Water Range Sustainability Environmental Program Assessment

Potomac River Test Range Complex

Naval Surface Warfare Center Dahlgren Division

Dahlgren, Virginia

May 2013

Water Range Sustainability Environmental Program Assessment

Potomac River Test Range

Naval Surface Warfare Center
Dahlgren Division

Dahlgren, Virginia

May 2013

THIS PAGE INTENTIONALLY LEFT BLANK

EXECUTIVE SUMMARY

Naval Surface Warfare Center, Dahlgren Division (NSWCDD) has prepared this water range sustainability environmental program assessment (WRSEPA) for the Potomac River Test Range (PRTR) water range in response to a requirement and process developed by the Chief of Naval Operations, Environmental Readiness Division (N45). The assessment has been prepared pursuant to the *Navy Policy for Conducting Operational Water Range Sustainability Environmental Program Assessments* (United States Navy [US Navy], 2008).

ES.1 WRSEPA Policy and Process

The WRSEPA policy (US Navy, 2008) establishes procedures to:

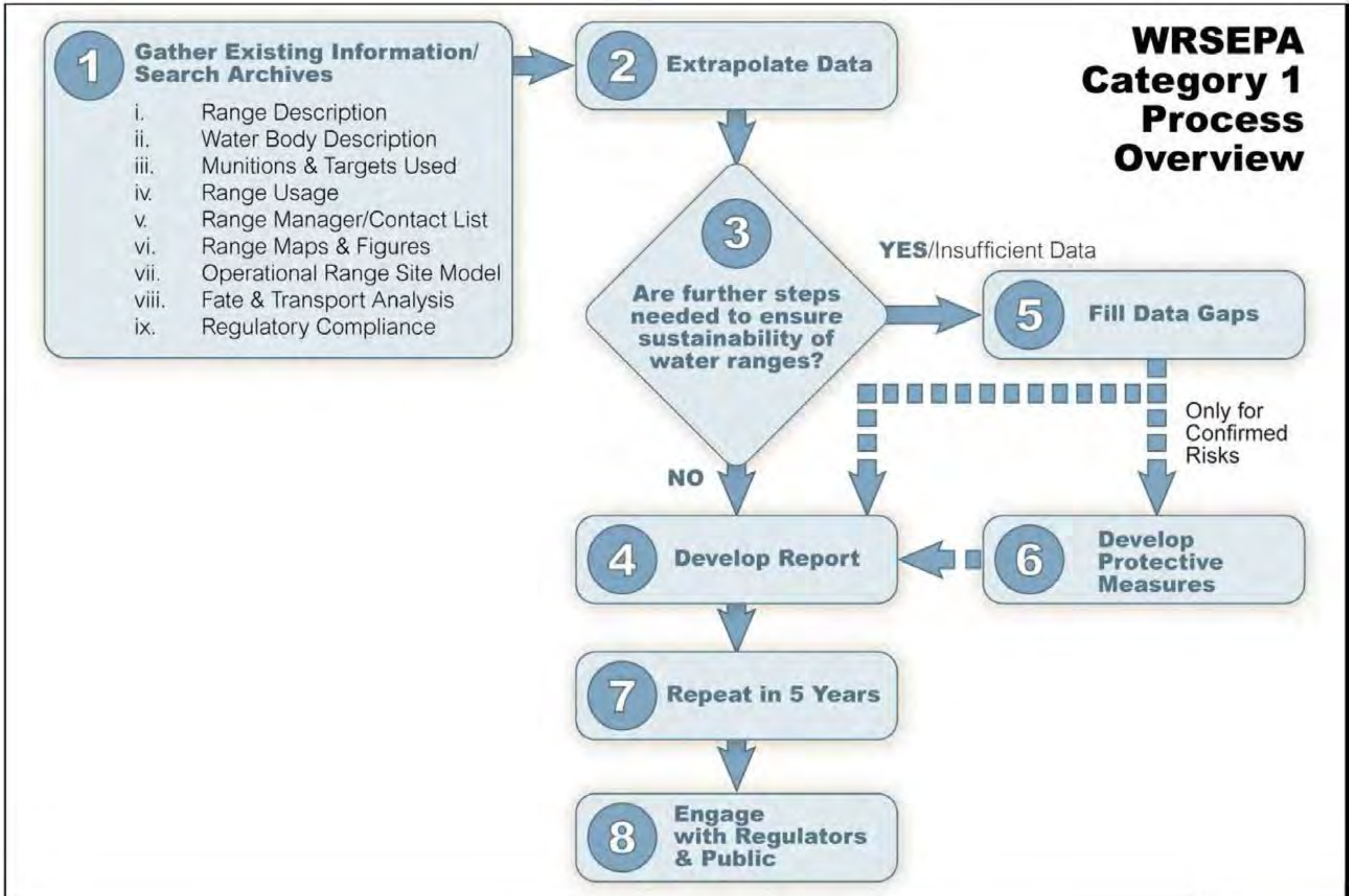
- Ensure the long-term sustainability of water ranges and operating areas.
- Determine whether there has been a release or a substantial threat of a release of munitions constituents (MCs) of potential concern (MCOPCs) and/or military expended material constituents (MEMCs) from an operational range to an off-range area.
- Determine whether the release or substantial threat of a release of MCOPCs and/or MEMCs from an operational range to an off-range area poses an unacceptable risk to human health or the environment.
- Assess the potential environmental impacts of the use of military munitions on operational ranges.
- Implement, where appropriate, protective measures for Navy operational ranges that are primarily in water.

WRSEPA policy must be executed for all Category 1 and Category 2 ranges. The PRTR at NSWCDD is a Category 1 range because it is within US territory. Category 2 ranges (and operating areas) are outside of US territory.

The WRSEPA process was developed to ensure long-term sustainability using a phased approach. Each step of the process is performed sequentially, based on the findings of the previous step, as shown in Figure ES-1 (WRSEPA Category 1 Process Overview). Steps 1 to 4, which include the process from the gathering of existing information to the development of a report, are covered in this document.

ES.2 Naval Surface Warfare Center, Dahlgren Division/ Potomac River Test Range

NSWCDD's mission is to provide research, development, test and evaluation (RDT&E), analysis, systems engineering, integration and certification of complex naval warfare systems related to surface warfare, strategic systems, combat and weapons systems associated with surface warfare. NSWCDD also provides system integration and certification for weapons,



Source: US Navy, 2008

Figure ES-1

combat systems and warfare systems. NSWCDD is a tenant on Naval Support Facility (NSF) Dahlgren, on the western shore of the Potomac River in King George County, Virginia.

The Navy established an over-water proving ground for naval ordnance at Dahlgren in 1918. NSWCDD's PRTR (Figure ES-2, Potomac River Test Range Complex) is the nation's largest fully-instrumented, over-water gun-firing range. Set in a shallow-water coastal, or littoral, environment bounded by land, the PRTR replicates the littoral areas of the world where almost 45 percent of the world's population lives and in which the Navy operates with increasing frequency.

The guns positioned to fire down the PRTR include one of every type of gun currently used by the Navy, as well as models that represent a new generation of guns. Nearly every ammunition lot and gun barrel that is fitted on a Navy ship is tested by NSWCDD to ensure performance is as specified. The Navy at Dahlgren has been testing and performing RDT&E on naval ordnance as part of its mission since 1918.

The PRTR is 51 nautical miles (NM) (95 kilometers [km]) long, covers 169 square NM (sq NM), (580 square km [sq km]) and is divided into areas designated on nautical charts as the Upper, Middle, and Lower Danger Zones (UDZ, MDZ, and LDZ, respectively). The MDZ receives the heaviest use; it is 2.6 NM (4.8 km) wide, 15.4 NM (28.5 km) long, and covers 38.8 sq NM (133 sq km). Danger zones are controlled during test events by NSWCDD range boats and staff observers stationed along the Potomac River. Live fire can be tested up to 40,000 yards (36,576 meters or approximately 20 NM [37 km]) down range.

