Castle Hayne Aquifer

The Castle Hayne aquifer is the source of potable water supply at MCB Camp Lejeune and the city of Jacksonville. The upper portion of the aquifer is composed of fine sand, shell rock, limestone, and discontinuous silt and clay. The top of the aquifer is between 0 and 75 ft below msl. The Castle Hayne aquifer ranges in thickness from 175 ft in the northern part of the base to 375 ft along the coast. The aquifer is a complex heterogeneous aquifer that varies in lithology both vertically and horizontally, which significantly affects its hydraulic properties.

The recognition of layering within an aquifer is important to properly evaluate hydraulic response of water supply wells during pumping and to correctly model groundwater flow and the potential fate and transport of MC. Transmissivity is the ability of the aquifer to transmit fluids and is the product of the aquifer thickness and hydraulic conductivity. Triangle Environmental, as part of the 1999 Wellhead Protection Plan, estimated the Castle Hayne aquifer's hydraulic transmissivity. The transmissivity was calculated using the specific capacity method described by Driscoll (1986). There is large variability in the transmissivity of the Castle Hayne aquifer. On average, the transmissivities on the west side of the New River (6,343 ft^2/day) are greater than those on the east side of the New River. Since the Castle Hayne aquifer is generally thicker to the east of MCAS New River, it is evident that aquifer thickness is not the main factor controlling transmissivity in the area. The hydraulic conductivity, which is an intrinsic property of aquifer material (porous sands are more hydraulically conductive than clays), appears to be the main factor. Limestones, which are part of the Castle Hayne aquifer, have high heterogeneity.

As mentioned earlier, the Castle Hayne aquifer in the MCB Camp Lejeune area is under semiconfined conditions underlying the Castle Hayne confining unit. Vertical leakage, both upward and downward, occurs throughout the Castle Hayne confining unit.

Recharge to the Castle Hayne aquifer occurs along its outcrop, located to the west-northwest of MCB Camp Lejeune. In this area, the aquifer is unconfined, and rainwater can infiltrate into the aquifer. If the Castle Hayne was capped by a thick nonpermeable confining unit, then recharge would occur only within the outcrop belt. Because leakage can occur through the confining unit, groundwater will flow downward as long as the water level in the Surficial aquifer is higher than the potentiometric surface in the Castle Hayne aquifer. When the water table drops below the Castle Hayne potentiometric surface, groundwater will flow upward through the semiconfining layer.

The absence of the confining unit below the New River and the rapid drop in the water table from the uplands to the river create a potential for groundwater flow toward the New River. It appears that at the base not only does surface water and shallow groundwater discharge to the New River, but so does groundwater from the Castle Hayne aquifer (Triangle, 1999).

4.1.7. Water Supply Wells and Well Fields

More than 120 drinking water supply wells have been installed at MCB Camp Lejeune over the last 60 years. Of these, 67 are active, with the remaining wells currently being inactive or abandoned. Some of the inactive wells are being abandoned due to contamination or failure issues, and others are temporarily down for repairs (AH Environmental, 2002). In addition to the water supply wells located at MCB Camp Lejeune, there are 10 county public water supply wells located in proximity to MCB Camp Lejeune.

AH Environmental updated the existing Wellhead Protection Plan for MCB Camp Lejeune in August 2002. Three zones are delineated within each wellhead protection area (WHPA) defined for each water supply well. The zones are defined as follows:

- **Zone 1 – Primary Protection Area:** This is a 200-foot fixed radius exclusionary zone. The purpose of the 200-foot fixed radius is to prevent all personnel from conducting activities near a wellhead that could adversely affect water quality and to provide a quick reference in the event of a spill response.
- **Zone 2 – Secondary Protection Area:** This area is defined as the approximate 10-year zone of transport (ZOT) using average pumping and aquifer conditions. Contaminants released to the surface or near surface within Zone 2 could reach a production well in 10 years or less. Zone 2 uses average estimated pumping rates for each well (Triangle, 1999).
- **Zone 3 – Planning Area:** This area represents an estimate of the 10-year ZOT if maximum pumping (continuous pumping at installed capacity) were occurring. Continuous operation of wells currently is not being practiced and is not recommended due to increased potential for saltwater intrusion (AH Environmental, 2002). Zone 3 is to be used for long-term planning and land use considerations or if groundwater patterns change.

4.1.8. Receptors

Portions of MCB Camp Lejeune are situated on both sides of the New River, which is tidally influenced. The Intracoastal Waterway and Atlantic Ocean are located to the south. Receptors are human populations or T/E species (ecological receptors) that use or are exposed to surface water and groundwater at MCB Camp Lejeune. These users would represent receptors of potential MC if a complete transport pathway existed.

4.1.8.1. Surface Water Receptors

Streams and other surface water bodies are located in and around MCB Camp Lejeune. These water bodies include numerous small creeks and wetland areas. Surface waters on the installation are not used as a potable water supply. Humans potentially use these waters for recreational purposes (such as swimming and fishing). There are commercial oyster beds located adjacent to the K-2 Impact Area along the eastern and southeastern boundaries within the New River. Other recreational and fishing activities are conducted in the New River, the Intracoastal Waterway, and the Atlantic Ocean.

Potential T/E ecological receptors at MCB Camp Lejeune also exist. Camp Lejeune is home to federally-listed T/E animals and plants (MCB Camp Lejeune, 2003). In addition, there are several species of endangered marine mammals and three species of endangered sea turtles that can frequent the adjacent waters. The following is a list of the protected animals, plants, and marine mammals identified:

- Red-cockaded woodpecker
- Sea turtles – Atlantic loggerhead turtle and green sea turtle
- Bald eagle (now removed from T/E species list)
- American alligator
- Endangered plants – rough-leaved loosestrife and seabeach amaranth

Other species of conservation significance include migratory shorebirds that receive federal protection. They use the southern section of Onslow Beach as a unique and important nesting habitat. The Venus flytrap is a state-listed species and is protected by North Carolina.

Additionally, the streams and wetland areas can provide support to aquatic/wildlife habitat. Federal- and state-listed T/E species may consume surface water in habitat areas on Camp Lejeune as well as in the Intracoastal Waterway and in the Atlantic Ocean.

Section 4.1.3 identifies potential surface water sources near operational ranges, training areas, and MC loading areas at MCB Camp Lejeune, based on information contained in the INRMP.

4.1.8.2. Groundwater Receptors

The primary exposure to groundwater for humans is groundwater pumped from the drinking water supply wells found on MCB Camp Lejeune. The shallow groundwater in the area of MCB Camp Lejeune is not used as a drinking water source. All of the water supply wells are screened in the Castle Hayne aquifer, which is the source of potable water supply for MCB Camp Lejeune and the city of Jacksonville. As discussed in the previous section, the Castle Hayne aquifer lies below the Castle Hayne confining layer which provides some protection from direct recharge from the overlying Surficial aquifer. Therefore the potential for off-site receptors of shallow groundwater use is very low.

4.1.9. Pathways

The CSM includes the identification of possible pathways for MC migration from the loading area to the receptors identified in Section 4.1.7. The surface water and groundwater pathways are described below. At MCB Camp Lejeune, the CSM assumes that the groundwater pathway is the potential for exposure by human receptors through drinking water wells. The surface water pathway is critical for consideration of exposure to ecological receptors as well as human receptors. The concepts developed in the CSM are important to understanding potential transport mechanisms for MC and the potential for receptors to be impacted.

4.1.9.1. Surface Water Pathways

Surface water runoff, direct release to surface water bodies, vadose zone movement, and shallow groundwater movement, are the primary MC transport mechanisms at MCB Camp Lejeune. By way of these transport mechanisms, dissolved and soil-associated MC could be transported to habitats containing ecological receptors located downstream of MC loading areas at MCB Camp Lejeune, as identified in Section 4.1.3.

4.1.9.2. Groundwater Pathways

All water supply wells used for drinking water at MCB Camp Lejeune are located on the installation. All drinking water supply wells used for drinking water on the base, as well as the city of Jacksonville, are screened in the Castle Hayne aquifer. Since the shallow groundwater in the Surficial aquifer is not used as a drinking water source, MC that potentially enter the Surficial aquifer would not have a pathway for a human receptor. MC would need to migrate with groundwater into the Castle Hayne aquifer and in areas where water supply wells are located.

5. Surface Water Analysis Methods and Assumptions

Under REVA, screening-level models are used to estimate potential MC concentrations in surface water runoff at the edge of the MC loading areas. If this analysis predicts impacts at the edge of the loading area, then further calculations are performed to estimate the MC concentrations at a downstream receptor. Average annual surface water concentrations of the indicator MC (TNT, RDX, HMX, and perchlorate) are estimated based on the average annual MC loading of each indicator MC to each MC loading area. For MCB Camp Lejeune, the surface water screening-level analysis was carried out for the time period from 1950 to 2005. Section 3 provides more details on the assumptions for MC loading for MCB Camp Lejeune.

The estimation of MC concentrations in surface water assumes that a portion of the MC could enter the surface water by several mechanisms: 1) erosion of particulate or adsorbed MC in soil; 2) direct dissolution of MC in surface water runoff; and 3) connectivity of groundwater and surface water. At MCB Camp Lejeune, it was assumed that MC primarily enter surface water through either erosion or dissolution into surface water runoff.

The mass loading of the indicator MC on each identified operational range was estimated as described in Section 3. Based on the procedures defined in the *REVA Reference Manual* for surface water modeling, it was conservatively assumed that the entire annual MC load was uniformly mixed in the upper 6 inches of soil and was uniformly distributed across the loading area. Thus, the MC load present in the upper 6 inches of the soil was available for surface transport. A conservative, screening-level modeling approach was taken to estimate the annual average concentrations of MC in surface water runoff from the MC loading areas. Results of the surface water screening-level analysis were compared to the REVA trigger values (Table 5-1) to evaluate the potential for MC releases to off-range receptors. The REVA trigger values are applicable to all water sources (results of the groundwater screening-level analyses were also compared to these REVA trigger values). The screening-level analysis method is described briefly in the following sections. Additional details on the method are provided in the *REVA Reference Manual* (HQMC, 2006).

Table 5-1.
REVA Trigger Values for MC

MC	Trigger Value (µg/L)
RDX	0.16
TNT	0.08
HMX	0.08
Perchlorate	0.98

Note: µg/L – micrograms per liter

5.1. Losses to Surface Water in Target (Impact) Areas

The primary transport mechanisms at MCB Camp Lejeune were assumed to be erosion and direct dissolution into surface water runoff. The manner in which these mechanisms are quantified is discussed in this section.

5.1.1. Erosion

The amount of soil eroded was estimated using the Revised Universal Soil Loss Equation (RUSLE), which incorporates the major factors affecting erosion to predict the rate of soil loss in mass per area per year. The RUSLE is expressed as follows:

$$A = RKLSCP$$

Where: A = predicted soil loss, metric tons per hectare per year
R = rainfall and runoff factor
K = soil erodibility factor
LS = topographic factor (factor influenced by length and steepness of slope)
C = cover and management factor
P = erosion control practice factor

These factors were estimated for each modeled MC loading area using available information, such as soil type from the USDA SCS soil survey of Onslow County, NC (1992), land use, land cover, and topography. The estimated amount of soil eroded from the MC loading area was used to calculate the mass of MC transported with the eroded soil from MC loading areas to downstream receptors. Estimation of the soil erosion to calculate transported MC mass is especially important for MC that strongly adsorb to soil (such as TNT). Table 5-2 lists the parameter values used in estimating soil erosion.

Table 5-2.
Parameters Used to Estimate Soil Erosion

MC Loading Area	R[a]	K[b]	LS[c]	C[d]	P[e]	A (kg/m^2/day)
G-10 Impact Area	275	0.10	0.11	0.15	1.00	1.22E-04
K-2 Impact Area	275	0.19	0.11	0.15	1.00	2.25E-04
F-5	275	0.10	0.10	0.3	1.00	2.36E-04
F-2 Field Firing Range	275	0.10	0.10	0.3	1.00	2.36E-04
Musketry Range A	275	0.10	0.10	0.3	1.00	2.36E-04
F-14 Field Firing Range	275	0.16	0.11	0.009	1.00	1.18E-05
F-6	275	0.10	0.11	0.2	1.00	1.63E-04
L-Impact Area	275	0.17	0.12	0.005	1.00	7.57E-06
L-Ranges	275	0.12	0.32	0.3	1.00	9.05E-04
Combat Town	275	0.10	0.21	0.005	1.00	7.99E-06
M-10 Range	275	0.10	0.22	0.005	1.00	8.42E-06
M-115 Range	275	0.20	0.22	0.005	1.00	1.69E-05

Note:
Kg/m2/day – kilograms per square meter per day
R –rainfall and runoff factor
K – soil erodibility factor
LS – topographic factor (influence of length and steepness of slope)
C –cover and management factor
P – erosion control practice factor
A – predicted soil loss

[a] Brady, 1984
[b] NRCS, 1994
[c] Slope length and gradient were used to select LS values from Ontario Agriculture and Food, 2000.
[d] Highest crop factor with no tillage was selected to account for erosion due to sparsely vegetated cover and higher soil disturbances at target areas (Brady, 1984).
[e] Highest factor used due to the unknown erosion control practice implemented at MC loading areas.

5.1.2. Surface Water Runoff

Annual surface runoff rates were estimated by multiplying the annual precipitation rate with runoff coefficients. Runoff coefficients were selected from published tabular data based on soil hydrologic group, slope, and land cover of the MC loading area being analyzed (McCuen, 1989) (Table 5-3). Annual precipitation data were obtained from a weather station in Jacksonville, NC, for the period 1996-2005 and a weather station in New Bern, NC, for the period 1970-2005. Average yearly precipitation was evaluated from these two stations and was used to represent the yearly precipitation rate in the analysis. The average annual precipitation rate calculated from these data was 72.5 inches/year (1.84 meters/year).

Table 5-3.
Soil Types and Hydrologic Properties of MC Loading Areas

MC Loading Areas	Land Use	Predominant Soil Types	Hydrologic Soil Group	Soil Organic Content (%)[a]	Soil Bulk Density (kg/m^3)[a]	Runoff Coefficient[b]	Annual Recharge (% of precip)[c]
G-10 Impact Area	Vacant / shrub and scrub	Ln, KuB, and Mu	Groups A/D	7.45	1,500	0.1	30
K-2 Impact Area	Vacant / shrub and scrub	MaC and Mk	Groups B/D	0.75	1,500	0.1	30
F-5	Vacant	BmB	Group A	0.75	1,670	0.1	30
F-2 Field Firing Range	Vacant	BmB	Group A	0.75	1,670	0.1	30
Musketry Range A	Vacant	BmB	Group A	0.75	1,670	0.1	30
F-14 Field Firing Range	1% crop, 2% vacant, 97% forest with mixed pine and hardwood	Mk, MaC, and BmB	Groups A/B/D	0.75	1,670	0.081	30
F-6	70% vacant, 30% forest with mixed pine and hardwood	KuB	Group A	1.00	1,700	0.085	30
L-Impact Area	Pine and hardwood forest	MaC	Group B	0.75	1,500	0.05	30
L-Ranges	Vacant	KuB, MaC, and BmB	Groups A/B	0.75	1,620	0.05	30
Combat Town	Built up – nonresidential	KuB	Group A	0.75	1,700	0.7	30
M-10 Range	Forest	Da	Group D	0.75	450	0.1	30
M-115 Range	Forest	NoB	Group B	1.25	1,650	0.05	30

Note:
BmB – Baymeade-Urban land complex
Da – Dorovan muck
kg/m^3 – kilograms per cubic meter
KuB – Kureb fine sand
Ln – Leon fine sand
MaC – Marvyn loamy fine sand
Mk – Muckalee loam
Mu – Murville fine sand
NoB – Norfolk loamy fine sand
precip – precipitation

[a] USDA SCS, 1992
[b] McCuen, 1998
[c] Estimated annual average to surficial aquifer at MCB Camp Lejeune (Baker, 1994, 2001, and 2002)

5.1.3. Partitioning into Surface Water

A multimedia partitioning model, CalTOX, was used to estimate the mass of MC transported from surface soil to surface water runoff. This model simulates the major transport mechanisms (erosion of adsorbed MC in soil and direct dissolution in runoff and leaching to the subsurface environment) that are likely to affect MC from their point of origin in surface soils to their release into surface water runoff. The rate at which MC will partition between these media is dependent upon both the chemical properties of the MC and the physical/hydrological properties of the site. CalTOX requires the input of both landscape properties of the MC loading areas (Tables 5-2 and 5-3) and chemical properties of the compounds of interest (Tables 5-4 and 5-5). Values of landscape and chemical properties were selected based on local reports, soil surveys, mapping information, and scientific literature. Estimates of soil erosion and surface water runoff were calculated as described in previous sections and entered into CalTOX.

Table 5-4.
Chemical Properties of MC

MC	Molecular Weight (g/mol)	K_{ow} [a,b]	Melting Point (K)[a]	Vapor Pressure (Pa)[a]	Solubility (mol/m^3)[a]	Henry's Law Constant ($Pa\text{-}m^3/mol$)	Half-life in Surface Soil (days)
RDX	222.1	7.24	477.25	5.47E-07	1.90E-01	2.67E-06	2.5E+06[c]
TNT	227.1	72.4	354.00	1.47E-04	5.72E-01	2.40E-02	1.0E+07[d]
HMX	296.2	1.15	551.15	4.40E-12	1.69E-02	2.63E-10	1.2E+06[c]
Perchlorate	99.4	1.45E-06	571.09	3.75E-09	2.01E+03	Calculated by model[e]	1.0E+07[d]

Note:
g/mol – grams per mole
K – Kelvin
K_{ow} – Octanol-water partition coefficient
mol/m^3 – moles per cubic meter
Pa – Pascals
Pa- m^3 /mole – Pascal cubic meters per mole

[a] Walsh et al, 1995
[b] Meylan and Howard, 1995
[c] Value was obtained from the Multimedia Environmental Pollutant Assessment System model parameter.
[d] No reported values were available; input variables used are based on conservative assumptions. Diffusion coefficient in air used was 7.0E-0.2 m^2/day, and diffusion coefficient in water used was 1.0E+0.5 m^2/day.
[e] CalTOX includes an option for estimating the Henry's law constant from the chemical vapor pressure and solubility values.

Table 5-5.
Organic Carbon Fraction (f_{oc}), MC Organic Carbon Partition Coefficients (K_{OC}), and MC Soil Partition Coefficients (K_D) at MCB Camp Lejeune

MC Loading Area	f_{oc} (%)[a]	MC	K_{oc} (mL/g) [b]	K_D (mL/g) [c]
G-10 Impact Area	7.45E+00	HMX	5.52E-01	4.11E-02
		RDX	3.48E+00	2.59E-01
		TNT	3.48E+01	2.59E+00
		Perchlorate	6.94E-07	5.17E-08
K-2 Impact Area	7.50E-01	HMX	5.52E-01	4.14E-03
		RDX	3.48E+00	2.61E-02
		TNT	3.48E+01	2.61E-01
		Perchlorate	6.94E-07	5.21E-09
F-5	7.50E-01	HMX	5.52E-01	4.14E-03
		RDX	3.48E+00	2.61E-02
		TNT	3.48E+01	2.61E-01
		Perchlorate	6.94E-07	5.21E-09
F-2 Field Firing Range	7.50E-01	HMX	5.52E-01	4.14E-03
		RDX	3.48E+00	2.61E-02
		TNT	3.48E+01	2.61E-01
		Perchlorate	6.94E-07	5.21E-09
Musketry Range A	7.50E-01	HMX	5.52E-01	4.14E-03
		RDX	3.48E+00	2.61E-02
		TNT	3.48E+01	2.61E-01
		Perchlorate	6.94E-07	5.21E-09
F-14 Field Firing Range	7.50E-01	HMX	5.52E-01	4.14E-03
		RDX	3.48E+00	2.61E-02
		TNT	3.48E+01	2.61E-01
		Perchlorate	6.94E-07	5.21E-09
F-6	1.00E+00	HMX	5.52E-01	5.52E-03
		RDX	3.48E+00	3.48E-02
		TNT	3.48E+01	3.48E-01
		Perchlorate	6.94E-07	6.94E-09
L-Impact Area	7.50E-01	HMX	5.52E-01	4.14E-03
		RDX	3.48E+00	2.61E-02
		TNT	3.48E+01	2.61E-01
		Perchlorate	6.94E-07	5.21E-09
L-Ranges	7.50E-01	HMX	5.52E-01	4.14E-03
		RDX	3.48E+00	2.61E-02
		TNT	3.48E+01	2.61E-01
		Perchlorate	6.94E-07	5.21E-09

MC Loading Area	f_{oc} (%)[a]	MC	K_{oc} (mL/g) [b]	K_D (mL/g) [c]
Combat Town	7.50E-01	HMX	5.52E-01	4.14E-03
		RDX	3.48E+00	2.61E-02
		TNT	3.48E+01	2.61E-01
		Perchlorate	6.94E-07	5.21E-09
M-10 Range	7.50E-01	HMX	5.52E-01	4.14E-03
		RDX	3.48E+00	2.61E-02
		TNT	3.48E+01	2.61E-01
		Perchlorate	6.94E-07	5.21E-09
M-115 Range	1.25E+00	HMX	5.52E-01	6.90E-03
		RDX	3.48E+00	4.35E-02
		TNT	3.48E+01	4.35E-01
		Perchlorate	6.94E-07	8.68E-09

Note: mL/g – milliliters per gram
[a]USDA SCS, 1992
[b]Estimated in CalTOX model from the chemical octanol-water partition coefficient
[c]Estimated in CalTOX model from the chemical organic carbon partition coefficient and the soil organic carbon fraction on site

The CalTOX output of interest for the surface water screening-level analysis was the MC mass transferred from surface soil to surface water, which CalTOX expresses as an average daily load in grams per day. This daily mass transfer rate was divided by the daily runoff volume to estimate the MC concentration in surface water runoff at the edge of the MC loading area, prior to down gradient mixing/dilution in streams. Although CalTOX requires input of daily loading rates, the MC mass loading is available only as annual values. For this reason, the model has an effective time step of one year, and the results are interpreted as annual average concentrations in surface water runoff.

For MC that have elevated soil partition coefficient values, such as TNT and RDX, the residual mass in surface soil after each time step (one year) was calculated as the product of the MC partition coefficient, the dissolved MC concentration in runoff, and the mass of the surface soil. This provided an estimate of the mass of MC that would be sorbed to the surface soil compartment assuming sorption equilibrium. The estimated residual MC mass was added to the “new” MC loading to surface soil for the following year.

5.2. Estimation of MC Concentration Potentially Entering New River and Intracoastal Waterway at MCB Camp Lejeune Boundary

MC loading areas within MCB Camp Lejeune drain to streams that ultimately drain into the New River and the Intracoastal Waterway. Both the New River and the Intracoastal Waterway are tidally influenced and flow along the installation boundary. For MC

loading areas where MC concentrations in surface water runoff at the edge of the MC loading area were estimated to be above the REVA trigger value, a simple approach was used to estimate potential concentrations in surface water runoff entering the New River and the Intracoastal Waterway.

To estimate potential MC concentrations entering the New River and the Intracoastal Waterway, an approach was taken to estimate the order of magnitude of reduction in the concentrations at MC loading area boundaries that would be expected to be caused by down gradient mixing with runoff from non-loading areas. Estimated concentrations at the edge of MC loading areas were multiplied by the ratio of the loading area to the subwatershed area in which the MC loading area is located. The down gradient, mixed concentrations entering the New River and the Intracoastal Waterway at MCB Camp Lejeune boundary were estimated as an area weighted sum of the concentrations from the individual loading areas draining to the tidal creeks:

$$C_{mixed} = [\sum (C_{runoff} \times A_L)] / A_D$$

Where: C_{mixed} = postmixed concentrations entering the New River and the Intracoastal Waterway at MCB Camp Lejeune boundary (µg/L)

C_{runoff} = concentration in runoff from loading areas (µg/L)

A_L = area receiving MC loading (m^2)

A_D = Drainage area up gradient of streams entering the New River or the Intracoastal Waterway at the MCB Camp Lejeune boundary (m^2)

Inherent in this method is the assumption that all areas other than MC loading areas contribute runoff that has negligible MC concentrations. This provides a simple estimate of the potential for estimated concentrations to be reduced by mixing with other runoff prior to entry into major tidal water bodies, such as the New River embayment and the Intracoastal Waterway.

6. Groundwater Analysis Methods and Assumptions

The purpose of the groundwater screening-level analysis in the REVA program is to make best use of the available information to infer whether indicator MC can be transported in groundwater from MC loading areas to receptors. Both conceptual and quantitative methods are used. The first step in the groundwater analysis is the development of a CSM of MC transport, including a description of the groundwater flow system and identification of groundwater receptors. Even without additional modeling, the CSM provides a great deal of insight into the potential for MC to reach receptors. The general CSM for MCB Camp Lejeune is presented in Section 4 with specific CSMs for individual ranges and training areas discussed in Section 7.

After development of the CSM, quantitative screening-level analysis methods were used at selected ranges, in accordance with the groundwater analysis approach described in the *REVA Reference Manual* (HQMC, 2006). The quantitative methods used in REVA are considered screening-level models. They rely on multiple conservative assumptions, are more likely to overestimate than underestimate MC concentrations, and are used solely to determine whether or not particular ranges merit additional investigation. The groundwater screening-level analysis methods employed for MCB Camp Lejeune are discussed below.

6.1. REVA Groundwater Analysis Procedure

The first step in analyzing groundwater characteristics is an initial analysis of the MC loading rate and the annual groundwater recharge rate. The analysis calculates the concentration of MC in recharge water by assuming all MC loaded in a given year are dissolved in the groundwater recharge water volume of that year. This conservative approach estimates a greater potential concentration in the infiltrating water than would exist in reality since MC are not completely soluble in water (except for perchlorate) and their solubility further decreases when in mixtures. Further, most of the indicator MC compounds have a high rate of decay and a greater affinity to the soil particles than to water passing through the soil. Perchlorate is the only recalcitrant (persistent) indicator MC that does not readily degrade, is miscible (completely soluble) in water, and does not sorb to solid soil particles. Also, this analysis assumes that there is no removal of MC in the surface water runoff or other means. If this initial, highly conservative analysis indicates the potential for an indicator MC to have a potential concentration in the infiltrating water above the REVA trigger values (Table 5-1), a more detailed screening-level modeling analysis is done for that MC using the models outlined in the *REVA*

Reference Manual (HQMC, 2006). The REVA trigger values are applicable to all water sources, including surface water.

The initial groundwater analysis is performed as a spreadsheet-based mass balance calculation. The basic input data are the estimated average annual MC loading rates at each identified MC loading area and the estimated infiltration as a percentage of average annual precipitation. Precipitation data from Jacksonville, NC, (data from 1996 to 2005) and New Bern, NC, (data from 1970 to 2005) were averaged to estimate the total average annual precipitation (72.5 inches) for the operational ranges being assessed. An infiltration rate of 30% was selected based on reported annual recharge to the Surficial aquifer at MCB Camp Lejeune (Baker, 1994, 2001, and 2002). All MC loaded to the ground surface are assumed to dissolve instantaneously in the infiltrating rainwater.

The result of the above mass balance analysis is a maximum possible concentration of MC in the infiltrating water. If the concentration is below the REVA trigger value (Table 5-1), the loading area is eliminated from further analysis. For those areas with potential MC concentrations greater than the REVA trigger values in the infiltrating water, the next step of the REVA process is to perform a screening-level modeling analysis of the transport of MC from the ground surface through the vadose zone to the groundwater table. The model used to estimate the MC transported through the vadose zone is called VLEACH and includes the following transport mechanisms: advection in the liquid phase and diffusion in the vapor phase. In all cases, conservative parameters were used to ensure that the model overpredicted the concentration of MC arriving at the water table. Tables 6-1 and 6-2 list the model parameters used for each MC loading area and MC.

Table 6-1.
Soil Characteristics For VLEACH Model

MC Loading Areas	Predominant Soil Types	Fraction of Organic Carbon, f_{oc} (%)	Bulk Density (kg/m^3)	Vadose Zone Thickness (m)	Effective Porosity, n (unitless)
G-10 Impact Area	KuB, Mu	0.75	1,500	1.95	0.33
K-2 Impact Area	MaC, Mk	0.75	1,500	1.37	0.33
F-5, F-2 Field Firing Range, and Musketry Range A	BmB	0.75	1,670	3.05	0.33
F-14 Field Firing Range	Mk, MaC, BmB	0.75	1,670	3.05	0.33
F-6	KuB	1	1,700	3.05	0.33
L-Impact Area	MaC	0.75	1,500	1.37	0.33
L-Ranges	KuB, MaC, BmB	0.75	1,617	1.37	0.33
Combat Town	KuB	0.75	1,700	1.95	0.33
M-10 Range	Da	0.75	450	1.37	0.33
M-115 Range	NoB	1.25	1,650	1.37	0.33

Note:

BmB – Baymeade-urban land complex
Da – Dorovan muck
KuB – Kureb fine sand
MaC – Marvyn loamy fine sand
Mk – Muckalee loam
Mu – Murville fine sand
NoB – Norfolk loamy fine sand
kg/m^3 – kilograms per cubic meter
m - meters

Table 6-2.
Chemical Properties of MC

MC	K_{ow} [a,b]	Solubility (mol/m^3)	Henry's Law Constant (unitless)	Diffusion Coefficient in Air[d] (m^2/day)	Diffusion Coefficient in Water[c] (m^2/day)
TNT	72.4	0.572	9.68E-06	0.07	1.0E+05
RDX	72.4	0.189	1.08E-09	0.07	1.0E+05
HMX	1.15	0.169	1.06E-13	0.07	1.0E+05
Perchlorate	1.45E-06	2.01E+03	7.50E-16 [d]	0.07	1.0E+05

Note:
K_{ow} = Octanol-water partition coefficient
[a] Walsh et al., 1995
[b] Meylan and Howard, 1995
[c] No reported values available; input variables are based on conservative assumptions
[d] Calculated by CalTOX (model gives the option of estimating Henry's Law constant from the chemical vapor pressure and solubility values).
mol/m^3 – moles per cubic meter
m^2/day – square meters per day

According to the REVA groundwater screening-level analysis approach outlined in the *REVA Reference Manual* (HQMC, 2006), those sites that show no potential for arrival of MC at the water table with concentrations above the REVA trigger values are eliminated from further consideration. Those sites that do show the potential for the water table concentration above the trigger values are analyzed further using a saturated zone groundwater model. For most REVA evaluations where groundwater transport is first considered, the saturated groundwater model used for this phase of the groundwater analysis was BIOCHLOR, a simplistic two-dimensional transport model that estimates contaminant transport in a 1-dimensional horizontal flow field with retardation (sorption) and first-order decay. This type of model can only be used where the site groundwater conditions are simplistic. At a site such as MCB Camp Lejeune, this type of model cannot accurately predict potential MC transport due to the complexities of the hydrogeologic system, including pumping wells, stratified lithology, and vertical gradients.

Because of the complexities encountered when assessing the groundwater at MCB Camp Lejeune, two possible options were evaluated for continuation of the groundwater analysis and the determination of the possibilities for MC migrations off range. The first option required an advanced three-dimensional groundwater model, which would have required significant data, time, and resources to build and calibrate. The second option was groundwater sampling and hydraulic testing at two of the larger MC loading areas (G-10 and K-2 impact areas) in order to determine directly whether MC have migrated from the operational range areas. It was determined that groundwater sampling was the best option. The groundwater sampling results and hydraulic assessment data are presented in Section 9.

6.2. Groundwater Characteristics at Low-Lying Island and Peninsula Areas

Low-lying island and peninsula areas were considered low priority and were not modeled for shallow groundwater pathway impact. All of these areas are tidally influenced and completely surrounded by high salinity seawater. The topographic relief of the surface is relatively flat, with elevations not exceeding 6 ft above msl. However, the south/southeasterly portion of Brown's Island is comprised of hills with a sharp topographic relief consisting of elevations ranging from 12 to 44 ft above msl. Fresh groundwater, if it exists, is in the form of a very thin lens floating over the higher density salt water. The thickness of this fresh groundwater lens would vary based on the size of the island/peninsula area and the topographic high. The groundwater flow direction would follow the same general pattern: from the high centrally located areas, where the lens is the thickest, radially toward the coastline. However, because of the very low relief and strong tidal influence, it is likely that true fresh groundwater does not exist in the shallow subsurface at most of the island/peninsula operational ranges. In cases where

shallow fresh groundwater does exist, there are no current users or potential off-site human receptors because all shallow groundwater discharges directly into the surrounding saltwater bays.

The contact of fresh shallow groundwater with the underlying high density seawater acts as a hydraulic boundary. In other words, shallow groundwater cannot flow through this dense boundary toward the deeper aquifers, only along it, with the ultimate discharge zone at the coastline. Where the fresh groundwater lens is thick enough to connect with an underlying aquitard formation, it is still assumed that the groundwater flow would be horizontal along this contact and toward the coastal discharge zone. This is because of the absence of any groundwater withdrawal from deeper regional aquifers at the island/ peninsula operational ranges that would cause the vertical hydraulic gradients needed for potential vertical migration of shallow groundwater. There are no shallow groundwater receptors, and there is no complete groundwater pathway for either shallow or deep groundwater at the island/peninsula operational ranges.

7. Operational Range Training Areas

The operational ranges assessed in REVA include fixed ranges, live-fire maneuver areas, SARs, and training areas where military munitions are known or suspected to have been used. The areas assessed at MCB Camp Lejeune were based upon discussions with installation personnel and the data presented in the Training Range Sustainment Planning and TRI, 2003 NDAA Section 366 Report.

Although surface danger zones (SDZs) were available or could be estimated, these features were only used to assist in the determination of MC loading areas because the majority of fired military munitions are anticipated to have impacted at the target areas of the operational ranges or historical use areas within an operational range. The MC loading areas were more accurately defined based on GIS layers, aerial photography, direction of fire, flight patterns, and any additional information available on the operational range.

MCB Camp Lejeune maintains operational ranges within its boundaries and over the waters of its Atlantic Coast. The current uses of these operational ranges, as well as historical uses within the operational ranges, were assessed under REVA. The assessments for the operational ranges are presented in Sections 7.1 through 7.10. The section for each operational range area contains discussions on the operational range background, the CSM, MC loading areas, and screening-level modeling results (if applicable). Section 7.11 discusses the Marine Corps Outlying Fields – Oak Grove which was originally assessed as part of the MCAS Cherry Point REVA. However, it has been included here as the operation and control of this area has been transferred from MCAS Cherry Point to MCB Camp Lejeune. In addition, Section 8 provides a qualitative analysis of the MCB Camp Lejeune SARs.

7.1. G-10 Impact Area (Operational)

The operational G-10 Impact Area is located southeast of the main cantonment area of MCB Camp Lejeune and east of Sneads Ferry Road, in the center of Tactical Maneuver Training Area G (Figure 7-1). This multiuse operational impact area was first used in 1953, and its use continues today. Although this area is surrounded by operational tactical maneuver training area, residential and commercial areas exist beyond the northern and eastern boundaries of the installation, which are approximately 1.2 miles to the north and 1.7 miles to the east of the impact area.