The safety of civilian, military, and contractor personnel in addition to that of visitors and the general public is paramount to NSWCDD. Safety is an integral part of all range operations and is emphasized in all aspects of NSWCDD's mission and decision-making processes.

Potomac River Test Range Complex

Potomac River Test Range (PRTR) Complex

Naval Support Facility (NSF) Dahlgren

7 0 7 Miles

11 0 11 Kilometers

Source: NSWCDD GIS (2008 - 2011); Danger Zones defined in 33 CFR § 334.230.

Figure ES-2

ES.3 Physical Environment

The Potomac River flows over 333 NM (616 km) from Fairfax Stone, West Virginia to the river mouth at Point Lookout, Maryland. The length of the tidal reach of the river is 99 NM (183 km). The Potomac River flows into the Chesapeake Bay about 43 NM (80 km) south of NSF Dahlgren. Within the PRTR portion of the Potomac River, the river ranges in width from approximately 1.5 NM (2.7 km) at a narrow section within the PRTR UDZ to more than 9.7 NM (18 km) at the river's mouth.

The PRTR portion of the Potomac River is a tidal estuary with strong tidal currents, moderate vertical stratification, and considerable longitudinal variation in salinity. Within the PRTR, the mean salinity of the Potomac ranges from approximately 4 to 8 parts per thousand (ppt) in the vicinity of NSF Dahlgren, between the UDZ and the MDZ, to approximately 11 to 16 ppt around the downstream end of the LDZ, near the mouth of the Potomac River. The PRTR portion of the Potomac River has a semidiurnal tide period with the tidal range extending up to 2.2 feet (ft) (0.7 meter [m]) at NSF Dahlgren.

Because of the constriction in the Potomac River channel above NSF Dahlgren, in the area of the Governor Harry W. Nice Memorial Bridge Station near Route 301 (Figure ES-2), current velocities there are higher than downstream. In the vicinity of the MDZ of the PRTR, the river makes a bend to the south and widens considerably. As this occurs, the velocity decreases drastically, causing this part of the river to have a high potential for the rapid deposition of sediment.

Human activities (e.g., industry, farming, etc.) in the Potomac River watershed have affected sedimentation rates and sediment quality in the Potomac estuary, including the area of the PRTR. Analyses of sediments indicate concentrations of trace metals and nutrient content related to human activities.

ES.4 Munitions Usage on the PRTR

Many types of ordnance have been tested on the PRTR since 1918, including small- and large-caliber guns up to 16 inches (16"), aircraft bombs and guns (ended in 1957), rockets (ended in the 1970s), mortars, grenades, mines, depth charges, and torpedoes (underwater explosives have not been tested since the 1970s). Much of the information on historical ordnance use is based on anecdotal accounts and the quantities of many of the types of munitions used are not readily available. Therefore, the quantitative analysis in this WRSEPA focuses on munitions, defined as the gun rounds recorded in the log books, for which detailed information is available. The records available pertain to rounds greater than 20 millimeters (mm), which are the focus of this report. Testing and improving ordnance reliability, safety, lethality, accuracy, fuzing, distance for small-, medium-, and large-caliber guns up to 8", and assessing explosive compounds will remain a primary part of NSWCDD's mission into the future because these weapons remain core components of Navy ships.

Distribution of Large-caliber Projectiles in the Middle Danger Zone

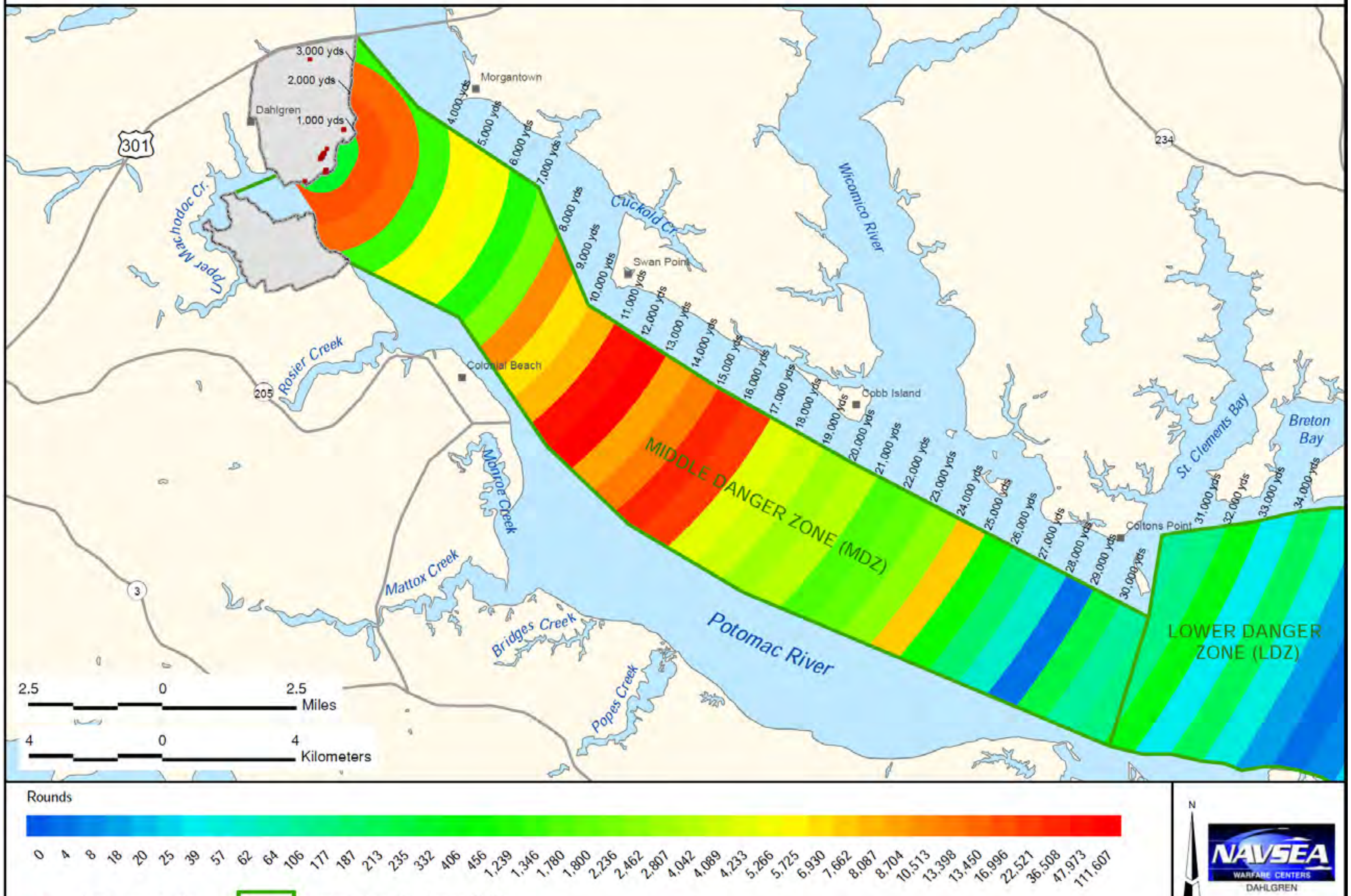


Figure ES-3

Records of historical and current munitions usage were analyzed to determine:

- Testing years
- Number of inert rounds
- Number of live (or high explosive [HE]) rounds
- Total number of rounds fired
- Gun type
- Range or distance fired
- MCs contained in each round by weight

These data were used to estimate the quantities of MCs associated with ordnance fired into the PRTR and their locations.

From 1918 to 2007, NSWCDD tested 291,971 inert rounds and 51,844 live rounds on the PRTR, for a total of 343,815 rounds. Inert rounds accounted for 84.9 percent of the total, live rounds for 15.1 percent. Over the 90 years considered, an average of 3,820 rounds – comprising an estimated 3,244 inert rounds and 576 live rounds – were tested each year. Most of the rounds (99.7 percent) were fired into the MDZ, with a small number (0.3 percent) fired in the LDZ.