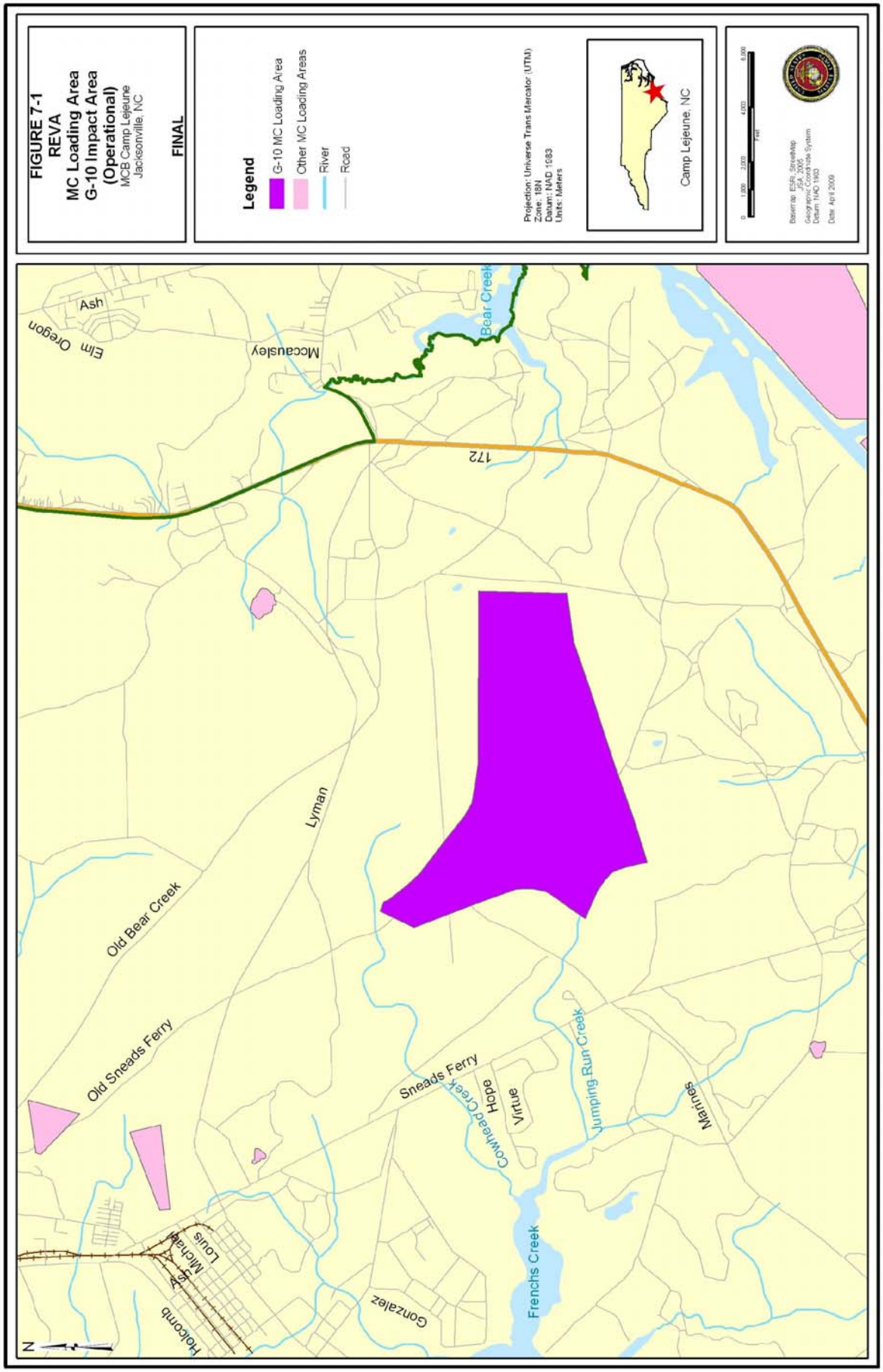


FIGURE 7-1
REVA
MC Loading Area
G-10 Impact Area
(Operational)
MCB Camp Lejeune
Jacksonville, NC
FINAL
Legend
G-10 MC Loading Area
Other MC Loading Areas
River
Road
Projection: Universe Trans Mercator (UTM)
Zone: 18N
Datum: NAD 1983
Units: Meters
Camp Lejeune, NC
0 1,000 2,000 4,000 6,000
Feet
Basemap: ESRI, StreetMap USA, 2005
Geographic Coordinate System
Datum: NAD 1983
Date: April 2009
Ash
Elm
Oregon
Mccausley
Bear Creek
172
Lyman
Old Bear Creek
Old Sneads Ferry
Sneads Ferry
Cowhead Creek
Hope
Virtue
Jumping Run Creek
Marines
Frenchs Creek
Gonzalez
Holcomb
St
Michael
Louis
N

The G-10 Impact Area MC loading area was delineated based on interviews with EOD and Range Control, who indicated that the highest density of military munitions exists at the central region of the G-10 Impact Area and that these high-density conditions begin approximately 1,640 ft to the inside of the G-10 Impact Area boundary. All MC loading was assumed to have been within the resulting 1,349-acre designated area. The loading period for the G-10 Impact Area MC loading area was from 1953 to present. According to Range Control's military munitions expenditure data, operational ranges currently firing into the G-10 Impact Area include G-3, G-3 .50-Caliber, G-3 TOW, G-5, G-5 (LC), G-6, G-6 (CBC), G-7, G-8, G-9, G-10A, G-10 Fixed, and G-10 Helo. In addition, all gun positions, mortar positions, naval gunfire, observation posts, and R5306D[6] expenditures are assumed to have occurred within the G-10 Impact Area.

7.1.1. MC Loading

The MC loading area for the G-10 Impact Area is shown in Figure 7-1. The MC Loading Rate Calculator was used to estimate the amount of MC loaded at this MC loading area over time. The MC loading amounts estimated for each identified time period during which the impact area was operated (time periods C, D, and E) are listed in Table 7-1. The resulting annual MC loading rate was extrapolated backward to the range's inception. Since the G-10 Impact Area was first used in 1953, there was no MC loading prior to 1953.

Table 7-1.
Estimated Annual MC Loading for the G-10 Impact Area

MC Loading Area	Period	Begin Use	End Use	HMX (kg/m^2)	RDX (kg/m^2)	TNT (kg/m^2)	Perchlorate[a] (kg/m^2)
G-10 Impact Area	C (1938-1976)	1953	1976	1.52E-07	3.29E-05	3.82E-05	4.07E-08
	D (1977-1988)	1977	1988	1.15E-07	8.27E-06	1.02E-05	1.92E-08
	E (1989-Present)	1989	Present	1.44E-07	1.03E-05	1.27E-05	2.40E-08

Note:
[a] Perchlorate was only used in military munitions after 1962.

7.1.2. Range-Specific CSM

The range specific CSM information for the G-10 Impact Area MC loading area is presented in the following sections.

[6] R5306D is airspace; these expenditures are Marine Corps air support requests called in by observation posts.

7.1.2.1. Geography and Topography

The G-10 Impact Area covers a large portion of the eastern side of MCB Camp Lejeune, most of which consists of relatively flat Talbot surface at elevations of 25-50 ft above msl. The area includes small topographic depressions.

7.1.2.2. Surface Water Features

The eastern portion of the G-10 Impact MC loading area drains within the subwatershed of Bear Creek upstream of its confluence with the Intracoastal Waterway (Figure 7-2). Within this subwatershed, the loading area drains east into Mill Creek, which joins with Bear Creek and discharges into the Intracoastal Waterway. The remaining large portion of the G-10 Impact MC loading area drains within the subwatershed of the New River between Town Creek and Stones Bay. Within this subwatershed, the loading area drains westward to Jumping Run Creek. Jumping Run Creek then drains into French Creek, which discharges into the New River between Town Creek and Stones Bay.

7.1.2.3. Soil Characteristics and Land Cover

The G-10 Impact Area consists primarily of bare ground (military operations area) and pocosin. The predominant soils are sandy soils of the Leon-Murville-Kureb association. However, some lower areas are underlain by mucky soils of the Croatan series.

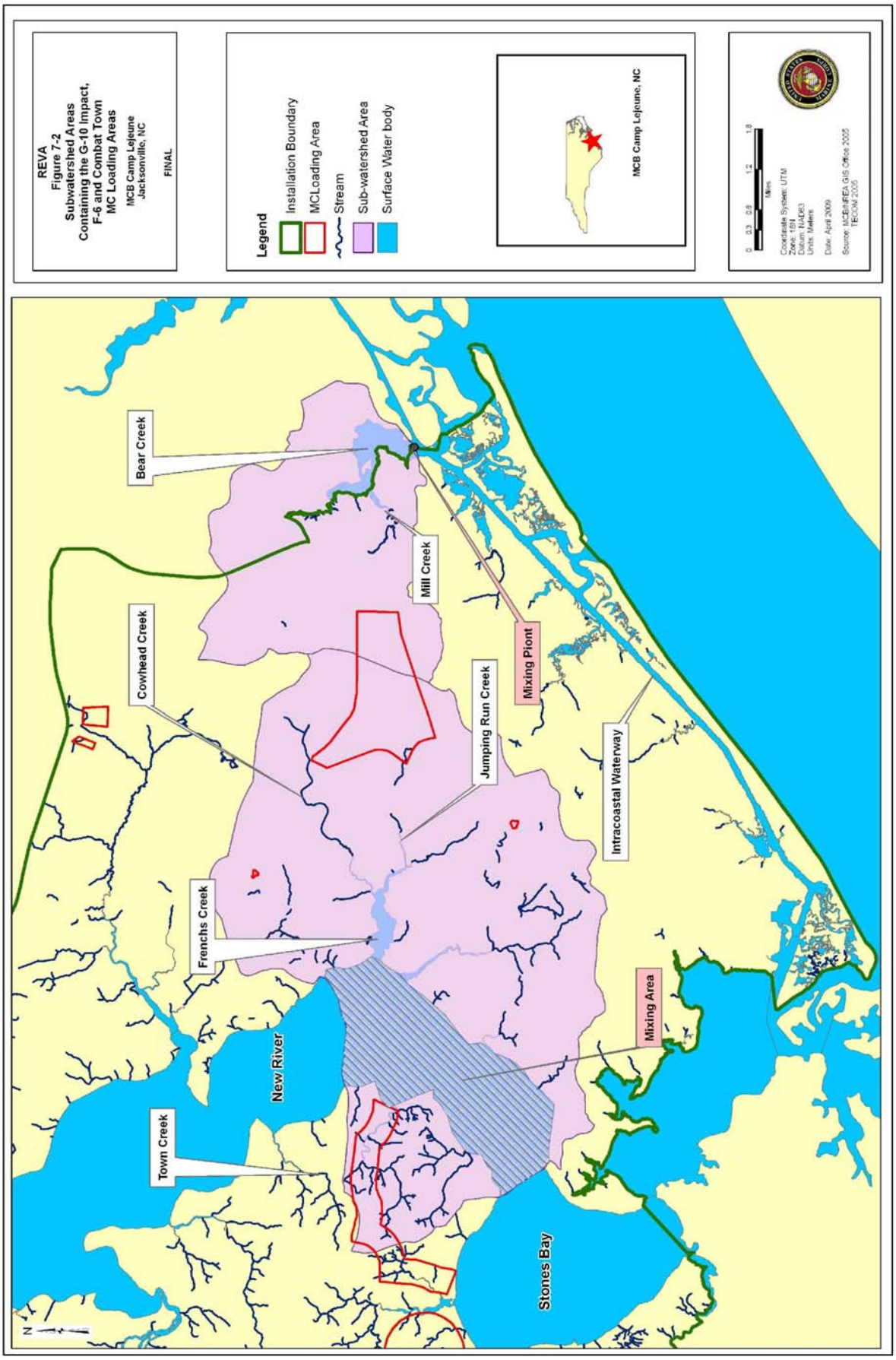
7.1.2.4. Erosion Potential

The erodibility of the G-10 Impact Area MC loading area is moderate due to the combination of flat topography and low to moderate erodibility soils with localized disturbance of soil.

7.1.2.5. Groundwater Characteristics

The operational MC loading area for the G-10 Impact Area is located on the eastern side of the New River. In 2003, the USGS began a study to examine groundwater flow in the Surficial aquifer at the G-10 Impact Area and the K-2 Impact Area to provide MCB Camp Lejeune with information needed to optimize the placement of monitoring wells near these areas. Below is a summary of the USGS findings, as well as information gathered during REVA.

Since the USGS could not access the interior of the impact areas for safety reasons, it was not possible to install monitoring wells and collect water level data directly from the interior of these areas. Therefore, the USGS developed an approach for estimating water elevations in the interior of these locations. The water table contour maps produced by the USGS are considered qualitative.


REVA
Figure 7-2
Subwatershed Areas
Containing the G-10 Impact,
F-6 and Combat Town
MC Loading Areas
MCB Camp Lejeune
Jacksonville, NC
FINAL
Legend
Installation Boundary
MCLoading Area
Stream
Sub-watershed Area
Surface Water body
MCB Camp Lejeune, NC
0 0.3 0.6 1.2 1.8
Miles
Coordinate System: UTM
Zone: 18N
Datum: NAD83
Units: Meters
Date: April 2009
Source: MCB/NREA GIS Office 2005
TECOM 2005
Bear Creek
Mill Creek
Cowhead Creek
Mixing Piont
Jumping Run Creek
Intracoastal Waterway
Frenchs Creek
Mixing Area
New River
Town Creek
Stones Bay
N

Based on the hydrogeologic framework developed for MCB Camp Lejeune by Cardinell and others (1993), the thickness of the Surficial aquifer is estimated to vary from about 10 to 70 ft at the G-10 Impact Area. Monitoring wells installed around the perimeter of this area during the USGS study indicated the presence of silty fine sand, clay, and sandy clay to depths of 20 ft below ground surface (bgs) (Harden and others, 2004). Figure 4-4 illustrates a hydrogeologic section across MCB Camp Lejeune passing between the G-10 and K-2 impact areas.

7.1.2.6. Area Hydrogeology (Aquifers and Aquitards)

The Castle Hayne confining unit isopach map developed by Cardinell and others (1993) indicates that the confining unit underlying the Surficial aquifer at the G-10 Impact Area is approximately 5 ft thick; however, detailed information is insufficient to determine if the confining unit is laterally continuous through this impact area. The elevation of the top of the Castle Hayne aquifer at the G-10 Impact Area ranges from about 5 ft below msl near the northern boundary to about 25 ft below msl near the southern boundary. The Castle Hayne aquifer is more than 400 ft thick at the G-10 Impact Area. Cardinell and others (1993) indicate that the upper part of the Castle Hayne aquifer in the MCB Camp Lejeune area primarily consists of calcareous sand that contains some beds of clay and silt. Consolidated limestone and sandy limestone inter-bedded with clay and sand are in the lower part of the aquifer.

Recharge to the Surficial aquifer at the G-10 Impact Area occurs from precipitation. Theoretically, some of the groundwater in the Surficial aquifer may move downward into the Castle Hayne aquifer depending on the existence of the Castle Hayne confining unit (i.e., in areas beneath the New River as discussed in Section 4). The movement of groundwater between the Surficial and Castle Hayne aquifers is controlled by the magnitude of vertical gradients between the aquifers and by the hydraulic conductivity of the Castle Hayne confining unit. Cardinell and others (1993) estimated the vertical hydraulic conductivity to range from 0.0014 to 0.41 ft/day and indicated that the confining unit may only partially restrict the vertical flow of groundwater between the Surficial and Castle Hayne aquifers. However, as part of their study, the USGS evaluated water level records at MCB Camp Lejeune and reported that there is no significant hydraulic connection between the Surficial aquifer and the Castle Hayne aquifer as described in the following discussions. Long-term water level data for the period of October 1994 through September 2004 at selected MCB Camp Lejeune wells were used to examine trends in groundwater fluctuations. Water level data were examined from wells located west of the New River, including a well in the Surficial aquifer and a well pair in the Surficial aquifer and Castle Hayne aquifer, respectively. East of the New River, water level data were examined from a well in the Castle Hayne aquifer and a well pair in the Surficial and Castle Hayne aquifers, respectively. Evaluation of the water level data at the wells in the Surficial aquifer indicated no significant temporal trends, while water level data evaluated for the Castle Hayne aquifer indicated a decline in water

levels. This is likely the result of the removal of groundwater by local pumping of the Castle Hayne aquifer. A more detailed discussion of the hydrogeologic setting at MCB Camp Lejeune is presented in reports by Harned and others (1989), Harden and others (2004), and Cardinell and others (1993).

7.1.3. Initial Groundwater Screening-Level Analysis

To determine the maximum MC concentrations potentially reaching the groundwater table at the MC loading areas, the estimated MC loading rates (Table 7-1) were divided by the infiltration rate of 30% of the total annual precipitation. As shown in Table 7-2, this initial mass loading screening-level analysis indicates that HMX, RDX, and TNT for time periods C, D, and E could possibly reach the water table at concentrations greater than the REVA trigger values.

Table 7-2.
Estimated Maximum Concentrations of MC in Infiltrating Water

Period	Begin Use	End Use	HMX (mg/L)	RDX (mg/L)	TNT (mg/L)	Perchlorate[a] (mg/L)
C (1938-1976)	1953	1976	2.77E-04	5.99E-02	6.96E-02	7.42E-05
D (1977-1988)	1977	1988	2.10E-04	1.51E-02	1.86E-02	3.50E-05
E (1989-Present)	1989	Present	2.62E-04	1.88E-02	2.31E-02	4.37E-05

Note:
mg/L – milligrams per liter
Yellow cells indicate exceedence of REVA trigger values (Table 5-1).
[a]Perchlorate was only used in military munitions after 1962.

7.1.4. Vadose Zone Modeling

Based on the result of the screening-level analysis above, REVA indicator MC were modeled in VLEACH to determine if they would reach the water table and, if so, at what estimated concentrations. Table 7-3 shows the results of this modeling effort, presenting the estimated soil water concentrations potentially entering the water table at the end of the final time period, based on the cumulative assessment of MC loading over time. See Appendix A for a summary of the model input parameters.

Table 7-3.
Vadose Zone Model Results: MC Concentrations Reaching Groundwater at the G-10 Impact Area

MC	Soil Water Concentration (mg/L)
HMX	2.62E-04
RDX	1.88E-02
TNT	2.31E-02
Perchlorate[a]	--

Note:
Yellow cells indicate exceedence of REVA trigger values (Table 5-1).
[a] Perchlorate did not exceed REVA trigger value and was not modeled.

All of the results are above the REVA trigger values, indicating that there is a potential for HMX, RDX, and TNT to reach the water table at a detectable concentration. As explained in Section 6, saturated zone modeling was not conducted and groundwater sampling was recommended instead of continuing with groundwater modeling because the complexities of the system precluded the use of a screening-level saturated flow groundwater model. The analysis of the groundwater samples did not detect MC in significant concentrations, and the hydraulic and geochemical testing indicated that there does not appear to be a significant hydraulic connection between the Surficial aquifer and the Castle Hayne aquifer near the G-10 MC loading area. Detailed results of the groundwater sampling are presented in Section 9.

7.1.5. Surface Water Screening-Level Analysis Result

A screening-level analysis of MC concentrations in surface water was conducted for the G-10 Impact MC loading area and its upstream drainages. A large portion of the G-10 Impact MC loading area drains west into Jumping Run, which drains into French Creek, which in turn discharges into the New River between Town Creek and Stones Bay (Figure 7-2). The remaining portion of the G-10 Impact MC loading area drains east into Mill Creek, which joins with Bear Creek and discharges into the Intracoastal Waterway (Figure 7-2). Surface water in and around MCB Camp Lejeune is not used as a drinking water supply; however, humans potentially use it for recreational purposes (including fishing) and it may contain ecological receptors.

The surface water screening-level analysis was conducted as described in Section 5 and was carried out for a time period ranging from 1953 to 2005. Table 7-4 presents the estimated percentage of MC mass contributed by individual loading areas to the New River between Town Creek and Stones Bay at the MCB Camp Lejeune installation boundary. The G-10 Impact Area MC loading area was predicted to contribute almost the entire total HMX and TNT mass (greater than 98%) and a significant portion of the total RDX mass draining into the New River between Town Creek and Stones Bay. The K-2 Impact Area MC loading area was predicted to contribute a significant portion of the total

perchlorate mass draining into the New River between Town Creek and Stones Bay. F-6 and Combat Town MC loading areas were predicted to contribute greater than 1% perchlorate mass and less than 1% HMX, RDX and TNT mass to the New River. The G-10 Impact MC loading area is the only MC loading area draining into the Intracoastal Waterway.

Table 7-4.
Screening-Level Estimate of Percent MC Mass Contributed by Individual MC Loading Areas into New River Downstream of Town Creek and Upstream of Stones Bay

MC	From G-10 Impact Area	From K-2 Impact Area	From F-6	From Combat Town
HMX	99.6	0.4	NA	0.0
RDX	81.3	18.1	0.6	0.0
TNT	98.2	1.6	0.1	0.0
Perchlorate	11.6	77.8	9.0	1.5

Note:
Data are provided in percent mass.

Table 7-5 presents the estimated average annual edge-of-loading-area concentrations in surface water runoff from the G-10 Impact MC loading area, as well as other upstream MC loading areas that drain into the New River between Town Creek and Stones Bay and the New River at Stones Bay. Based on surface water screening-level calculations, concentrations of HMX, RDX, and TNT, concentrations of RDX, TNT, and perchlorate, concentrations of RDX and TNT and concentration of RDX leaving the G-10 Impact Area, F-6, K-2 Impact Area, and L-Ranges MC loading areas are estimated to exceed the REVA trigger values.

Table 7-5.
Screening-Level Estimates of Annual Average Edge-of-Loading-Area MC Concentrations in Runoff (µg/L)

MC	From G-10 Impact Area	From K-2 Impact Area	From F-6	From Combat Town	From L-Ranges
HMX	**0.2**	1.6E-03	NA	7.5E-05	NA
RDX	**16**	**6.4**	**29**	0.01	**0.35**
TNT	**109**	**3.3**	**38**	0.017	5.5E-06
Perchlorate	0.03	0.4	**7.2**	0.014	0.02

Note:
NA – No loading estimate of the MC is available.
Shading and bold indicate that the predicted concentration is above the REVA trigger value.
µg/L – micrograms per liter

Table 7-6 presents the total subwatershed drainage areas containing G-10 Impact Area MC loading area as well as the MC loading areas contributing MC to the downstream receptor locations at the New River between Town Creek and Stones Bay and Bear Creek upstream of its confluence with the Intracoastal Waterway. The contributing MC loading areas and the total watershed drainage presented in Table 7-6 and the annual average edge of loading area concentrations presented in Table 7-5 include the specific inputs used in the equation presented in Section 5, which calculates the downstream mixed concentrations.

Table 7-6.
Total Watershed Drainages/Individual MC Loading Areas Contributing MC to the Downstream Receptor Locations at New River between Town Creek and Stones Bay and Bear Creek Upstream of its Confluence with Intracoastal Waterway

Watershed/ MC Loading Area	Area (acres)
Subwatershed of New River between Town Creek and Stones Bay	21,123
G-10 Impact Area MC loading area draining within the subwatershed of New River between Town Creek and Stones Bay	945
K-2 Impact Area MC loading area draining within the subwatershed of New River between Town Creek and Stones Bay	522
F-6 MC loading area draining within the subwatershed of New River between Town Creek and Stones Bay	3.6
Combat Town MC loading area draining within the subwatershed of New River between Town Creek and Stones Bay	5.9
Subwatershed of Bear Creek upstream of its confluence with Intracoastal Waterway	6,886
G-10 Impact Area MC loading area draining within the subwatershed of Bear Creek upstream of its confluence with Intracoastal Waterway	405

Tables 7-7 and 7-8 present the estimated MC concentrations in surface water entering the New River and the Intracoastal Waterway, following downstream mixing. Concentrations of RDX and TNT in surface water runoff entering the New River and the Intracoastal Waterway, after downstream mixing, were predicted to potentially exceed the REVA trigger values. However, the postmixing HMX and perchlorate concentrations entering the New River and the Intracoastal Waterway were estimated to be below the REVA trigger values.

Table 7-7.
Screening-Level Estimates of Annual Average MC Concentrations in Runoff Entering New River Downstream of Town Creek and Upstream of Stones Bay

MC	Postmixing Concentrations Entering New River (µg/L)
HMX	9.0E-03
RDX	**0.9**
TNT	**5.0**
Perchlorate	0.013

Note:
Shading and bold indicate that the predicted concentration is above the REVA trigger value.
µg/L – micrograms per liter

Table 7-8.
Screening-Level Estimates of Annual Average MC Concentrations in Runoff Entering the Intracoastal Waterway at the Confluence Point with Bear Creek

MC	Postmixing Concentrations Entering Intracoastal Waterway (µg/L)
HMX	0.012
RDX	**0.9**
TNT	**6.4**
Perchlorate	0.002

Note:
Shading and bold indicate that the predicted concentration is above the REVA trigger value.
NA – Not Applicable
µg/L – micrograms per liter

Although the postmixing concentrations of RDX and TNT in runoff reaching the New River and the Intracoastal Waterway were predicted to potentially exceed the REVA trigger values, actual concentrations are expected to be lower (potentially below detection levels) in these tidally influenced surface water bodies. The surface water screening-level analysis used a conservative approach where MC decay and tidal mixing were not taken into account, and these mechanisms are likely to reduce concentrations in the tidal water bodies. In response to these screening-level results, surface water sampling was carried out to evaluate the actual concentrations of MC in streams draining to the New River and the Intracoastal Waterway from the G-10 Impact Area MC loading area. These results are discussed in Section 9.

7.1.6. Potential Pathways

The screening-level modeling results indicate that HMX, RDX, and TNT have the potential to reach the water table at the G-10 Impact Area after being dissolved by the infiltrating rain. If dissolved MC reach the water table, they will continue flowing with groundwater according to existing gradients. Conceptually, groundwater in the Surficial aquifer flows from areas of high hydraulic head (in the interstream divides) toward areas of low hydraulic head (at the surface water discharge areas). At the G-10 Impact Area, groundwater in the Surficial aquifer flows radially from the interior areas toward the boundaries in all directions (Harden et al, 2004). The recent fieldwork at the G-10 Impact Area indicates that there does not appear to be a significant hydraulic connection between the Surficial and Castle Hayne aquifers near the G-10 Impact Area MC loading area (see Section 9).

The surface water screening-level analysis results indicated that postmixing concentrations of RDX and TNT are estimated to reach the New River and Intracoastal Waterway above the REVA trigger values. A large portion of the G-10 Impact Area MC loading area drains west into Jumping Run, which drains into French Creek, which in turn discharges into the New River between Town Creek and Stones Bay (Figure 7-2). The remaining portion of the G-10 Impact Area MC loading area drains east into Mill Creek, which joins with Bear Creek and discharges into the Intracoastal Waterway (Figure 7-2). All of these surface water bodies are potential surface water pathways.

7.1.7. Potential Receptors

There are no current users of shallow groundwater at MCB Camp Lejeune because all water supplies at the installation originate from water wells tapping the deeper aquifers (upper and lower Castle Hayne). Surface water in and around MCB Camp Lejeune is not used as a drinking water supply; however, humans potentially use it for recreational (including fishing) purposes. Additionally, streams draining from the G-10 Impact MC loading area drain near areas where federal T/E species including the red-cockaded woodpecker, rough-leaved loosestrife, and the American alligator have been documented to exist.

7.2. K-2 Impact Area (Operational)

The operational K-2 Impact Area is located southeast of Verona Loop Road and south of Rhodes Point Road (Figure 7-3). The K-2 Impact Area is bordered to the north and west by operational maneuver training areas and to the south and east by the New River. This multiuse operational impact area was first used in 1950, and its use continues today.

The K-2 Impact Area MC loading area was delineated based on interviews with EOD and Range Control, who indicated that the highest density of military munitions exists between 200 and 800 yards from the firing lines for the operational K-ranges, as these are

line-of-sight targets[7]. All MC loading was assumed to have been within the resulting 870-acre designated area. The loading period for the K-2 Impact Area MC loading area was from 1950 to present. According to Range Control's military munitions expenditure data, operational ranges currently firing into the K-2 Impact Area include: K-2A, K-211, K-212A, K-301, K-302, K-303, K-304, K-305, K-309, K-315, K-317, K-319, K-321, K-321A, K-322, K-323, K-325, K-402, K-402A, K-405, K-405A, K-406A, K-406B, K-407, and K-408.

7.2.1. MC Loading

The MC loading area for the K-2 Impact Area is shown in Figure 7-3. The MC Loading Rate Calculator was used to estimate the amount of MC loaded at this area over time. The MC loading amounts estimated for each identified time period during which the impact area was operated (time periods C, D, and E) are listed in Table 7-9. The resulting annual MC loading rate was extrapolated backward to the range's inception. Since the K-2 Impact Area was first used in 1950, there was no MC loading prior to 1950.

Table 7-9.
Estimated Annual MC Loading for the K-2 Impact Area

MC Loading Area	Period	Begin Use	End Use	HMX (kg/m^2)	RDX (kg/m^2)	TNT (kg/m^2)	Perchlorate[a] (kg/m^2)
K-2 Impact Area	C (1938-1976)	1950	1976	1.11E-09	4.49E-06	1.94E-06	2.90E-07
	D (1977-1988)	1977	1988	8.85E-10	3.59E-06	1.56E-06	2.32E-07
	E (1989-Present)	1989	Present	1.11E-09	4.49E-06	1.94E-06	2.90E-07

Note:
[a] Perchlorate was only used in military munitions after 1962.

7.2.2. Range-Specific CSM

The range-specific CSM information for the K-2 Impact Area MC loading area is presented in the following sections.

7.2.2.1. Geography and Topography

The K-2 Impact Area occupies a neck of upland on the western side of MCB Camp Lejeune, dissected by stream valleys. The upland is relatively flat, but the sides of the stream valleys are relatively steep (up to 15% slope).

[7] Line-of-sight target indicates the weapon system operator must see the target in order to fire at it, unlike activities being conducted at the G-10 Impact Area.

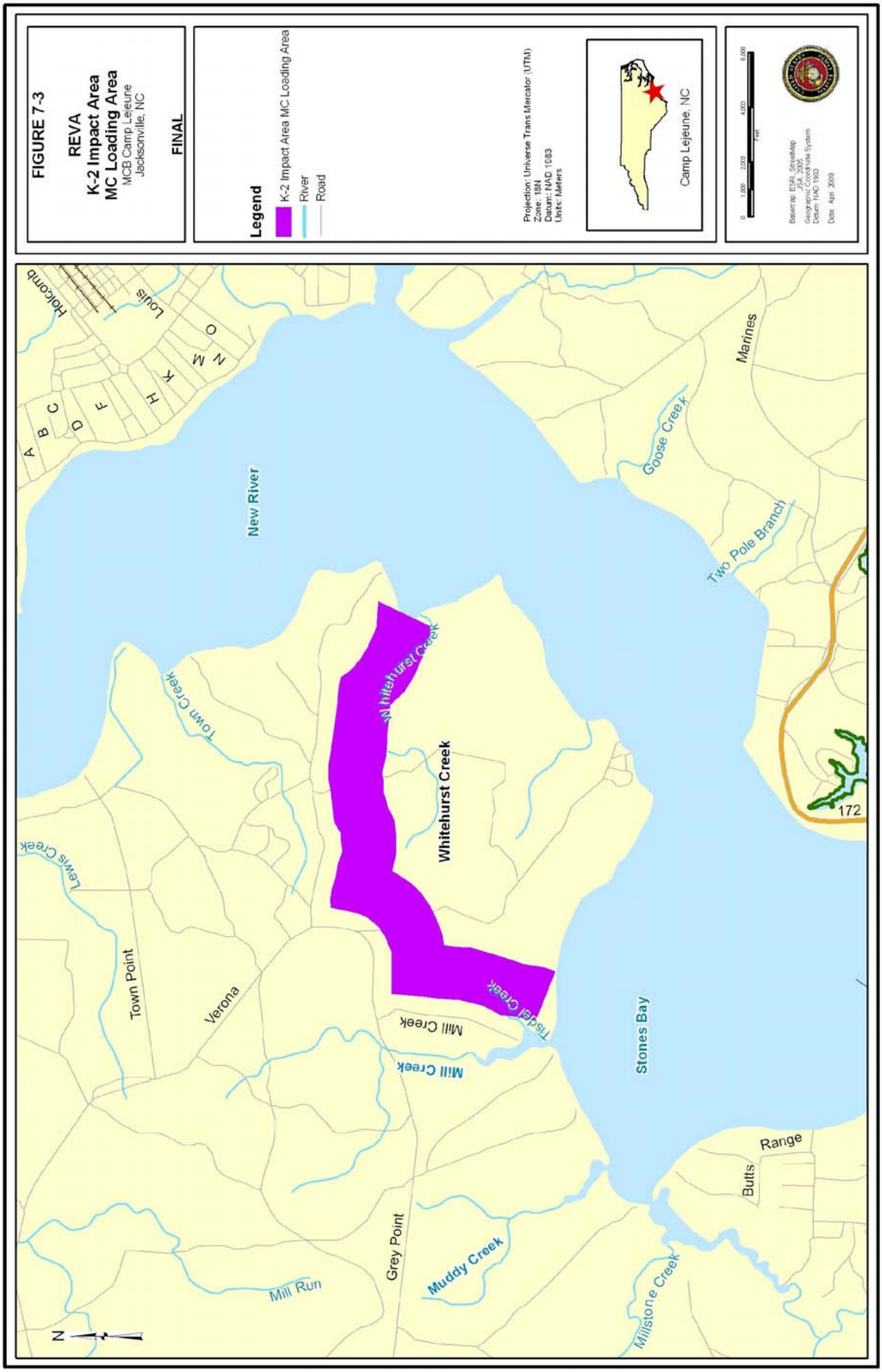


FIGURE 7-3
REVA
K-2 Impact Area
MC Loading Area
MCB Camp Lejeune
Jacksonville, NC
FINAL
Legend
K-2 Impact Area MC Loading Area
River
Road
Projection: Universe Trans Mercator (UTM)
Zone: 18N
Datum: NAD 1983
Units: Meters
Camp Lejeune, NC
0 1,000 2,000 4,000 6,000
Feet
Basemap: ESRI, StreetMap USA, 2005
Geographic Coordinate System
Datum: NAD 1983
Date: Apr, 2009
New River
Holcomb
Louis
A
B
C
D
F
H
K
M
N
O
Marines
Goose Creek
Two Pole Branch
Whitehurst Creek
Town Creek
Lewis Creek
Town Point
Verona
Mill Creek
Tisdale Creek
Stones Bay
Range
Butts
Grey Point
Muddy Creek
Mill Run
Millstone Creek
172
N

7.2.2.2. Surface Water Features

The eastern portion of the K-2 Impact MC loading area drains within the subwatershed of New River between Town Creek and Stones Bay (Figure 7-4). Within this subwatershed, a large part of the eastern portion of the K-2 Impact MC loading area drains to the New River embayment by way of Whitehurst Creek, which is perennial in its upper reaches and tidal in the middle and lower reaches. The remaining western portion of the K-2 Impact MC loading area drains within the subwatershed of the New River at Stones Bay. Within this subwatershed, the K-2 Impact MC loading area drains to the New River at Stones Bay by way of an unnamed tidal tributary of Mill Creek.

7.2.2.3. Soil Characteristics and Land Cover

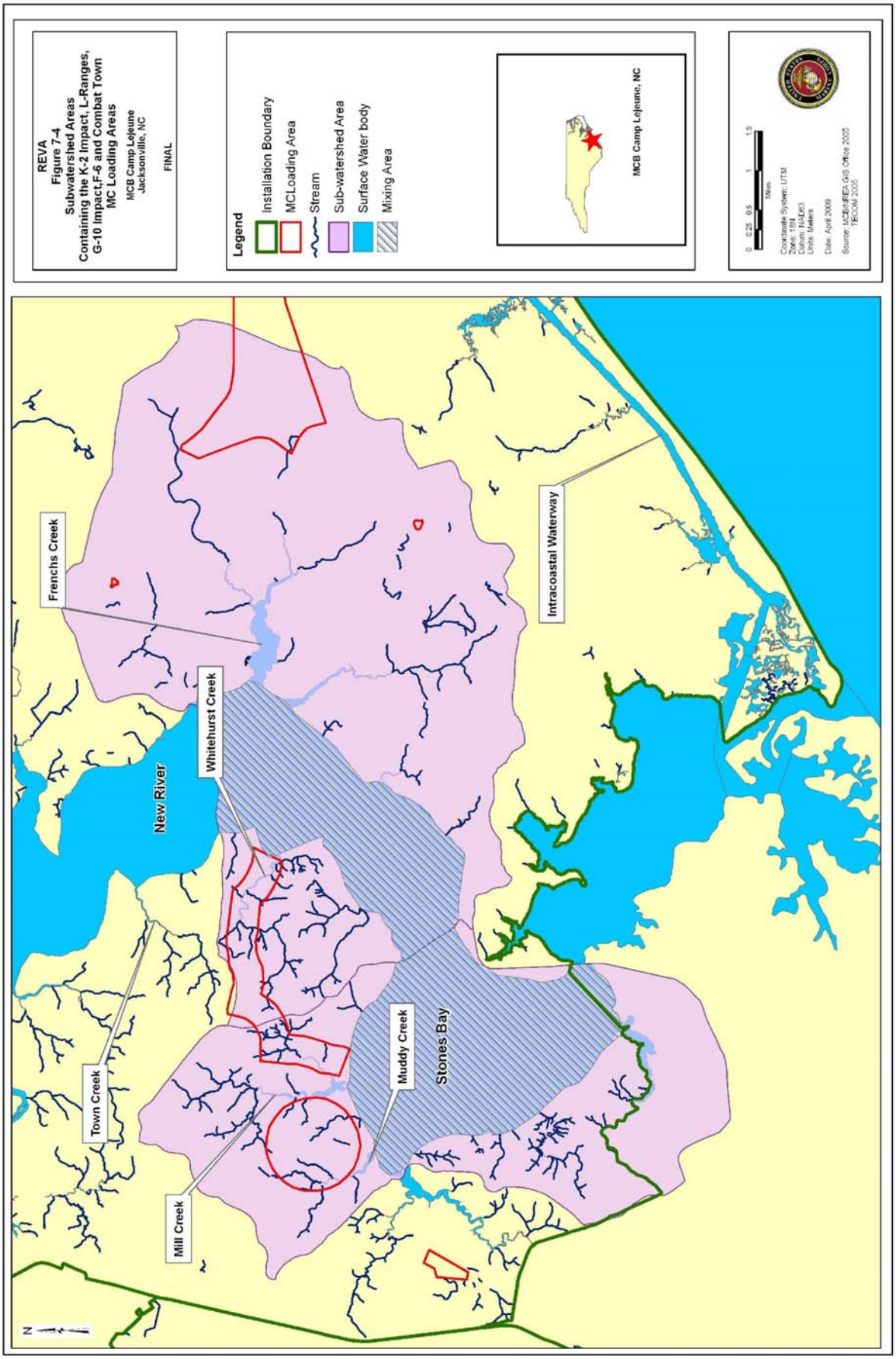
The flat, upland regions of MCB Camp Lejeune are underlain by a variety of sandy and loamy soils of highly variable drainage characteristics (USDA SCS, 1992). Most upland areas that are designated as MC loading areas at MCB Camp Lejeune are underlain by the loamy Baymeade-Foreston-Stallings association or the sandy Leon-Murville-Kureb association (Figure 4-3). These soils have an organic content of 0.5% to 2%.

7.2.2.4. Erosion Potential

The erodibility of the K-2 Impact Area MC loading area is moderate due to the combination of flat topography and low to moderately erodible soils with localized disturbance of vegetation and soil.