The area between the Gun Firing Line (0 yard [yd]) and 25,000 yds in the MDZ (0 to 22,860 m) is estimated to account for 341,706 rounds, or 99.4 percent of all munitions tested on the PRTR (Figure ES-3, Distribution of Large-caliber Projectiles in the Middle Danger Zone). This area was termed the "diffuse zone." Within this area, the zone from 11,000 to 13,000 yds (10,058 to 11,887 m) – termed the "dense zone" – has the highest density of rounds. The dense zone has a surface area of approximately 2.29 sq NM (7.86 sq km) and is estimated to contain approximately 159,580 rounds, yielding a density of 69,686 rounds per sq NM (20,303 rounds per sq km).

The available firing activity data from 1918 to the present time were sorted, compiled, and cross-referenced with information on MCs that was obtained from the Munitions Items Disposition Action System (MIDAS) database. The MIDAS database contains detailed technical data for a wide range of munitions, including the weight and material specifications for individual munitions. These specifications were entered into the WRSEPA database and were used to determine the constituents associated with each munition type.

Separate reports were obtained for all live and inert rounds. Reports were selected for only the projectile portion of the round, excluding the cartridge (when appropriate), as the cartridge casing usually stays in the vicinity of the gun and does not enter the water range. The total weight for each MC associated with each munition type was calculated by multiplying the number of times a munition type was tested by the weight of the MC in each munition of that type. Summing those data across munition types provided the total amount of each constituent associated with live and inert testing.

Based on the MIDAS database, 110 MCs are associated with the 57 different munitions types tested on the PRTR. A total of approximately 33 million pounds (lbs) (15 million kilograms [kg]) of constituents are associated with the 343,815 total rounds fired into the PRTR.

The MCs comprising the majority of the total weight are metals in the projectile casing that is common to both live and inert rounds. The predominant constituent is iron, contributing 31 million lbs (14 million kg) or 93.2 percent of the total constituent weight. The second largest contributor is copper at 958,087 lbs (434,580 kg), followed by manganese at 463,239 lbs (197,874 kg); these two metals contribute 2.9 percent and 1.4 percent of the total amount of constituent weight, respectively. Combined, iron, copper, and manganese account for 97.5 percent of the total constituent weight of munitions over the 90 years of testing considered.

Ammonium picrate (also known as Explosive D), cyclotrimethylenetrinitramine (commonly referred to as Royal Demolition eXplosive [RDX]), and 2,4,6-trinitrotoluene (TNT) are common explosives and are among the top ten constituents by weight associated with live munitions tested at the PRTR.

ES.5 Operational Range Site Model (ORSM)

As part of the first step of the WRSEPA process (see Figure ES-1), an operational range site model (ORSM) was developed. The ORSM provides an overview of the operational usage of the PRTR, the release of constituents, potential migration and exposure pathways, and the links among potential sources of MCs and human and ecological receptors. The ORSM provides a framework to estimate potential human and ecological exposures to MCs, inclusive of military and non-military uses (e.g., commercial boating, recreation, industry).

The ORSM is used to determine if people may be exposed to MCs through the consumption of locally-caught fish and shellfish obtained through recreational fishing or by commercial purchase. Exposure may also occur via direct contact with surface water and sediments at recreational locations like Colonial Beach, which are used for swimming, boating, water-skiing, and other aquatic sports.

Aquatic plants and animals may be exposed to MCs in the water column, sediments, and in prey. Wildlife feeding on fish and other aquatic life in the Potomac River may also be exposed to MCs.

ES.6 Fate and Transport of Munitions Constituents

A subset of MCs – the MCOPCs – comprising the majority of the total mass fired and having the greatest potential for toxic effects on human health and the environment were selected for modeling and evaluation in the ecological and human health screening risk assessments. Based on the overall mass introduced into the PRTR and potential toxicity, the following seven metals were selected as MCOPCs: cadmium, chromium, copper, lead, manganese, nickel, and zinc. All of these metals were in the top ten contributors of metals to the PRTR by weight.

The top seven constituents – ammonium picrate, RDX, phosphorus, TNT, ethylbenzene, wax, and tetryl – comprise more than 99.9 percent of the weight of all organics/explosives. RDX, TNT, and tetryl – and also HMX (11th by weight) are listed as MCOPCs in *US Navy Range Sustainability Environmental Program Assessment Policy Implementation Manual, Revision 1* (US Navy, 2006a) and were selected as MCOPCs. The top-ranking explosive by weight, ammonium picrate, is a relatively insensitive[1] substance that was used widely during the First World War. Due to the large mass of ammonium picrate used, it was also selected as an MCOPC.

The seven inorganic and five organic MCOPCs, summarized in Table ES-1, were used for fate and transport modeling and for the screening-level ecological and human health risk assessments. The first step of the fate and transport modeling entailed determining the percentage of inert rounds, live rounds, and duds of the total number of munitions used from NSWCDD firing records. Dud rates from the literature were used when site-specific information was not available. Inert rounds and duds were assumed to be buried in Potomac River sediments based on the force at which they are propelled and hit the bottom and the results of retrieving canisters fired from guns. Live rounds were divided into high-order and low-order detonations, which determined the percentage of explosives expended during detonation, prior to the round entering the water. Detonation was assumed to shatter the explosive casing into small pieces and fragments that settle on surface sediments.

Table ES-1
MCOPCs Selected for Further Evaluation

Metals	Explosives
Cadmium	Ammonium picrate
Chromium	HMX
Copper	RDX
Lead	Tetryl
Manganese	TNT
Nickel	
Zinc	

After munitions enter water or sediments, the environmental fate of explosives and metal constituents varies depending on environmental factors, geochemical conditions, and attenuation mechanisms that redistribute the constituents. Adsorption, the adhesion of a chemical species onto the surface of particles, was the key process evaluated for explosives. Explosive concentrations were distributed between river water and sediment using an adsorption coefficient. For metals, a geochemical equilibrium model (PHREEQC) developed by the US Geological Survey (USGS) was used; the model distributes metals to different phases (dissolved, precipitated, or adsorbed) based on reactions and governing equilibrium constants. The results of the modeling were provided as annual concentrations, which were converted to daily input to the water column and monthly input to the sediments.

The geochemical modeling predicted the following concentrations of explosives from munitions usage in the part of the river where munitions are most concentrated (dense zone): sediment concentrations of 4 parts per billion (ppb) or less; water concentrations of 20 ppb or less. Comparison of metals from modeling and upstream samples indicates that contributions due to munitions are orders of magnitude less than concentrations already present in the Potomac River from natural and manmade sources. These results indicate that munitions usage at the PRTR have not contributed significant concentrations of metals to river water and sediments.

[1] The sensitivity of an explosive refers to the ease with which it can be ignited or detonated.

The Potomac River is a dynamic system that is influenced by freshwater flow from within its watershed and tidal flow from the Chesapeake Bay and the Atlantic Ocean. The MDZ is in a tidal reach of the river. Therefore, a hydrodynamic model was applied to the results of the geochemical modeling to determine the potential effects that hydrodynamic factors would have on MCOPCs. The approach used was to model extreme flow and tidal conditions within the Potomac River, evaluating low- and high-energy scenarios for dilution energy, as well as the fate and transport potential for both dissolved (in water) and sediment-bound constituents.

Based on the modeling, the freshwater flow from the Potomac River makes up only a small percentage of the total flow near the PRTR, with the greatest amount of flow being the result of tidal forces. Thus, at this location, tidal forces have a much stronger impact on flow than freshwater discharges.

For concentrations of MCOPCs in the water column, mass-loading simulations indicated that there will be hydrodynamic dilution rates of about 71 percent in the dense and diffuse zones within the first 24 hours of release.