7.2.2.5. Groundwater Characteristics

The operational MC loading area for the K-2 Impact Area is located on the western side of the New River. Based on the hydrogeologic framework developed for MCB Camp Lejeune by Cardinell and others (1993), the thickness of the Surficial aquifer is estimated from about 0 to 40 ft at the K-2 Impact Area. The USGS examined groundwater flow in the Surficial aquifer in the area of the K-2 Impact Area. Wells installed around the perimeter of this area during the USGS study indicated the presence of silty fine sand, clay, and sandy clay to depths of 20 ft bgs (Harden and others, 2004). Figure 4-4 illustrates a segment of hydrogeologic section across MCB Camp Lejeune between the G-10 and K-2 impact areas.


REVA
Figure 7-4
Subwatershed Areas
Containing the K-2 Impact, L-Ranges,
G-10 Impact,F-6 and Combat Town
MC Loading Areas
MCB Camp Lejeune
Jacksonville, NC
FINAL
Legend
Installation Boundary
MCLoading Area
Stream
Sub-watershed Area
Surface Water body
Mixing Area
MCB Camp Lejeune, NC
0 0.25 0.5 1 1.5
Miles
Coordinate System: UTM
Zone: 18N
Datum: NAD83
Units: Meters
Date: April 2009
Source: MCBJ&FEA GIS Office 2005
TECOM 2005
Frenchs Creek
Whitehurst Creek
New River
Intracoastal Waterway
Town Creek
Muddy Creek
Stones Bay
Mill Creek
N

7.2.2.6. Area Hydrogeology (Aquifers and Aquitards)

The Castle Hayne confining unit isopach map developed by Cardinell and others (1993) indicates that the confining unit underlying the Surficial aquifer at the K-2 Impact Area is approximately 5 ft thick; however, detailed information is insufficient to determine if the confining unit is laterally continuous throughout this impact area. The elevation of the top of the Castle Hayne aquifer at the K-2 Impact Area ranges from about sea level to 25 ft below msl in the western and eastern parts of the site, respectively. The Castle Hayne aquifer is 225 ft thick at the K-2 Impact Area. Cardinell and others (1993) indicate that the upper part of the Castle Hayne aquifer in the MCB Camp Lejeune area primarily consists of calcareous sand that contains some beds of clay and silt. Consolidated limestone and sandy limestone interbedded with clay and sand are in the lower part of the aquifer.

Recharge to the Surficial aquifer at the K-2 Impact Area occurs from precipitation. Some of the groundwater in the Surficial aquifer may move downward into the Castle Hayne aquifer depending on the existence of the Castle Hayne confining unit (i.e., in areas beneath the New River as discussed in Section 4). The movement of groundwater between the Surficial and Castle Hayne aquifers is controlled by the magnitude of vertical gradients between the aquifers and by the hydraulic conductivity of the Castle Hayne confining unit. Refer to Section 7.1.2.6 for information concerning vertical hydraulic conductivity of the Castle Hayne aquifer and the results from the evaluation by the USGS. In addition, the analysis of the groundwater samples performed as part of this assessment did not detect MC in significant concentrations, and the geochemical testing indicated that there does not appear to be a significant hydraulic connection between the Surficial aquifer and the Castle Hayne aquifer near the K-2 Impact Area MC loading area (Section 9). A more detailed discussion of the hydrogeologic setting at MCB Camp Lejeune is presented in reports by Harned and others (1989), Harden and others (2004), and Cardinell and others (1993).

7.2.3. Initial Groundwater Screening-Level Analysis

As shown on Table 7-10, the initial mass loading screening-level analysis for the K-2 Impact Area indicates that the maximum concentrations of RDX and TNT in the infiltrating water exceed REVA trigger values for time periods C, D, and E.

Table 7-10.
Estimated Maximum Possible Concentration of MC in Infiltrating Water at the K-2 Impact Area

Period	Begin Use	End Use	HMX (mg/L)	RDX (mg/L)	TNT (mg/L)	Perchlorate[a] (mg/L)
C (1938-1976	1950	1976	2.02E-06	8.18E-03	3.54E-03	5.29E-04
D (1977-1988)	1977	1988	1.61E-06	6.54E-03	2.84E-03	4.23E-04
E (1989-Present)	1989	Present	2.02E-06	8.18E-03	3.54E-03	5.29E-04

Note:
Yellow cells indicate exceedence of REVA trigger values (Table 5-1).
[a] Perchlorate was only used in military munitions after 1962.

7.2.4. Vadose Zone Modeling

Based on the results of the screening-level analysis above, REVA indicator MC at or above the REVA trigger values were modeled in VLEACH to determine if they would reach the water table and, if so, at what estimated concentrations. Table 7-11 shows the results of this modeling effort, presenting the estimated soil water concentrations potentially entering the water table at the end of the final time period (representing the year 2006), based on the cumulative assessment of MC loading over time. See Appendix A for a summary of the model input parameters.

Table 7-11.
Vadose Zone Model Results: MC Concentrations Reaching Groundwater at the K-2 Impact Area

MC	Soil Water Concentration (mg/L)
HMX[a]	--
RDX	8.18E-03
TNT	3.54E-03
Perchlorate[a]	--

Note:
Yellow cells indicate exceedence of REVA trigger values (Table 5-1).
[a] The concentrations of HMX and Perchlorate reaching the water table were expected to be less than REVA trigger values; therefore, they were not further modeled.

The model results predicted RDX and TNT at the water table with potential concentrations greater than the REVA trigger values. As explained in Section 6, saturated zone modeling was not conducted and groundwater sampling was recommended instead of continuing with groundwater modeling because the complexities of the system precluded the use of a screening-level saturated flow groundwater model. The analysis of the groundwater samples did not detect MC in significant concentrations, and the geochemical testing indicated that there does not appear to be a significant hydraulic

connection between the Surficial aquifer and the Castle Hayne aquifer near the K-2 Impact Area MC loading area. Detailed results of the groundwater sampling are presented in Section 9.

7.2.5. Surface Water Screening-Level Analysis Result

A screening-level analysis of MC concentrations in surface water was conducted for the K-2 Impact Area MC loading area and its upstream drainages. A large portion of the K-2 Impact Area MC loading area (approximately 60% of the area) drains eastward into Whitehurst Creek, which in turn drains into the New River between Town Creek and Stones Bay (Figure 7-4). The remaining portion of the K-2 Impact Area MC loading area drains west into Mill Creek, which discharges into the New River at Stones Bay. Surface water in and around MCB Camp Lejeune is not used as a drinking water supply; however, humans potentially use it for recreational purposes (including fishing), and it may be home to potential ecological receptors.

The surface water screening-level analysis was conducted as described in Section 5 and carried out for a time period ranging from 1950 to 2005. Table 7-4 presents the estimated percentage of MC mass contributed by individual loading areas to the New River between Town Creek and Stones Bay; Table 7-12 presents the estimated percentage of MC mass contributed by individual loading areas to the New River at Stones Bay (Figure 7-4). The K-2 Impact Area MC loading area was predicted to contribute a significant portion (more than 75%) of the total perchlorate mass draining into the New River between Town Creek and Stones Bay, whereas the G-10 Impact MC loading area was predicted to contribute almost all of the total mass of HMX and TNT and a significant portion (more than 80%) of the total mass of RDX draining into New River between Town Creek and Stones Bay. The F-6 and Combat Town MC loading areas were predicted to contribute small portions of the total perchlorate mass and negligible amounts of HMX, RDX, and TNT into the New River between Town Creek and Stones Bay. The K-2 Impact Area MC loading area was predicted to contribute almost all of the total mass of HMX, RDX, and TNT and a significant portion (greater than 90%) of the total perchlorate mass draining into the New River at Stones Bay.

Table 7-12.
Screening-Level Estimate of Percent MC Mass Contributed by Individual MC Loading Areas into New River at Stones Bay

MC	From L-Ranges	From K-2 Impact Area
HMX	NA	100.0
RDX	0.9	99.1
TNT	0.0	100.0
Perchlorate	4.4	95.6

Note:
Data are provided in percent mass.
NA – No loading estimate of the MC is available.

Table 7-5 presents the estimated average annual edge-of-loading-area concentrations in surface water runoff from the K-2 Impact Area MC loading area (as well as upstream MC loading areas that drain the New River between Town Creek and Stones Bay and the New River at Stones Bay). Based on surface water screening-level calculations, the potential concentrations of RDX and TNT leaving K-2 Impact Area MC loading area were predicted to potentially exceed the REVA trigger value. Table 7-13 presents the total subwatershed drainage areas containing K-2 Impact MC loading area and the MC loading areas contributing MC to the downstream receptor locations at the New River between Town Creek and Stones Bay and the New River at Stones Bay. The contributing MC loading areas and the total watershed drainage presented in Table 7-13 and the annual average edge of loading area concentrations presented in Table 7-5 include the specific inputs used in the equation presented in Section 5, which calculates the downstream mixed concentrations.

Table 7-13.
Total Watershed Drainages/Individual MC Loading areas Contributing MC to the Downstream Receptor Locations at New River between Town Creek and Stones Bay and New River at Stones Bay

Watershed/ MC Loading Area	Area (acres)
Subwatershed of New River between Town Creek and Stones Bay	21,123
K-2 Impact Area MC loading area draining within the subwatershed of New River between Town Creek and Stones Bay	522
G-10 Impact Area MC loading area draining within the subwatershed of New River between Town Creek and Stones Bay	945
F-6 MC loading area draining within the subwatershed of New River between Town Creek and Stones Bay	3.6
Combat Town MC loading area draining within the subwatershed of New River between Town Creek and Stones Bay	5.9
Subwatershed of New River at Stones Bay	12,294
K-2 Impact Area MC loading area draining within the subwatershed of New River at Stones Bay	348
L-Range MC loading area draining within the subwatershed of New River at Stones Bay	706

Table 7-7 presents the potential estimated MC concentrations in surface water entering the New River between Town Creek and Stones Bay; Table 7-14 presents the potential estimated MC concentrations in surface water entering the New River at Stones Bay, following downstream mixing. Postmixing concentrations of RDX and TNT entering the New River between Town Creek and Stones Bay and the New River at Stones Bay were predicted to be above the REVA trigger values. However, HMX and perchlorate concentrations entering the New River between Town Creek and Stones Bay and the New River at Stones Bay were predicted to be below the REVA trigger values.

Table 7-14.
Screening-Level Estimates of Annual Average MC Concentrations in Runoff Entering New River at Stones Bay

MC	Postmixing Concentrations Entering the New River (µg/L)
HMX	4.5E-05
RDX	**0.2**
TNT	**0.09**
Perchlorate	0.01

Note:
Shading and bold indicate that the predicted concentration is above the REVA trigger value.

Although the postmixing concentrations of RDX and TNT in runoff entering the New River were predicted to potentially exceed the REVA trigger values, actual concentrations are expected to be lower (potentially below detection levels) in the tidally influenced surface water body. The surface water screening-level analysis used a conservative approach where MC decay and tidal mixing were not taken into account, whereas these mechanisms are likely to reduce concentrations in the tidal water body. As a result of the above screening-level analyses results, surface water sampling was carried out to determine whether actual MC migration was occurring in streams draining to the New River from the K-2 Impact Area MC loading area and in the New River downstream from the K-2 Impact Area MC loading area. These results are presented in Section 9.

7.2.6. Potential Pathways

The screening-level modeling results indicate that RDX and TNT have the potential to reach the water table at the K-2 Impact Area after being dissolved by the infiltrating rain. The highest hydraulic head at the K-2 Impact Area is found in the northwestern part of the impact area. Groundwater in this area flows southeastward into the K-2 Impact Area. Generally, groundwater flow in the interior of the K-2 Impact Area has a southward and eastward trend. Locally, groundwater may flow in other directions depending on specific location and proximity to streams. Ultimately, groundwater discharges from the Surficial aquifer directly into the New River or its tributaries.

The surface water screening-level analysis results indicated that postmixing concentrations of RDX and TNT are estimated to reach the New River above REVA trigger values. A large portion of the K-2 Impact Area MC loading area (approximately 60% of the area) drains eastward into Whitehurst Creek, which in turn drains into the New River between Town Creek and Stones Bay (Figure 7-4). The remaining portion of the K-2 Impact Area MC loading area drains west into Mill Creek, which discharges into the New River at Stones Bay. All of these surface water bodies are potential surface water pathways.

7.2.7. Potential Receptors

Based on the proximity of the K-2 Impact Area to the New River, the possible absence of the confining unit below the New River, and the rapid drop in the water table from the uplands to the river, groundwater likely flows toward the New River. It is also likely that groundwater discharges to the New River from the Castle Hayne aquifer beneath the K-2 Area as well (Triangle, 1999). There are no current users of shallow groundwater at MCB Camp Lejeune since all water supplies at the installation originate from water wells tapping the Castle Hayne aquifer. Surface water in and around MCB Camp Lejeune is not used as a drinking water supply; however, humans potentially use it for recreational purposes (including fishing). Commercial oyster beds are located adjacent to the K-2 Impact Area along the eastern and southeastern boundaries within the New River. Streams draining from the K-2 Impact Area MC loading area drain near areas where

federal T/E species, including the red-cockaded woodpecker, rough-leaved loosestrife, and the American alligator have been documented to exist.

7.3. F-5 (Operational), F-2 Field Firing Range (Historical Use within Operational Area), Musketry Range A (Historical Use)

The operational F-5 MC loading area includes the historical use of the F-2 Field Firing Range and Musketry Range A MC loading areas and is located just south of Highway 24, along the northern boundary of MCB Camp Lejeune (Figure 7-5). This area is bordered to the north by commercially zoned areas of the city of Jacksonville and to the east, west, and south by operational tactical maneuver training areas. The predominant use of this area since 1976 has been small arms training. However, this area was first used for artillery activities from 1950 to 1976 (F-2 Field Firing Range) and from 1942 to 1947 (Musketry Range A).

The F-5, F-2 Field Firing Range, and Musketry Range A MC loading areas were delineated using pre-existing GIS shapefiles and aerial photography retrieved during the data collection site visit. All MC loading was assumed to have been within the resulting 19-acre designated area. The loading period for F-5 was from 1972 to present; the historical use of the F-2 Field Firing Range was from 1950 until 1976 and of Musketry Range A was from 1942 until 1947.

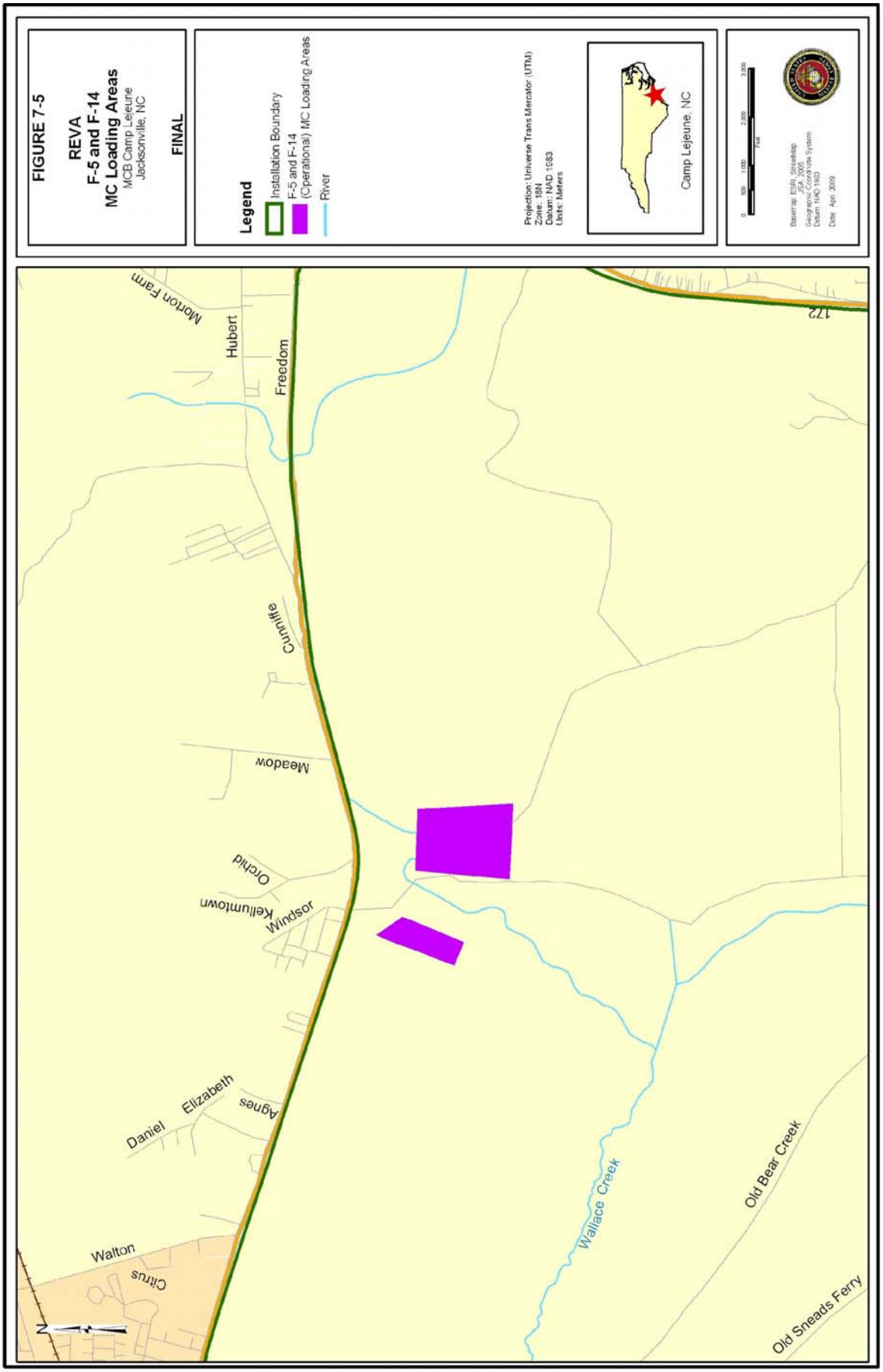


FIGURE 7-5
REVA
F-5 and F-14
MC Loading Areas
MCB Camp Lejeune
Jacksonville, NC
FINAL
Legend
Installation Boundary
F-5 and F-14 (Operational) MC Loading Areas
River
Projection: Universe Trans Mercator (UTM)
Zone: 18N
Datum: NAD 1983
Units: Meters
Camp Lejeune, NC
Motton Farm
Hubert
Freedom
Cunniffe
Meadow
Orchid
Kellumtown
Windsor
Agnes
Elizabeth
Daniel
Walton
Citrus
Wallace Creek
Old Bear Creek
Old Sneads Ferry
172

7.3.1. MC Loading

The combined MC loading area for F-5/F-2 Field Firing Range/Musketry Range A is shown in Figure 7-5. The MC Loading Rate Calculator was used to estimate the amount of MC loaded at these MC loading areas over time. The MC loading amounts estimated for each identified time period during which the operational range or historical use area was operated (time periods C, D, and E) are listed in Table 7-15. The resulting MC loading rate derived from the current expenditure data received from Range Control was extrapolated backward to this operational range's inception. Since the F-5 operational range was first used in 1972, the MC loading prior to 1972 was from the historical uses associated with the F-2 Field Firing Range and Musketry Range A.

The estimated MC loading rates for Musketry Range A were derived from the military munitions usage data presented in the ASR and PRA report, while the quantities were based on those of similar items or groups of items from the current Range Control expenditure data. The resulting annual Musketry Range A MC loading rate was applied to the F-5, F-2 Field Firing Range, and Musketry Range A MC loading areas from 1942 until 1947. Based on Musketry Range A's dates of use, there was no MC loading for this MC loading area prior to 1942 or after 1947.

Table 7-15.
Estimated Annual MC Loading for F-5, F-2, and Musketry Range A

MC Loading Area	Period	Begin Use	End Use	HMX (kg/m^2)	RDX (kg/m^2)	TNT (kg/m^2)	Perchlorate[a] (kg/m^2)
F-5	C (1938-1976)	1972	1976	0.00	1.50E-06	4.33E-11	9.36E-10
	D (1977-1988)	1977	1988	NA	1.20E-06	3.47E-11	7.49E-10
	E (1989-Present)	1989	Present	NA	1.50E-06	4.33E-11	9.36E-10
F-2 Field Firing Range	C (1938-1976)	1950	1976	NA	NA	1.90E-12	NA
	D (1977-1988)	NA	NA	NA	NA	NA	NA
	E (1989-Present)	NA	NA	NA	NA	NA	NA
Musketry Range A	C (1938-1976)	1942	1947	NA	5.01E-05	3.14E-05	8.23E-09
	D (1977-1988)	NA	NA	NA	NA	NA	NA
	E (1989-Present)	NA	NA	NA	NA	NA	NA

Note:
NA – Not applicable
[a] Perchlorate was only used in military munitions after 1962.

7.3.2. Range-Specific CSM

The range-specific CSM information for the F-5, F-2 Field Firing Range, and Musketry Range A MC loading areas is provided in the following sections.

7.3.2.1. Geography and Topography

The F-5, F-2 Field Firing Range, and Musketry Range A MC loading areas are located on the Talbot surface at an elevation of 25-40 ft in the northeast portion of MCB Camp Lejeune.

7.3.2.2. Surface Water Features

The F-5, F-2 Field Firing Range, and Musketry Range A MC loading areas drain within the subwatershed of Wallace Creek upstream of its confluence with the New River. Within this subwatershed, the MC loading areas drain to an unnamed perennial tributary to Wallace Creek. Wallace Creek drains westward and ultimately discharges as a tidal creek into the New River embayment (Figure 7-6).

7.3.2.3. Soil Characteristics and Land Cover

The F-5, F-2 Field Firing Range, and Musketry Range A MC loading areas primarily consist of bare ground (military operations area) underlain by loamy soils of the Baymeade-Foreston-Stalling association.

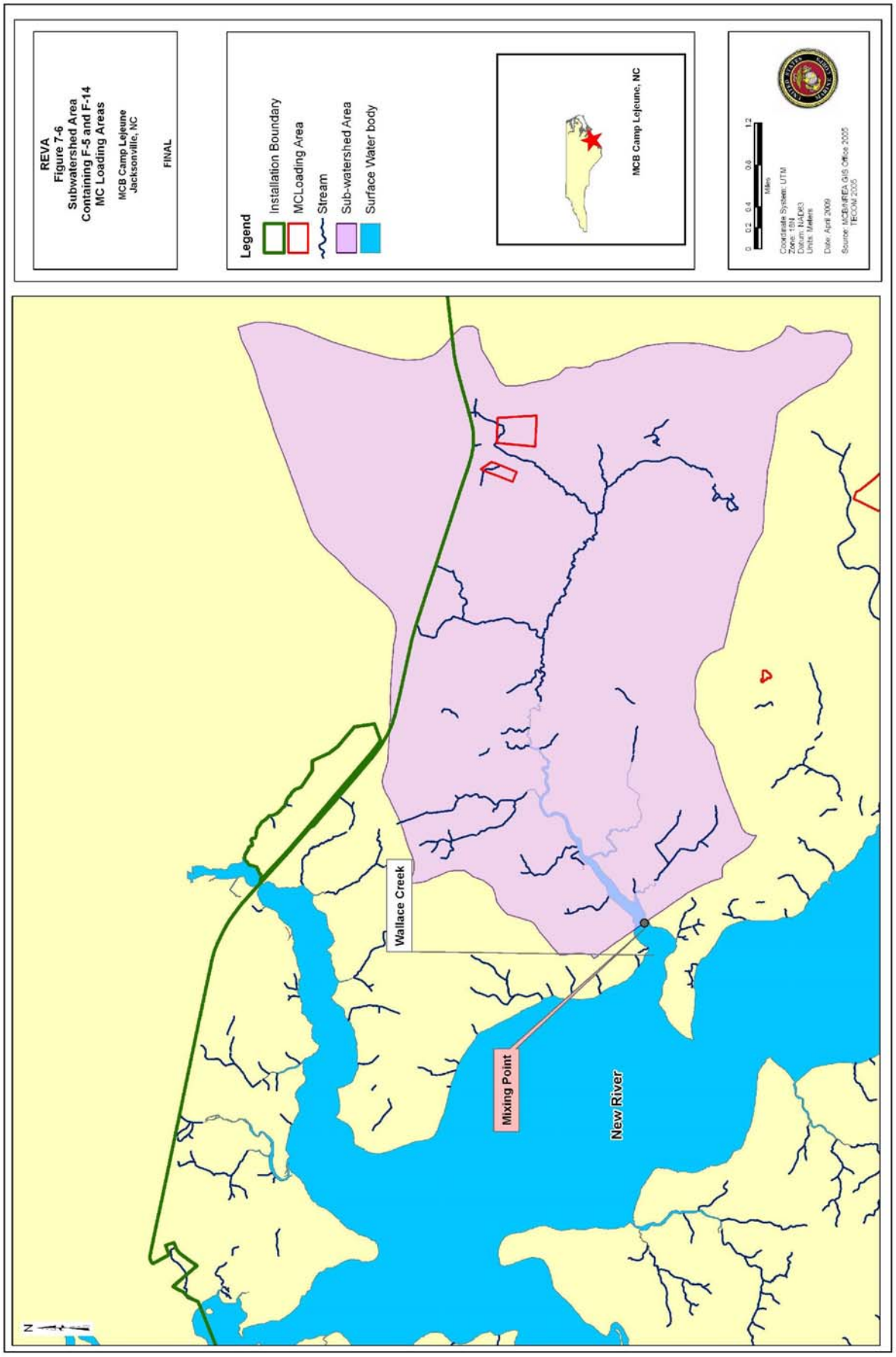
7.3.2.4. Erosion Potential

The erodibility of the F-5, F-2 Field Firing Range, and Musketry Range A MC loading areas is moderate due to the combination of flat topography and low erodibility soils with localized disturbance of soil.

7.3.2.5. Groundwater Characteristics

The F-5, F-2 Field Firing Range, and Musketry Range A MC loading areas are in proximity of several IRP sites, including Sites 6, 9, 21, 22, 23, 24, 26, 28, 78, 82, and 94. Environmental Science and Engineering, Inc. prepared a Characterization Step Report for the Hadnot Point Industrial Area in May 1988. IRP Sites 21, 22, 24, and 28 were located within this study area.

The shallow aquifer in this area is encountered at a depth of less than 10 ft bgs at most locations. Lithologic data collected during shallow groundwater monitoring well installation indicated the study area is underlain primarily by silty sand and extensive, but discontinuous, layers of silty clay and sandy clay, which dip to the south-southwest.


REVA
Figure 7-6
Subwatershed Area
Containing F-5 and F-14
MC Loading Areas
MCB Camp Lejeune
Jacksonville, NC
FINAL
Legend
Installation Boundary
MCLoading Area
Stream
Sub-watershed Area
Surface Water body
MCB Camp Lejeune, NC
0 0.2 0.4 0.8 1.2
Miles
Coordinate System: UTM
Zone: 18N
Datum: NAD83
Units: Meters
Date: April 2009
Source: MCB-LFEA GIS Office 2005
TEC/M 2003
Wallace Creek
Mixing Point
New River
N

7.3.2.6. Area Hydrogeology (Aquifers and Aquitards)

A detailed hydrogeologic study was performed, including a 72-hour pump test in the Castle Hayne aquifer (ESE, 1988). An existing water supply well was the pumping well used in the pump test. The Castle Hayne aquifer was encountered at 100 ft bgs at the F-5, F-2 Field Firing Range, and Musketry Range A MC loading areas. Between the Surficial aquifer and the Castle Hayne aquifer is an alternating sequence of sands, silts and clays, which is poorly described both in lithology and water-bearing properties. Lithologic data collected during deep groundwater monitoring well installation (up to 150 ft) showed the silty sand-sandy clay layer continued to a depth of approximately 50 ft bgs, where a zone of sand, shells, and cemented clastics was encountered. This zone ranged in thickness from 35 ft to greater than 80 ft.

The stratigraphic sequence of geologic materials creates two aquifer systems separated by the clayey interval. From the surface of the shallow groundwater to the top of the clayey interval, an unconfined aquifer is present in the near-surface sands. The regional literature indicates that the clay interval acts as a semiconfining unit, retarding flow between the unconfined aquifer above and a semiconfined aquifer present in the sand and limestone below. The sand and limestone aquifer is assumed to extend to the base of the freshwater system, a depth of approximately 300 ft below msl.

The Castle Hayne aquifer pumping test resulted in transmissivities ranging from 7,300 to 12,000 gallons per day per foot. The analysis indicates the sand and limestone aquifer is semiconfined and is receiving recharge through a clayey layer overlying the aquifer near the surface. The average hydraulic conductivity of this layer was estimated to be 4.6E-03 ft/day, typical of silty sands and silty clays. Such material acts more as a semiconfining layer than a complete confining layer.

7.3.3. Initial Groundwater Screening-Level Analysis

To determine the estimated MC concentrations potentially reaching the groundwater table at the MC loading areas, the estimated MC loading rates (Table 7-15) were divided by the infiltration rate of 30% of the total annual precipitation. As shown in Table 7-16, the initial mass loading screening-level analysis indicates RDX concentrations in the infiltrating water have the potential to exceed REVA trigger values at the F-5 and Musketry Range A loading areas. TNT may exceed the REVA triggers at Musketry Range A only.

Table 7-16.
Estimated Maximum Concentration of MC in Infiltrating Water at F-5/F-2/Musketry Range A

MC Loading Area	Period	Begin Use	End Use	HMX (mg/L)	RDX (mg/L)	TNT (mg/L)	Perchlorate[a] (mg/L)
F-5	C (1938-1976)	1976	1976	NA	2.73E-03	7.89E-08	1.71E-06
	D (1977-1988)	1977	1988	NA	2.19E-03	6.32E-08	1.37E-06
	E (1989-Present)	1989	Present	NA	2.73E-03	7.89E-08	1.71E-06
F-2 Field Firing Range	C (1938-1976)	1950	1972	NA	NA	3.46E-09	NA
	D (1977-1988)	NA	NA	NA	NA	NA	NA
	E (1989-Present)	NA	NA	NA	NA	NA	NA
Musketry Range A	C (1938-1976)	1942	1947	NA	9.13E-02	5.72E-02	1.50E-05
	D (1977-1988)	NA	NA	NA	NA	NA	NA
	E (1989-Present)	NA	NA	NA	NA	NA	NA

Note:

Yellow cells indicate exceedence of REVA trigger values (see Table 5-1).
[a] Perchlorate was only used in military munitions after 1962.
NA – Not Applicable

7.3.4. Vadose Zone Modeling

Based on the results of the screening-level analysis above, REVA indicator MC at or above the REVA trigger values were modeled in VLEACH to determine if they would reach the water table and, if so, at what estimated concentrations. Table-7-17 shows the results of this modeling effort, presenting the soil water estimated concentrations entering the water table at the end of the final time period (representing the year 2006), based on the cumulative assessment of MC loading over time. See Appendix A for a summary of model input parameters.

Table 7-17.
Vadose Zone Model Results: MC Concentrations Reaching Groundwater at F-5, F-2 Field Firing Range, and Musketry Range A Loading Areas

MC Loading Area	Soil Water Concentration (mg/L)			
	HMX	RDX	TNT	Perchlorate
F-5	a	2.73E-03	b	b
F-2 Field Firing Range	a	a	b	a
Musketry Range A	a	0.0	0.0	b

Note:
Yellow cells indicate exceedence of REVA trigger values (see Table 5-1).
[a] HMX, RDX, and perchlorate were not estimated to reach the water tables and therefore were not modeled.
[b] TNT and perchlorate did not exceed REVA trigger values at the water table and were therefore not modeled.

The model predicted that RDX could be at the water table at a concentration above the REVA trigger value in the F-5 MC loading area. As explained in Section 6, saturated zone modeling was not conducted and groundwater sampling was recommended instead of continuing with groundwater modeling because the complexities of the system precluded the use of a screening-level saturated flow groundwater model. The initial groundwater sampling event for the G-10 and K-2 impact areas was conducted because the modeling results indicated larger MC concentrations at these sites and because these two areas are more highly loaded over greater area than the F-5 MC loading area. However, a groundwater water supply well, located in the vicinity of the F-5/F-2/Musketry A Range, was sampled as part of the groundwater sampling event investigation (Section 9). The investigations indicate that MC are not migrating off range. If the sampling results had indicated high MC concentrations in the groundwater sampled, additional sampling would have been recommended as appropriate. Detailed results of the groundwater sampling are presented in Section 9.

7.3.5. Surface Water Screening-Level Analysis Results

A screening-level analysis of MC concentrations in surface water was conducted for the F-5, F-2 Field Firing Range, and Musketry Range A MC loading areas and their upstream drainages. The F-5 MC loading area includes the historical use of F-2 Field Firing Range and Musketry Range A MC loading areas. The F-5 MC loading area drains south into Wallace Creek, which discharges westward into the New River (Figure 7-6). The surface water in and around MCB Camp Lejeune is not used as a drinking water supply; however, humans potentially use it for recreational purposes (including fishing). Streams draining from the F-5 MC loading area drain near areas where federally-listed T/E red-cockaded woodpecker and American alligator have been documented to exist. The surface water screening-level analysis was conducted as described in Section 5 and was carried out for a time period ranging from 1942 to 2005. Historical MC loading areas within the drainage area of the New River at its confluence point with Wallace Creek include F-2 Field Firing Range, Musketry Range A, and F-14 Field Firing Range. MC loading at these historical areas was estimated to occur for a time period ranging from 1942 to 1976. MC concentrations in runoff at the edge of these historical MC loading areas were predicted to be negligible by the year 2005. As a result, the F-5 MC loading area was predicted to contribute almost all of the MC mass draining to the New River at its confluence point with Wallace Creek.

Table 7-18 presents the estimated average annual edge-of-loading-area concentrations in surface water runoff from the F-5 MC loading area. The potential concentration of RDX leaving the F-5 MC loading area was predicted to potentially exceed the REVA trigger value.

Table 7-18.
Screening-Level Estimates of Annual Average Edge-of-Loading-Area MC Concentrations in Runoff Leaving the F-5 MC Loading Area

MC	Edge-of-Loading MC Concentrations Leaving F-5 MC Loading Area (µg/L)
HMX	NA
RDX	**1.5**
TNT	1.3E-05
Perchlorate	8.9E-04

Note:
NA – No loading estimate of the MC is available.

Table 7-19 presents the total subwatershed drainage area containing F-5 MC loading areas that contributes MC to the downstream receptor location in Wallace Creek upstream of its confluence with the New River. F-5 MC loading area is the only loading area contributing MC to the downstream receptor location. The contributing MC loading area and the total watershed drainage presented in Table 7-19 and the annual average edge of loading area concentrations presented in Table 7-18 include the specific inputs used in the equation presented in Section 5, which calculates the downstream mixed concentrations.

Table 7-19.
Total Watershed Drainage and the MC Loading area Contributing MC to the Downstream Receptor Locations in Wallace Creek upstream of its Confluence with New River

Watershed/ MC Loading Area	Area (acres)
Subwatershed of Wallace Creek upstream of its confluence with New River	12,868
F-5 MC loading area draining within the subwatershed of Wallace Creek upstream of its confluence with New River	19

Table 7-20 presents the estimated potential MC concentrations in surface water entering the New River at its confluence point with Wallace Creek, following downstream mixing. All of these potential concentrations were predicted to be below the REVA trigger values.

Table 7-20.
Screening-Level Estimates of Annual Average MC Concentrations in Runoff Entering New River at its Confluence Point with Wallace Creek

MC	Postmixing Concentrations in New River (µg/L)
HMX	NA
RDX	2.0E-03
TNT	< 1.3E-05
Perchlorate	< 8.9E-04

Note:
NA – No loading estimate of the MC is available.

7.3.6. Potential Pathways

As discussed in Section 7.3.4, RDX has the potential to reach the water table above the REVA trigger values at the F-5 MC loading area after being dissolved by the infiltrating rain. If a dissolved MC reaches the water table, it will continue flowing with the shallow groundwater according to the existing gradients and conditions. In general, the shallow groundwater flows toward the New River, generally in a south-southwest direction. Groundwater flow in the deep zone would be expected to be toward the Atlantic Ocean (east, southeast). Pumping of water supply wells may cause local differences in the flow direction. All of these operational and historical MC loading areas fall within WHPA Zones 2 and 3 in this area . If the shallow groundwater infiltrated into the deep aquifer in this area, the deep groundwater would be expected to potentially flow toward the pumping wells in this area.

The surface water screening-level analysis results indicate that postmixing concentrations of MC are estimated to reach the New River at its confluence point with Wallace Creek below the REVA trigger values. These surface water bodies are potential surface water pathways.

7.3.7. Potential Receptors

There are no current users of shallow groundwater at MCB Camp Lejeune since all water supplies at the installation originate from water wells tapping the Castle Hayne aquifer. Surface water in and around MCB Camp Lejeune is not used as a drinking water supply; however, humans potentially use it for recreational purposes (including fishing). Streams draining from the F-5 MC loading area discharge near areas where the federally-listed T/E red-cockaded woodpecker and the American alligator have been documented to exist.

7.4. F-14 Field Firing Range (Historical Use)

The historical use area F-14 Field Firing Range is within an operational range area at the intersections of the boundaries of the operational Tactical Maneuver Training Areas FA,

FB, and FE. This range was located just south of Highway 24, along the northern boundary of MCB Camp Lejeune (Figure 7-5). The historical location of the F-14 Field Firing Range is bordered to the north by commercially zoned areas of the city of Jacksonville and to the east, west, and south by operational tactical maneuver training areas. This historical use area was first used in 1950, and its use ceased in 1961.