With regard to concentrations of MCOPCs in sediments, the Potomac River experiences deposition (sediment particles suspended in the water are deposited on the river floor rather than being moved downriver or picked up by the river's flow) throughout the modeled area. The entire area is considered depositional – no scouring conditions were observed in any hydraulic event modeled. The greatest depths of deposition occur near, and directly downstream of, NSF Dahlgren, where the velocities in the mid-channel part of the Potomac River tend to be lower than the velocities upstream of the PRTR.

The MDZ diffuse zone was shown to be depositional for all hydraulic events modeled and all river bed scenarios modeled. This region is ideal for deposition of sediments due to its low velocity, which encourages rapid particle-settling at the PRTR and downstream. If additional sediments that enter the Potomac River upstream (e.g., during storm events) are considered, the deposition rate is greater and it can be considered that a "capping" effect of sediments in the river occurs at this location.

Based on the hydrodynamic modeling, both water and sediment MCOPC concentrations are projected to be significantly lower than predicted by geochemical modeling. Water column concentrations will be rapidly diluted, while sediment concentrations will be reduced via deposition of sediments from upstream. However, to provide a conservative estimate of MCOPC concentrations for use in the range-specific ecological and human health screening-level risk assessments, the higher MCOPC concentrations predicted from the geochemical modeling were used.

ES.7 Screening-level Ecological Risk Assessment

A range-specific screening-level ecological risk assessment was performed to evaluate the exposure of ecological receptors in the Potomac River and the surrounding area to MCOPCs in the water column and sediments. Ecological receptors evaluated included aquatic life (e.g., invertebrates, plants), fish, and wildlife. Exposure may occur directly via water and/or sediment or indirectly via consumption of contaminated food.

The predicted concentrations of MCOPCs in water and sediments based on geochemical modeling were compared to the federal and state criteria and guidelines for aquatic organisms. The areas of the MDZ with the highest predicted concentrations – the dense zone and the diffuse zone – were used for the comparisons. Both freshwater and saltwater criteria were considered, when possible. All concentrations of metal and explosive MCOPCs were well below the relevant criteria and guidelines. Most of these levels were also many orders of magnitude below levels at which adverse effects are predicted to occur.

As sediment criteria and guidelines are generally based on benthic community (organisms that live on the river bottom) metrics and toxicity studies, an additional comparison of modeled fish-tissue concentrations based on bioconcentration factors (BCFs) from the water column was performed for metals. There is a low level of confidence in all metal screening values, but these values were used to provide a screening comparison for fish. All calculated metal concentrations in fish were orders of magnitude below concentrations potentially resulting in adverse effects. A comparison of explosives in fish tissue was not performed due to the lack of tissue data associated with toxicity. However, the predicted concentrations of explosives in fish tissue are extremely low (below parts per trillion) – much lower than the modeled concentrations of explosives in water and sediment that were themselves well below screening values – indicating that explosives in the PRTR are unlikely to adversely affect fish.

Exposure of avian and mammalian wildlife that use the Potomac River for food and shelter was estimated using a food-web model. The concentrations of MCOPCs that wildlife would be exposed to through food (fish), water, and sediment pathways were estimated using conservative screening assumptions. Target levels were selected based on concentrations of MCOPCs that were associated with no adverse effects in avian and mammalian studies – the no-observed-adverse-effect level (NOAEL). The modeled concentrations were orders of magnitude below these target levels. Uncertainties associated with the modeling were biased to be conservative (protective). Thus, the food-web screening indicates that MCOPCs from RDT&E activities at the PRTR pose negligible risk to wildlife in the area.

The range-specific screening-level ecological risk assessment showed that concentrations of the MCOPCs in Potomac River water and sediments, both in the dense and diffuse zones, are well below concentrations that may cause adverse effects to aquatic organisms living in the Potomac River and to wildlife using the river for feeding, shelter, and/or reproduction. These results indicate that even if the use of munitions increased more than a hundredfold – which is not feasible given that existing operating hours already use 36 percent of all available operating hours within a year (i.e., typically from 8 am to 5 pm, Monday through Friday) – the MCOPCs entering the PRTR would not pose unacceptable risks to aquatic life or wildlife, although other issues associated with testing activities, such as noise, could be a cause for concern. Based on this screening-level analysis, further evaluation of ecological risk is not required and no protective measures are warranted.

ES.8 Screening-level Human Health Risk Assessment

A range-specific screening-level human health risk assessment was performed to evaluate the potential exposure of people to MCOPCs. Within the PRTR, complete exposure pathways exist for use of the Potomac River by local residents for recreational activities. Evaluation of exposure based on current land use is also considered applicable for future exposures.

The following exposure pathways were evaluated assuming no institutional controls or other restrictions:

- Ingestion of fish from the PRTR.
- Incidental ingestion of and dermal contact with surface water during recreational uses (e.g., wading, boating, or swimming) in the PRTR.
- Incidental ingestion of and dermal contact with surface sediments during recreational uses (e.g., wading, boating, or swimming) in the PRTR.

The modeled concentrations of constituents in fish were compared to US Environmental Protection Agency (USEPA) fish-ingestion screening levels. No exceedance of these levels was identified and ratios of modeled concentrations were orders of magnitude below the target ratio of one (i.e., below the screening level concentration).

For the pathway of incidental ingestion of, and dermal contact with, surface water, the modeled concentrations of MCOPCs in the water were compared to USEPA tap water screening levels (no generic surface water concentrations are available for human health screening). The calculated ratios were well below the target ratio of one; projected concentrations are hundreds of times to more than a billion times lower than concentrations that could result in adverse effects.

The modeled concentrations of constituents in river sediments were compared to USEPA residential-soil screening levels (no generic sediment concentrations are available for human health screening). No exceedances of the residential-soil screening levels were identified; the ratios of modeled concentrations to the screening levels were orders of magnitude below the target ratio of one. These results indicate that even if munitions RDT&E activities increased more than a hundred times – which is not feasible given that existing operating hours already use about a third of all available operating hours within a year (i.e., typically from 8 am to 5 pm, Monday through Friday) – the MCOPCs entering the PRTR would not pose unacceptable risks to human health, although other issues associated with testing activities, such as noise, could be a cause for concern.

Therefore, based on the analysis of recreational exposure scenarios, exposure to RDT&E activities-related MCOPCs in the PRTR through the ingestion of fish and/or incidental ingestion of surface water and/or sediments does not pose unacceptable risks. No additional analyses are necessary, nor are protective measures warranted.

ES.9 Conclusions

The overall objective of the WRSEPA policy is to ensure range sustainability while protecting human health and the environment. For Category 1 ranges, such as the PRTR, WRSEPA policy requires a determination of whether MCs and MEMCs create an unacceptable risk to human health and/or the environment.

As there is potential at the PRTR for interaction between the munitions fired into the Potomac River and human and ecological receptors, range-specific screening-level risk assessments

(RSSRAs) were performed. A subset of MCs was selected as MCOPCs, based on their total mass (cumulative over the 90 years of range activities considered), toxicity of constituents, and US Navy guidance.

The ecological and human health RSSRAs employed conservative (stringent, protective) assumptions to evaluate existing conditions and determine whether additional analysis is necessary and protective measures warranted, or whether the range poses acceptable risks, in which case no further analysis is needed. As an example of the conservative assumptions used, the analysis did not apply any dilution or burial factors for water or sediment concentrations. The RSSRAs compared modeled concentrations of MCOPCs in water, sediment, and fish tissues to risk-based screening concentrations. The results indicate that the levels of MCOPCs from munitions testing in the PRTR are orders of magnitude – hundreds to billions of times – below concentrations that could cause adverse effects to human health or the environment. Therefore, no further analyses are required at this time. Based on WRSEPA policy, a re-evaluation of the PRTR is required at least every five years from the completion of this WRSEPA or if significant changes (e.g., changes in range operations, site conditions, applicable statues, regulations, DoD issuances, or other policies) occur that affect the determination made during this assessment (US Navy, 2008).