The F-14 Field Firing Range MC loading area was delineated based on ASR and PRA maps. All MC loading was assumed to have been within the resulting 63-acre designated area. The loading period for the F-14 Field Firing Range MC loading area was from 1950 to 1961.

7.4.1. MC Loading

The MC loading area for the F-14 Field Firing Range is shown in Figure 7-5. The MC Loading Rate Calculator was used to estimate the amount of MC loaded at this MC loading area over time. The MC loading amounts estimated for the identified time period during which the range was operated (time period C) are listed in Table 7-21. The estimated MC loading rates for the F-14 Field Firing Range were derived based on the military munitions usage data presented in the ASR and PRA report, while the quantities were based on those of similar items or groups of items from the current Range Control expenditure data. The resulting annual MC loading rate was extrapolated backward to the range's inception. Based on the dates of use of the F-14 Field Firing Range, there was no MC loading prior to 1950 or after 1961.

Table 7-21.
Estimated Annual MC Loading for the F-14 Field Firing Range

MC Loading Area	Period	Begin Use	End Use	HMX (kg/m^2)	RDX (kg/m^2)	TNT (kg/m^2)	Perchlorate[a] (kg/m^2)
F-14 Field Firing Range	C (1938-1976)	1950	1961	7.68E-11	1.92E-05	5.57E-04	NA

Note:
NA – Not applicable
[a] Perchlorate was only used in military munitions after 1962.

7.4.2. Range-Specific CSM

The range-specific CSM information for the F-14 Field Firing MC loading area is provided in the following sections.

7.4.2.1. Geography and Topography

The F-14 Field Firing Range MC loading area is located on the Talbot surface at an elevation of 25-40 ft in the northeast portion of MCB Camp Lejeune. Portions of this area occupy a stream floodplain at elevations of 15-25 ft.

7.4.2.2. Surface Water Features

The F-14 Field Firing Range MC loading area drains within the subwatershed of Wallace Creek upstream of its confluence with the New River. Within this subwatershed, the nontidal headwaters of Wallace Creek flow near the F-14 Field Firing Range MC loading area. Wallace Creek drains westward and, ultimately, discharges as a tidal creek into the New River embayment.

7.4.2.3. Soil Characteristics and Land Cover

The F-14 Field Firing Range MC loading area consists primarily of forest with some bare ground and is underlain by loamy, sandy, and mucky soils of the Baymeade-Foreston-Stalling, Leon-Murville-Kureb, and Muckalee-Dorovan associations.

7.4.2.4. Erosion Potential

The erodibility of the F-14 Field Firing Range MC loading area is moderate due to the combination of flat topography and soils of low to moderate erodibility with localized disturbance of vegetation and soil.

7.4.2.5. Groundwater Characteristics

The F-14 Field Firing Range MC loading area is close to several IRP sites, including Sites 6, 9, 21, 22, 23, 24, 26, 28, 78, 82, and 94. Environmental Science and Engineering, Inc., prepared a Characterization Step Report for the Hadnot Point Industrial Area in May 1988. IRP Sites 21, 22, 24, and 28 were located within this study area. Refer to Section 7.3.2.5 for additional groundwater information pertinent to this MC loading area.

The shallow aquifer in this area is encountered at a depth of less than 10 ft bgs in most areas. Lithologic data collected during shallow groundwater monitoring well installation indicated the study area is underlain primarily by silty sand and extensive, but discontinuous, layers of silty clay and sandy clay, which dip to the south-southwest.

7.4.2.6. Area Hydrogeology (Aquifers and Aquitards)

Refer to Section 7.3.2.6 for area hydrogeology information pertinent to this MC loading area.

7.4.3. Initial Groundwater Screening-Level Analysis

To determine the estimated MC concentrations potentially reaching the groundwater table at the MC loading areas, the MC loading rates (Table 7-21) were divided by the infiltration rate of 30% of the total annual precipitation. As shown in Table 7-22, the

initial mass loading screening-level analysis indicates that maximum possible concentrations of RDX and TNT exceed the REVA trigger values for period C.

Table 7-22.
Estimated Maximum Concentrations of MC in Infiltrating Water at F-14 Field Firing Range

Period	Begin Use	End Use	HMX (mg/L)	RDX (mg/L)	TNT (mg/L)	Perchlorate[a] (mg/L)
C (1938-1976)	1950	1961	1.40E-07	3.50E-02	1.02	NA

Note:
Yellow cells indicate exceedence of REVA trigger values (Table 5-1).
[a] Perchlorate was only used in military munitions after 1962.
NA – Not Applicable

7.4.4. Vadose Zone Modeling

Based on the results of the screening-level analysis above, REVA indicator MC at or above the REVA trigger values were modeled in VLEACH to determine if they would reach the water table and, if so, at what estimated concentrations. Table 7-23 shows the model-predicted soil water concentrations at the water table at the end of the final time period, based on the cumulative assessment of MC loading over time. See Appendix A for a summary of model input parameters.

Table 7-23.
Vadose Zone Model Results: MC Concentrations Reaching Groundwater at F-14 Field Firing Range

MC	Soil Water Concentration (mg/L)
HMX[a]	--
RDX	0.0
TNT	0.0
Perchlorate[a]	--

Note:
[a] HMX and perchlorate did not exceed REVA trigger values at the water table and therefore were not further modeled.

None of the MC are predicted to be found at the water table at concentrations above the REVA trigger values for the F-14 Field Firing Range. No further analysis of groundwater at this loading area was conducted.

7.4.5. Surface Water Screening-Level Analysis Result

A screening-level analysis of MC concentrations in surface water was conducted for the F-14 MC loading areas and its upstream drainages. The F-14 MC loading area drains

southwestward into Wallace Creek, which discharges west into the New River (Figure 7-6).

The F-14 Field Firing Range is a historical loading area. The surface water screening-level analysis was carried out for a time period ranging from 1950 to 1961. As discussed in Section 7.3.5, MC concentrations in surface water runoff at the edge of this MC loading area were predicted to be negligible by the year 2005. Other MC loading areas that drain within the same subwatershed as F-14 Field Firing Range MC loading area are discussed in Section 7.3.5.

7.4.6. Potential Pathways

As discussed in Section 7.4.4, none of the MC were predicted to be found at the water table at concentrations above the REVA trigger values for the F-14 Field Firing Range; therefore, no pathways exist for this historical use area to groundwater. The surface water screening-level results also indicate that surface water is not a viable pathway for MC migration relating to this historical use area.

7.4.7. Potential Receptors

Potential human and ecological receptors do not appear to be impacted by this MC loading area based on the above screening-level analyses results.

7.5. F-6 (Operational)

The operational F-6 area is located within Tactical Maneuver Training Area FD, east of Sneads Ferry Road and south of Lyman Road (Figure 7-7). F-6 is bordered to the west by the southern portion of the main cantonment area and to the north, south, and east by operational tactical maneuver training areas. This area was first used in 1972, and its use continues today.

The F-6 MC loading area was delineated based on existing GIS data and aerial photographs collected during the site visit. All MC loading was assumed to have been within the resulting 39-acre designated area. The loading period for the F-6 MC loading area was from 1972 to present.

7.5.1. MC Loading

The MC loading area for F-6 is shown in Figure 7-7. The MC Loading Rate Calculator was used to estimate the amount of MC loaded at this MC loading area over time. The MC loading amounts estimated for each identified time period during which the range was operated (time periods C, D, and E) are listed in Table 7-24. The resulting annual MC loading rate was extrapolated backward to this operational range's inception. Since F-6 was first used in 1972, there was no MC loading prior to 1972.

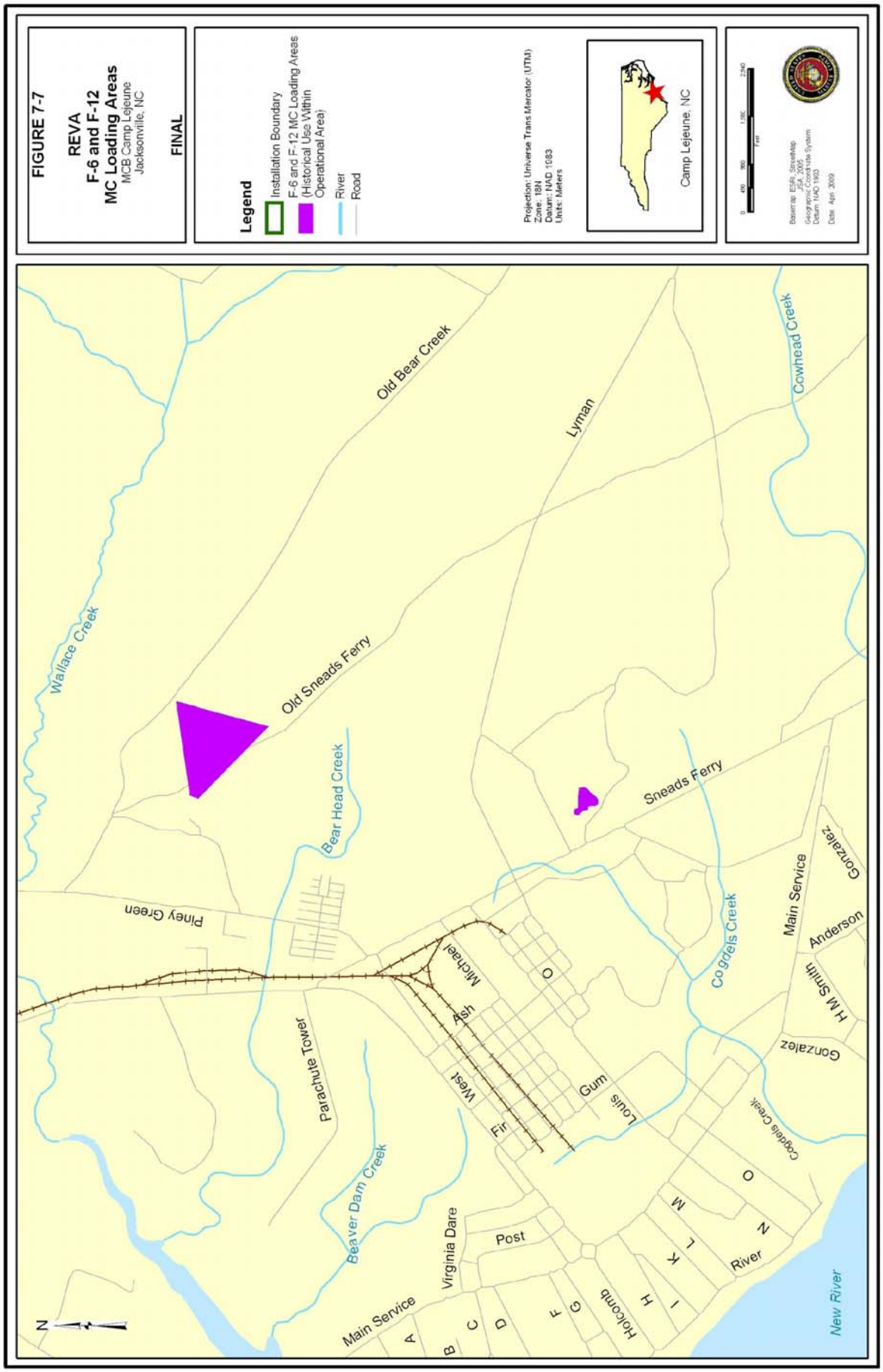


FIGURE 7-7
REVA
F-6 and F-12
MC Loading Areas
MCB Camp Lejeune
Jacksonville, NC
FINAL
Legend
Installation Boundary
F-6 and F-12 MC Loading Areas (Historical Use Within Operational Area)
River
Road
Projection: Universe Trans Mercator (UTM)
Zone: 18N
Datum: NAD 1983
Units: Meters
Camp Lejeune, NC
0 480 960 1,920 2,840
Feet
Basemap: ESRI, StreetMap
Date: April 2009
Wallace Creek
Old Bear Creek
Old Sneads Ferry
Lyman
Cowhead Creek
Bear Head Creek
Sneads Ferry
Piney Green
Parachute Tower
Beaver Dam Creek
Cogdels Creek
Main Service
Gonzalez
Anderson
H M Smith
Michael
Ash
West
Fir
Gum
Louis
Post
Virginia Dare
Holcomb
River
New River
A
B
C
D
F
G
H
I
K
L
M
N
O
N

Table 7-24.
Estimated Annual MC Loading for F-6

MC Loading Area	Period	Begin Use	End Use	HMX (kg/m^2)	RDX (kg/m^2)	TNT (kg/m^2)	Perchlorate (kg/m^2)
F-6	C (1938-1976)	1972	1976	NA	1.98E-05	2.34E-05	6.03E-06
	D (1977-1988)	1977	1988	NA	1.58E-05	1.87E-05	4.82E-06
	E (1989-Present)	1989	Present	NA	1.98E-05	2.34E-05	6.03E-06

Note:
NA – Not applicable

7.5.2. Range-Specific CSM

The range-specific CSM information for the F-6 range MC loading area is provided in the following sections.

7.5.2.1. Geography and Topography

F-6 is located in an upland area of Talbot surface at an elevation of 25-30 ft above msl on the eastern side of MCB Camp Lejeune. It is adjacent to a small topographic low area in the form of a large pit.

7.5.2.2. Surface Water Features

The F-6 MC loading area drains within the subwatershed of the New River between Town Creek and Stones Bay. Within this subwatershed, a portion of the F-6 MC loading area drains to an unnamed perennial tributary of Cogdels Creek, which discharges as a tidal creek to the New River embayment. Another portion of the F-6 MC loading area drains to a low upland area with no surface water outlet.

7.5.2.3. Soil Characteristics and Land Cover

The F-6 MC loading area consists primarily of bare ground (military operations area) and forest underlain by sandy soils of the Leon-Murville-Kureb association.

7.5.2.4. Erosion Potential

The erodibility of the F-6 MC loading area is moderate due to the combination of flat topography and low erodibility soils with localized disturbance of soil.

7.5.2.5. Groundwater Characteristics

The F-6 MC loading area is near several IRP sites, including Sites 6, 9, 21, 22, 23, 24, 26, 28, 78, 82, and 94. Environmental Science and Engineering, Inc., prepared a Characterization Step Report for the Hadnot Point Industrial Area in May 1988. IRP Sites

21, 22, 24, and 28 were located within this study area. Refer to Section 7.3.2.5 for additional groundwater information pertinent to this MC loading area.

7.5.2.6. Area Hydrogeology (Aquifers and Aquitards)

Refer to Section 7.3.2.6 for area hydrogeology information pertinent to this MC loading area.

7.5.3. Initial Groundwater Screening-Level Analysis

To determine the estimated MC concentrations potentially reaching the groundwater table at the MC loading areas, the estimated MC loading rates (Table 7-24) were divided by the infiltration rate of 30% of the total annual precipitation. As shown in Table 7-25, the initial mass loading screening-level analysis indicates that estimated maximum concentrations of RDX, TNT, and perchlorate exceed the REVA trigger values for periods C, D, and E.

Table 7-25.
Estimated Maximum Concentrations of MC in Infiltrating Water at the F-6 MC Loading Area

Period	Begin Use	End Use	HMX (mg/L)	RDX (mg/L)	TNT (mg/L)	Perchlorate (mg/L)
C (1938-1976)	1972	1976	NA	3.61E-02	4.27E-02	1.10E-02
D (1977-1988)	1977	1988	NA	2.88E-02	3.41E-02	8.79E-02
E (1989-Present)	1989	Present	NA	3.61E-02	4.27E-02	1.10E-02

Note:
Yellow cells indicate exceedence of REVA trigger values (Table 5-1).
NA – Not Applicable

7.5.4. Vadose Zone Modeling

Based on the results of the screening-level analysis above, REVA indicator MC at or above the REVA trigger values were modeled in VLEACH to determine if they would reach the water table and, if so, at what estimated concentrations. Table 7-26 shows the model-predicted soil water concentrations at the water table at the end of the final time period, based on the cumulative assessment of MC loading over time. See Appendix A for a summary of model input parameters.

Table 7-26.
Vadose Zone Model Results: MC Concentrations Reaching Groundwater at the F-6 MC Loading Area

MC	Soil Water Concentration (mg/L)
HMX[a]	--
RDX	3.61E-02
TNT	4.27E-02
Perchlorate	1.10E-02

Note:
Yellow cells indicate exceedence of REVA trigger values (Table 5-1).
[a] HMX was not estimated to reach the water table and therefore was not further modeled.

The model predicted that RDX, TNT, and perchlorate have the potential to reach the water table at concentrations exceeding the REVA trigger concentrations. As explained in Section 6, saturated zone modeling was not conducted and groundwater sampling was recommended instead of continuing with groundwater modeling because the complexities of the system precluded the use of a screening-level saturated flow groundwater model. The initial groundwater sampling event for the G-10 and K-2 impact areas was conducted because these two areas are larger than F-6 and are expected to have a greater impact on groundwater conditions. However, groundwater supply wells were sampled near the F-6 area as part of the investigation. Groundwater was collected from three water supply wells located north of the F-6 area, and one water supply well and one monitoring well located south of the F-6 area. The investigation indicates that MC are not migrating off range. Detailed results of the groundwater sampling are presented in Section 9. If the sampling results had indicated high MC concentrations in the groundwater sampled, additional sampling would have been recommended, as appropriate.

7.5.5. Surface Water Screening-Level Analysis Results

A screening-level analysis of MC concentrations in surface water was conducted for the F-6 MC loading area and its upstream drainages. The F-6 MC loading area drains westward into Cogdels Creek, which drains into the New River (Figure 7-7). Surface water in and around MCB Camp Lejeune is not used as a drinking water supply; however, humans potentially use it for recreational purposes (including fishing). Streams draining from the F-6 MC loading area drain near areas where the federally-listed T/E red-cockaded woodpecker, rough-leaved loosestrife and the American alligator have been documented to exist.

The surface water screening-level analysis was conducted as described in Section 5 for a time period ranging from 1953 to 2005. Table 7-5 presents the estimated average annual edge-of-loading-area concentrations in surface water runoff from the F-6 MC loading area, as well as upstream MC loading areas that drain the New River between Town

Creek and Stones Bay. Based on surface water screening-level calculations, concentrations of RDX, TNT, and perchlorate leaving the F-6 MC loading area were predicted to potentially exceed the REVA trigger values.

The F-6 MC loading area was predicted to contribute a small portion of the total perchlorate mass (less than 10%), negligible mass of RDX and TNT, and no HMX mass into the New River between Town Creek and Stones Bay. As discussed in Sections 7.1.5 and 7.2.5, the G-10 and K-2 impact area MC loading areas were predicted to contribute significant portions of MC mass into the New River between Town Creek and Stones Bay. These concentrations were predicted to be above the REVA trigger values even after downstream mixing; however, this was a result of MC mass contributions from G-10 and K-2 impact area MC loading areas rather than from the F-6 MC loading area.

7.5.6. Potential Pathways

The screening-level modeling results show that RDX, TNT, and perchlorate have the potential to reach the water table at the F-6 MC loading area after being dissolved by the infiltrating rain. If dissolved MC reach the water table, they will continue flowing with groundwater according to the existing gradient and conditions. The F-6 MC loading area falls within WHPA Zones 2 and 3 near two water supply wells . Groundwater was collected from three water supply wells located north of the F-6 area and one water supply well and one monitoring well located south of the F-6 area. The surface water screening-level analysis results indicate that postmixing concentrations of RDX and TNT are estimated to reach the New River above the REVA trigger values; however, the F-6 MC loading area is predicted to contribute small to negligible MC mass compared to the MC mass contributions from the G-10 and K-2 impact area MC loading areas. The F-6 MC loading area drains westward into Cogdels Creek, which drains into the New River (Figure 7-7). These surface water bodies are potential surface water pathways.

7.5.7. Potential Receptors

There are no current users of shallow groundwater at MCB Camp Lejeune because all water supplies at the installation originate from water wells tapping the deeper aquifers (upper and lower Castle Hayne). There are also no potential off-site receptors since all shallow groundwater at the installation discharges into the interior surface water features or, ultimately, to the New River, the Intracoastal Waterway, and the Atlantic Ocean. Surface water in and around MCB Camp Lejeune is not used as a drinking water supply; however, humans potentially use it for recreational purposes (including fishing). Streams draining from the F-6 MC loading area drain near areas where the federally-listed T/E red-cockaded woodpecker, rough-leaved loosestrife and the American alligator have been documented to exist.

7.6. L-Impact Area (Historical Use)

The historical use L-Impact Area is located within the operational Tactical Maneuver Training Area LA (Figure 3-1). The historical L-Impact Area is located east of Highway 17 and north of Highway 210 (Figure 7-8) and is bordered to the south by undeveloped publicly owned lands and to the north, west, and east by operational tactical maneuver training areas. This historical use impact area was first used in 1951, and its use ceased in 1962.

The historical L-Impact Area MC loading area was delineated based on maps presented in the ASR and PRA report. All MC loading was assumed to have been within the resulting 66-acre designated area. The loading period for the L-Impact Area MC loading area was from 1951 to 1962.

7.6.1. MC Loading

The MC loading area for the historical L-Impact Area is shown in Figure 7-8. The MC Loading Rate Calculator was used to estimate the amount of MC loaded at this MC loading area over time. The MC loading amounts estimated for the identified time period during which the impact area operated (time period C) are listed in Table 7-27. The estimated MC loading rates for the historical L-Impact Area were derived based on the military munitions usage data presented in the ASR and PRA report, while the quantities were based on those of similar items or groups of items from the current Range Control expenditure data. The resulting annual MC loading rate was extrapolated backward to this range's inception. Based on the dates of use of the historical L-Impact Area, there was no MC loading prior to 1951 or after 1962.

Table 7-27.
Estimated Annual MC Loading for the Historical L-Impact Area

MC Loading Area	Period	Begin Use	End Use	HMX (kg/m^2)	RDX (kg/m^2)	TNT (kg/m^2)	Perchlorate[a] (kg/m^2)
Historical L-Impact Area	C (1938-1976)	1951	1962	1.08E-10	1.48E-06	9.56E-07	NA

Note:
NA – Not applicable
[a] Perchlorate was only used in military munitions after 1962.

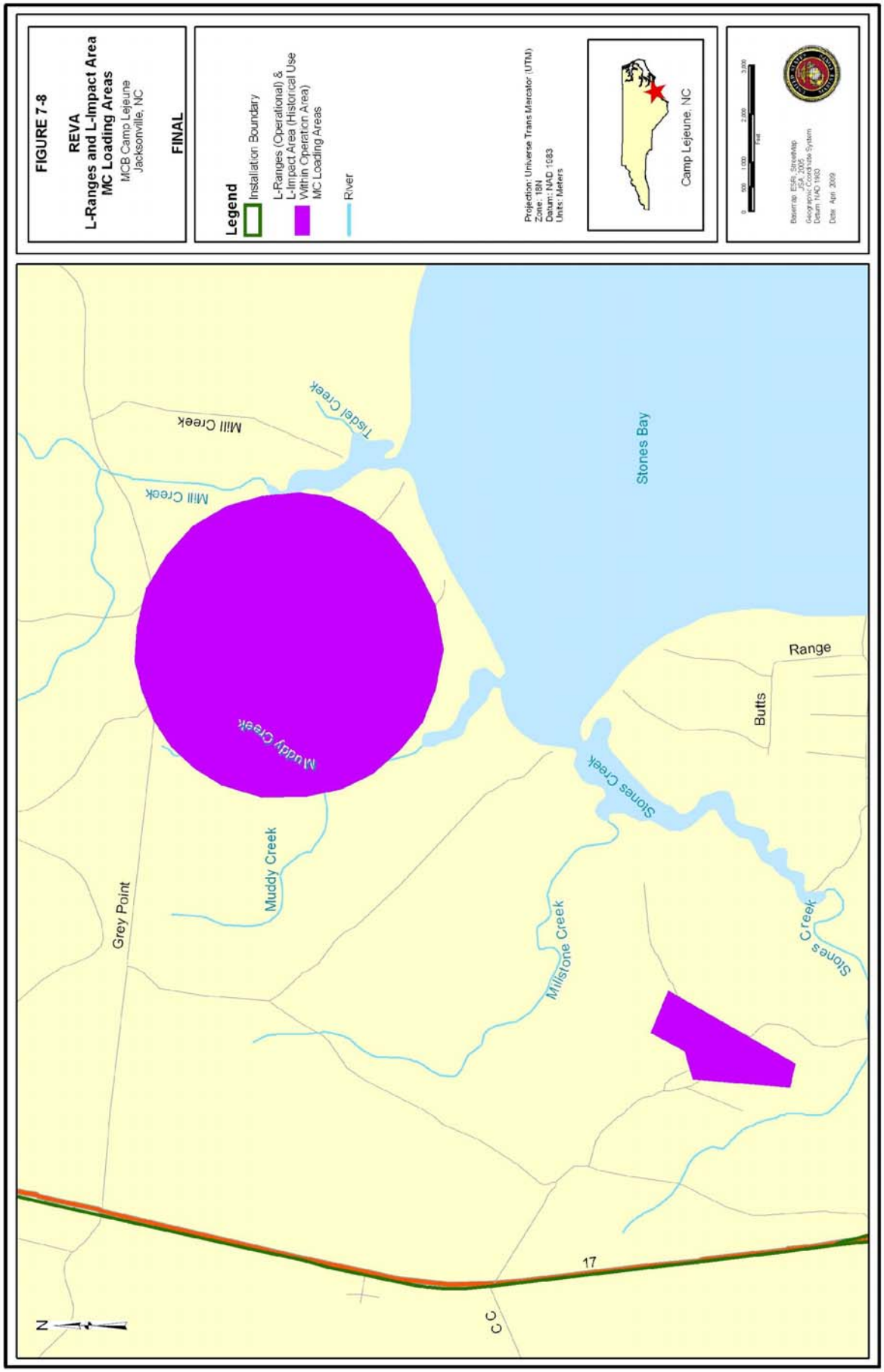


FIGURE 7-8
REVA
L-Ranges and L-Impact Area
MC Loading Areas
MCB Camp Lejeune
Jacksonville, NC
FINAL
Legend
Installation Boundary
L-Ranges (Operational) &
L-Impact Area (Historical Use
Within Operation Area)
MC Loading Areas
River
Projection: Universe Trans Mercator (UTM)
Zone: 18N
Datum: NAD 1983
Units: Meters
Camp Lejeune, NC
Stones Bay
Tisdel Creek
Mill Creek
Mill Creek
Muddy Creek
Muddy Creek
Grey Point
Stones Creek
Milstone Creek
Stones Creek
Butts
Range
17
N

7.6.2. Range-Specific CSM

The range-specific CSM information for the historical L-Impact Area MC loading area is provided in the following sections.

7.6.2.1. Geography and Topography

The historical L-Impact Area MC loading area occupies a neck of upland on the western side of MCB Camp Lejeune, bordered by stream valleys to the north and south. The upland is gently sloping (< 5% slope), but the sides of the stream valleys are relatively steep (up to 15% slope).

7.6.2.2. Surface Water Features

The historical L-Impact Area MC loading area drains within the subwatershed of Stones Creek upstream of its confluence with Stones Bay. Within this subwatershed, the L-Impact Area MC loading area drains northward to an unnamed tributary of the tidal Millstone Creek and south and southwest to unnamed tributaries of the tidal Stones Creek. Millstone Creek empties into Stones Creek, which discharges to Stones Bay, (part of the New River embayment), about 1 mile to the east-northeast of the historical L-Impact Area MC loading area.

7.6.2.3. Soil Characteristics and Land Cover

The historical L-Impact Area MC loading area consists primarily of bare ground (military operations area) and is underlain by loamy, sandy, and mucky soils of the Baymeade-Foreston-Stalling, Leon-Murville-Kureb, and Muckalee-Dorovan associations.

7.6.2.4. Erosion Potential

The erodibility of the historical L-Impact Area MC loading area is moderate due to the soils of low to moderate erodibility with localized disturbance of vegetation and soil.

7.6.2.5. Groundwater Characteristics

IRP Site 69 is located near the historical L-Impact Area MC loading area. Baker Environmental completed a Phase I and Phase II Treatability Study Report for IRP Site 69. IRP Site 69 is underlain by silty sands from the ground surface to a depth of approximately 12 to 15 ft bgs. Groundwater levels for the Surficial aquifer range from 0.34 to 3.3 ft bgs. The water table gradient was calculated to be 0.065 for the Surficial aquifer (Baker, 1996a).

7.6.2.6. Area Hydrogeology (Aquifers and Aquitards)

Beneath the surficial aquifer material (silty sand) is a fairly continuous sandy clay, sand, and clay unit to a depth of approximately 26 to 36 ft bgs at the L-Impact Area MC loading area. The clay horizons of this unit act as an aquitard. The upper unit of the Castle Hayne aquifer, which was encountered below the clay confining unit, consists of silty sand with shell and limestone fragments. Groundwater levels for the Castle Hayne

aquifer were 25 to 30 ft below the top of the casing. The estimated hydraulic conductivity for the historical L-Impact Area MC loading area is 3.28E-07 ft/sec.

7.6.3. Initial Groundwater Screening-Level Analysis

To determine the estimated MC concentrations potentially reaching the groundwater table at the MC loading areas, the estimated MC loading rates (Table 7-27) were divided by the infiltration rate of 30% of the total annual precipitation. As shown in Table 7-28, the initial mass loading screening-level analysis indicates that estimated concentrations of RDX and TNT for period C exceed the REVA trigger concentrations.

Table 7-28.
Estimated Maximum Concentrations of MC in Infiltrating Water at the Historical L-Impact Area

Period	Begin Use	End Use	HMX (mg/L)	RDX (mg/L)	TNT (mg/L)	Perchlorate[a] (mg/L)
C (1938-1976)	1951	1962	1.97E-07	2.70E-03	1.74E-03	NA

Note:
Yellow cells indicate exceedence of REVA trigger values (Table 5-1).
[a] Perchlorate was only used in military munitions after 1962.
NA – Not Applicable

7.6.4. Vadose Zone Modeling

Based on the results of the screening-level analysis above, REVA indicator MC at or above the REVA triggers were modeled in VLEACH to determine if they would reach the water table and, if so, at what estimated concentrations. Table 7-29 shows the results of this modeling effort, presenting the soil water estimated concentrations entering the water table at the end of the final time period, based on the cumulative assessment of MC loading over time. See Appendix A for a summary of the model input parameters.

Table 7-29.
Vadose Zone Model Results: MC Concentrations Reaching Groundwater at the L-Impact Area

MC	Soil Water Concentration (mg/L)
HMX[a]	--
RDX	0.0
TNT	0.0
Perchlorate[b]	--

Note:
Yellow cells indicate exceedence of REVA trigger values (Table 5-1).
[a] HMX did not exceed REVA trigger value and was not modeled.
[b] Perchlorate was not estimated to reach the water table and therefore was not further modeled.

The modeling results indicated no potential for RDX or TNT to be found at the water table at concentrations above the REVA trigger values at the historical L-Impact Area. No further analyses were conducted for this loading area.

7.6.5. Surface Water Screening-Level Analysis Results

A screening-level analysis of MC concentrations in surface water was conducted for the historical L-Impact Area MC loading area. The historical L-Impact Area MC loading area drains north into Millstone Creek and south into Stones Creek. Millstone and Stones creeks come to a confluence and drain into the New River at Stones Bay.

The historical L-Impact MC loading area is a historical loading area. The surface water screening-level analysis was carried out for a time period ranging from 1951 to 1962. MC concentrations estimated in surface water runoff at the edge of this MC loading area were predicted to be negligible by year 2005.

7.6.6. Potential Pathways

As discussed in Section 7.6.4, none of the MC are predicted to be found at the water table at concentrations above the REVA trigger values for the historical L-Impact Area, and surface water screening-level analyses indicate negligible MC concentrations by 2005. Therefore, there are no current MC migration pathways relating to the historical L-Impact Area MC loading area.

7.6.7. Potential Receptors

Potential human and ecological receptors do not appear to be impacted by this MC loading area based on the above screening-level analyses results.

7.7. L-Ranges (Operational)

The operational L-Ranges are located within the operational Tactical Maneuver Training Area LF (Figure 3-1). The L-Ranges are bordered to the east by the K-2 Impact Area, to the southeast by Stones Bay, and to the south, west, and north by operational tactical maneuver training areas (Figure 7-8). Stones Bay encroaches on the L-Ranges at the northwestern extent of its SDZ. These ranges were first used in 1957, and their use continues today.

The L-Ranges MC loading area was delineated based on review of existing GIS data and aerial photographs collected during the site visit. All MC loading was assumed to have been within the resulting 706-acre designated area. The loading period for the L-Ranges MC loading area was from 1957 to present.

7.7.1. MC Loading

The MC loading area for the L-Ranges is shown in Figure 7-8. The MC Loading Rate Calculator was used to estimate the amount of MC loaded at this MC loading area over

time. The MC loading amounts estimated for each identified time period during which the range was operated (time periods C, D, and E) are listed in Table 7-30. The resulting annual MC loading rates were extrapolated backward to this operational range's inception. Since the L-Ranges were first used in 1957, there was no MC loading prior to 1957.

Table 7-30.
Estimated Annual MC Loading for the L-Ranges

MC Loading Area	Period	Begin Use	End Use	HMX (kg/m^2)	RDX (kg/m^2)	TNT (kg/m^2)	Perchlorate[a] (kg/m^2)
L-Ranges	C (1938-1976)	1957	1976	1.50E-07	9.41E-05	6.00E-05	2.11E-08
	D (1977-1988)	1977	1988	NA	2.95E-07	1.98E-11	1.69E-08
	E (1989-Present)	1989	Present	NA	3.69E-07	2.47E-11	2.11E-08

Note:
NA – Not applicable
[a] Perchlorate was only used in military munitions after 1962.

7.7.2. Range-Specific CSM

The range-specific CSM for the L-Ranges MC loading area is provided in the following sections.

7.7.2.1. Geography and Topography

The L-Ranges MC loading area occupies an area to the west of the MCB Camp Lejeune K-2 Impact Area, bordered by stream valleys to the east and west. The upland is gently sloping (< 5% slope), but the sides of the stream valleys are relatively steep (up to 15% slope).

7.7.2.2. Surface Water Features

The L-Ranges MC loading area drains within the subwatershed of the New River at Stones Bay. Within this subwatershed, the L-Ranges MC loading area drains eastward to the tidal Mill Creek, westward to the tidal Muddy Creek, and southward directly to the Stones Bay region of the New River embayment.

7.7.2.3. Soil Characteristics and Land Cover

The L-Ranges MC loading area consists primarily of forest and is underlain by loamy, sandy, and mucky soils of the Baymeade-Foreston-Stalling, Leon-Murville-Kureb, and Muckalee-Dorovan associations.

7.7.2.4. Erosion Potential

The erodibility of the L-Ranges MC loading area is slight due to the low erodibility soils and high vegetative cover.

7.7.2.5. Groundwater Characteristics

The L-Ranges MC loading area is to the west of the K-2 Impact Area and has similar soil types. The USGS completed an investigation that examined groundwater flow in the K-2 Impact Area (Harden and others, 2004). For the purposes of this evaluation, the results and conclusions of this study for the K-2 Impact Area were applied to the L-Ranges. Refer to Section 7.2.2.5 for further information on groundwater characteristics in this area.

7.7.2.6. Area Hydrogeology (Aquifers and Aquitards)

For the purposes of this evaluation, the results and conclusions of this study for the K-2 Impact Area were applied to the L-Ranges due to their proximity to each other. Refer to Section 7.2.2.6 for further information on the hydrogeology of the area.

7.7.3. Initial Groundwater Screening-Level Analysis

To determine the estimated MC concentrations potentially reaching the groundwater table at the MC loading areas, the estimated MC loading rates (Table 7-30) were divided by the infiltration rate of 30% of the total annual precipitation. As shown in Table 7-31, the initial mass loading screening-level analysis indicates that estimated concentrations of RDX exceed the REVA trigger value for time periods C, D, and E. In addition, HMX and TNT concentrations exceed REVA triggers for period C.

Table 7-31.
Estimated Maximum Concentrations of MC in Infiltrating Water at the L-Ranges MC Loading Area

Period	Begin Use	End Use	HMX (mg/L)	RDX (mg/L)	TNT (mg/L)	Perchlorate[a] (mg/L)
C (1938-1976)	1957	1976	2.73E-04	1.72E-01	1.09E-01	3.85E-05
D (1977-1988)	1977	1988	NA	5.38E-04	3.61E-08	3.08E-05
E (1989-Present)	1989	Present	NA	6.73E-04	4.50E-08	3.85E-05

Note:
Yellow cells indicate exceedence of REVA trigger values (Table 5-1).
[a] Perchlorate was only used in military munitions after 1962.
NA – Not Applicable

7.7.4. Vadose Zone Modeling

Based on the results of the screening-level analysis above, REVA indicator MC at or above the REVA triggers were modeled in VLEACH to determine if they would reach the water table and, if so, at what estimated concentrations. Table 7-32 shows the model-predicted soil water concentrations at the water table at the end of the final time period (representing the year 2006), based on the cumulative assessment of MC loading over time. See Appendix A for a summary of the model input parameters.

Table 7-32.
Vadose Zone Model Results: MC Concentrations Reaching Groundwater at the L-Ranges Loading Area

MC	Soil Water Concentration (mg/L)
HMX	0.0
RDX	6.73E-04
TNT	4.5E-08
Perchlorate[a]	--

Note:
Yellow cells indicate exceedence of REVA trigger values (Table 5-1).
[a] Perchlorate did not exceed REVA trigger value and was not modeled.

The model predicted that RDX would potentially be at the water table at a concentration above the REVA trigger value in the L-Ranges MC loading area. As explained in Section 6, saturated zone modeling was not conducted and groundwater sampling was recommended instead of continuing with groundwater modeling because the complexities of the system precluded the use of a screening-level saturated flow groundwater model. The initial groundwater sampling event occurred only for the G-10 and K-2 impact areas because the modeling results indicated larger MC concentrations and these two areas are larger in size than the L-Ranges MC loading area. The investigations at the G-10 and K-2 impact areas indicate that MC are not migrating off range from these more intensively loaded and larger loading areas, so this smaller range is not expected to have MC migrating off range. If the sampling results had indicated high MC concentrations in the groundwater for the investigated areas, additional sampling would have been recommended at the L-Ranges MC loading area. Detailed results of the groundwater sampling are presented in Section 9.

7.7.5. Surface Water Screening-Level Analysis Results

A screening-level analysis of MC concentrations in surface water was conducted for the L-Ranges MC loading area and its upstream drainages. The L-Ranges MC loading area drains east into Mill Creek and west into Muddy Creek. Mill and Muddy creeks drain south into the New River at Stones Bay (Figure 7-4). Surface water in and around MCB Camp Lejeune is not used as a drinking water supply; however, humans potentially use it for recreational purposes (including fishing), and it may be home to potential ecological receptors.

The surface water screening-level analysis was conducted as described in Section 5 for a time period ranging from 1957 to 2005. Table 7-12 presents the estimated percentage of MC mass contributed by individual loading areas to the New River at Stones Bay. The L-Ranges MC loading area was predicted to contribute a very small percent of the total perchlorate mass (less than 5%), negligible amounts of the total RDX and TNT mass, and none of the total HMX mass into the New River at Stones Bay.

Table 7-5 presents the estimated average annual edge-of-loading-area concentrations in surface water runoff from the L-Ranges MC loading area, as well as upstream MC loading areas that drain to the New River at Stones Bay. The concentration of RDX leaving L-Ranges MC loading area was predicted to potentially exceed the REVA trigger value. As discussed in Section 7.2.5 and noted in Table 7-14, RDX and TNT concentrations entering the New River at Stones Bay were predicted to be above the REVA trigger values even after downstream mixing; however, this was a result of MC mass contributions from K-2 Impact Area MC loading area rather than the L-Ranges MC loading area.

7.7.6. Potential Pathways

According to the screening-level model results, RDX has the potential to reach the water table at the L-Ranges MC loading area after being dissolved by the infiltrating rain. If a dissolved MC reaches the water table, it will continue flowing with groundwater according to the existing gradient and groundwater conditions. The L-Ranges MC loading area is within 3,300 ft of Millstone Creek, which flows directly into the New River. In general, the shallow groundwater appears to flow radially from the center portion of the L-Ranges MC loading area to the outer, low-lying areas.

The surface water screening-level analysis results indicated that postmixing concentrations of RDX and TNT are estimated to reach the New River. However, as discussed above, the L-Range MC loading area was estimated to contribute very little mass of MC (maximum of less than 5%) into the New River at Stones Bay.

7.7.7. Potential Receptors

Based on the proximity of the L-Range to the New River, the absence of the confining unit below the New River, and the rapid drop in the water table from the uplands to the river, groundwater likely flows toward the New River. It is also likely that groundwater discharges to the New River from the Castle Hayne aquifer beneath the K-2 Impact Area (Triangle, 1999). There are no current users of shallow groundwater at MCB Camp Lejeune since all water supplies at the installation originate from water wells tapping the Castle Hayne aquifer. There are no water supply wells in the immediate area of the L-Ranges. Surface water in and around MCB Camp Lejeune is not used as a drinking water supply; however, humans potentially use it for recreational purposes (including fishing).There are commercial oyster beds located adjacent to the K-2 Impact Area along the eastern and southeastern boundaries within the New River. Streams draining the L-Ranges MC loading area drain near areas where the federally-listed T/E red-cockaded woodpecker has been documented to exist.

7.8. Combat Town (Operational)

The operational range Combat Town is located on Combat Town Road, between Sneads Ferry Road and Marines Road (Figure 7-9). Combat Town is bordered on all sides by operational tactical maneuver training areas. This operational urban warfare training facility was first used in 1976, and its use continues today.

The Combat Town MC loading area was delineated based on interviews with Range Control and existing GIS data collected during the site visit. All MC loading was assumed to have been within the resulting 6-acre area. The loading period for the Combat Town MC loading area was from 1976 to present.

7.8.1. MC Loading

The MC loading area for Combat Town is shown in Figure 7-9. The MC Loading Rate Calculator was used to estimate the amount of MC loaded at this MC loading area over time. The MC loading amounts estimated for each identified time period during which the range was operated (time periods C, D, and E) are listed in Table 7-33. The resulting annual MC loading rate was extrapolated backward to the range's inception. Since Combat Town was first used in 1976, there was no MC loading prior to 1976.

Table 7-33.
Estimated Annual MC Loading for Combat Town

MC Loading Area	Period	Begin Use	End Use	HMX (kg/m^2)	RDX (kg/m^2)	TNT (kg/m^2)	Perchlorate (kg/m^2)
Combat Town	C (1938-1976)	1976	1976	1.12E-10	1.52E-08	4.13E-08	2.33E-08
	D (1977-1988)	1977	1988	8.97E-11	1.22E-08	3.30E-08	1.87E-08
	E (1989-Present)	1989	Present	1.12E-10	1.52E-08	4.13E-08	2.33E-08

7.8.2. Range-Specific CSM

The range-specific CSM for the Combat Town MC loading area is provided in the following sections.

7.8.2.1. Geography and Topography

The Combat Town MC loading area occupies a gently sloping region of Talbot surface on the eastern side of MCB Camp Lejeune at an elevation of 35-45 ft.

7.8.2.2. Surface Water Features

The Combat Town MC loading area drains within the subwatershed of the New River between Town Creek and Stones Bay (Figure 7-2). Within this subwatershed, Combat Town MC loading area drains to the perennial headwaters of Frenchs Creek, which becomes tidal downstream and drains into the New River embayment (Figure 7-9).

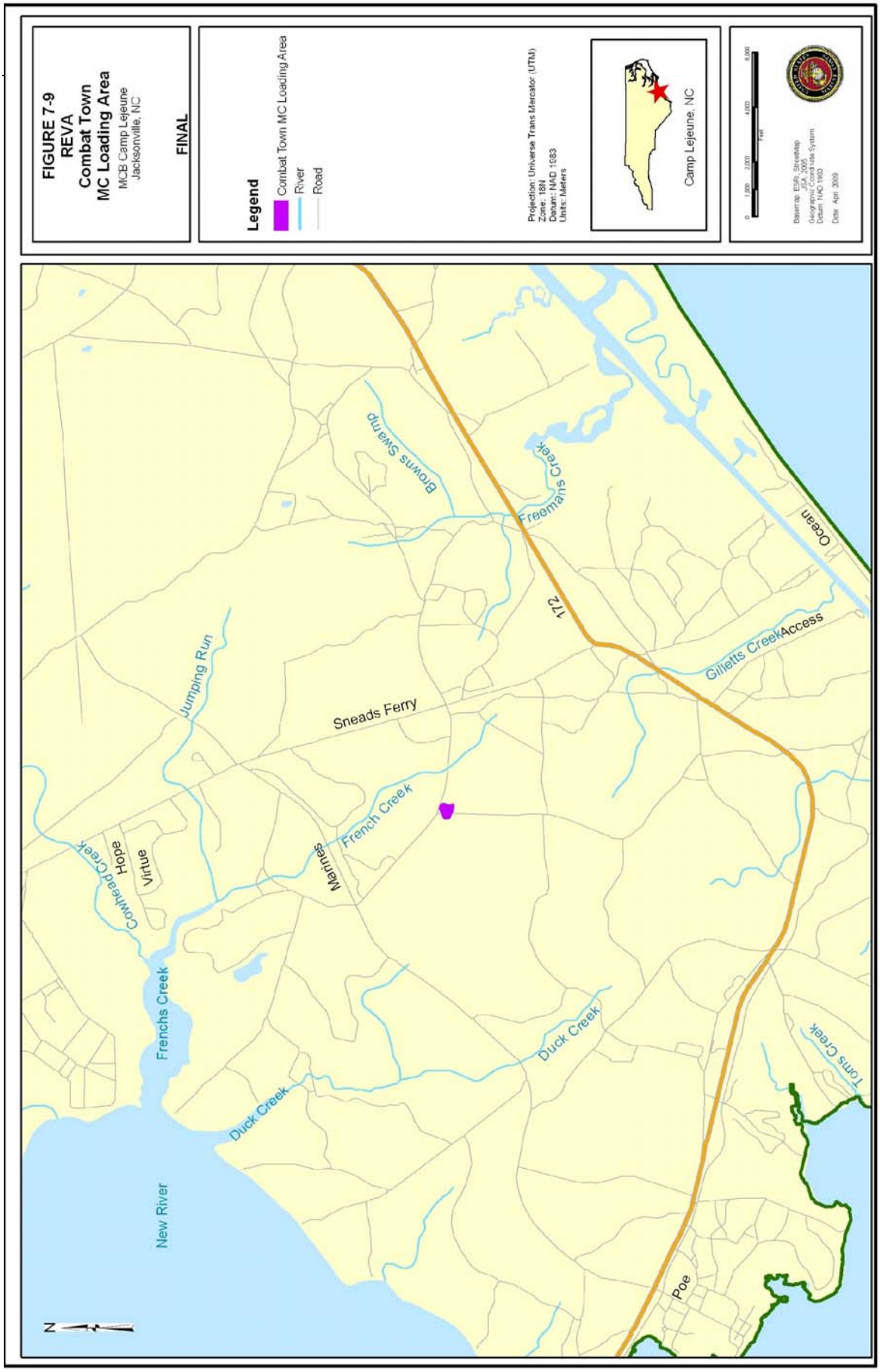


FIGURE 7-9
REVA
Combat Town
MC Loading Area
MCB Camp Lejeune
Jacksonville, NC
FINAL
Legend
Combat Town MC Loading Area
River
Road
Projection: Universe Trans Mercator (UTM)
Zone: 18N
Datum: NAD 1983
Units: Meters
Camp Lejeune, NC
0 1,000 2,000 4,000 6,000
Feet
Dataset by: ESRI, StreetMap USA, 2005
Geographic Coordinate System
Datum: NAD 1983
Date: April 2009
Ocean
Browns Swamp
Freemans Creek
172
Gilletts Creek
Access
Jumping Run
Sneads Ferry
French Creek
Marines
Virtue
Hope
Cowhead Creek
Frenchs Creek
Duck Creek
Duck Creek
Toms Creek
New River
Poe
N

7.8.2.3. Soil Characteristics and Land Cover

The Combat Town MC loading area is underlain by sandy soils of the Leon-Murville-Kureb association. The land use of the Combat Town MC loading area is classified as "developed—non-residential."

7.8.2.4. Erosion Potential

The erodibility of the Combat Town MC loading area is moderate due to the combination of flat topography and low erodibility soils with localized disturbance of vegetation and soil.

7.8.2.5. Groundwater Characteristics

The Combat Town MC loading area is located approximately 3,300 ft from Operable Unit 7 Site 30, for which a remedial investigation (RI) was completed. The physical setting of Operable Unit 7 Site 30 was reviewed to assist in assessing Combat Town for REVA. The surficial groundwater flow for Operable Unit 7 Site 30 is assumed to be in the direction of French Creek. The average hydraulic gradient across Operable Unit 7 Site 30 was 0.015, indicating a moderately steep gradient (Baker, 1995). Groundwater flow velocity within the Surficial aquifer for Operable Unit 7 Site 30 was estimated by Baker to be 0.15 ft/day.

7.8.2.6. Area Hydrogeology (Aquifers and Aquitards)

No site-specific information regarding the underlying aquitards and aquifers for this MC loading area was identified. The closest information for underlying aquitards and aquifers is the data collected for the G-10 Impact Area (Section 7.1.2.6), which is located to the northeast of Combat Town.

7.8.3. Initial Groundwater Screening-Level Analysis

To determine the estimated MC concentrations potentially reaching the groundwater table at the MC loading area, the estimated MC loading rates (Table 7-33) were divided by the infiltration rate of 30% of the total annual precipitation. As shown in Table 7-34, the initial mass loading screening-level analysis indicates that maximum concentrations of HMX, RDX, TNT, and perchlorate for time periods C, D, and E do not exceed the applicable REVA trigger values. Thus, no further groundwater analysis of this loading area was conducted.

Table 7-34.
Estimated Maximum Concentrations of MC in Infiltrating Water at Combat Town

Period	Begin Use	End Use	HMX (mg/L)	RDX (mg/L)	TNT (mg/L)	Perchlorate (mg/L)
C (1938-1976)	1976	1976	2.04E-07	2.77E-05	7.53E-05	4.25E-05
D (1977-1988)	1977	1988	1.63E-07	2.22E-05	6.01E-05	3.41E-05
E (1989-Present)	1989	Present	2.04E-07	2.77E-05	7.53E-05	4.25E-05

7.8.4. Vadose Zone Modeling

Based on the results in Section 7.8.3, no additional groundwater analysis of this loading area was conducted.

7.8.5. Surface Water Screening-Level Analysis Results

A screening-level analysis of MC concentrations in surface water was conducted for the Combat Town MC loading area and its upstream drainages. The Combat Town MC loading area drains west into Duck Creek and north into Frenchs Creek. Both Duck Creek and Frenchs Creek drain northwesterly into the New River between Town Creek and Stones Bay (Figures 7-2 and 7-9). Surface water in and around MCB Camp Lejeune is not used as a drinking water supply; however, humans potentially use it for recreational purposes (including fishing), and it may be home to potential ecological receptors.

The surface water screening-level analysis was conducted as described in Section 5 for a time period ranging from 1953 to 2005. Table 7-5 presents the estimated average annual edge-of-loading-area concentrations in surface water runoff from the Combat Town MC loading area, as well as upstream MC loading areas that drain the New River between Town Creek and Stones Bay. Concentrations of all four MC leaving the Combat Town MC loading area were predicted to be below the REVA trigger values.

The Combat Town MC loading area was predicted to contribute a small portion of the total perchlorate mass (less than 2%) and negligible mass of HMX, RDX and TNT into the New River between Town Creek and Stones Bay. As discussed in Sections 7.1.5 and 7.2.5, the G-10 and K-2 Impact Areas MC loading areas were predicted to contribute significant portions of MC mass into the New River between Town Creek and Stones Bay. MC concentrations entering the New River between Town Creek and Stones Bay were predicted to be above the REVA trigger values even after downstream mixing; however, this was a result of MC mass contributions from G-10 and K-2 Impact Areas MC loading areas (refer to Sections 7.1.5 and 7.2.5) rather than from the Combat Town MC loading area.

7.8.6. Potential Pathways

MC initial screening-level analysis of Combat Town MC loading indicates no potential for the MC to reach the water table at concentrations above the REVA trigger values or to impact nearby surface water bodies; therefore, no pathways exist for this MC loading area to groundwater. The surface water screening-level results also indicate that surface water is not a viable pathway for MC migration relating to this MC loading area.

7.8.7. Potential Receptors

Potential human and ecological receptors do not appear to be impacted by this MC loading area based on the above screening-level analyses results.

7.9. M-10 Range (Historical Use)

The historical use M-10 Range is located within the operational Tactical Maneuver Training Area MA, north of Verona Loop Road and east of Highway 17 (Figure 7-10). The M-10 Range is bordered on all sides by operational tactical maneuver training areas; however, to the west and southwest, the city of Verona lies just across the installation boundary. MCAS New River lies to the north of the historical use M-10 Range. Southwest Creek, a tributary to the New River, is to the east. This historical range was first used in 1958, and its use ceased in 1961.

The historical use M-10 Range MC loading area was delineated based on maps presented in the ASR and PRA report. All MC loading was assumed to have been within the resulting 0.3-acre area. The loading period for the M-10 Range MC loading area was from 1958 to 1961.

7.9.1. MC Loading

The MC loading area for the historical use M-10 Range is shown in Figure 7-10. The MC Loading Rate Calculator was used to estimate the amount of MC loaded at this MC loading area over time. The MC loading amounts estimated for the identified time period during which the historical use area was operated (time period C) are listed in Table 7-35. The estimated MC loading rates for the historical use M-10 Range were derived based on the military munitions usage data presented in the ASR and PRA report, while the quantities were based on those of similar items or groups of items from the current Range Control expenditure data. The resulting annual MC loading rate was extrapolated backward to this range's inception. Based on the dates of use of the historical use M-10 Range, there was no MC loading prior to 1958 or after 1961.

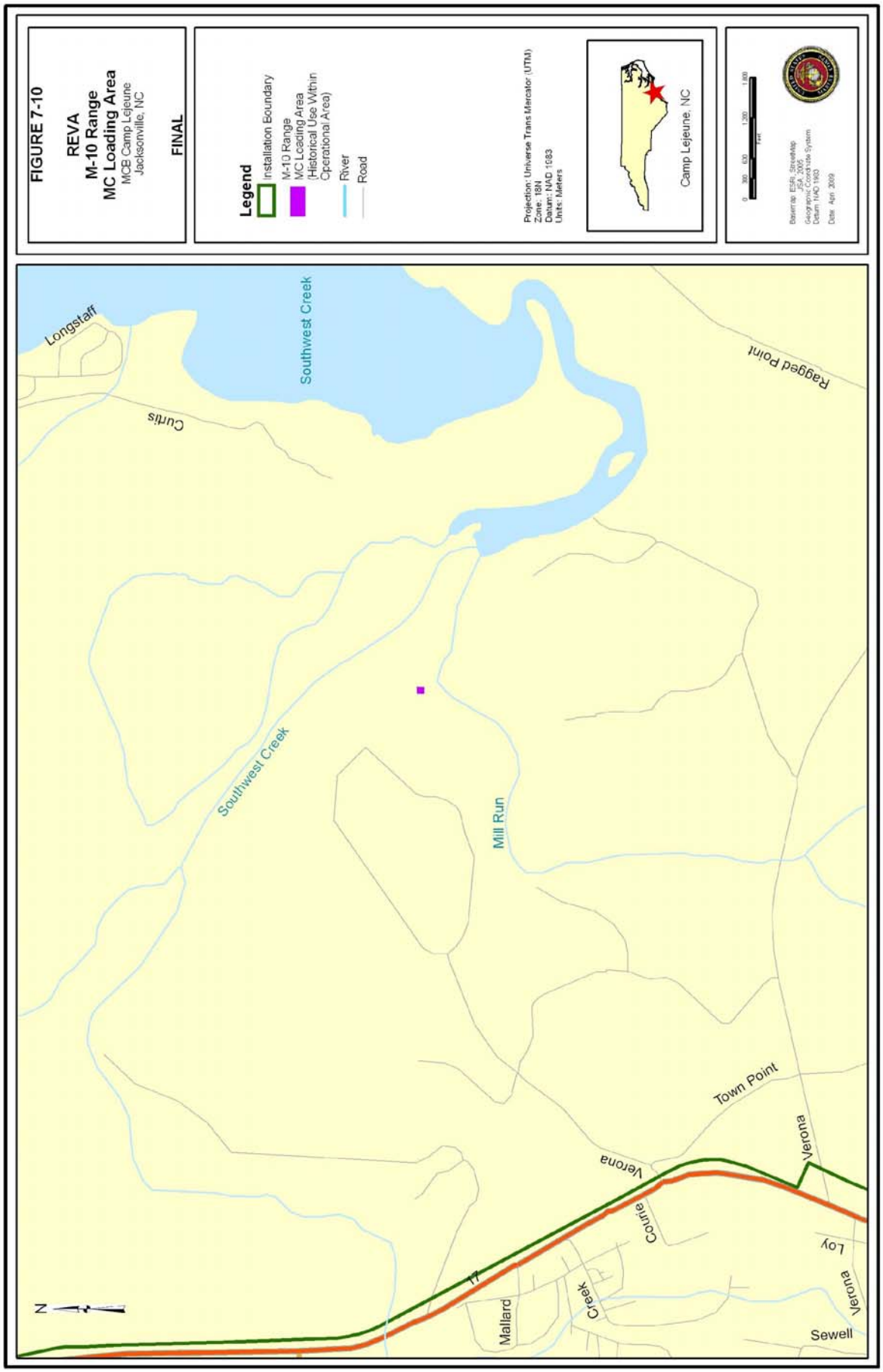


FIGURE 7-10
REVA
M-10 Range
MC Loading Area
MCB Camp Lejeune
Jacksonville, NC
FINAL
Legend
Installation Boundary
M-10 Range
MC Loading Area
(Historical Use Within
Operational Area)
River
Road
Projection: Universe Trans Mercator (UTM)
Zone: 18N
Datum: NAD 1983
Units: Meters
Camp Lejeune, NC
0 300 600 1,200 1,800
Feet
Basemap: ESRI, Streetmap USA, 2005
Geographic Coordinate System
Datum: NAD 1983
Date: April 2009
Longstaff
Southwest Creek
Curtis
Ragged Point
Southwest Creek
Mill Run
Town Point
Verona
Verona
Conine
Loy
Verona
Mallard
Creek
Sewell
N

Table 7-35.
Estimated Annual MC Loading for the M-10 Range

MC Loading Area	Period	Begin Use	End Use	HMX (kg/m^2)	RDX (kg/m^2)	TNT (kg/m^2)	Perchlorate[a] (kg/m^2)
M-10 Range	C (1938-1976)	1958	1961	NA	3.54E-04	4.55E-04	NA

Note:
NA – Not applicable
[a] Perchlorate was only used in military munitions after 1962.

7.9.2. Range-Specific CSM

The range-specific CSM for the historical use M-10 Range MC loading area is provided in the following sections.

7.9.2.1. Geography and Topography

The historical use M-10 Range MC loading area is located in a flat, swampy area at less than 5 ft elevation.

7.9.2.2. Surface Water Features

The historical use M-10 Range MC loading area drains within the subwatershed of Southwest Creek upstream of its confluence with the New River. Within this subwatershed, the M-10 Range MC loading area drains directly to the tidal wetlands associated with Southwest Creek and it tributary, Mill Run. Southwest Creek empties into the northern portion of the New River embayment (Figure 7-10).

7.9.2.3. Soil Characteristics and Land Cover

The historical use M-10 Range MC loading area is located in forested bottomland and is underlain by mucky soils of the Muckalee-Dorovan association.

7.9.2.4. Erosion Potential

The erodibility of the historical use M-10 Hand MC loading area is moderate due to the soils of low to moderate erodibility with localized disturbance of vegetation and soil.

7.9.2.5. Groundwater Characteristics

The historical use M-10 Range MC loading area is located northwest of IRP Site 63. Baker Environmental completed investigations for IRP Site 63. The borings that were installed as part of the RI for Site 63 were relatively shallow and did not penetrate the Castle Hayne aquifer. The upper soils consist of relatively coarse-grained sediments and fine sands with lesser amounts of silt and clay. Groundwater was encountered at approximately 3 to 9 ft bgs (Baker, 1997b).

7.9.2.6. Area Hydrogeology (Aquifers and Aquitards)

Only the Surficial aquifer was investigated as part of the RI for Site 63. The thickness of the Surficial aquifer at Site 63 was not determined because of the relatively shallow depths of the borings (Baker, 1996b and 1997b). Cross sections from USGS Report 93-4046 indicate the Castle Hayne confining unit is absent west of Site 63 (Cardinell et al., 1993).

The conductivity values for the Surficial aquifer for Site 63 are an order of magnitude lower than a value presented in the USGS report (Cardinell et al., 1993). This difference has been observed at other sites at MCB Camp Lejeune, as well. The average hydraulic conductivity at Site 63, based on the RI slug test, is 2.9 ft/day. The M-10 Range is located north of the K-2 Impact Area. Refer to Section 7.2.2.6 for additional groundwater area hydrogeology.

7.9.3. Initial Groundwater Screening-Level Analysis

To determine the estimated MC concentrations potentially reaching the groundwater table at the MC loading areas, the estimated MC loading rates (Table 7-35) were divided by the infiltration rate of 30% of the total annual precipitation. As shown in Table 7-36, the initial mass loading screening-level analysis indicates that estimated concentrations of RDX and TNT for time period C exceed the REVA trigger values.

Table 7-36.
Estimated Maximum Concentrations of MC in Infiltrating Water at the M-10 Ranges

Period	Begin Use	End Use	HMX (mg/L)	RDX (mg/L)	TNT (mg/L)	Perchlorate (mg/L)
C (1938-1976)	1958	1961	NA	0.645	0.829	NA

Note:
Yellow cells indicate exceedence of REVA trigger values (Table 5-1).
NA – Not Applicable

7.9.4. Vadose Zone Modeling

Based on the results of the screening-level analysis above, REVA indicator MC at or above the REVA triggers were modeled in VLEACH to determine if they would reach the water table and, if so, at what estimated concentrations. Table 7-37 shows the model-predicted soil water concentrations at the water table at the end of the final time period (representing the year 2006), based on the cumulative assessment of MC loading over time. See Appendix A for a summary of model input parameters.

Table 7-37.
Vadose Zone Modeled MC Concentrations

MC	Soil Water Concentration (mg/L)
HMX[a]	--
RDX	0.0
TNT	0.0
Perchlorate[a]	--

Note:
Yellow cells indicate exceedence of REVA trigger values.
[a] HMX and perchlorate were not estimated to reach the water table and therefore were not further modeled.

None of the MC were predicted to be at the water table with a concentration above the REVA trigger values in the year 2006. No further analysis was conducted.

7.9.5. Surface Water Screening-Level Analysis Results

A screening-level analysis of MC concentrations in surface water was conducted for the historical use M-10 Range MC loading area. The historical use M-10 MC loading area drains into Southwest Creek that drains into the New River. The historical use M-10 Range MC loading area is a historical loading area. The surface water screening-level analysis was carried out for a time period ranging from 1958 to 1961. MC concentrations in runoff at the edge of this MC loading area were predicted to be negligible by the year 2005.

7.9.6. Potential Pathways

MC initial screening-level analysis of historical use M-10 Range MC loading area indicates no potential for the MC to reach the water table at concentrations above the REVA trigger values and no potential impacts to nearby surface water bodies; therefore, no pathways exist for this loading area to groundwater. The surface water screening-level results also indicate that surface water is not a viable pathway for MC migration relating to this MC loading area.

7.9.7. Potential Receptors

Potential human and ecological receptors do not appear to be impacted by this MC loading area based on the above screening-level analyses results.

7.10. M-115 Range (Historical Use)

The historical use M-115 Range is located within the operational Tactical Maneuver Training Area MA, north of Verona Loop Road and east of Highway 17 (Figure 7-11). The historical use M-115 Range is bordered on all sides by operational tactical maneuver training areas; however, to the west and southwest, the city of Verona lies just across the installation boundary. MCAS New River lies to the north of the historical use M-115

Range. Southwest Creek, a tributary to the New River, is to the east. This historical range was used from 1970 to 1977.

The historical use M-115 Range MC loading area was delineated based on maps presented in the ASR and PRA report. All MC loading was assumed to have been within the resulting 0.3-acre area. The loading period for the M-115 Range MC loading area was from 1970 to 1977.

7.10.1. MC Loading

The MC loading area for the historical use M-115 Range is shown in Figure 7-11. The MC Loading Rate Calculator was used to estimate the amount of MC loaded at this MC loading area over time. The MC loading amounts estimated for each identified time period during which the range was operated (time periods C and D) are listed in Table 7-38. The estimated annual MC loading rates for the historical use M-115 Range were derived from the military munitions usage data presented in the ASR and PRA report, while the quantities were based on those of similar items or groups of items from the current Range Control expenditure data. The resulting MC loading rate was extrapolated backward to this range's inception. Based on the dates of use of the historical use M-115 Range, there was no MC loading prior to 1970 or after 1977.

Table 7-38.
Estimated Annual MC Loading for the Historical Use M-115 Range

MC Loading Area	Period	Begin Use	End Use	HMX (kg/m^2)	RDX (kg/m^2)	TNT (kg/m^2)	Perchlorate (kg/m^2)
Historical Use M-115 Range	C (1938-1976)	1970	1976	NA	3.47E-04	4.46E-04	1.24E-04
	D (1977-1988)	1977	1977	NA	2.78E-04	3.57E-04	9.93E-05

Note:
NA – Not applicable

7.10.2. Range-Specific CSM

The range-specific CSM for the historical use M-115 Range MC loading area is provided in the following sections.

7.10.2.1. Geography and Topography

The historical use M-115 Range MC loading area is located on gently sloping upland at an elevation of 15-20 ft.

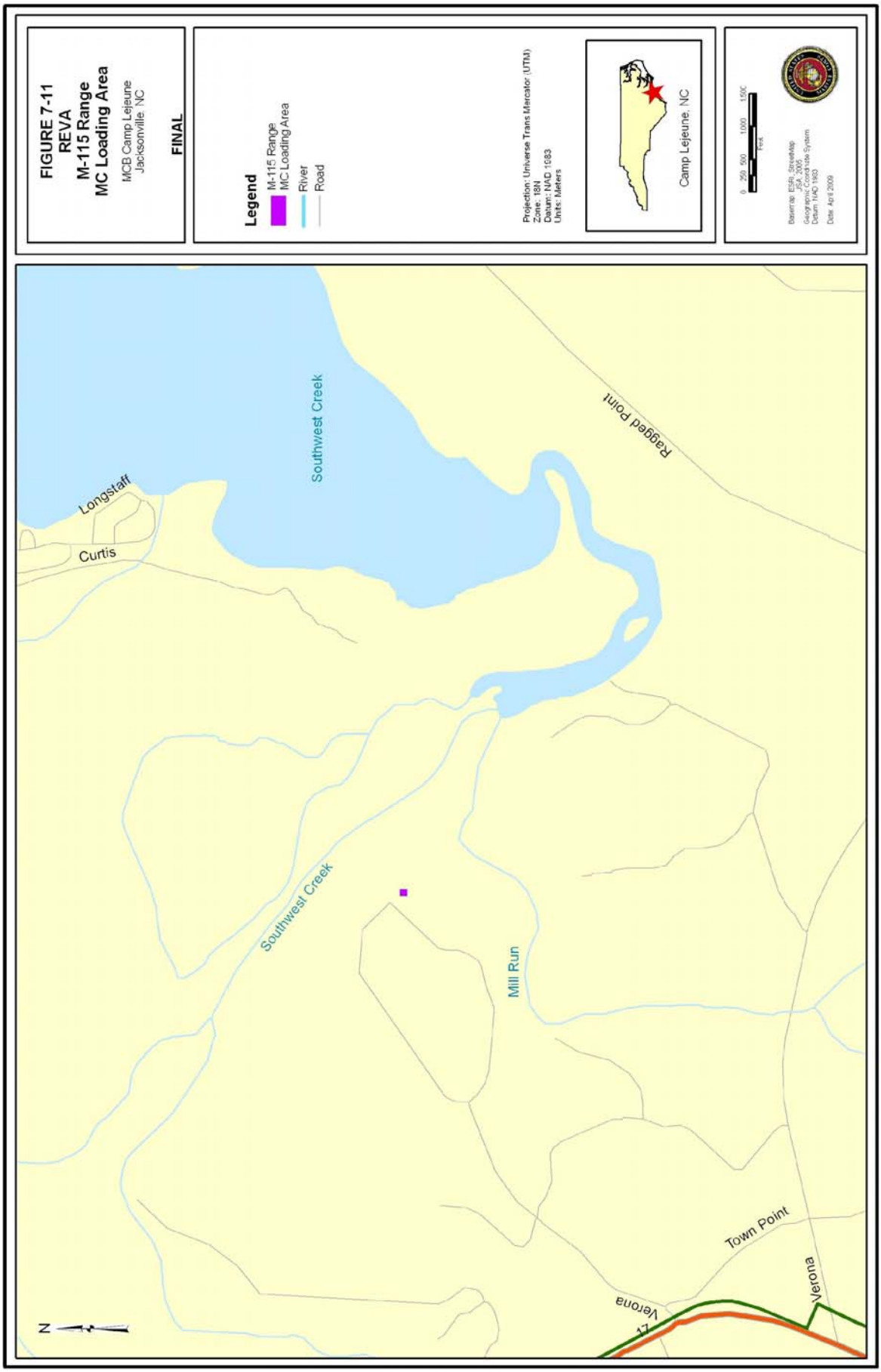


FIGURE 7-11
REVA
M-115 Range
MC Loading Area
MCB Camp Lejeune
Jacksonville, NC
FINAL
Legend
M-115 Range
MC Loading Area
River
Road
Projection: Universe Trans Mercator (UTM)
Zone: 18N
Datum: NAD 1983
Units: Meters
Camp Lejeune, NC
0 250 500 1000 1500
Feet
Basemap: ESRI, StreetMap USA, 2005
Geographic Coordinate System
Datum: NAD 1983
Date: April 2009
Southwest Creek
Ragged Point
Longstaff
Curtis
Southwest Creek
Mill Run
Town Point
Verona
Verona
N

7.10.2.2. Surface Water Features

The historical use M-115 Range MC loading area drains within the subwatershed of Southwest Creek upstream of its confluence with the New River. Within this subwatershed, the M-115 Range MC loading area drains directly to the tidal wetlands associated with Southwest Creek and it tributary, Mill Run. Southwest Creek empties into the northern portion of the New River embayment (Figure 7-11).

7.10.2.3. Soil Characteristics and Land Cover

The historical use M-115 Range MC loading area is located on forested upland and is underlain by loamy soils of the Norfolk-Goldsboro-Onslow association.

7.10.2.4. Erosion Potential

The erodibility of the historical use M-115 Range MC loading area is moderate due to the soils of low to moderate erodibility with localized disturbance of vegetation and soil.

7.10.2.5. Groundwater Characteristics

The historical use M-115 Range MC loading area is located northwest of IRP Site 63. Baker Environmental completed investigations for IRP Site 63. The borings that were installed as part of the RI for Site 63 were relatively shallow and did not penetrate the Castle Hayne aquifer. The upper soils consist of relatively coarse-grained sediments and fine sands with lesser amounts of silt and clay. Lenses of silt and clay are present throughout the study area (Site 63). Groundwater was encountered at approximately 3 to 9 ft bgs (Baker, 1997b).

7.10.2.6. Area Hydrogeology (Aquifers and Aquitards)

Only the Surficial aquifer was investigated as part of the RI for site 63 (Baker, 1996b and 1997b). The thickness of the Surficial aquifer at Site 63 was not determined because of the relatively shallow depths of the borings. Cross sections from USGS Report 93-4046 indicate the Castle Hayne confining unit is absent west of Site 63 (Cardinell et al., 1993).

The conductivity values for the Surficial aquifer for Site 63 are an order of magnitude lower than a value presented in the USGS report (Cardinell et al., 1993). This difference has been observed at other sites at MCB Camp Lejeune, as well. The average hydraulic conductivity at Site 63, based on the RI slug test, is 2.9 ft/day. The historical use M-10 Range is located north of the K-2 Impact Area. Refer to Section 7.2.2.6 for additional groundwater area hydrogeology.

7.10.3. Initial Groundwater Screening-Level Analysis

To determine the estimated MC concentrations potentially reaching the groundwater table at the MC loading area, the estimated MC loading rates (Table 7-38) were divided by the infiltration rate of 30% of the total annual precipitation. As shown in Table 7-39, the

initial mass loading screening-level analysis indicates that estimated concentrations of RDX, TNT, and perchlorate for time periods C and D exceed the REVA trigger values.

Table 7-39.
Estimated Maximum Concentration of MC in Infiltrating Water at the M-115 Range

Period	Begin Use	End Use	HMX (mg/L)	RDX (mg/L)	TNT (mg/L)	Perchlorate (mg/L)
C (1938-1976)	1970	1976	NA	0.632	0.813	0.226
D (1977-1988)	1977	1977	NA	0.507	0.651	0.181

Note:
NA – Not applicable
Yellow cells indicate exceedence of REVA trigger values (Table 5-1).

7.10.4. Vadose Zone Modeling

Based on the results of the screening-level analysis above, REVA indicator MC at or above the REVA trigger values were modeled in VLEACH to determine if they would reach the water table and, if so, at what estimated concentrations. Table 7-40 shows the model-predicted soil water concentrations at the water table at the end of the final time period (representing the year 2006), based on the cumulative assessment of MC loading over time. See Appendix A for a summary of the model input parameters.

Table 7-40.
Vadose Zone Model Results: MC Concentrations Reaching Groundwater at the Historical Use M-115 Range

MC	Soil Water Concentration (mg/L)
HMX[a]	--
RDX	0.0
TNT	0.0
Perchlorate	0.0

Note:
[a] HMX was not estimated to reach the water table and therefore was not further modeled.

According to the screening-level modeling, none of the MC are potentially found at the groundwater table at concentrations above the REVA trigger values for the year 2006. No additional analysis was conducted for the historical use M-115 Range.

7.10.5. Surface Water Screening-Level Analysis Results

A screening-level analysis of MC concentrations in surface water was conducted for the historical use M-115 MC loading area. The M-115 MC loading area drains into Southwest Creek, which drains into the New River. The M-115 MC loading area is a historical loading area. The surface water screening-level analysis was carried out for a

time period ranging from 1970 to 1977. MC concentrations in runoff at the edge of this MC loading area were predicted to be negligible by the year 2005.