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

Chapter/Section **Page**

LIST OF TABLES

Table **Page**

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

List of Acronyms and Abbreviations

2D	Two-Dimensional
AA	Anti-Aircraft
ac	Acre(s)
AET	Apparent Effects Threshold
ARARs	Applicable or Relevant and Appropriate Requirements
ARCS	Assessment and Remediation of Contaminated Sediments
ATSDR	Agency for Toxic Substances and Disease Registry
AWQC	Ambient Water Quality Criteria
BCF	Bioconcentration Factor
BMP	Best Management Practice
BSAF	Biota-Sediment Accumulation Factor
bw	body weight
CFR	Code of Federal Regulations
cm	centimeter(s)
CCC	Criteria Continuous Concentration
CMC	Criteria Maximum Concentration
cms	cubic meters per second
COPC	Constituent of Potential Concern
CSF	Cancer Slope Factor
DO	Dissolved Oxygen
DoD	Department of Defense
DoN	Department of the Navy
dw	dry weight
EEA	Explosive Experimental Area (Pumpkin Neck)
EED	Estimated Environmental Dose
EER	Estimated Exposure Rate
Eh	reduction potential (or oxidation-reduction potential)
EIS	Environmental Impact Statement
EM	Electromagnetic
ER-L	Effects Range-Low
ER-M	Effects Range-Median

FCM	Food Chain Multiplier
FI	Food Ingestion
FIR	Food Ingestion Rate
f_{oc}	fraction of organic carbon
ft	foot/feet
FW	Freshwater
g	gram(s)
g/kg	grams per kilogram
HE	High Explosive
HHRA	Human Health Risk Assessment
HI	Hazard Index
HMX	High-Melting eXplosive (octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine)
HQ	Hazard Quotient
K_d	Adsorption Coefficient
K_{oc}	Adsorption factor for organic carbon specific to the adsorbed constituent
kg	kilogram(s)
$kg/m^2/s$	kilograms per square meter per second.
kg/m^3	kilograms per cubic meter
km	kilometer(s)
l	liter(s)
lb(s)	pound(s)
LC50	Lethal Concentration 50
LDZ	Lower Danger Zone
LOEC	Lowest-Observed-Effect Concentration
LOAEL	Lowest-Observed-Adverse-Effect Level
l/kg	liters per kilogram
m	meter(s)
m^2/g	square meters per gram
m^3	cubic meter(s)
MAIA	Mid-Atlantic Integrated Assessment
MC(s)	Munitions Constituent(s)
MCL	Maximum Contaminant Level
MCOPC(s)	Munitions Constituent(s) of Potential Concern
MDE	Maryland Department of the Environment
MDNR	Maryland Department of Natural Resources
MDZ	Middle Danger Zone
MEMC(s)	Military Expended Material Constituent(s)

mi	mile(s)
MIDAS	Munitions Items Disposition Action System (database)
mg(s)	milligram(s)
mg/kg	milligrams per kilogram
mg/l	milligram(s) per liter
mm	millimeter(s)
mm/s	millimeters per second
MR	Munitions Rule
mV(s)	millivolt(s)
µg(s)	microgram(s)
µg/d	micrograms per day
µg/g	micrograms per gram
NA	Not Applicable
NM	nautical miles
NOAA	National Oceanic and Atmospheric Administration
NOAEL	No-Observed-Adverse-Effect Level
NOEC	No-Observed-Effect Concentration
NSF	Naval Support Facility
NSWC	Naval Surface Warfare Center
NSWCDD	Naval Surface Warfare Center Dahlgren Division
NSWCDL	Naval Surface Warfare Center Dahlgren Laboratory
ORSM	Operational Range Site Model
pe	Eh measurement log transformed
PEL	Probable Effects Level
PEP	Propellants, Explosives, and Pyrotechnics
PHREEQC	PH (pH), RE (redox), EQ (equilibrium), C (computer program written in C)
pH	Potential of Hydrogen ion concentration
ppb	parts per billion
ppm	parts per million
ppt	parts per thousand
PRTR	Potomac River Test Range
RCRA	Resource Conservation and Recovery Act
RDT&E	Research, Development, Testing, and Evaluation
RDX	Royal Demolition eXplosive (cyclotrimethylenetrinitramine)
RfD	Reference Dose
RHA	Risk Hazard Analysis
ROC	Range Operations Center
RSEPA	Range Sustainability Environmental Program Assessment
RSSRA	Range-Specific Screening-Level Risk Assessment

SIR	Sediment Ingestion Rate
SLERA	Screening-Level Ecological Risk Assessment
SMS	Surface-Water Modeling System
SOP(s)	Standard Operating Procedure(s)
sq km(s)	square kilometer(s)
sq mi(s)	square mile(s)
sq NM(s)	square nautical mile(s)
SQuiRTs	Screening Quick Reference Tables
SW	Saltwater
TEL	Threshold Effects Level
tetryl	trinitrophenylmethylnitramine
TNT	2,4,6-trinitrotoluene
TOC	Total Organic Carbon
TRI	Toxic Release Inventory
UDZ	Upper Danger Zone
UET	Upper Effects Threshold
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UXO	Unexploded Ordnance
VA	Virginia
VDEQ	Virginia Department of Environmental Quality
VDGIF	Virginia Department of Game and Inland Fisheries
VOC	Volatile Organic Compound
WIR	Water Ingestion Rate
WRSEPA	Water Range Sustainability Environmental Program Assessment
WSE	Water Surface Elevation
WQC	Water Quality Criteria
ww	wet weight
yd(s)	yard(s)
˚C	degrees Celsius
˚F	degrees Fahrenheit

1 INTRODUCTION

Naval Surface Warfare Center, Dahlgren Division (NSWCDD) has prepared this water range sustainability environmental program assessment (WRSEPA) for the Potomac River Test Range (PRTR) water range in response to a requirement and process developed by the Chief of Naval Operations, Environmental Readiness Division (CNO 45). The assessment has been prepared pursuant to the *Navy Policy for Conducting Operational Water Range Sustainability Environmental Program Assessments* (United States Navy [US Navy], 2008).

1.1 WRSEPA Policy and Process

The WRSEPA policy establishes procedures to:

1. Ensure the long-term sustainability of water ranges and operating areas.
2. Determine whether there has been a release or a substantial threat of a release of munitions constituents (MCs) of potential concern (MCOPCs) and/or military expended material constituents (MEMCs) from an operational range to an off-range area.
3. Determine whether the release or substantial threat of a release of MCOPCs and/or MEMCs from an operational range to an off-range area poses an unacceptable risk to human health or the environment.
4. Assess the potential environmental impacts of the use of military munitions[1] on operational ranges[2].
5. Implement, where appropriate, protective measures for Navy operational ranges that are primarily in water.

WRSEPA policy must be executed for all Category 1 and Category 2 ranges. Category 1 ranges are within the baseline from which the territorial sea is measured – with the ranges encompassing the waters of bays, lakes, and rivers, etc. – and have specific or distinct operational aim or use points, typically within state waters[3]. The PRTR at NSWCDD is a Category 1 range because it is within United States territory. Category 2 ranges (and operating areas) are outside United States territory.

The WRSEPA compliance management process was developed to ensure long-term sustainability using a phased approach. Each step of the process is performed sequentially, based on the findings of

[1] United States Code, Title 10, Section 101 defines "military munitions" as all ammunition products and components produced for or used by the armed forces for national defense and security, including ammunition products or components under the control of the Department of Defense, the Coast Guard, the Department of Energy, and the National Guard.

[2] United States Code, Title 10, Section 101 defines "operational range" as a range that is under the jurisdiction, custody, or control of the Secretary of a military department and (A) is used for range activities, or (B) although not currently being used for range activities, is still considered by the Secretary to be a range and has not been put to a new use that is incompatible with range activities.