7.10.6. Potential Pathways

MC initial screening analysis of historical use M-115 MC loading area indicates no potential for the MC to reach the water table at concentrations above the REVA trigger values; therefore, no pathways exist for this historical use area to groundwater. The surface water screening-level results also indicate that surface water is not a viable pathway for MC migration relating to this historical use area.

7.10.7. Potential Receptors

Potential human and ecological receptors do not appear to be impacted by this MC loading area based on the above screening-level analyses results.

7.11. Marine Corps Outlying Field – Oak Grove

Marine Corps Outlying Field – Oak Grove was originally assessed as part of the MCAS Cherry Point REVA. However, it has been included here as the operation and control of this area has been transferred from MCAS Cherry Point to MCB Camp Lejeune. The assessment is provided in Appendix B.

8. Small Arms Range Assessments

The REVA indicator MC for SARs is lead, as it is the most prevalent (by weight) potentially hazardous constituent associated with small arms ammunition. Fate and transport parameters for lead at SARs are dependent on site-specific geochemical properties, which cannot be determined solely by physical observation. Therefore, ranges that solely utilize small arms ammunition for training purposes are qualitatively assessed under the REVA program. Ranges that perform joint small arms and live-fire training with HE munitions are not qualitatively assessed through this process; rather, they are assessed through the MC loading process previously described, and no lead loading is performed. In addition, only operational SARs are addressed in this protocol; historical use SARs that are no longer used are not assessed due to lack of information to adequately perform an assessment. Range D-9 is a recreational skeet range and was not included in this assessment since it is not used for training purposes

This qualitative approach is referred to as the REVA Small Arms Range Assessment Protocol (SARAP). The REVA SARAP employs a consistent methodology to identify and assess factors that influence the potential for lead migration at an operational range. Through this protocol, ranges are prioritized for possible further assessment or management practices.

The purpose of the REVA baseline study was to identify whether there has been a release or there is a substantial threat of a release of MC of concern from the operational range or range complex areas to off-range areas. The SARAP was developed as a qualitative approach to identify and assess factors that influence the potential for lead to migrate from an operational range. These factors include the following:

- Range design and layout
- Physical and chemical characteristics of the area
- Past and present operation and maintenance practices

In addition, potential receptors and pathways are identified relative to the SAR being assessed. The potential for an identified receptor to be impacted by MC migration through an identified pathway is evaluated.

8.1. Summary of the SARAP

The SARAP is to be used for:

1. Identification of the SARs within the Marine Corps that have the greatest potential for environmental concern (i.e., potential for lead to impact receptors).
2. Assessing the need for implementing further actions. Recommended further actions can include, but are not limited to, the following:
   - Sampling surface water, groundwater, and/or soil
   - Conducting additional studies
   - Identifying/implementing best management practices

The qualitative assessment process for a SAR involves describing and documenting its physical and environmental conditions, as well as how the range is utilized and maintained (including the dates of use and types and amounts of small arms ammunition expended). The SAR data collection form in Section 3 of the REVA Reference Manual is a guide to collecting and documenting the necessary information used to complete the evaluation forms in this protocol (Tables 1 through 6 for each SAR are contained in Appendix C). The data collection form includes a comprehensive list of data elements that are useful in establishing the historical and current physical conditions, as well as capturing the types of information on conditions that influence the potential for lead to migrate from the range. The data collection form is organized by the following major topics or information areas associated with the operational ranges:

- Basic range information
- Current range information
- Current range layout
- Historical range operations
- Amount of lead potentially deposited
- Environmental characteristics
- Potential receptors
- Surrounding land use
- Environmental activities conducted at the range

The data collection form in the REVA Reference Manual was used in the field to collect pertinent data on the major factors that can influence the ability of lead to migrate from each SAR. The assessment process involves identifying and evaluating possible factors that can influence the potential for lead to migrate off range. The protocol produces two scores: the sum of surface water elements and the sum of groundwater elements. Existing

data characterizing range operations, the physical environment, transport mechanisms, and potential receptors were gathered to complete the SAR assessments. The data were used to populate the SAR assessment tables, which produce scores for specific factors that may influence potential MC transport and exposure to receptors. The scores are aggregated to determine the overall environmental concern evaluation rankings for surface water and groundwater conditions. The scoring system assigns minimal, moderate, and high values for each environmental concern category:

- Minimal (0 to 29 points) – The SAR has minimal or no potential for lead migration and environmental concern, indicating minimal threat of environmental concern. No further action is currently required, but actions may be considered to maintain a minimal ranking.
- Moderate (30 to 49 points) – The SAR may have the potential for lead migration and environmental concern, most likely indicating that there is no immediate environmental concern but actions may be necessary to prevent a greater or future concern.
- High (50 to 65 points) – The SAR most likely has the potential for lead migration and environmental concern, creating the greatest level of environmental concern and requiring the recommendation of additional action(s).

Additional documentation describing the purpose, requirements, and supporting drivers for the performance of the SAR assessment is provided with the range-specific assessments in Appendix C, which contains the SAR assessments of the 23 operational SARs at MCB Camp Lejeune. While each range was evaluated separately using the SARAP, several of the ranges had similar periods of use, types of ammunition, and physical/environmental characteristics that resulted in similar scoring results. Therefore, the discussions of the evaluation of some of the ranges have been grouped together.

Information necessary to complete the protocol for these ranges was obtained during the site visit or from investigations completed at the installation. Information used for each range is summarized in Tables 1 through 5 of Appendix C. The SARAP results were evaluated to determine the environmental concern evaluation rankings for surface water and groundwater (Table 6 of Appendix C for each range). The ranking designations of minimal, moderate, and high are described in Table 7 of each of the assessments (Appendix C).

Figure 8-1 shows the locations of the MCB Camp Lejeune SARs assessed. A summary of the results of these range assessments is provided in the following sections. Table 8-1 provides a summary of the assessment of each range. Range SR-227 is also located at MCB Camp Lejeune. However, this range was not included in the NDAA Section 366 Report of ranges and, therefore, was not included in this baseline assessment. However, this range will be included in future operational range assessments.

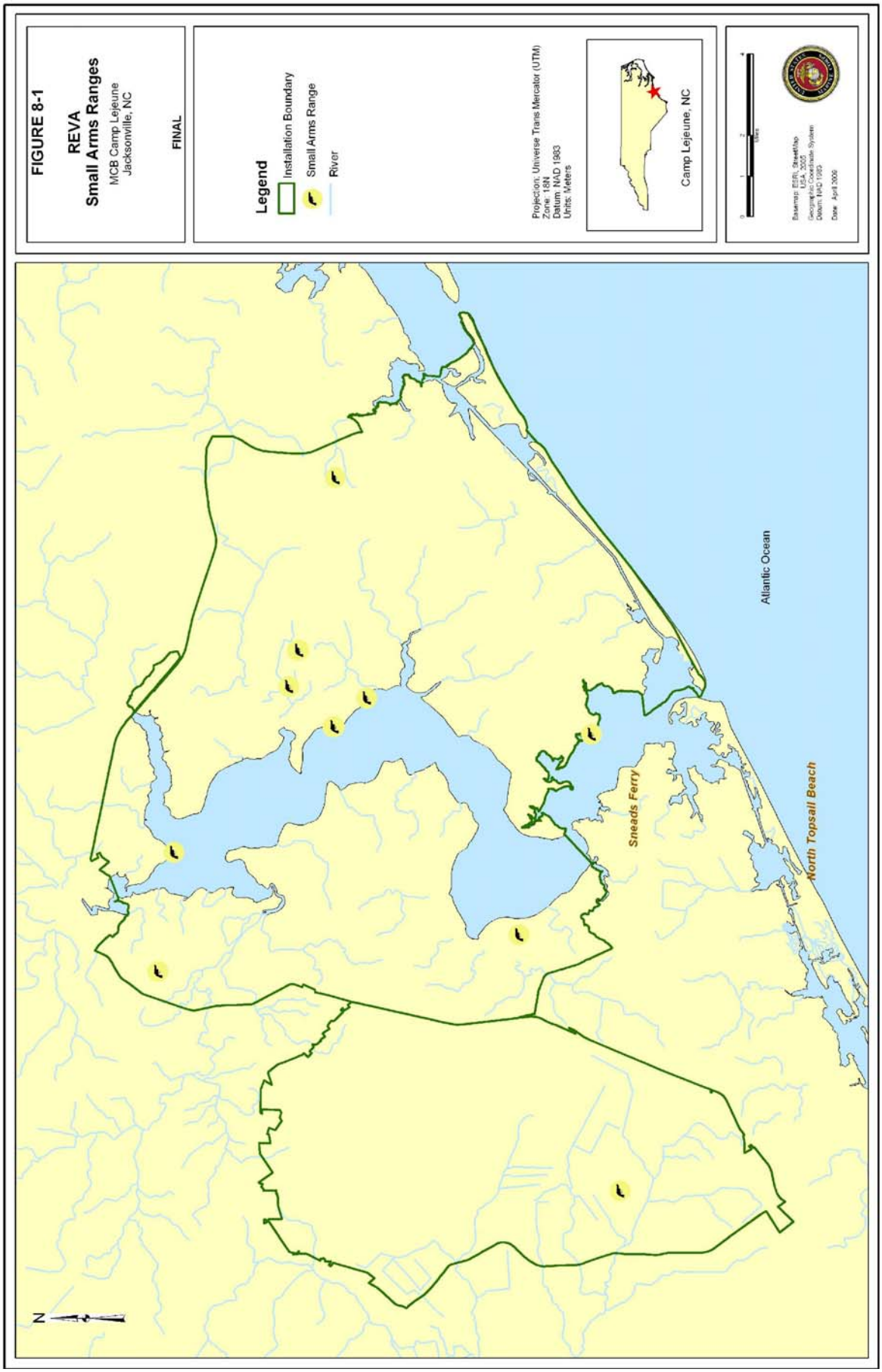


FIGURE 8-1
REVA
Small Arms Ranges
MCB Camp Lejeune
Jacksonville, NC
FINAL
Legend
Installation Boundary
Small Arms Range
River
Projection: Universe Trans Mercator (UTM)
Zone: 18N
Datum: NAD 1983
Units: Meters
Camp Lejeune, NC
Miles
Basemap: ESRI, StreetMap USA, 2002
Geographic Coordinate System
Datum: NAD 1983
Date: April 2006
Atlantic Ocean
Sneads Ferry
North Topsail Beach
N

Table 8-1.
Summary of SAR Prioritizations

Range Name	Surface Water Environmental Concern	Groundwater Environmental Concern
A-1	Moderate	Moderate
B-12	Moderate	Moderate
D-29A and B	Moderate	Moderate
D-30	High[a]	High
F-11A and F-11B	Moderate	Moderate
F-18	Moderate	High
I-1	Minimal	Moderate
MAC 1 - 5	Moderate	Moderate
SR-11	Minimal	Moderate
Stone Bay Complex Range		
o Dodge City	High[a]	Moderate
o Multipurpose Range	Moderate	Moderate
o Mechanical Range	Moderate	Moderate
o Non-Mechanical Range	Moderate	Moderate
o Alpha Range	High[a]	Moderate
o Bravo Range	High[a]	Moderate
o Charlie Range	High[a]	Moderate
o Hathcock Range	High[a]	Moderate

[a] Ranking increased based on professional judgment

The Marine Corps Recruit Depot (MCRD) Parris Island, South Carolina, currently is working with the University of South Carolina-Beaufort to evaluate lead in the areas surrounding the SARs at MCB Camp Lejeune as part of an on-going investigation. This information (when available) can be used to further identify whether potential lead migration at the SARs at MCB Camp Lejeune is a concern to human health and/or environment.

8.2. A-1

8.2.1. Site Background

Range A-1 has been operational since 1958 and is still in use today; however, it is not heavily used. Range A-1 is an operational qualification range located at Camp Johnson in the Cape Hart area (Figure 8-1). There is a shallow drainage ditch that traverses the range between the firing lanes and a parking area. The SDZ for Range A-1 extends over the New River. Range A-1 consists of 10 firing lanes, 14 targets, a horseshoe-shaped berm, and a bullet trap system.

The bullet trap system was installed in July 1999. During installation of the bullet trap system, the previous impact berm was mined and removed lead was disposed off-site. The range is fully baffled (walls and ceiling), capable of preventing rounds from escaping

under normal firing situations. Ammunition unintentionally fired toward the ceiling is deflected to the ground surface. The armored bullet trap contains the spent projectiles until they are removed manually for recycling or disposal. The bullet trap designer, Action Targets, is called to perform regular inspections and maintenance.

Range Operations inspects and files an inspection report following each use of the operational range. In addition, it is Marine Corps policy to pick up any brass remaining on the ground after a firing session.

8.2.2. Assessment Results

Surface Water

The surface water environmental concern evaluation ranking resulted in a score near the low end of the moderate range (31 points). The proximity of the range to the New River and the habitat the river supports provide the basis for the ranking to be in the moderate range. However, the installation of the bullet traps and removal of lead from the former impact berm should reduce the potential for lead reaching the river or being available to the river habitat. On the basis of the SARAP, there is moderate potential for lead migration and impact to surface water; however, the range does not appear to present an immediate environmental concern.

Groundwater

The groundwater environmental concern evaluation ranking resulted in a moderate score (47 points). The factors that lead to the moderate ranking include shallow depth to groundwater, sandy soil, and the low pH of the soil and groundwater. The pH values used were from groundwater sampling conducted as part of the REVA investigation and general information on the soil series. However, the installation of the bullet traps and removal of lead from the former impact berm should reduce the potential for lead leaching to groundwater.

8.3. B-12

8.3.1. Site Background

Operational Range B-12 has been operational since 1970 and is still in use today. Range B-12 is an operational qualification range located at MCAS New River (Figure 8-1). There is a shallow drainage ditch that traverses Range B-12 between the firing lanes and a parking area. Access to the firing lanes from the parking area is by a pedestrian bridge over the drainage ditch. Forested areas surround the operational range on three sides. Range B-12 consists of ten firing lanes, ten targets, a horseshoe-shaped berm and a bullet trap system.

The bullet trap system was installed in the mid to late 1990s. During installation of the bullet trap system, it is general practice to remove lead from the soil impact berm previously used.

8.3.2. Assessment Results

Surface Water

The surface water environmental concern evaluation ranking resulted in a score near the low end of the Moderate range (33 points). The proximity of the range to the New River and the habitat the river supports provides the basis for the ranking to be in the lower portion of the moderate range. The installation of the bullet traps and removal of lead from the former impact berm; however, should reduce the potential for lead reaching the river or being available to the river habitat. On the basis of the SARAP, there is moderate potential for lead migration and impact to surface water.

Groundwater

The groundwater environmental concern evaluation ranking resulted in a Moderate score (49 points). The factors that lead to the moderate ranking include shallow depth to groundwater, sandy soil and the low pH of the soil and groundwater. The pH values used were from groundwater sampling conducted as part of the REVA investigation and general information on the soil series. The installation of the bullet traps and removal of lead from the former impact berm; however, should reduce the potential for lead leaching to groundwater. On the basis of the SARAP, there is moderate potential for lead migration to impact receptors via groundwater.

8.4. D-29A and D-29B

8.4.1. Site Background

Ranges D-29A and D-29B have been in use since 1958 and are still in use today. Ranges D-29A and D-29B are operational qualification ranges located in the MCB Camp Lejeune main cantonment area (Figure 8-1). Between the firing lanes and Julian C. Smith Road, there is a heavily forested area. A gravel parking area is adjacent to the firing lanes. The New River is located beyond the target area. Between the operational ranges and the water's edge is an earthen berm protected on the water side by riprap. In 2003, the water body was dredged and lead was removed from the berm.

Ranges D-29A and D-29B are adjacent to one another and consist of 34 firing lanes and 28 targets. The SDZ for the operational ranges extends over the New River. Both operational ranges contain the previously mentioned earthen berm and a bullet trap system with a vacuum to remove lead dust. The bullet trap system was installed in June 1999. During installation of the bullet trap system, the previous impact berm was mined and removed lead was disposed off-site. In addition, it is Marine Corps policy to pick up any brass remaining on the ground after a firing session.

8.4.2. Assessment Results

Surface Water

The surface water environmental concern evaluation ranking resulted in a moderate ranking (35 points). The proximity of the range to the New River and the habitat the river supports provide the basis for the ranking to be in the moderate range. However, the installation of the bullet traps and removal of lead from the former impact berm should reduce the potential for lead reaching the river or being available to the river habitat. On the basis of the SARAP, there is moderate potential for lead migration and impact to surface water. However, the range does not appear to create an immediate environmental concern.

Groundwater

The groundwater environmental concern evaluation ranking resulted in a moderate score (49 points). The factors that lead to the moderate ranking include shallow depth to groundwater, sandy soil, and the low pH of the soil and groundwater. The pH values used were from groundwater sampling conducted as part of the REVA investigation and general information on the soil series. The installation of the bullet traps and removal of lead from the former impact berm and river should reduce the potential for lead leaching to groundwater.

8.5. D-30

8.5.1. Site Background

The D-30 range has been in use since 1958 and is still in use today. D-30 is an operational qualification range located in the MCB Camp Lejeune main cantonment area (Figure 8-1). Adjacent to the firing lanes on one side is a heavily forested area. Drainage ditches are on the opposite side of the firing lanes. Beyond the berm associated with the range is the New River. At the water's edge, the earthen berm is protected on the water side by riprap. The operational range consists of 32 firing lanes, 32 targets, and the previously mentioned earthen berm designed to capture fired bullets.

In 2003, lead was removed from the berm and tri-sulfur phosphate was added to the berm to stabilize lead that could not be removed. The shoreline behind the range was also screened for lead extending approximately 20 feet in the New River. Riprap was added to the river side of the berm to prevent erosion. Lead is removed from the berm on an as needed basis. Any recovered lead projectiles are properly disposed off-site. In addition, it is Marine Corps policy to pick up any brass remaining on the ground after a firing session.

There is a plan to relocate this range to include the installation of a bullet trap. Remediation of the berm at the current location is planned after the opening of the relocated range. As of July 2008, this range relocation had not yet occurred.

8.5.2. Assessment Results

Surface Water

The surface water environmental concern evaluation ranking resulted in a moderate ranking (44 points). The proximity of the range to the New River and the habitat the river supports provide the basis for the ranking to be in the moderate range. Based on the range duration, the amount of lead loading (approximately 3,700 pounds per year), the SDZ extending into the New River, and an earthen berm with no bullet trap capturing technology, the potential for lead migration and possible impact to surface water was determined by professional judgment to warrant a high evaluation ranking.

Groundwater

The groundwater environmental concern evaluation ranking resulted in a high score (53 points). The evaluation was calculated as high due to the shallow depth to groundwater, sandy soil, low pH of the soil and groundwater, and duration of range use (over 50 years).

8.6. F-11A and F-11B

8.6.1. Site Background

Range F-11A and Range F-11B have been in use since 1950 and are still in use today. Ranges F-11A and F-11B are located adjacent to one another and were evaluated together. These ranges are operational 30-meter firing ranges located in Tactical Maneuver Training Area FG (Figure 8-1). Surrounding the operational ranges on three sides are forested areas. The ranges contain an earthen berm and a bullet trap system. The bullet trap systems were installed in October 1999. During installation of the bullet trap systems, lead was screened and removed from the previously used earthen impact berms. In addition, it is Marine Corps policy to pick up any brass remaining on the ground after a firing session.

8.6.2. Assessment Results

Surface Water

The surface water environmental concern evaluation ranking resulted in a score near the low end of the moderate range (33 points). The proximity of the range to the New River and the habitat the river supports provide the basis for the ranking to be in the moderate range. However, the installation of the bullet traps and removal of lead from the former impact berm reduce the potential for lead migration into the river or possibly lead's availability to the river habitat.

Groundwater

The groundwater environmental concern evaluation ranking resulted in a moderate score (49 points). The factors that lead to the moderate ranking included shallow depth to

groundwater, sandy soil, and the low pH of the soil and groundwater. However, the installation of the bullet traps and removal of lead from the former impact berm and river reduce the potential for lead leaching to groundwater.

8.7. F-18

8.7.1. Site Background

Range F-18 has been in use since 1970 and is still in use today. This range is an operational range used for field firing and is located in Tactical Maneuver Training Area FG (Figure 8-1). Adjacent to both sides of the operational range are forested areas. Between the firing points and Piney Green Road, there is a parking area. The operational range contains approximately five targets and two firing areas. These firing areas consist of large and small earthen mounds with the munitions impacting the ground behind the targets. The range does not contain impact berms or bullet traps. Marine Corps policy is to pick up any brass remaining on the ground after a firing session.

8.7.2. Assessment Results

Surface Water

The surface water environmental concern evaluation ranking resulted in a moderate ranking (43 points). The location of the range near the New River and Atlantic Ocean and the habitats these water bodies support provide the basis for the ranking to be in the moderate range. On the basis of the SARAP, there is moderate potential for lead migration to impact receptors via surface water.

Groundwater

The groundwater environmental concern evaluation ranking resulted in a high score (53 points). In addition to the shallow depth to groundwater, sandy soil, and the low pH of the soil and groundwater, the high ranking is also affected by the duration of range use (over 30 years) and use of the range (approximately 2,300 pounds of lead deposited annually). On the basis of the SARAP, there is a high potential for lead migration to impact receptors via groundwater.

8.8. I-1

8.8.1. Site Background

Range I-1 has been in use since 1960 and is still in use today (Figure 8-1). This range is an operational qualification range located at Courthouse Bay. The operational range consists of 16 firing lanes, 16 targets, a bullet trap system, and the former impact berm. The former impact berm is located between the bullet trap and the New River.

The bullet traps were installed in July 1999. At that time, lead was removed from the original impact berm; however, there is no record documenting that the New River was

evaluated for the presence of lead. Tri-sulfur phosphate was also added to the original berm when the lead was removed to help stabilize any lead that was missed during the recovery actions. In addition, it is Marine Corps policy to pick up any brass remaining on the ground after a firing session.

8.8.2. Assessment Results

Surface Water

The surface water environmental concern evaluation ranking resulted in a score near the high end of the minimal range (29 points). The proximity of the range to the New River and the habitat the river supports increase the scoring, but the limited use (approximately 80 pounds of lead deposited annually) and installation of the bullet traps keep the ranking in the minimal range. The bullet traps and the removal of lead from the former impact berm reduce the potential for lead migration to the river or possible availability to the river habitat. However, there is no documentation that lead was removed from the New River at the time the bullet traps were installed, so there is a possibility that lead migration may have occurred from historical lead loading.

Groundwater

The groundwater environmental concern evaluation ranking resulted in a moderate score (45 points). The factors that lead to the moderate ranking include the shallow depth to groundwater, sandy soil, and the low pH of the soil and groundwater. The installation of the bullet traps and removal of lead from the former impact berm reduce the potential for lead leaching to groundwater. On the basis of the SARAP, there is moderate potential for lead migration to impact receptors via groundwater.

8.9. MAC 1 through 5

8.9.1. Site Background

The operational MAC Ranges 1 through 5 are located on the eastern side of the installation (Figure 8-1). The ranges were dedicated in 1990 and are used for training in urban combat. No impact earthen berm is in place, but a berm is planned to be installed that would cover the distance of all five ranges. Since these ranges are adjacent to one another, they were grouped and assessed together.

8.9.2. Assessment Results

Surface Water

The surface water environmental concern evaluation ranking resulted in a moderate ranking (37 to 39 points) for the five MAC ranges. The location of the ranges near the New River and Atlantic Ocean and the habitats these water bodies support provide the basis for the rankings to be in the moderate range. Limited use (10 to 825 pounds of lead

deposited annually) of these ranges reduces the potential impacts that these ranges may have on nearby surface water bodies.

Groundwater

The groundwater environmental concern evaluation ranking resulted in a moderate score (47 to 49 points) for the five ranges. The shallow depth to groundwater, sandy soil, and low pH of the soil and groundwater resulted in the moderate ranking. Limited use (10 to 825 pounds of lead deposited annually) of these ranges reduces the potential impacts that these ranges may have on groundwater.

8.10. SR-11

8.10.1. Site Background

Range SR-11 has been in use since 2001 and is located in the southern region of the GSRA (Figure 8-1). The operational range consists of 14 firing lanes, 14 targets, and a bullet trap system. The bullet trap system was installed in March 2001 when the range was constructed. It is also Marine Corps policy to pick up any brass remaining on the ground after a firing session.

8.10.2. Assessment Results

Surface Water

The surface water environmental concern evaluation ranking resulted in a minimal ranking (20 points). This low ranking is the result of the range utilizing a bullet-capturing technology from its inception. Another factor for the low ranking is the limited range use (approximately 350 pounds of lead deposited annually). On the basis of the SARAP, there is minimal potential for lead migration from SR-11 to impact receptors via surface water.

Groundwater

The groundwater environmental concern evaluation ranking resulted in a moderate score (36 points). The factors that lead to the moderate ranking include the shallow depth to groundwater, sandy soil, and the low pH of the soil and groundwater. However, the bullet trap installed during construction of the range reduces the potential for lead leaching to groundwater; therefore, this range does not appear to cause an immediate environmental concern.

8.11. Stone Bay Range Complex

8.11.1. Site Background

The Stone Bay Range Complex (Figure 8-1) consists of the following eight operational SARs:

- Dodge City
- Multipurpose Range
- Mechanical Range
- Non-Mechanical Range
- Alpha Range
- Bravo Range
- Charlie Range
- Hathcock Range

Dodge City

Dodge City is an operational range adjacent to a berm on one side and a forested area on the opposite side. A dirt road traverses Dodge City, and a parking area is located south of the operational range. The operational range consists of buildings used to simulate urban warfare. Wetlands are located in the northern portions of the SDZ, where it is possible that projectiles land. It is Marine Corps policy to pick up any brass remaining on the ground after a firing session.

Multipurpose Range

The Multipurpose Range is a battle sight zero range. A parking area and a water pump are located on the site. The operational range consists of covered firing points and is surrounded on three sides by berms that were designed to capture fired bullets until bullet-capturing technology was installed in 2006. Lead was removed from the berms at the time of the installation of the bullet trap (granulated rubber trap), and tri-sulfur phosphate was added to help stabilize any remaining lead in the berms. Any recovered lead projectiles were properly disposed off-site. In addition, it is Marine Corps policy to pick up any brass remaining on the ground after a firing session.

Mechanical Range

The Mechanical Range is an operational range. A shallow drainage ditch traverses the Mechanical Range, and a small building is located behind the firing lanes. The operational range consists of covered firing positions and is surrounded on three sides by berms that were designed to capture fired bullets until bullet-capturing technology was installed in 2006. Lead was removed from the berms at the time of the installation of the

bullet trap (steel trap), and tri-sulfur phosphate was added to help stabilize any remaining lead in the berms. Any recovered lead projectiles were properly disposed off-site. In addition, it is Marine Corps policy to pick up any brass remaining on the ground after a firing session.

Non-Mechanical Range

The Non-Mechanical Range is an operational walk-down range. The operational range consists of covered firing positions, 50 targets, and a bullet trap. The bullet trap system was installed in April 2004. Prior to installation of the bullet traps, earthen berms were present on the three sides of the range and served as impact berms. During installation of the bullet trap system, lead was removed from the previous impact berm with tri-sulfur phosphate added to help stabilize any lead remaining in the soil. The portion of the berm behind the bullet trap has been removed, and the area is currently forested. It is Marine Corps policy to pick up any brass remaining on the ground after a firing session.

Alpha Range

The Alpha Range is an operational range. There are berms located on both sides of the operational range, one of which contains a bunker providing access to adjacent operational ranges. There is no impact berm located at the site. Wetlands are located in the northern portions of the SDZ, where it is possible that lead projectiles land. In addition, it is Marine Corps policy to pick up any brass remaining on the ground after a firing session.

Bravo Range

The Bravo Range is an operational range. There are berms located on both sides of the operational range. The berm on the left serves as an underground walkway/bunker with access from above ground at a couple of points. There is no impact berm, although some munitions are discharged into the side berms. Wetlands are located in the northern portions of the SDZ, where it is possible that lead projectiles land. In addition, it is Marine Corps policy to pick up any brass remaining on the ground after a firing session.

Charlie Range

The Charlie Range is an operational range. There are berms located on both sides of the operational range, but no impact berm. There is a large pond near the center of the range. It is believed that only a minimal amount of munitions reaches the pond because of the way the range is configured. Marine Corps policy is to pick up any brass remaining on the ground after a firing session.

Hathcock Range

The Hathcock Range is an operational range. An observation tower is located on the operational range. A pond is located adjacent to the operational range, which is

surrounded on three sides by berms with pop-up targets located behind the berms. The earthen berms are designed to capture fired lead bullets. The berms are mined on an as needed basis. Any recovered lead projectiles are properly disposed off-site. In addition, it is Marine Corps policy to pick up any brass remaining on the ground after a firing session.

8.11.2. Assessment Results

Surface Water

Each of the eight ranges comprising the Stone Bay Range Complex was assessed in accordance with the SARAP. The surface water environmental concern evaluation ranking was moderate for each of the ranges as specified below.

Surface Water Ranking Score – 31	Surface Water Ranking Score – 36
Multi-Purpose, Mechanical, and Non-Mechanical ranges	Dodge City, Alpha, Bravo, Charlie, and Hathcock ranges

The ranges were constructed around the same time and are located near each other. Therefore, evaluation factors such as soil type, pH of groundwater, amount of precipitation, and vegetative cover are all similar. Military munitions usage is recorded for the Stone Bay Range Complex but is not recorded by specific individual range. So, the total lead loading recorded for the Stone Bay Range Complex was divided among the eight ranges. Differences at the ranges include the installation of bullet traps (Multi-Purpose, Mechanical, and Non-Mechanical ranges), the number and locations of side berms (which can control surface water movement), and the presence or not of wetlands (Dodge City, Alpha, Bravo, and Charlie ranges) and/or ponds (Hathcock range) in the SDZ area.

Based on the presence of wetlands or ponds in the SDZ, the surface water environmental concern evaluation ranking at Dodge City, Alpha, Bravo, Charlie, and Hathcock ranges was adjusted from moderate to high based on professional judgment. These assessments can be re-evaluated after data from the MCRD Parris Island / University of South Carolina-Beaufort study has been completed.

Groundwater

Each of the eight ranges comprising the Stone Bay Range Complex was assessed in accordance with the SARAP. The groundwater environmental concern evaluation ranking for each range was moderate (score of 47 points). As stated above, the ranges are located in proximity to one another; therefore, evaluation factors such as depth to groundwater, soil type, and pH of the soil and groundwater were the same for all of the ranges. The evaluation of these parameters leads to the moderate ranking. Military munitions usage is recorded for the Stone Bay Range Complex but is not recorded by specific individual

range. So, the total lead loading recorded for the Stone Bay Range Complex was divided among the eight ranges. The Multi-purpose, Mechanical, and Non-Mechanical ranges have had bullet traps installed and lead removed from the former impact berms, which reduce the possibility of lead migration and subsequent availability for lead to impact the groundwater. On the basis of the SARAP, there is moderate potential for lead migration to impact receptors via groundwater for the remaining ranges.

8.12. Additional Information

Lead was included in the field sampling effort, discussed in Section 9, as a proactive measure at locations already selected on the basis of predicted HE concentrations. Lead is also known to be a constituent of HE munitions, therefore, its inclusion was expected to provide an indicator of possible heavy metal constituents.

The SARAP was applied to the SARs independent of field sampling conducted at MCB Camp Lejeune discussed in Section 9 and irrespective of other assessment for HE. Based on the SARAP results presented in this section, however, additional lead assessment will be conducted as necessary to further control and prevent possible MC migration.

9. Field Data Collections Results

9.1. Background

This section summarizes the results of surface water and groundwater sampling events and hydraulic investigation conducted between November 2007 and April 2008. The *Final Field Sampling Report* contains additional details from the sampling events (Appendix D).

Based on the results of the groundwater and surface water screening-level analyses performed and the inability to conduct groundwater modeling based on the complexities of the groundwater flow system at MCB Camp Lejeune (see Section 9.1.1), additional investigations were conducted to determine whether MC migration was occurring from operational ranges to off-range areas. This section documents the results of initial surface water and groundwater sampling and the assessment of the hydraulic connection between the Surficial and Castle Hayne aquifers at MCB Camp Lejeune, as discussed in the *Sampling and Analysis Plan (SAP) for the Range Environmental Assessment for Areas Adjacent to the G-10 and K-2 Impact Areas at MCB Camp Lejeune* (Malcolm Pirnie, 2008). The groundwater and surface water samples were collected on November 10-15, 2007, and April 27-30, 2008. The hydraulic assessment field effort was conducted on December 10-13, 2007. This information was necessary to further evaluate the potential for off-range migration of MC at MCB Camp Lejeune.

Field sampling locations discussed herein were selected based on the modeling results for HE, not on the SARAP described in Section 8. The SARAP had not yet been completed, and was developed independently of the modeling effort. Field sampling was conducted prior to completion of the SARAP, in part, due to timing of accessibility with training activities.

9.1.1. Purpose of Field Effort

As previously reported, the one-dimensional groundwater modeling typically completed as part of the initial REVA baseline assessment was not completed for MCB Camp Lejeune because the groundwater flow system that underlies the installation was potentially too complex and not well enough understood for a one-dimensional analysis to be meaningful. These complexities include a two-aquifer flow system with an intervening aquitard of unknown characteristics and extent limiting the ability to quantify the connection between aquifers, as well as the presence of multiple nearby pumping wells tapping the deeper aquifer. Based on these complexities, it was determined that the

one-dimensional groundwater modeling would not yield results representative of actual site conditions and would not accurately identify the potential for off-range migration.

The two potentially impacted aquifers at MCB Camp Lejeune are the Surficial aquifer and the Castle Hayne aquifer. These aquifers are separated by the Castle Hayne confining unit. There is evidence that these aquifers are interconnected at some locations on MCB Camp Lejeune (Harden and others, 2004); however, the degree of connectivity between the aquifers at the MC loading areas is unknown. Uncertainties regarding the connectivity and effects of the MCB Camp Lejeune water supply wells on the groundwater flow system led to the collection of additional field data.

The additional field activities conducted for this effort included the following:

- Collecting surface water samples along stream channels adjacent to the K 2 and G-10 impact areas to further evaluate the potential for off-range MC release through surface water. The surface water sampling locations were selected to facilitate a screening-level assessment of potential MC impacts based on actual sampling data results.
- Collecting groundwater samples from the Surficial aquifer obtained from monitoring wells surrounding the K-2 and G-10 impact areas and collecting groundwater samples from the Castle Hayne aquifer obtained from MCB Camp Lejeune water supply wells located around the G-10 Impact Area to further evaluate the potential for off-range MC release to groundwater in the vicinity of the K-2 and G-10 impact areas. The existing shallow monitoring wells surrounding the K-2 and G-10 impact areas were used to evaluate the groundwater from the Surficial aquifer and several water supply wells located near the G-10 Impact Area were used to evaluate the groundwater from the Castle Hayne aquifer.
- Assessing the hydraulic connection between the Surficial and Castle Hayne aquifers during a shutdown of selected MCB Camp Lejeune water supply wells and measuring the corresponding effect on the water levels in monitoring wells in the Surficial aquifer and water supply wells in the Castle Hayne aquifer near the G-10 Impact Area. This assessment helped identify whether potential MC in the Surficial aquifer have the potential to impact the deeper water supplying Castle Hayne aquifer.

The K-2 and G-10 impact areas were identified as priority areas for the additional assessment and field data collection. The chemical analyses for MC in the MCB Camp Lejeune-USGS monitoring wells at the boundaries of the two impact areas were used to provide insight into the MC fate and transport in the groundwater. The groundwater data was also necessary to assess the need for further action for the operational ranges. Analytical data on major inorganic ions in the Surficial and Castle Hayne aquifers provide information on possible natural geochemical differences between the two aquifers, including their possible mixing at the water supply well fields, which would indicate a hydraulic connection between the aquifers. The additional field sampling work

discussed in this section improves the understanding of the groundwater flow system and the potential for off-range MC migration at MCB Camp Lejeune.

9.2. Sampling Methods and Locations

This section identifies the sampling methods, sample locations, and types of samples collected during the field activities conducted at MCB Camp Lejeune during November and December 2007 and April 2008. These field activities included surface water sampling, groundwater sampling, and the assessment of the hydraulic connection between the Surficial and Castle Hayne aquifers at MCB Camp Lejeune.

9.2.1. Groundwater Sampling

Groundwater samples were collected from near the boundaries of both the G-10 and K-2 impact areas during fieldwork conducted on November 10-15, 2007, and April 27-30, 2008. Groundwater samples were analyzed for a full explosives suite, perchlorate, lead, and major inorganic ions (calcium, magnesium, sodium, potassium, chloride, sulfate, bicarbonate and carbonate, nitrates, and nitrites). Lead was included in the field sampling as a proactive measure at locations already selected on the basis of predicted HE concentrations. Lead is also known to be a constituent of HE munitions; therefore, its inclusion was expected to provide an indicator of possible heavy metal constituents.

Groundwater samples were collected from each of the selected MCB Camp Lejeune-USGS monitoring wells using a peristaltic pump and low-flow methods. Raw groundwater samples were also collected from selected water supply wells by filling the laboratory-supplied sample bottles directly from the sampling port of the well. Ten gallons were allowed to flow through the sample port prior to collecting the sample. Sample bottles were sealed immediately following sample collection and put on ice in coolers. The pH, temperature, dissolved oxygen, salinity, and conductivity of the groundwater collected from the water supply wells and the monitoring wells were measured in the field with a portable multimeter. Samples were filtered in the field for dissolved lead. Quality Assurance/Quality Control (QA/QC) samples were also collected.