[3] "State waters" commonly refers to the region that extends 3 nautical miles (NM) (5.6 kilometers [km]) seaward from the "baseline" and is the area over which states have jurisdiction. The baseline divides the land from the ocean and is defined by the United States as the mean lower low water line along the coast (as shown on official nautical charts). The baseline is drawn across river mouths, the openings of bays, and along the outer points of complex coastlines.

the previous step, as shown in Figure 1-1, WRSEPA Category 1 Process Overview. Steps 1 to 4, which include the process from the gathering of existing information to the development of a report, are covered in this document.

1.2 Command Structure

1.2.1 Mission Command

NSWCDD is one of eight Naval Surface Warfare Center (NSWC) divisions under the Naval Sea Systems Command (NAVSEA). NSWCDD is comprised of two organizations, NSWCDD at Dahlgren, Virginia (VA) and Combat Direction Systems Activity at Dam Neck, Virginia Beach, Virginia.

1.2.2 Host Command

In October 2003, Commander, Naval Installation Command (CNIC) was commissioned to provide shore support services for Navy activities. All land and buildings on Navy bases transitioned to CNIC in six US regional commands. One of these commands, Naval District Washington, includes Naval Support Activity South Potomac (NSASP), commissioned in November 2005. Naval Support Facility Dahlgren (NSF Dahlgren) reports to NSASP. NSF Dahlgren is responsible for oversight and maintenance of all real property (land and all structures assigned and constructed on or in the land).

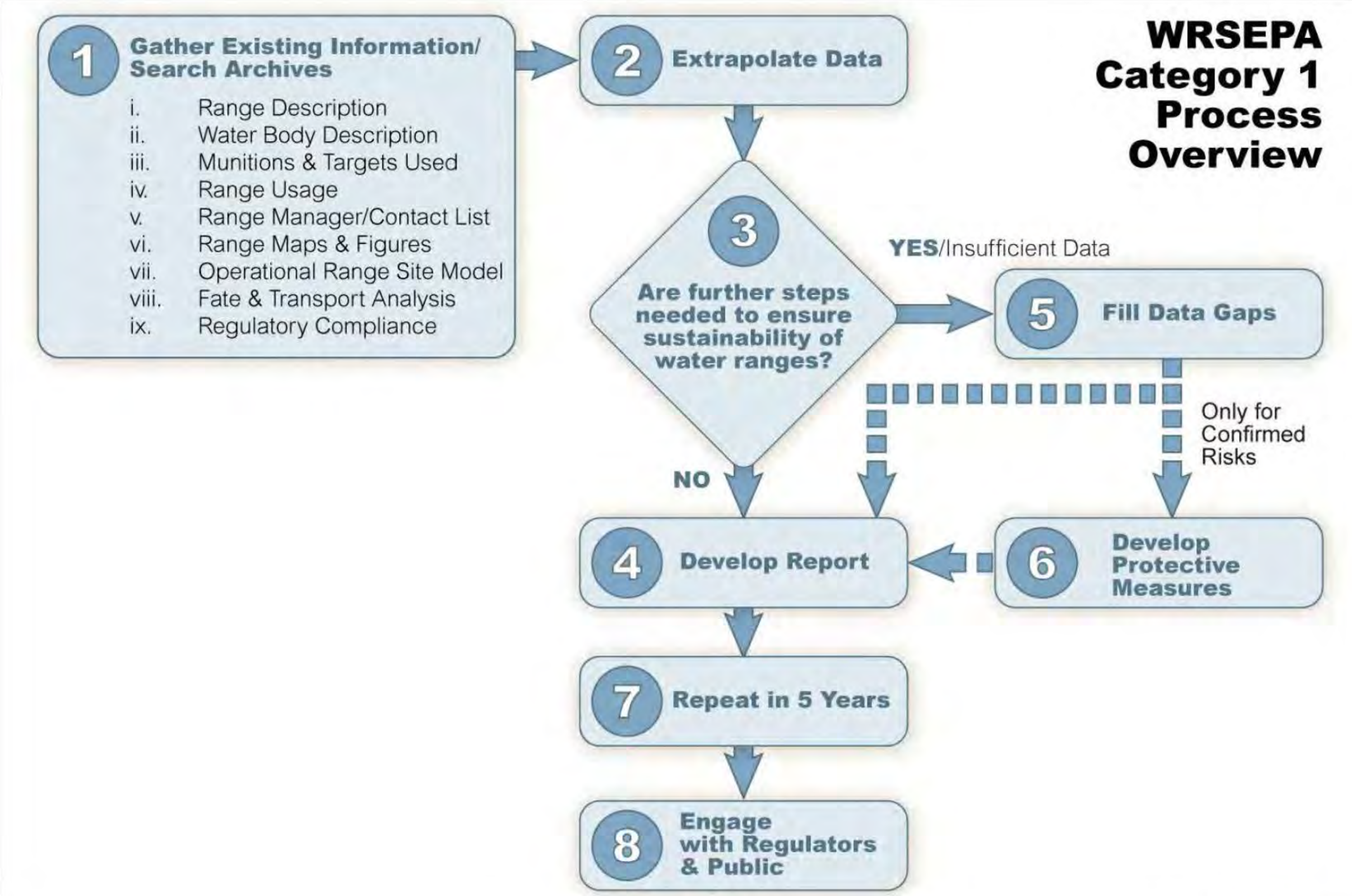
NSF Dahlgren is located on the western shore of the Potomac River in King George County, Virginia (Figure 1-2, Location of Naval Support Facility Dahlgren). NSF Dahlgren is located 25 miles (mi) (40 kilometers [km]) east of Fredericksburg, Virginia and 53 mi (85 km) south of Washington, DC.

1.2.3 Tenant Commands

NSWCDD is NSF Dahlgren's primary tenant. Other tenants on NSF Dahlgren include: the Joint Warfare Analysis Center; the Aegis Training and Readiness Center/Center for Surface Combat Systems; Aegis Ballistic Missile Defense; the Navy Air and Missile Defense Command; and the 20th Space Control Squadron Detachment 1.

1.3 Naval Surface Warfare Center, Dahlgren Division's Range Activities

NSWCDD's mission is to provide research, development, test and evaluation (RDT&E), analysis, systems engineering, integration and certification of complex naval warfare systems related to surface warfare, strategic systems, combat and weapons systems associated with surface warfare. NSWCDD also provides system integration and certification for weapons, combat systems and warfare systems.



Source: US Navy, 2008

Figure 1-1

Location of Naval Support Facility Dahlgren

Source: NSWCDD GIS (2008 - 2011); Danger Zones defined in 33 CFR § 334.230.

Figure 1-2

NSWCDD's RDT&E activities take place on two range complexes and the Mission Area (Figure 1-3, Potomac River Test Range Complex; Figure 1-4, Range Complexes and Mission Area; and Figure 1-5a, b, and c, PRTR on Nautical Charts):

- The PRTR Complex includes the over-water PRTR plus five land ranges (Terminal Range, Missile Test Range, Main Range, Anti-Aircraft [AA] Fuze Range [the name was assigned in World War II], and Machine Gun Range). Among other activities, small-caliber (defined for purposes of this WRSEPA as those with calibers of less than or equal to 20 millimeters [mm] or 0.8") and large-caliber guns (> 20 mm or 0.8") have been fired from the land-based ranges into the PRTR since 1918.

Potomac River Test Range (PRTR)

The **PRTR** is a water range controlled by NSWCDD that extends 51 nautical miles (95 kilometers) along the lower Potomac River. The PRTR is divided into areas designated on nautical charts as the Upper, Middle, and Lower Danger Zones (UDZ, MDZ, and LDZ, respectively).

The **PRTR *Complex*** includes the PRTR **plus** five land-based ranges (Terminal Range, Missile Test Range, Main Range, AA Fuze Range, and Machine Gun Range). Guns are fired from the land ranges into the PRTR.