The collected groundwater samples were submitted to TestAmerica Laboratories located in Savannah, Georgia, for analysis. Lead and major inorganic analyses were completed at the Savannah laboratory, while explosives and perchlorate were analyzed at the TestAmerica laboratory in Denver, Colorado.

9.2.1.1. G-10 Impact Area

Fourteen groundwater samples were collected from the area surrounding the G-10 Impact Area during the November sampling event. Figure 9-1 generally shows the sampling locations. Nine of the groundwater samples were collected from MCB Camp Lejeune-USGS monitoring wells screened in the Surficial aquifer near the boundary of the G-10 Impact Area. The other five groundwater samples were collected from MCB Camp

Lejeune water supply wells screened in the Castle Hayne aquifer. During the April 2008 sampling event, four additional water supply wells were sampled and two water supply wells were resampled for lead. Figure 9-2 generally shows the locations of the water supply well sampling areas.

9.2.1.2. K-2 Impact Area

Three groundwater samples were collected from the area surrounding the K-2 Impact Area during the November 2007 sampling event. Figure 9-3 generally shows the sampling locations. . The three groundwater samples were collected from MCB Camp Lejeune-USGS monitoring wells screened in the Surficial aquifer. Two additional MCB Camp Lejeune-USGS monitoring wells were intended to be sampled but the water from the aquifer did not flow quickly enough into the well during purging to allow for sample collection. During the April 2008 sampling event, four groundwater samples were collected from MCB Camp Lejeune-USGS monitoring wells screened in the Surficial aquifer. The second sampling event was conducted to further verify the results of the first sampling event and collect additional samples from several additional locations.

9.2.2. Surface Water Sampling

Surface water samples were collected from areas surrounding the G-10 and K-2 impact areas during fieldwork conducted November 10-15, 2007. The surface water samples were analyzed for a full explosives suite, perchlorate, and lead. Lead was included in the field sampling as a proactive measure at locations already selected on the basis of predicted HE concentrations. Lead is also known to be a constituent of HE munitions; therefore, its inclusion was expected to provide an indicator of possible heavy metal constituents.

All surface water samples were collected as grab samples using the grab sample methodologies described in the SAP (Malcolm Pirnie, 2008). The grab samples were collected using precleaned, disposable Teflon bailers and/or immediately collected into the laboratory-supplied sample bottles and sealed for shipment. Field parameters (pH, temperature, dissolved oxygen, salinity, turbidity, and conductivity) of the surface water were measured at each sampling location using a multimeter. Samples were filtered in the field for dissolved lead.

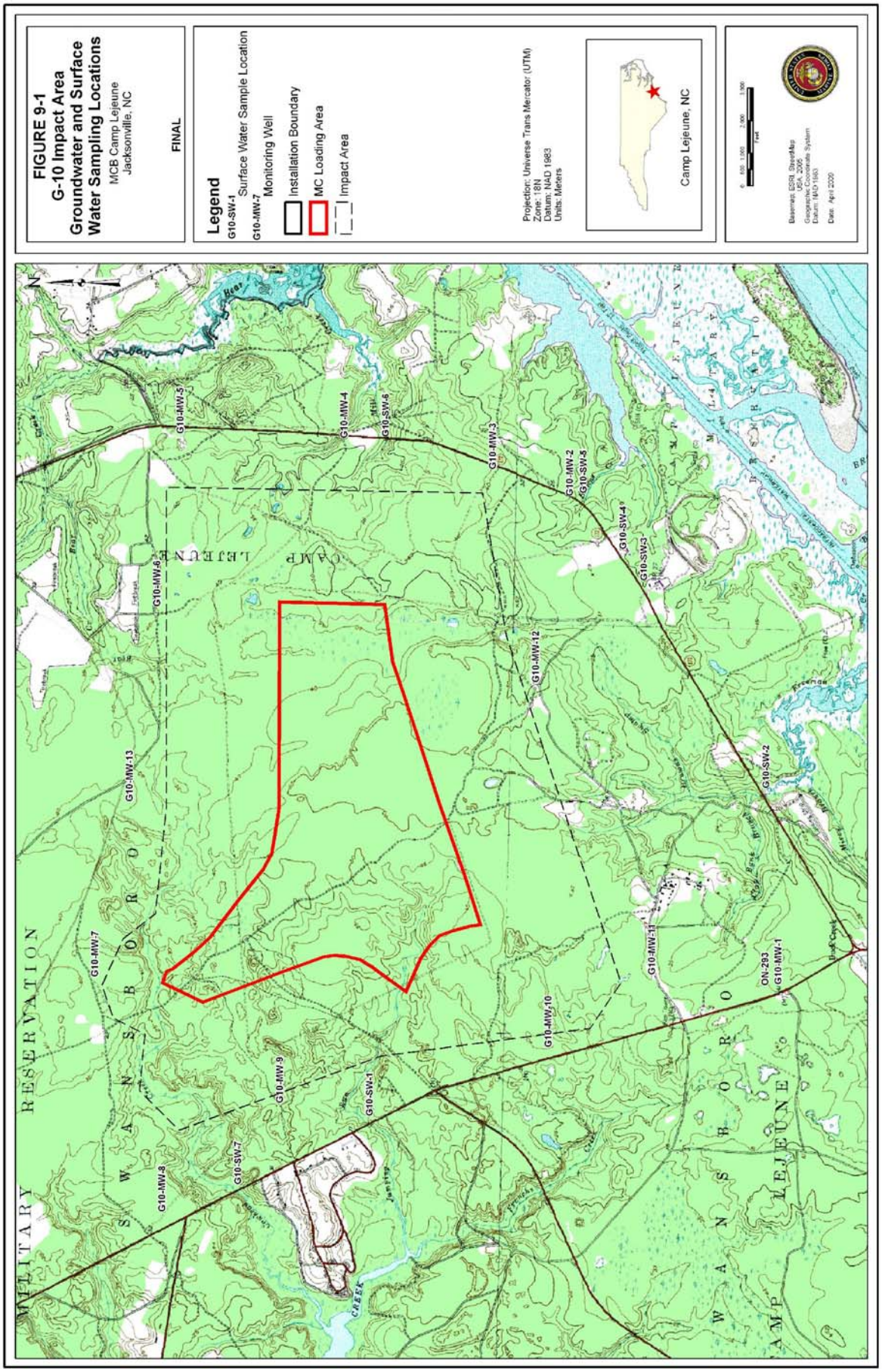


FIGURE 9-1
G-10 Impact Area
Groundwater and Surface
Water Sampling Locations
MCB Camp Lejeune
Jacksonville, NC
FINAL
Legend
G10-SW-1
Surface Water Sample Location
G10-MW-7
Monitoring Well
Installation Boundary
MC Loading Area
Impact Area
Projection: Universe Trans Mercator (UTM)
Zone: 18N
Datum: NAD 1983
Units: Meters
Camp Lejeune, NC
Basemap: ESRI, StreetMap USA, 2005
Geographic Coordinate System:
Datum: NAD 1983
Date: April 2005
MILITARY RESERVATION
CAMP LEJEUNE
WANSBORO
G10-MW-5
G10-MW-4
G10-SW-6
G10-MW-3
G10-MW-2
G10-SW-5
G10-SW-4
G10-SW-3
G10-MW-6
G10-MW-13
G10-MW-12
G10-SW-2
G10-MW-7
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G10-SW-1
G10-SW-7
G10-MW-8

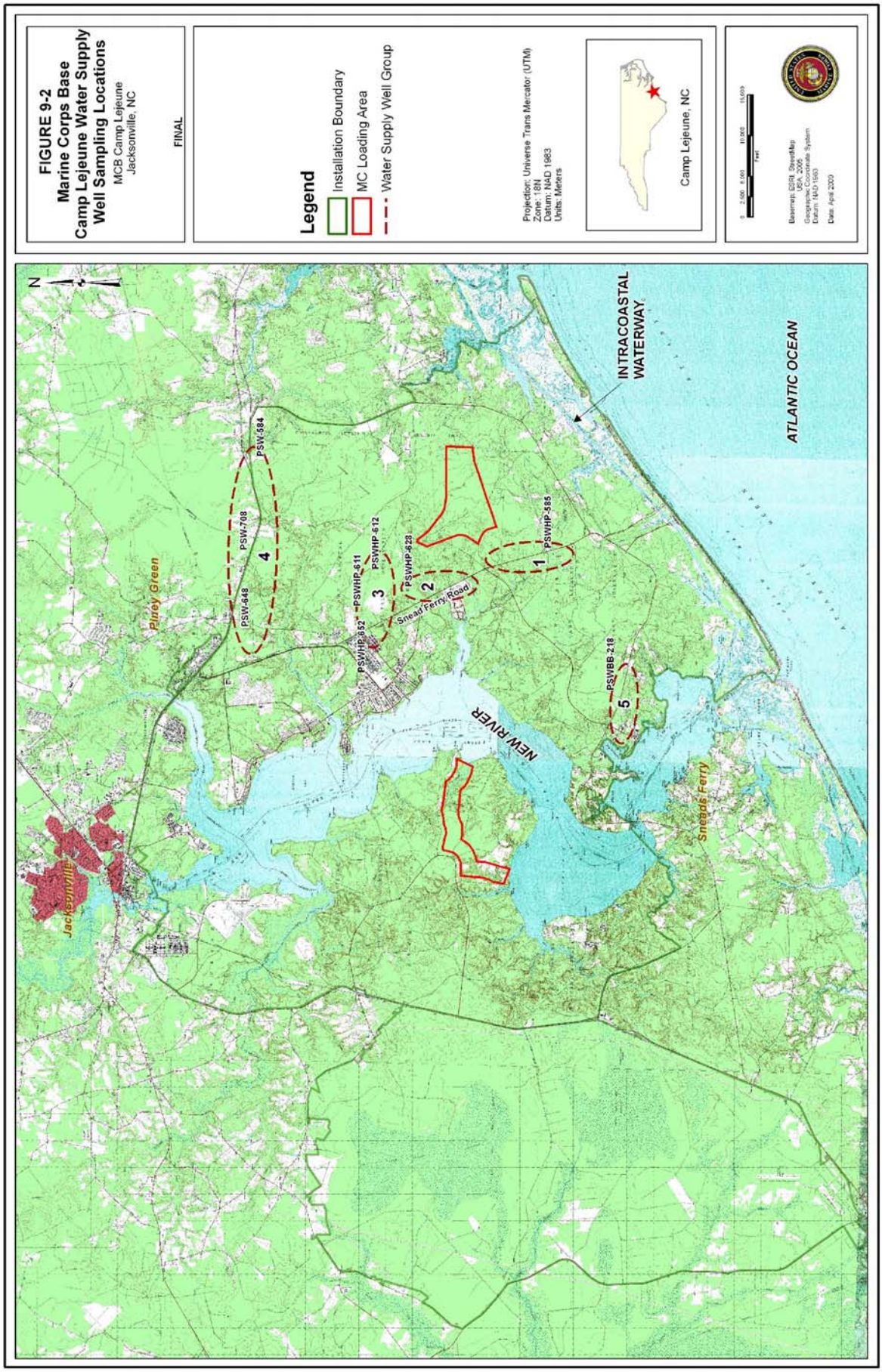
FIGURE 9-2
Marine Corps Base
Camp Lejeune Water Supply
Well Sampling Locations
MCB Camp Lejeune
Jacksonville, NC
FINAL
Legend
Installation Boundary
MC Loading Area
Water Supply Well Group
Projection: Universe Trans Mercator (UTM)
Zone: 18N
Datum: NAD 1983
Units: Meters
Camp Lejeune, NC
Basemap: ESRI, StreetMap USA, 2005
Geographic Coordinate System
Datum: NAD 1983
Date: April 2009
N
INTRACOASTAL WATERWAY
ATLANTIC OCEAN
NEW RIVER
Jacksonville
Piney Green
Sneads Ferry
Snead Ferry Road
PSW-584
PSW-708
PSW-648
PSWHP-612
PSWHP-611
PSWHP-628
PSWHP-585
PSWHP-352
PSWBB-218
1
2
3
4
5

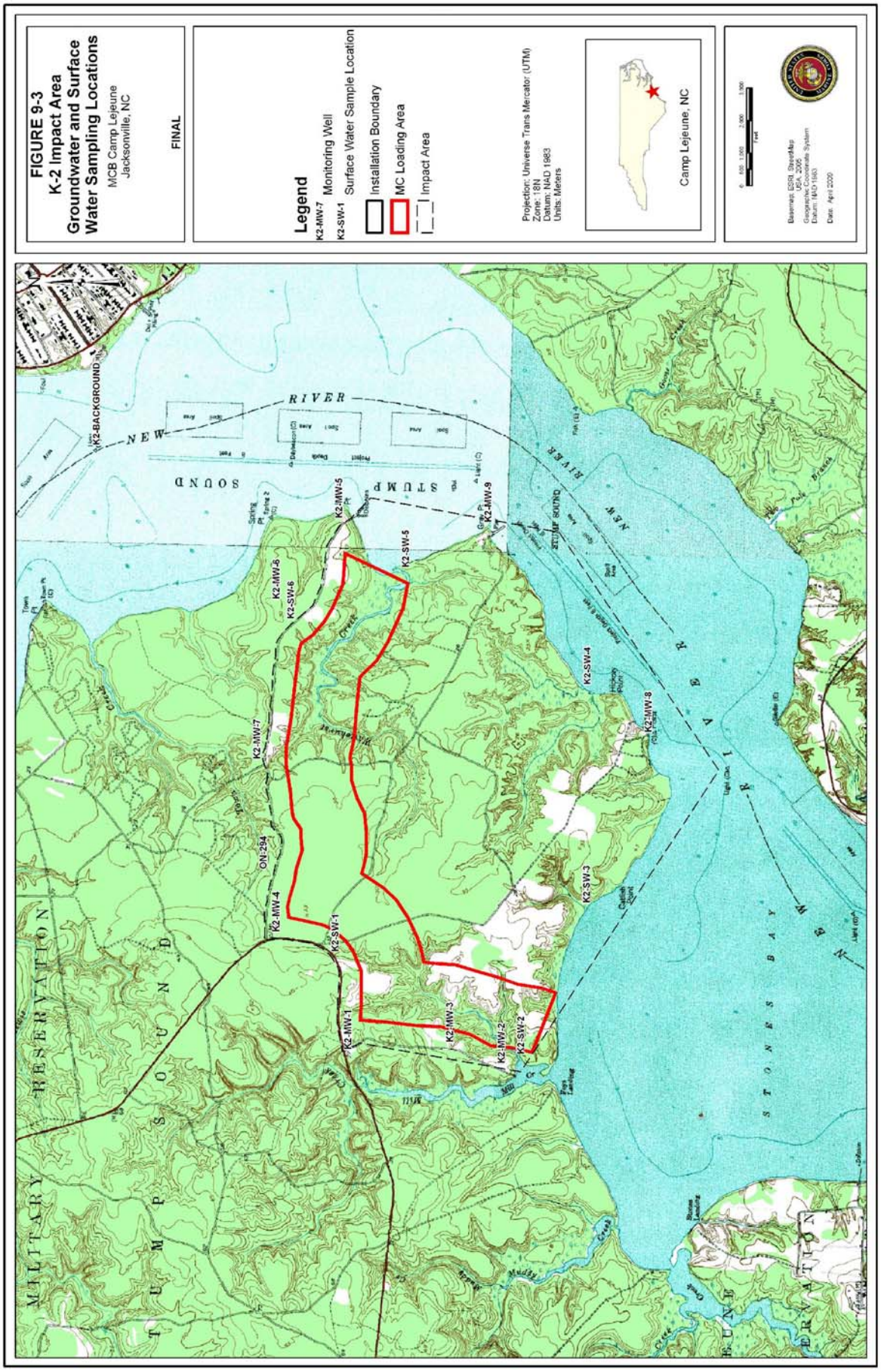
FIGURE 9-3
K-2 Impact Area
Groundwater and Surface
Water Sampling Locations
MCB Camp Lejeune
Jacksonville, NC
FINAL
Legend
K2-MW-7 Monitoring Well
K2-SW-1 Surface Water Sample Location
Installation Boundary
MC Loading Area
Impact Area
Projection: Universe Trans Mercator (UTM)
Zone: 18N
Datum: NAD 1983
Units: Meters
Camp Lejeune, NC
Date: April 2020
K2-BACKGROUND
NEW RIVER
SOUND
STUMP
K2-MW-9
K2-MW-5
K2-SW-5
K2-MW-6
K2-SW-6
K2-MW-7
K2-MW-4
K2-SW-1
K2-MW-1
K2-MW-3
K2-MW-2
K2-SW-2
K2-SW-3
K2-SW-4
K2-MW-8
ON-294
MILITARY RESERVATION
TUMPSOUND
NEW RIVER
STONES BAY

Many of the streams where surface water sampling was conducted can be tidally influenced (potential water level fluctuations) and are not appropriate for the use of an autosampler. At these surface water sampling locations, the samples were collected during ebb tide to ensure that sampled waters were derived primarily from the tidal creek of interest. The REVA assessment team planned to deploy an autosampler at one sample location, but it was determined during a subsequent REVA meeting that the autosampler was not necessary during this sampling and if a storm event occurred, a grab sample should be collected during the rain event. A storm event did occur during the sampling week, and a grab sample was collected. QA/QC samples were also collected.

The surface water samples were submitted to TestAmerica Laboratories located in Savannah, Georgia, for analysis. Lead analyses were completed at the Savannah laboratory, while explosives and perchlorate were analyzed for at the TestAmerica facility in Denver, Colorado.

9.2.2.1. G-10 Impact Area

Four surface water samples were collected from the area surrounding the G-10 Impact Area. Figure 9-1 generally shows the sampling locations. Three other locations were originally proposed to be sampled but were not sampled due to field conditions. These locations did not have any water at the time of sample collection and, based on their locations, did not appear to drain any of the identified MC loading areas. No off-range, upgradient location was identified to represent background conditions for sampling near the G-10 Impact Area; therefore, no specific background sample was collected at this location.

9.2.2.2. K-2 Impact Area

Three surface water samples were collected from the area surrounding the K-2 Impact Area. Figure 9-3 generally shows the sampling locations. Three other locations were proposed to be sampled but were not sampled due to field conditions. Two of the surface water locations did not have any water at the time of sample collection, and it appeared that they would be highly influenced by road runoff during a storm rather than from the MC loading areas. A storm water event sample was not collected at the K-2 Area. One surface water sampling location had only stagnant standing water and no evidence that the water had been flowing in the recent past. A background surface water sample was also collected from the New River, upstream of the K-2 Impact Area.

9.3. Laboratory Analytical Methods

Laboratory analytical methods were selected based on the project data quality objectives and in consideration of the method detection limit (MDL) achievable for each parameter. Each laboratory analytical method was chosen to address the intended use of the sampling data. Table 9-1 presents the laboratory analytical methods that were used during the field activities.

Table 9-1.
Summary of Sample Laboratory Analytical Methods, Containers, Holding Times, and Preservation Methods for Samples

Parameter	Analytical Methods	Sample Container	Preservation	Holding Time
Explosives	8330A	2 1-liter amber glass bottles with Teflon-lined lid	Cool to 4°C	7 days
Lead[a], total and dissolved	200.8	1 500 mL polyethylene bottle	Cool to 4°C HNO_3 to pH<2	180 days
Perchlorate[b]	6860[b]	1 100 mL polyethylene or glass bottle	Store samples with headspace to reduce potential anaerobic biodegradation	28 days
Metals (calcium, magnesium, sodium, potassium)	EPA 200.8	1 1-liter plastic bottle	Cool to 4°C HNO_3	6 months
Sulfate	EPA 300	Plastic (need 25 mL)[c]	Cool to 4°C	28 days
Chloride	EPA 300	Plastic (need 25 mL)[c]	Cool to 4°C	28 days
Carbonate and bicarbonate, alkalinity	SM 2320B	Plastic (need 150 mL)[c]	Cool to 4°C	14 days
Nitrate and nitrite	EPA 353.2	Plastic (need 25 mL)	Cool to 4°C	48 hours

Note:
°C – degrees Celsius
mL – milliliters
HNO_3 – nitric acid
EPA – U.S. Environmental Protection Agency
[a] If the measurement of total lead was required, the raw sample was acidified. If the measurement of dissolved lead was required, the sample was filtered through a 0.45-micrometer (µm) filter prior to acidification.
[b] The *DoD Perchlorate Handbook* recommends filtering groundwater samples through a 0.2 µm sterile filter to remove microorganisms and eliminate suspended solids (DoD, 2007).
[c]These parameters can be combined into one 500 mL plastic unpreserved bottle.

9.3.1. Quantitative Reporting Limits

Factors that influence the quantitative reporting limits of analytical methods include the analytical method itself, sample matrix interference, and high concentrations of the target analyte. Actual reporting limits may vary from sample to sample in accordance with standard laboratory practices. Table 9-2 provides the reporting limits for the analytical methods used for the surface water and groundwater analyses.

Table 9-2.
Analytical Reporting Limits

Analyte	Reporting Limit	MDL
Explosives		
HMX	0.4 µg/L	0.0876 µg/L
RDX	0.4 µg/L	0.0523 µg/L
1,3,5-Trinitrobenzene	1.0 µg/L	0.20 µg/L
2,4-Diamino-6-nitrotoluene	1.0 µg/L	0.36 µg/L
2,6-Diamino-4-nitrotoluene	1.0 µg/L	0.32 µg/L
Methyl-2,4,6-trinitrophenylnitramine (tetryl)	0.4 µg/L	0.0793 µg/L
1,3-Dinitrobenzene	0.4 µg/L	0.0887 µg/L

Analyte	Reporting Limit	MDL
2,4,6-Trinitrotoluene	0.4 µg/L	0.0724 µg/L
Nitrobenzene	0.4 µg/L	0.0910 µg/L
Nitroglycerin	4.0 µg/L	0.921 µg/L
4-Amino-2,6-dinitroluene	0.4 µg/L	0.0577 µg/L
2-Amino-4,6-dinitroluene	0.4 µg/L	0.0577 µg/L
2,4-Dinitrotoluene	0.4 µg/L	0.0887 µg/L
2,6-Dinitrotoluene	0.4 µg/L	0.0645 µg/L
2-Nitrotoluene	0.4 µg/L	0.0855 µg/L
3-Nitrotoluene	0.4 µg/L	0.0834 µg/L
4-Nitrotoluene	1.0 µg/L	0.20 µg/L
Pentaerythritol tetranitrate	2.0 µg/L	0.416 µg/L
Perchlorate		
Perchlorate	0.10 µg/L	0.0088 µg/L
Lead and Other Metals		
Lead	1.5 µg/L	0.12 µg/L
Dissolved Lead	1.5 µg/L	0.15 µg/L
Calcium	1300 µg/L	250 µg/L
Magnesium	1300 µg/L	43 µg/L
Sodium	1300 µg/L	400 µg/L
Potassium	1300 µg/L	100 µg/L
Sulfate and Chloride		
Sulfate	1.0 mg/L	0.5 mg/L
Chloride	1.0 mg/L	0.25 mg/L
Carbonate and Bicarbonate, Alkalinity		
Alkalinity	1.0 mg/L	1.0 mg/L
Bicarbonate alkalinity	1.0 mg/L	1.0 mg/L
Carbonate alkalinity	1.0 mg/L	1.0 mg/L
Nitrate and Nitrite		
Nitrate as N	0.050 mg/L	0.025 mg/L
Nitrite as N	0.050 mg/L	0.010 mg/L

Note: Reporting limits for explosives and perchlorate were provided by TestAmerica Laboratories, Inc., on August 13, 2007. The reporting limit for lead was provided by Analytical Laboratory Services, Inc., on July 19, 2007.
µg/L – micrograms per liter
mg/L – milligrams per liter

9.4. Hydraulic Assessment

To assess the potential hydraulic connection between the Surficial and Castle Hayne aquifers, a hydraulic test was conducted by shutting down several water supply wells tapping the Castle Hayne aquifer and then measuring the water level changes in neighboring wells tapping both the Castle Hayne and the Surficial aquifers. The

appropriate water supply wells were selected for the test based on discussions with the MCB Camp Lejeune Department of Public Works (LDPW) and Environmental Management Division. Based on the initial information obtained, nine water supply wells located along Sneads Ferry Road (were selected for the hydraulic conductivity testing. Figure 9-4 shows the general areas of the water supply well locations. One well located along Sneads Ferry Road needed to be rehabilitated and, therefore, was not included in the test.

Simultaneous water level measurements at the MCB Camp Lejeune-USGS monitoring wells and selected water supply wells within the MCB Camp Lejeune well field along Sneads Ferry Road provided information on the effects of pumping of the water supply wells. Water level changes in the Surficial aquifer in response to the changes in pumping were used to indicate the degree of hydraulic connection between the Surficial and Castle Hayne aquifers. Available measurement locations included shallow MCB Camp Lejeune-USGS monitoring wells screened in the Surficial aquifer and monitoring wells and water supply wells screened in the Castle Hayne aquifer. The water level of Cowhead Creek and Jumping Run Creek were also measured during the hydraulic test, since they cross under Sneads Ferry Road. The water level at Cowhead Creek was measured from the top of the hand railing on the wooden walk bridge on the east side of the road. The water level at Jumping Run Creek was measured from the center point at the top of the culvert pipe on the west side of the road.

The hydraulic test of the connectivity of the Surficial and Castle Hayne aquifers was conducted on December 10-13, 2007. Water level measurements were collected at the MCB Camp Lejeune-USGS monitoring wells and the selected water supply wells to establish their baseline conditions. Then the selected water supply wells located along Sneads Ferry Road were shut down, and the hydraulic response of the nearest MCB Camp Lejeune-USGS monitoring wells and at the selected water supply wells was measured. Figure 9-4 shows the general locations of the selected water supply and monitoring wells.

Due to the structure of the water supply wells wellheads, the pressure changes in the well casing were only able to be measured (using an air tank and measuring the pressure gauge on the well) to determine the water level. The actual water level was not able to be measured directly because it was impossible to access the interior of the water supply wells. The water level was not able to be measured in one well due to the air line not working. Monitoring equipment used to measure the water level at the water supply wells was obtained from the LDPW.

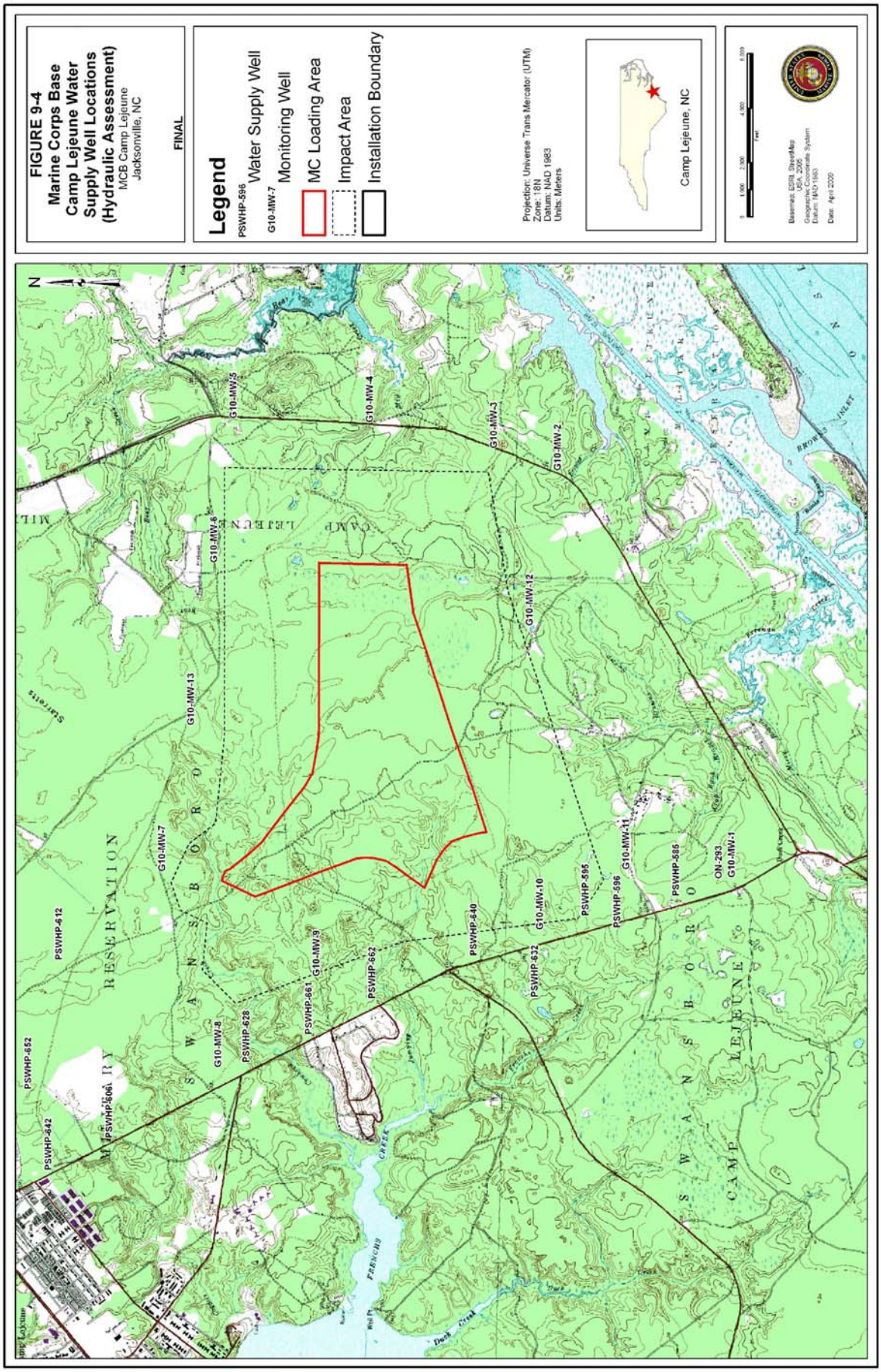
FIGURE 9-4
Marine Corps Base
Camp Lejeune Water
Supply Well Locations
(Hydraulic Assessment)
MCB Camp Lejeune
Jacksonville, NC
FINAL
Legend
PSWHP-596 Water Supply Well
G10-MW-7 Monitoring Well
MC Loading Area
Impact Area
Installation Boundary
Projection: Universe Trans Mercator (UTM)
Zone: 18N
Datum: NAD 1983
Units: Meters
Camp Lejeune, NC
Basemap: ESRI StreetMap USA, 2005
Geographic Coordinate System
Datum: NAD 1983
Date: April 2020
N
PSWHP-652
PSWHP-842
PSWHP-606
PSWHP-612
G10-MW-8
PSWHP-628
G10-MW-7
G10-MW-13
G10-MW-6
G10-MW-5
G10-MW-4
G10-MW-3
G10-MW-2
G10-MW-12
G10-MW-11
G10-MW-10
G10-MW-9
PSWHP-661
PSWHP-662
PSWHP-640
PSWHP-632
PSWHP-595
PSWHP-596
PSWHP-586
ON-293
G10-MW-1
RESERVATION
CAMP LEJEUNE
SWANSBORO
Starkeys
Parkins Creek
Duck Creek
Brown Inlet

Pressure transducers were placed in selected MCB Camp Lejeune-USGS monitoring wells around the G-10 Impact Area for collecting periodic water level measurements during the hydraulic test. Manual water levels were also measured at the monitoring locations, and the pressure transducer data were utilized as an extended backup data set.

For the week prior to the shutdown, the LDPW kept most of the selected municipal wells along Sneads Ferry Road constantly pumping. Three of the wells were not pumping prior to or during the hydraulic test. Following the installation of the transducers and measurement of the initial water levels, the LDPW shut off most of the selected wells at 1540 hours on December 10, 2007. However, three of the water supply wells, in the northern section along Sneads Ferry Road, could not be shut off until 2100 hours on December 10, 2007.

9.5. Field Observations and Results

This section describes the observations and results for the groundwater and surface water sampling program and the assessment of the hydraulic connection between the Surficial and Castle Hayne aquifers.

9.5.1. Groundwater Sampling Results and Observations

The analytical results are summarized in Tables 9-3, 9-4, and 9-5 for explosives, perchlorate and lead, and inorganic ions, respectively. The laboratory analytical data sheets are provided in Appendix D. The field parameters measured during the groundwater sampling have also been summarized and are provided in Table 9-6.

The groundwater analytical results were compared to the DoD Range and Munitions Use Subcommittee (RMUS) drinking water values (Table 1, Human Drinking Water Value) provided in Appendix D and on the appropriate tables.

DoD RMUS screening values were developed based on existing state and USEPA guidelines to promote consistency across the services' operational range assessment programs. This list of screening values is intended to be a general list of commonly found MC used in various range training activities. A hierarchy of sources was developed to guide the selection of screening values. This hierarchy is a prioritized list of screening value sources in order of recognized authority and applicability. All services compare their groundwater and surface water sampling data to these screening values to determine if further assessment is recommended. The groundwater results were also compared to the North Carolina NCAC 2L groundwater standards, where appropriate. Several pH values were outside the groundwater standard of 6.5-8.5. Also, one chloride sample was above the 250 mg/L groundwater standard; however, the well is located right next to the New River and is most likely representative of direct influx of water from the New River.

Table 9-3
Summary of Analytical Results - Explosives
MCB Camp Lejeune

			Screening Levels[a] and Analytical Results (in ug/L)																	
	Human Drinking Water Values		*3.7*	*73*	*37*	*3.4*	*1100*	*2.2*	*1800*	*0.61*	*150*	*370*	*122*	*4.2*	*73*	*73*	*3.7*	*NA*	*NL*	*NL*
	Surface Water Values: Ecological Receptors		*20*	*44*	*42*	*270*	*11*	*90*	*150*	*190*	*NA*	*NA*	*750*	*1900*	*NA*	*20*	*138*	*85000*	*NL*	*NL*
Pathway	Sample Identification	Collection Date	*1,3-Dinitrobenzene*	*2,4-Dinitrotoluene*	*2,6-Dintrotluene*	*Nitrobenzene*	*1,3,5-Trinitrobenzene*	*2,4,6-Trinitrotoluene*	*HMX*	*RDX*	*Tetryl*	*2-Nitrotoluene*	*3-Nitrotoluene*	*4-Nitrotoluene*	*4-Amino-2,6-Dinitrotoluene*	*2-Amino-4,6-Dinitrotoluene*	*Nitroglycerin*	*PETN*	*2,4-diamino-6-nitrotoluene*	*2,6-diamino-4-nitrotoluene*
Groundwater	G10-MW-1	14-Nov-07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	G10-MW-2	13-Nov-07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	G10-MW-3	13-Nov-07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	G10-MW-4	13-Nov-07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	G10-MW-5	13-Nov-07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	G10-MW-8	13-Nov-07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	G10-MW-9	13-Nov-07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	G10-MW-10	14-Nov-07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	G10-MW-13	14-Nov-07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	G10-PSWHP-611	14-Nov-07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	G10-PSW-708	14-Nov-07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	G10-PSWHP-628	14-Nov-07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	G10-PSWHP-585	14-Nov-07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	G10-PSWBB-218	14-Nov-07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	G10-Pump Blank	14-Nov-07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	K2-MW-2	12-Nov-07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	K2-MW-4	12-Nov-07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	K2-MW-9	12-Nov-07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	DUP-2	13-Nov-07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	PSW-648	30-Apr-08	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	PSW-584	30-Apr-08	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	PSWHP-612	29-Apr-08	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	PSWHP-652	29-Apr-08	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	K2-MW-1	28-Apr-08	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	K2-MW-6	29-Apr-08	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	K2-MW-7	28-Apr-08	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	K2-MW-8	27-Apr-08	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	REVA-blank	30-Apr-08	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	DUP-2	29-Apr-08	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	K2-DUP-1	28-Apr-08	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	G10-MW-5D	9-Oct-08	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	G10-Dup-1	9-Oct-08	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Surface Water	K2-SW-02	11-Nov-07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	K2-SW-04	11-Nov-07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	K2-SW-05	11-Nov-07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	DUP-1	11-Nov-07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Background SW	12-Nov-07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	G10-SW-1	15-Nov-07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	G10-SW-2	14-Nov-07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	G10-SW-6	14-Nov-07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	G10-SW-7	14-Nov-07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	DUP-3	14-Nov-07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Notes

NA - not available; ND - analyte not detected above listed MDL; NL - analyte not listed; SW - surface water; TBD - to be determined

ug/L - micrograms per liter, (parts per billion)

Explosives analyses were completed by EPA Method 8330A.

[a] Screening levels are based on the DoD Range and Munitions Use Subcommittee (RMUS) screening values. Screening levels for drinking water apply to tap water and are not directly applicable to raw groundwater.

Table 9-4
Summary of Analytical Results - Lead and Perchlorate
MCB Camp Lejeune

			Screening Levels[a] (in ug/L)		
			Lead, total	*Lead, dissolved*	*Perchlorate*
	Human Drinking Water Values		*15*	*15*	*15*
	Surface Water Values: Ecological Receptors		*NA*[b]	*2.5*	*9300*
Pathway	Sample Identification	Collection Date	Analytical Result (in ug/L)		
			Lead, total	*Lead, dissolved*	*Perchlorate*
Groundwater	G10-MW-1	14-Nov-07	0.17 J	0.15 U	0.022 J
	G10-MW-2	13-Nov-07	0.12 J	0.15 U	ND
	G10-MW-3	13-Nov-07	0.21 J	0.15 U	ND
	G10-MW-4	13-Nov-07	0.12 U	0.15 U	0.018 J
	G10-MW-5	13-Nov-07	0.12 U	0.15 U	0.29
	G10-MW-8	13-Nov-07	0.12 U	0.15 U	0.31
	G10-MW-9	13-Nov-07	0.12 U	0.32 J	0.050 J
	G10-MW-10	14-Nov-07	0.12 U	0.15 U	ND
	G10-MW-13	14-Nov-07	0.56 J	0.62 J	ND
	G10-PSWHP-611	11-Jan-08	<3.0[c]	0.18 J	ND
	G10-PSW-708	14-Nov-07	5.7	0.40 J	ND
	G10-PSWHP-628	14-Nov-07	0.56 J	0.38 J	0.061 J
	G10-PSWHP-585	14-Nov-07	0.12 U	0.15 U	ND
	G10-PSWBB-218	14-Nov-07	0.19 J	0.15 U	ND
	G10-Pump Blank	14-Nov-07	0.12 U	0.15 U	ND
	K2-MW-2	12-Nov-07	0.41 J	0.35 J	<0.080 J
	K2-MW-4	12-Nov-07	0.16 J	0.15 U	ND
	K2-MW-9	12-Nov-07	0.26 J	0.15 U	ND
	DUP-2	13-Nov-07	0.17 J	0.15 U	ND
	PSW-648	30-Apr-08	0.12 U	0.15 U	ND
	PSW-584	30-Apr-08	0.38 J	0.27 J	ND
	PSWHP-611	29-Apr-08	0.49 J[c]	0.15 U	NS
	PSWHP-612	29-Apr-08	0.15 J	0.15 U	ND
	PSWHP-652	29-Apr-08	0.24 J	0.15 U	ND
	PSW-708	29-Apr-08	1.5	0.24 J	NS
	K2-MW-1	28-Apr-08	0.59 J	0.15 U	ND
	K2-MW-6	29-Apr-08	0.56 J	0.41 J	0.14
	K2-MW-7	28-Apr-08	0.78 J	0.71 J	0.28
	K2-MW-8	27-Apr-08	0.14 J	0.21 J	0.020 J
	REVA-blank	30-Apr-08	0.12 U	0.15 U	ND
	DUP-2	29-Apr-08	0.21 J	0.15 U	ND
	K2-DUP-1	28-Apr-08	0.24 J	0.15 U	ND
	G10-MW-5D	9-Oct-08	0.12 U	0.15 U	ND
	G10-Dup-1	9-Oct-08	0.12 U	0.15 U	ND
Surface Water	K2-SW-02	11-Nov-07	0.95 J	0.15 U	<0.014 J
	K2-SW-04	11-Nov-07	0.34 J	0.15 U	ND
	K2-SW-05	11-Nov-07	0.55 J	0.15 U	ND
	DUP-1	11-Nov-07	0.86 J	0.15 U	ND
	Background SW	12-Nov-07	0.30 J	0.15 U	ND
	G10-SW-1	15-Nov-07	0.16 J	0.15 U	ND
	G10-SW-2	14-Nov-07	0.12 U	0.15 U	ND
	G10-SW-6	14-Nov-07	0.12 U	0.15 U	ND
	G10-SW-7	14-Nov-07	0.21 J	0.15 U	0.016 J
	DUP-3	14-Nov-07	0.18 J	0.15 U	0.015 J

Notes

U - analyte was not detected above listed MDL.

J - estimated; the analyte was positively identified, though the quantitation is an estimation.

ug/L - micrograms per liter, (parts per billion)

Lead analyses were completed by EPA Method 200.8, perchlorate analyses were completed by Method 6860.

NA- not available; ND - not detected; NS- not sampled; SW-surface water

[a] Screening levels are based on the DoD Range and Munitions Use Subcommittee (RMUS) screening values.

[b] Screening-level values apply to dissolved metals.

[c] Sample from G10 PSWHP-611 was resampled (January 2008) by the Camp Lejeune staff and (April 2008) by MPI staff, after a concentration of 100 ug/L was detected in the sample collected in November 2007 and thought to be abnormally high and erroneous.

Table 9-5
Summary of General Chemistry Analytical Results
MCB Camp Lejeune

Sample Identification	Collection Date	Analytical Result (in ug/L)				Analytical Result (in mg/L)						
		Calcium	*Sodium*	*Potassium*	*Magnesium*	*Chloride*	*Sulfate*	*Nitrate as N*	*Nitrite as N*	*Alkalinity*	*Bicarbonate*	*Carbonate*
G10-MW-1	14-Nov-07	31000	4700	340	800	8.3	16	0.15	0.010 U	61	61	1.0 U
G10-MW-2	13-Nov-07	5500	7000	640 J	990 J	12	6.5	0.025 U	0.010 U	8.3	8.3	1.0 U
G10-MW-3	13-Nov-07	740 J	8600	340 J	880 J	16	4.4	0.025 U	0.010 U	1.5	1.5	1.0 U
G10-MW-4	13-Nov-07	1100 J	9000	530 J	1500	12	9.4	0.025 U	0.010 U	1.6	1.6	1.0 U
G10-MW-5	13-Nov-07	690 J	6500	590 J	1100 J	7.4	4	0.025 U	0.010 U	3.2	3.2	1.0 U
G10-MW-8	13-Nov-07	620 J	5600	760 J	1200 J	6.1	7	0.025 U	0.010 U	1.2	1.2	1.0 U
G10-MW-9	13-Nov-07	550 J	6700	350 J	1300	7.1	8.7	0.025 U	0.010U	1.0 U	1.0 U	1.0 U
G10-MW-10	14-Nov-07	930	3900	340	960	7.6	4	0.025 U	0.010 U	1.5	1.5	1.0 U
G-10-MW-13	14-Nov-07	11000	8700	330	1400	25	22	0.025 U	0.010 U	1.0 U	1.0 U	1.0 U
G10-PSW-708	14-Nov-07	74000	6200	990	1600	8.6	1	0.025 U	0.010 U	180	180	1
G10-PSWHP-611	14-Nov-07	65000	6100	740	1200	9	2.2	0.025 U	0.010 U	160	160	1.5
G10-PSWHP-628	14-Nov-07	43000	5900	1000	1800	10	7.9	0.12	0.010 U	100	100	1.0 U
G10-PSWHP-585	14-Nov-07	68000	5400	530	1400	8.1	0.50 U	0.025 U	0.010 U	170	170	1
G10-PSWBB-218	14-Nov-07	71000	8600	950	2000	12	0.68 J	0.025 U	0.010 U	190	190	1.0 U
K2-MW-2	12-Nov-07	3400	22000	3100	4400	41	3.9	0.025 U	0.010 U	3.4	3.4	1.0 U
K2-MW-4	12-Nov-07	2800	10000	2200	2900	13	25	0.025 U	0.010 U	1.0 U	1.0 U	1.0 U
K2-MW-9	12-Nov-07	95000	140000	6300	19000	220	0.50 U	0.025 U	0.010 U	330	330	1.0 U
DUP-2	13-Nov-07	760 J	9100	380 J	920 J	16	5	0.025 U	0.010 U	1.7	1.7	1.0 U
G10-Pump Blank	14-Nov-07	420	80 U	20 U	8.5 J	0.25 U	0.50 U	0.025 U	0.010 U	1.1	1.1	1.0 U
Background SW	12-Nov-07	360000	8500000	350000	1000000							
PSW-648	30-Apr-08	97000	12000	1600	2600	20	8.0 M	0.025 U	0.010 U	240	240	1.0 U
PSW-584	30-Apr-08	74000	7100	1500	1500	8.7	0.50 U	0.025 U	0.010 U	220	220	1.1
PSWHP-612	29-Apr-08	77000	6300	860	1400	8.7	0.71 J	0.025 U	0.010 U	200	200	1.2
PSWHP-652	29-Apr-08	99000	8200	1000	1900	13	1.5	0.025 U	0.010 U	230	230	1.0 U
K2-MW-1	28-Apr-08	42000	15000	2300	9800	28	48	0.045 J	0.010 U	90	90	1.0 U
K2-MW-6	29-Apr-08	58000	7900	230 J	1100	42	110	0.035 J	0.010 U	1.0 U	1.0 U	1.0 U
K2-MW-7	28-Apr-08	4000	4000	1200	2000	4.4	14 M	1	0.010 U	4	4	1.0 U
K2-MW-8	27-Apr-08	100000	63000	210000	2100000	4700	3.6 M	NS	NS	79	79	1.0 U
REVA-blank	30-Apr-08	660	80 U	20 U	8.5 U	0.25 U	0.50 U	0.025 U	0.010 U	1.0 U	1.0 U	1.0 U
DUP-2	29-Apr-08	97000	8100	1000	1800	13	1.5	0.025 U	0.010 U	230	230	1
K2-DUP-1	28-Apr-08	39000	14000	2100	9200	27	47	0.085	0.010 U	86	86	1.0 U
G10-MW-5D	9-Oct-08	47000	14000	1600	1800	9.1	9.2	0.025 U	0.010 U	140	140	1.0 U
G10-Dup-1	9-Oct-08	48000	14000	1600	1700	9.1	9.4	0.025 U	0.010 U	140	140	1.6

Notes

U - analyte not detected above listed MDL.

J - estimated; the analyte was positively identified, though the quantitation is an estimation.

ug/L - micrograms per liter, (parts per billion); mg/L - milligrams per liter, (parts per million)

M - Manual integrated compound; NS - not sampled, insufficient amount of water; SW - surface water

Blank space - parameters not analyzed for background surface water.

PSWHP-611 and PSW-708 only sampled for lead during the April 2008 sampling event.

Table 9-6
Groundwater and Surface Water Field Parameters
MCB Camp Lejeune

General Location	Sample Identification	Collection Date	Field Parameters						
			Temperature (°C)	*Conductivity (mS/cm)*	*DO (%)*	*DO (mg/L)*	*pH*	*ORP*	*Turbidity (NTU)*
Groundwater	K2-MW-2	12-Nov-07	19.04	0.131	19.4	1.81	[a]4.53	157.5	130
	K2-MW-4	12-Nov-07	21.5	0.102	18.8	1.65	[a]4.07	-128.2	27
	K2-MW-7	12-Nov-07	18.37	0.256	35.6	3.49	[a]4.86	220	70
	K2-MW-8	12-Nov-07	15.51	13.53	NM	16.5	7.12	29.3	67.6
	K2-MW9	12-Nov-07	20.88	1.3	NM	8.4	6.66	-97.5	35.2
	G10-MW-1	14-Nov-07	23.3	0.193	8.8	0.78	6.57	47.5	5.09
	G10-MW-2	13-Nov-07	20.76	0.077	6.2	NM	[a]5.05	-116	1.84
	G10-MW-3	13-Nov-07	21.81	0.074	5.9	0.52	[a]4.72	107.9	3.52
	G10-MW-4	13-Nov-07	20.28	0.074	11.9	1.07	[a]4.65	119.5	1.0
	G10-MW-5	13-Nov-07	20.94	0.048	18.5	1.68	[a]4.65	212.20	1.64
	G10-MW-8	13-Nov-07	19.78	0.047	15.9	1.46	[a]4.61	203	5.09
	G10-MW-9	13-Nov-07	20.37	0.054	21.3	1.92	[a]4.79	202.5	0.39
	G10-MW-10	14-Nov-07	20.66	0.048	3.7	0.33	[a]4.64	-6.9	0.51
	G10-MW-13	14-Nov-07	20.12	0.148	21.6	1.96	[a]4.44	359.7	14.8
	PSWHP-611	14-Nov-07	17.8	0.332	31	2.91	6.31	-69.4	14.8
	PSW-708	14-Nov-07	18.08	0.378	37.6	3.49	7.07	-80	4.2
	PSWHP-628	14-Nov-07	19.08	0.266	27.6	2.55	7.19	-1.7	4.19
	PSWHP-585	14-Nov-07	18.84	0.355	20.5	1.91	7.42	-85	1.3
	PSWHP-218	14-Nov-07	18.87	0.399	30.3	2.77	7.55	-110.4	3.31
	PSW-648	30-Apr-08	18.0	0.546	91.2	8.52	7.96	-64.7	4.0
	PSW-584	30-Apr-08	18.0	0.435	62.5	5.8	7.85	-62.4	2.0
	PSWHP-611	29-Apr-08	17.84	0.4	44.1	4.18	11.19	-49.6	10.0
	PSWHP-612	29-Apr-08	17.37	0.402	60.4	5.77	7.33	-60.2	3.0
	PSWHP-652	29-Apr-08	17.21	0.488	75.7	7.4	7.46	-48.6	3.0
	PSW-708	29-Apr-08	17.71	0.37	51.1	4.8	7.51	-62.9	2.0
	K2-MW-1	28-Apr-08	18.05	0.366	2.5	0.24	5.89	72.9	320
	K2-MW-6	29-Apr-08	15.44	0.426	33.9	3.48	7.75	330.6	11
	K2-MW-7	28-Apr-08	16.54	0.079	5.85	5.7	5.2	354.5	7.5
	K2-MW-8	27-Apr-08	17.55	44.9	171.2	12.3	8.05	39.5	50
	G10-MW-5D	9-Oct-08	19.38	0.284	3.5	0.33	8.11	-176	10
Surface Water	K2-SW-02	11-Nov-07	12.4	47.87	179.1	12.51	7.5	214.70	5.75
	K2-SW-04	11-Nov-07	15.92	43	110.9	8.95	7.84	179.20	10
	K2-SW-05	11-Nov-07	13.88	44.21	93.7	8.1	8.14	162.20	6.02
	G10-SW-1	15-Nov-07	14.18	0.153	90.3	9.28	7.32	179.3	1.51
	G10-SW-2	14-Nov-07	13.02	0.776	51.1	5.17	7.56	13.20	1.88
	G10-SW-6	14-Nov-07	16.35	0.09	47	4.5	7.2	119.50	1.29
	G10-SW-7	14-Nov-07	14.92	0.211	37.7	3.75	7.82	62.30	3.56
	Background SW	12-Nov-07	12.6	43.2	169.6	12.15	8.05	37.80	4.69

Notes

°C - degrees celsius

DO - dissolved oxygen

mg/L - milligrams per liter

mS/cm - microSiemens per centimeter

NTU - nephelometric turbidity units

NM - not measured

Field parameters were measured with a calibrated YSI multiparameter water quality meter and Hach meter.

[a] Groundwater pH is in the mobility range for dissolved lead.

None of the groundwater samples had detectable concentrations of explosives (Table 9-3). Perchlorate was detected above the laboratory reporting limit in four samples at concentrations of 0.29, 0.31, 0.14, and 0.28 µg/L, respectively (Table 9-4). Eight samples had perchlorate concentrations that were estimated to be above the MDL but below the laboratory reporting limit. These concentrations ranged from 0.018 to 0.080 µg/L (Table 9-4). However, all the perchlorate concentrations were well below the RMUS human drinking water screening value of 15 µg/L.

Total lead was detected in two samples at concentrations of 5.7 and 100 µg/L, respectively (Table 9-4). The value from one well was abnormally high and was suspected to be erroneous. A second sample collected from the well by MCB Camp Lejeune on January 9, 2008, had less than 3 µg/L of total lead and less than 3 µg/L of dissolved lead, which are below the RMUS human drinking water screening value of 15 µg/L. This result confirms that the original sample was not representative of the actual lead concentration. Both wells were resampled during the April 2008 sampling event and had concentrations of total lead of 1.5 and 0.49 J, respectively. Again, both of these results were below the RMUS human drinking water screening value of 15 µg/L. Samples from several wells had total lead concentrations that were above the MDL but below the laboratory reporting limit. These total lead concentrations ranged from 0.12 to 0.78 µg/L (Table 9-4). Similarly, samples from 11 wells had concentrations of dissolved lead that were above the MDL but below the laboratory reporting limit. These dissolved lead concentrations ranged from 0.18 to 0.71 µg/L. However, all total and dissolved lead concentrations were below the RMUS human drinking water screening value of 15 µg/L.

9.5.2. Surface Water Sampling Results and Observations

The analytical results are summarized in Tables 9-3 and 9-4 for explosives, perchlorate and lead, and inorganic ions, respectively. The laboratory analytical data sheets are provided in Appendix D. The field parameters measured during the surface water sampling have also been summarized and are provided in Table 9-6.

The surface water analytical results were compared to the DoD RMUS surface water screening values provided in Appendix D and on the appropriate tables (Table 2, Ecological Freshwater Surface Water System Values).

None of the surface water samples had detectable concentrations of explosives (Table 9-3). Two samples had perchlorate detected at concentrations above the MDL but below the laboratory reporting limit (0.016 and 0.014 µg/L, respectively). However, the perchlorate concentrations were well below the RMUS ecological freshwater surface water screening value of 9,300 µg/L.

Total lead was detected in selected samples at concentrations above the MDL but below the laboratory reporting limit. The concentrations ranged between 0.16 and 0.95 µg/L

(Table 9-4). The dissolved lead concentrations were all nondetectable. The RMUS ecological freshwater surface water system screening value for lead is 2.5 µg/L, but is only applicable to dissolved lead. All the analytical results for both total and dissolved lead were below this screening value.

9.5.3. Data Quality Review

The verification process for the laboratory data involves ensuring that the holding times, precision, accuracy, laboratory blanks, and detection limits are within the acceptance criteria outlined in the project-specific data quality plan.

Data validation for groundwater samples collected from MCB Camp Lejeune were reviewed in accordance with procedures described in EPA Functional Guideline documents for organic and inorganic data review (1999; 2004) and quality assurance and control parameters set by the project laboratory (TestAmerica). Sample results were evaluated by the following quality control (QC) parameters:

- Sample receipt temperatures
- Holding times
- Method blanks
- Laboratory control samples
- Matrix spike / matrix spike duplicates (MS/MSD)
- Field duplicates
- Surrogates (for organic parameters)

Laboratory analytical results for the groundwater and surface water samples are considered usable for intended purposes and meet project data quality objectives. The data qualifiers used to qualify analytical results associated with QC parameters are defined below:

- J: The analyte was positively identified; however, the result should be considered an estimated value.
- UJ: The reporting limit is considered an estimated value.
- U: Nondetect result is above the laboratory reporting limit.

Table 9-7 summarizes results that required qualification based on the data validation review.

Table 9-7.
Summary of Required Laboratory Qualification

Sample Identification	Analyte	Result and Qualifier	Units	Comments
G10-MW10	Calcium	930 J	µg/L	Qualified due to contamination in the pump blank
G10-MW-10	Alkalinity	1.5 J	mg/L	Qualified due to contamination in the pump blank
K2-SW-05	Dissolved lead	< 0.15 UJ	µg/L	Qualified due to low MS/MSD recoveries
G10-MW-13	Sulfate	22 J	mg/L	Qualified due to low MS/MSD recoveries
G10-PSWHP-611	Sulfate	2.2 J	mg/L	Qualified due to low MS/MSD recoveries
G10-MW-10	Sulfate	4.0 J	mg/L	Qualified due to low MS/MSD recoveries
G10-MW-1	Sulfate	16 J	mg/L	Qualified due to low MS/MSD recoveries
G10-PSW-708	Sulfate	1.0 J	mg/L	Qualified due to low MS/MSD recoveries
G10-PSWHP-628	Sulfate	7.9 J	mg/L	Qualified due to low MS/MSD recoveries
G10-PSWHP-585	Sulfate	< 0.50 UJ	mg/L	Qualified due to low MS/MSD recoveries
G10-PSWBB-218	Sulfate	0.68 J	mg/L	Qualified due to low MS/MSD recoveries
G10-PSWHP-585	Sulfate	< 0.50 UJ	mg/L	Qualified due to low MS/MSD recoveries

Results qualified as “J” and “UJ” are of acceptable data quality and may be used quantitatively to fulfill the objectives of the analytical program, per EPA guidelines.

The overall QC objective is to generate documented data that are of known and defensible quality. Based on the review of the surface water analytical data, the data were of sufficient quality, including precision, accuracy, completeness, comparability, and representativeness, to meet the study objectives of determining if surface water samples showed a release of MC to off-range areas. Based on the review of the groundwater analytical data, the data were of sufficient quality, including precision, accuracy, completeness, comparability, and representativeness, to meet the study objectives of determining if groundwater samples showed a release of MC to off-range areas. Based on the review of the assessment of hydraulic connection data, the data were of sufficient quality, including precision, accuracy, completeness, comparability, and representativeness, to meet the study objectives of assessing the magnitude of hydraulic connection between the Surficial and Castle Hayne aquifers near the G-10 Impact Area.

9.5.4. Hydraulic Assessment Results

During the hydraulic assessment, water levels were measured manually and with data logging pressure transducers. The water level measurements in the Surficial aquifer did not change significantly during the beginning of the hydraulic test, so instead of trying to

cycle the wells on/off, it was decided to extend the shutdown for the remainder of the test to see if there were any changes that could be measured. Based on the measurements from the monitoring wells screened in the Surficial aquifer, there were no significant changes in the measured water levels that could be attributed to the shutdown of the water supply wells. The hydraulic test results measured only between a few hundredths to approximately a tenth of a foot change in the MCB Camp Lejeune-USGS monitoring wells screened in the Surficial aquifer. One monitoring well, screened in the Castle Hayne aquifer, showed a water level change of 0.90 feet. Water levels in the two streams along Sneads Ferry Road (Cowhead Creek and Jumping Run Creek) were also monitored but showed no change throughout the test. The water levels in the MCB Camp Lejeune water supply wells rose between 8 and 110 feet following the shutdown of the wells. The starting and ending manual water level measurements for the MCB Camp Lejeune-USGS monitoring wells, the selected MCB Camp Lejeune water supply wells, and the two creeks are shown in Table 9-8.

Table 9-8.
Water Level Data

Monitoring Location	Starting Depth to Water (ft)	Ending Depth to Water (ft)	Difference (ft)
Monitoring Wells			
G10-MW-1 (Surficial aquifer)	13.15	13.17	-0.02
G10-MW-5 (Surficial aquifer)	21.05	21.09	-0.04
G10-MW-8 (Surficial aquifer)	18.67	18.65	+0.02
G10-MW-9 (Surficial aquifer)	18.97	19.00	-0.03
G10-MW-10 (Surficial aquifer)	15.23	15.25	-0.02
G10-MW-11 (Surficial aquifer)	13.12	13.00	+0.12
G10 ON-293 (Castle Hayne aquifer)	18.50	17.60	+0.90
Water Supply Wells			
PSWHP-606 (Castle Hayne aquifer)[a]	50	19	+31
PSWHP-628 (Castle Hayne aquifer)[a]	38	25	+13
PSWHP-662 (Castle Hayne aquifer)[a]	41	9	+32
PSWHP-640 (Castle Hayne aquifer)	30	15	+15
PSWHP-632 (Castle Hayne aquifer)	25	17	+8
PSWHP-595 (Castle Hayne aquifer)[a]	122	12	+110
PSWHP-596 (Castle Hayne aquifer)[a]	85	10	+75
PSWHP-585 (Castle Hayne aquifer)[a]	35	20	+15
Creeks			
Cowhead Creek	10.2	10.2	0
Jumping Run Creek	2.4	2.4	0

[a] Water supply well was operating prior to start of hydraulic test.

As part of the groundwater sampling conducted in November 2007 and April 2008, major inorganic ion parameters were analyzed from the Surficial and Castle Hayne aquifers to assess the chemical similarity of groundwater in the two aquifers. The results of the sampling analysis were plotted on a Piper diagram, shown as Figure 9-5. The plot generally shows that there is a chemical difference between the groundwater in the two aquifers, which is an indication that they are not likely significantly hydraulically connected. Three of the monitoring wells screened in the Surficial aquifer plotted in different areas of the Piper diagram. The sample from one monitoring well plotted between the samples from the Surficial and Castle Hayne aquifers in the middle of the Piper diagram. However, this well is only screened from 3 to 8 ft bgs and is located along the shore of the New River; so it would be expected to be different than the other Surficial aquifer geochemistry as it is more influenced by the New River. The sample from one monitoring well also plotted between samples from the Surficial and Castle Hayne aquifers. However, the water from the well during sampling was very turbid compared to other sampled wells and may have affected the water chemistry results for this well. The sample from another Surficial aquifer well plotted closer to samples from the Castle Hayne aquifer wells due to higher calcium and alkalinity values.

Based on the hydraulic test results and the geochemical difference between the groundwater from the Surficial and Castle Hayne aquifers, there does not appear to be a significant hydraulic connection between the Surficial and Castle Hayne aquifers in the vicinity of the G-10 Impact Area MC loading area. There are no wells screening the Castle Hayne aquifer near the K-2 Impact Area MC loading area. The results of the hydraulic test indicate that there is minimal possibility of MC migration from the Surficial aquifer to the Castle Hayne aquifer in the area of the G-10 Impact Area.

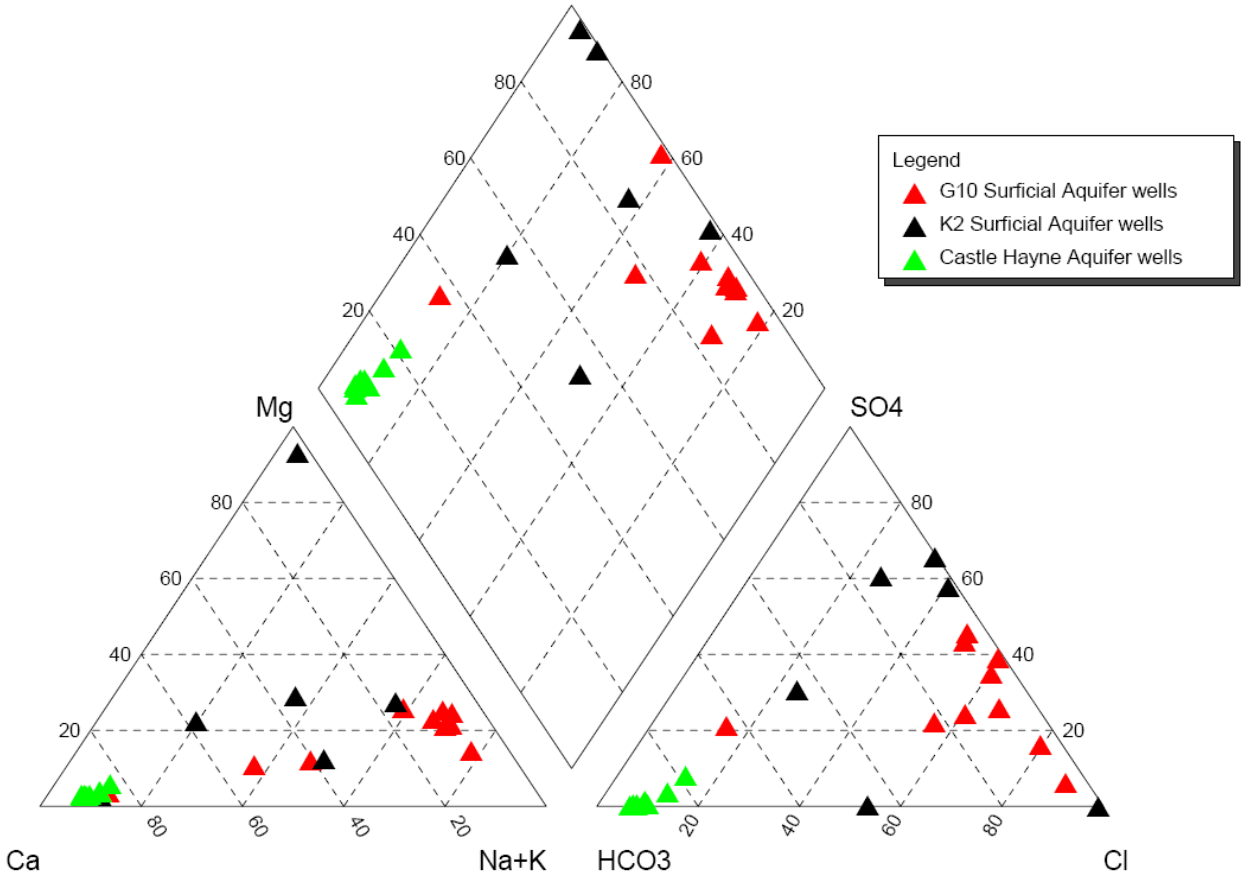

Figure 9-5: Piper Diagram Plot

9.5.5. New Monitoring Well Installation

During August 4-11, 2008, a deep monitoring well was installed at the request of the installation and HQMC in order to evaluate the groundwater in the Castle Hayne aquifer in this area of the G-10 Impact Area. The monitoring well is located on the northeast side of the G-10 Impact Area. The monitoring well was installed to screen the Castle Hayne aquifer since the nearby monitoring well currently screens the Surficial aquifer.

A surface casing was cemented in place from the surface into the Castle Hayne confining unit approximately 46 feet below grade. The monitoring well was then installed inside this casing. The well is screened from 90 to 100 feet below ground in the Castle Hayne aquifer. A copy of the well construction log is provided in Appendix D. The monitoring well was sampled for the full explosive suite, perchlorate, lead and inorganic ions on October 9, 2008. There were no detections of explosives, perchlorate, or lead. The analytical results are provided in Tables 9-3, 9-4, 9-5, and 9-6, respectively.

9.5.6. Conclusions and Further Action

The analytical results for groundwater and surface water samples collected from MCB Camp Lejeune have been compared to groundwater and surface water modeling results. The groundwater and surface water screening-level modeling predicted the possibility of explosives in the groundwater and surface water; however, explosives were not detected in the groundwater or surface water samples collected in the areas of the G-10 and K-2 Impact Areas. The difference between the sample results and the screening-level modeling predictions are attributed to the conservative parameters used in the surface water and groundwater models. The groundwater screening-level modeling did not indicate the possibility of perchlorate reaching the water table at the G-10 or K-2 Impact Areas; however, perchlorate detections were identified in the groundwater samples collected from two monitoring wells located around the G-10 Impact Area and from two monitoring wells located around the K-2 Impact Area. These detected concentrations of perchlorate were below the RMUS drinking water screening value of 15 µg/L. This difference between the sample results and the estimated modeling-predicted concentration most likely could be attributed to inaccuracy in obtained expenditure data and subsequent underestimation of potential perchlorate loading at these locations. The REVA field sampling results for MCB Camp Lejeune indicate that perchlorate and lead were detected more frequently than explosives at the locations sampled. No detections of lead or perchlorate exceeded DoD RMUS screening values for the identified receptors.

The field sampling effort was a continuation of the baseline assessment but was not intended to be a direct confirmation of the modeling results. Nevertheless, this REVA sampling provides a general confirmation of modeling results, which were based on conservative assumptions. Although modeling results reflect concentrations over an average year, the conditions prior to field sampling may not be reflective of average conditions. Sampling results may be considered a conservative snapshot of off-range MC migration at the time they were collected.

Based on the assessment results presented in this report, no immediate environmental concern of MC migration to off-range areas was identified; however, further actions may be evaluated to continue to mitigate the possibility of MC migration from operational ranges at MCB Camp Lejeune to ensure future range sustainability.

10. References

AH Environmental, Inc. 2002. *Wellhead Protection Plan-2002 Update*.

Baker Environmental, Inc. 1994. *Draft Evaluation of Metals in Groundwater*, Marine Corps Base Camp Lejeune, North Carolina.

------. 1995. *Final Record of Decision, Operable Unit No. 7, Sites 1, 28, and 30*, Marine Corps Base Camp Lejeune, North Carolina.

------. 1996a. *Final Remedial Investigation Report Operable Unit 14 (Site 69)*. Marine Corps Base, Camp Lejeune, North Carolina.

------. 1996b. *Final RI Report OU No. 13*, MCB Camp Lejeune, North Carolina.

------. 1997a. *Basewide remedial assessment groundwater study (BRAGS)*.

------. 1997b. *Final Record of Decision, Operable Unit No. 13 (Site 63)*, MCB Camp Lejeune, North Carolina.

------. 2001. *FY 2002 Site Management Plan*.

------. 2002. *Site 93 Additional Plume Characterization Letter Report for Site 93*, Marine Corps Base Camp Lejeune, Jacksonville, North Carolina.

Brady, N.C. 1984. *The Nature and Properties of Soil*. Ninth Edition. New York, New York: MacMillan Publishing Company.

Cardinell, A.P., Berg, S.A., and Lloyd, O.B., Jr. 1993. *Hydrogeologic Framework of U.S. Marine Corps Base at Camp Lejeune, North Carolina*. U.S. Geological Survey Water Resources Investigation Report 93.

Defense Ammunition Center. 2005. Munitions Items Disposition Action System. URL not for public distribution.

Department of Defense (DoD). 2004. Department of Defense Directive 4715.11 *Environmental and Explosives Safety Management on Operational Ranges within the United States*.

------. 2005. Department of Defense (DoD) Instruction 4715.14 *Operational Range Assessments*.

------. 2007. *DoD Perchlorate Handbook. Revision 1*. Prepared by the Department of Defense Environmental Data Quality Workgroup.

Driscoll, Fletcher G. 1986. *Groundwater and Wells*.

Environmental Science and Engineering, Inc. 1998. *Characterization Step Report for Hadnot Point Industrial Area.*

EPA. See United States Environmental Protection Agency.

Geophex, Ltd. 1993a. *Wellhead Management Program*. p 91-36.

------. 1993b. *Well Rehabilitation Plan*. p 91-11.

------. 1994. *Groundwater Resource Evaluation at Marine Corps Air Station, New River*. p 93-09.

Harden, S.L, S.S. Howe, S. Terziotti. 2004. *Direction of Ground-water Flow in the Surficial Aquifer in the Vicinity of Impact Areas G-10 and K-2, Marine Corps Base Camp Lejeune, North Carolina.* U.S. Geological Survey Scientific Investigation Report 2004-5270.

Harned, D.A., O.B. Lloyd, Jr., and M.W. Treece, Jr. 1989. *Assessment of Hydrologic and Hydrogeologic Data at Camp Lejeune Marine Corps Base, North Carolina*. U.S. Geological Survey Water Resources Investigations Report 89-4096.

Headquarters Marine Corps (HQMC). 2006. *Final REVA User's Manual*.

Integrated Natural Resources Management Plan (2002-2006), Marine Corps Base Camp Lejeune, Onslow County, North Carolina. November 2001.

Malcolm Pirnie, Inc., 2008. *Final Draft Sampling and Analysis Plan (Field Sampling Plan /Quality Assurance Project Plan) for the Range Environmental Vulnerability Assessment for Areas Adjacent to the G-10 and K-2 Impact Areas at MCB Camp Lejeune*.

Marine Corps Base (MCB) Camp Lejeune. 2003. *Environmental Handbook For Trainers.*

McCuen, R.H. 1989. *Hydrologic Analysis and Design*.

------. 1998. *Hydrologic Analysis and Design*. Prentice Hall: Saddle River, N.J.

Meylan, W.M. and P.H. Howard. 1995. Atom/fragment contribution method for estimating octanol-water partition coefficients. *J. Pharm. Sci.* 84:83-92.

NRCS. See United States Department of Agriculture Natural Resources Conservation Service.

Ontario Ministry of Agriculture Food and Rural Affairs. 2000. Universal Soil Loss Equation (USLE) Factsheet. http://www.omafra.gov.on.ca/english/engineer/facts/00-001.htm.

ORDDATA II (Enhanced International Deminer's Guide to UXO Identification, Recovery and Disposal; Version 1.0, 1999)

Triangle Environmental, Inc. 1999. *Wellhead Protection Plan Update.*

United States Army Corps of Engineers, St. Louis District. 2000a. *Archives Search Report, Marine Corps Base Camp Lejeune, Onslow County, North Carolina.*

------. 2000b. *Range Identification and Preliminary Range Assessment, Marine Corps Base Camp Lejeune, Onslow County, North Carolina.*

United States Army Technical Center for Explosives. 2000. *Safety Report of Finding for Study of Ammunition Dud and Low-order Detonation Rates*.

------. 2002. *Safety Report of Finding for Study of Ammunition Dud and Low-Order Detonation Rates.*

United States Department of Agriculture Natural Resources Conservation Service (NRCS). 1994. Web Soil Survey. http://websoilsurvey.nrcs.usda.gov/.

United States Department of Agriculture Soil Conservation Service (USDA SCS). 1992. *Soil Survey of Onslow County, North Carolina*.

United States Environmental Protection Agency (EPA). 1999. USEPA Contract Laboratory Program National Functional Guidelines for Organic Data Review. EPA540/R-99/008. http://www.epa.gov/superfund/programs/clp/guidance.htm.

------. 2001. Region 4 Freshwater Ecological Screening Values. http://www.epa.gov/region4/waste/ots/ecolbul.htm.

------. 2004. USEPA Contract Laboratory Program National Functional Guidelines for Inorganic Data Review. EPA540-R-04-004. http://www.epa.gov/superfund/programs/clp/guidance.htm.

------. 2007. Region 3 Ecological Freshwater Benchmarks. http://www.epa.gov/reg3hscd/risk/eco/btag/sbv/fw/screenbench.html.

------. 2008. Federal Freshwater Ambient Water Quality Criteria. http://www.epa.gov/waterscience/criteria/wqtable/index.html.

Walsh, M.E., T.F. Jenkins, and P.G. Thorne. 1995. Laboratory and field analytical methods for explosives residues in soil. *Proceedings of the Symposium on Alternatives to Incineration for Disposal of Chemical Munitions and Energetics*, Vol. 2, p. 17.