- The Explosives Experimental Area (EEA) Range Complex includes the land-based Harris and Churchill Ranges as well as other land-based RDT&E facilities. Among other activities, the EEA is used for land-based ordnance RDT&E.

The Mission Area includes a variety of indoor and outdoor RDT&E facilities but is not used for firing or detonating ordnance.

The focus of this WRSEPA analysis is the water range controlled by NSWCDD – the PRTR. The PRTR Complex's five land ranges, the EEA Range Complex's two land ranges, and the Mission Area have been addressed under a separate Range Condition Assessment (RCA) report (NSWCDD, 2010) and are not considered in this WRSEPA.

The Upper Machodoc Creek portion of the PRTR between the PRTR Complex land ranges and the EEA has been used by NSWCDD for RDT&E activities since the EEA was purchased during World War II. Currently this area supports non-destructive RDT&E explosive testing activities. From 1944 to 1957, this area and an adjacent area upstream in Upper Machodoc Creek were used as a bombing range. These activities are described in more detail in Section 3.1.3 and are illustrated in Figure 3-2. However, the two areas have not been used for more than 50 years (since 1957-58) for munitions testing, although it is possible that small fragments of detonations from the adjacent EEA may occasionally enter the this portion of the PRTR. Because the Upper Machodoc Creek area is not used for RDT&E of munitions, it does not fall under the WRSEPA objective of long-term sustainability (US Navy, 2008) and is not included in this assessment.

The remainder of the PRTR and the part of the Potomac River covered by the range are described in more detail in Chapter 2. Chapter 3 describes historical, current, and future use of munitions on the PRTR. The operational range site model is described in Chapter 4. Chapter 5 details the fate and transport analysis performed for munitions fired into the PRTR. Chapters 6 and 7 contain screening-level ecological and human health risk assessments, respectively. A summary of the findings and recommendations are presented in Chapter 8. References and a list of preparers are provided in Chapters 9 and 10, respectively.

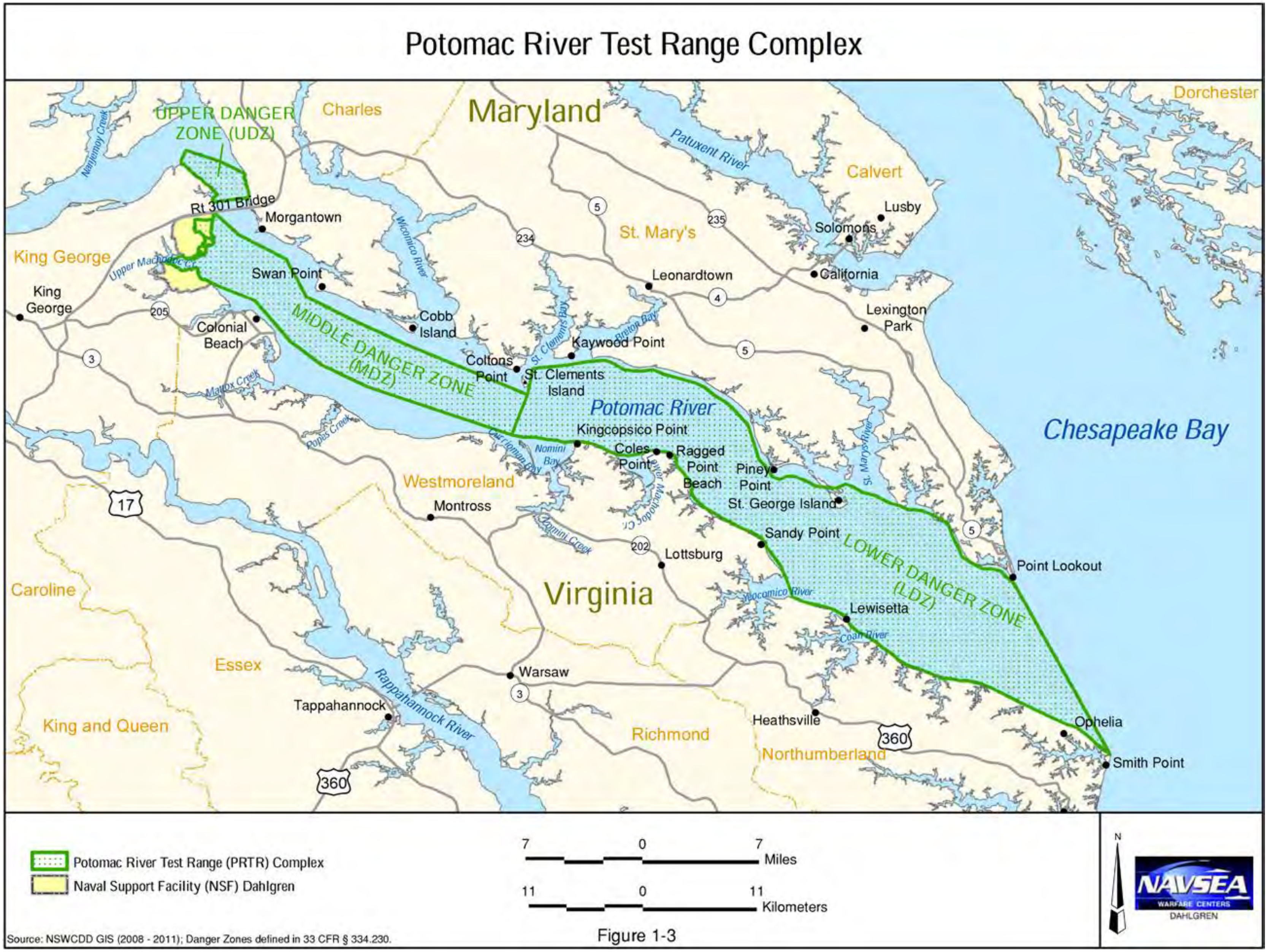

Potomac River Test Range Complex
Maryland
Virginia
Chesapeake Bay
Potomac River
UPPER DANGER ZONE (UDZ)
MIDDLE DANGER ZONE (MDZ)
LOWER DANGER ZONE (LDZ)
Charles
St. Mary's
Calvert
Dorchester
King George
Westmoreland
Caroline
Essex
King and Queen
Richmond
Northumberland
Rt 301 Bridge
Morgantown
Swan Point
Cobb Island
Colonial Beach
King George
Coltons Point
St. Clements Island
Kaywood Point
Leonardtown
California
Solomons
Lusby
Lexington Park
Kingcopsico Point
Coles Point
Ragged Point Beach
Piney Point
St. George Island
Sandy Point
Point Lookout
Lewisetta
Ophelia
Smith Point
Montross
Lottsburg
Warsaw
Tappahannock
Heathsville
Patuxent River
Rappahannock River
Potomac River Test Range (PRTR) Complex
Naval Support Facility (NSF) Dahlgren
7 0 7 Miles
11 0 11 Kilometers
NAVSEA WARFARE CENTERS DAHLGREN
Source: NSWCDD GIS (2008 - 2011); Danger Zones defined in 33 CFR § 334.230.

Figure 1-3

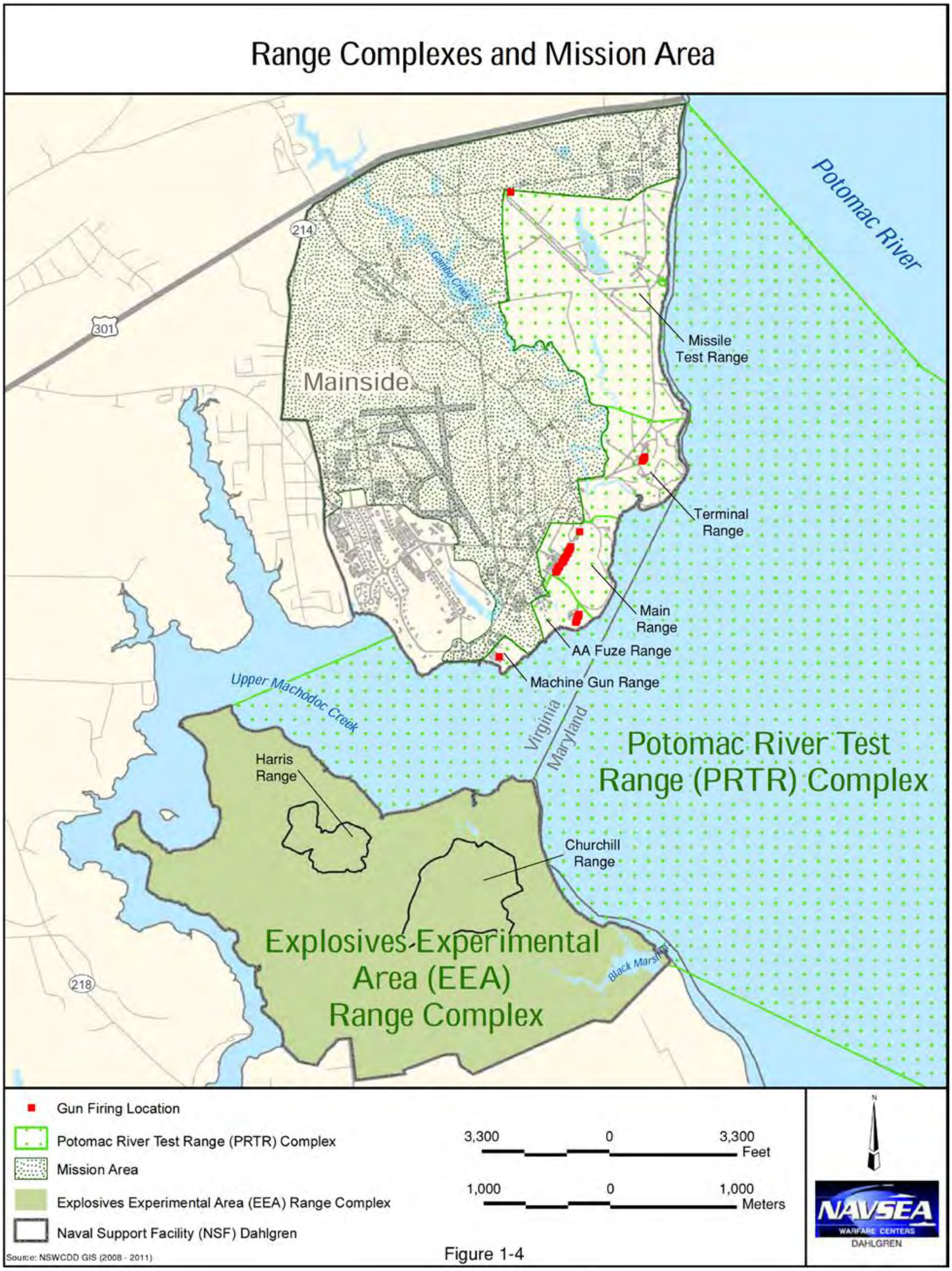

Range Complexes and Mission Area
Potomac River
Missile Test Range
Mainside
Terminal Range
Main Range
AA Fuze Range
Machine Gun Range
Upper Machodoc Creek
Gambo Creek
Virginia
Maryland
Potomac River Test Range (PRTR) Complex
Harris Range
Churchill Range
Explosives Experimental Area (EEA) Range Complex
Black Marsh
214
301
218
Gun Firing Location
Potomac River Test Range (PRTR) Complex
Mission Area
Explosives Experimental Area (EEA) Range Complex
Naval Support Facility (NSF) Dahlgren
3,300 0 3,300 Feet
1,000 0 1,000 Meters
N
NAVSEA WARFARE CENTERS DAHLGREN
Source: NSWCDD GIS (2008 - 2011)

Figure 1-4

THIS PAGE INTENTIONALLY LEFT BLANK

2 DESCRIPTION OF THE POTOMAC RIVER TEST RANGE AND THE POTOMAC RIVER

2.1 Potomac River Test Range (PRTR) Description

2.1.1 Purpose of PRTR

The PRTR is the nation's largest fully-instrumented, over-water gun-firing range. The PRTR allows the Navy to conduct testing in a realistic, controlled environment – it effectively operates as a "ship on shore," collecting real-time data from a number of instrument stations. The PRTR, as shown in Figures 1-3 and 1-4, historically has been used primarily for ordnance RDT&E. While this is still a major use, increasingly the water range is being used for RDT&E activities involving tests of sensors, lasers, electromagnetic (EM) energy, and chemical warfare sensors.

Looking east towards NSF Dahlgren and the Potomac River

The PRTR is used to conduct RDT&E for the purposes of:

- Assessing the performance and effectiveness of components and subsystems of warfare systems, including weapons, ordnance, projectiles, fuzes, sensors, missile system components, launchers, electric weapons, and directed energy (lasers, microwaves, and radio frequency).
- Warfare systems integration and testing, including weapons, sensors, platforms, weapons control systems, combat systems, electronic warfare systems, and unmanned and autonomous systems.
- Testing specialized systems used to detect and defend against chemical or biological threats and other asymmetric threats.

NSWCDD's guns, positioned to fire down the PRTR, include one of every type of gun currently used by the Navy, as well as models that represent a new generation of guns. Nearly every ammunition lot and gun barrel that is fitted on a Navy ship is tested on the PRTR to ensure performance is as specified. Testing and improving ordnance reliability, safety, lethality, accuracy, fuzing, and distance for small- and large-caliber guns and assessing explosive compounds will remain a primary part of NSWCDD's mission into the future because these weapons remain core components of Navy ships.

Testing over water is vital when evaluating the performance of detection and engagement systems such as radars and electro-optical tracking systems to ensure that these systems work over water as well as they do on land. The over-water range provides tracker and sensor testing with low over-water targets in situations in which background clutter, reflectivity, multi-path conditions, and wave height conditions can all vary. The range has a comprehensive instrumentation system, with both fixed and mobile components located along the PRTR to accurately measure test results. Figure 2-1, Range Stations, shows the location of the range instrumentation stations. The PRTR also serves as a safety buffer for land-based testing on the land ranges.

Figure 2-2, Potomac River Test Range Primary Gunnery Target Area, shows the main gunnery target area used today. There are no fixed targets on the PRTR. Rather, almost all targets are virtual (i.e., location coordinates with no physical target) a target rarely is towed to a location for a particular test. Danger zones are controlled during test events by NSWCDD range boats and staff observers stationed at range stations along the Potomac River. Live fire can be performed up to 40,000 yards (yds) (36,576 meters [m]) or approximately 20 nautical miles (NM) (37 km) or down range (i.e., down river on the PRTR). Live fire today is limited to the Middle Danger Zone (MDZ) or rarely the upper part of the Lower Danger Zone (LDZ). The upper end of the LDZ is located over 23 NM (43 km) upriver from where the Potomac River enters the Chesapeake Bay. (See Section 2.1.3 for more information on the danger zones within the PRTR.)

2.1.2 PRTR Operations Responsibilities

The Commander of NSWCDD is ultimately responsible for ensuring that ordnance activities on the PRTR are conducted in a safe and environmentally responsible manner. This responsibility for ordnance activities has been delegated to the Range Safety Director/Ordnance Officer and the Test and Evaluation Division Head. The Explosives Safety Officer and the Safety and Environmental Director provide operational oversight to further ensure that ordnance operations are safe and environmentally responsive.

Dahlgren's gunline, which includes every gun currently used on Navy ships, faces down the Potomac River Test Range.

The Range Operations Center (ROC), under the Engagement Systems Department, is responsible for controlling test operations on all ranges and test areas. The ROC monitors and controls all test sites with patrol boats, air surveillance radar, video surveillance, communications, and other measures required to ensure safe operations. The ROC is always staffed when any of the ranges are being used, when any airspace is reserved for firing, or when aircraft are conducting tests

Range Stations

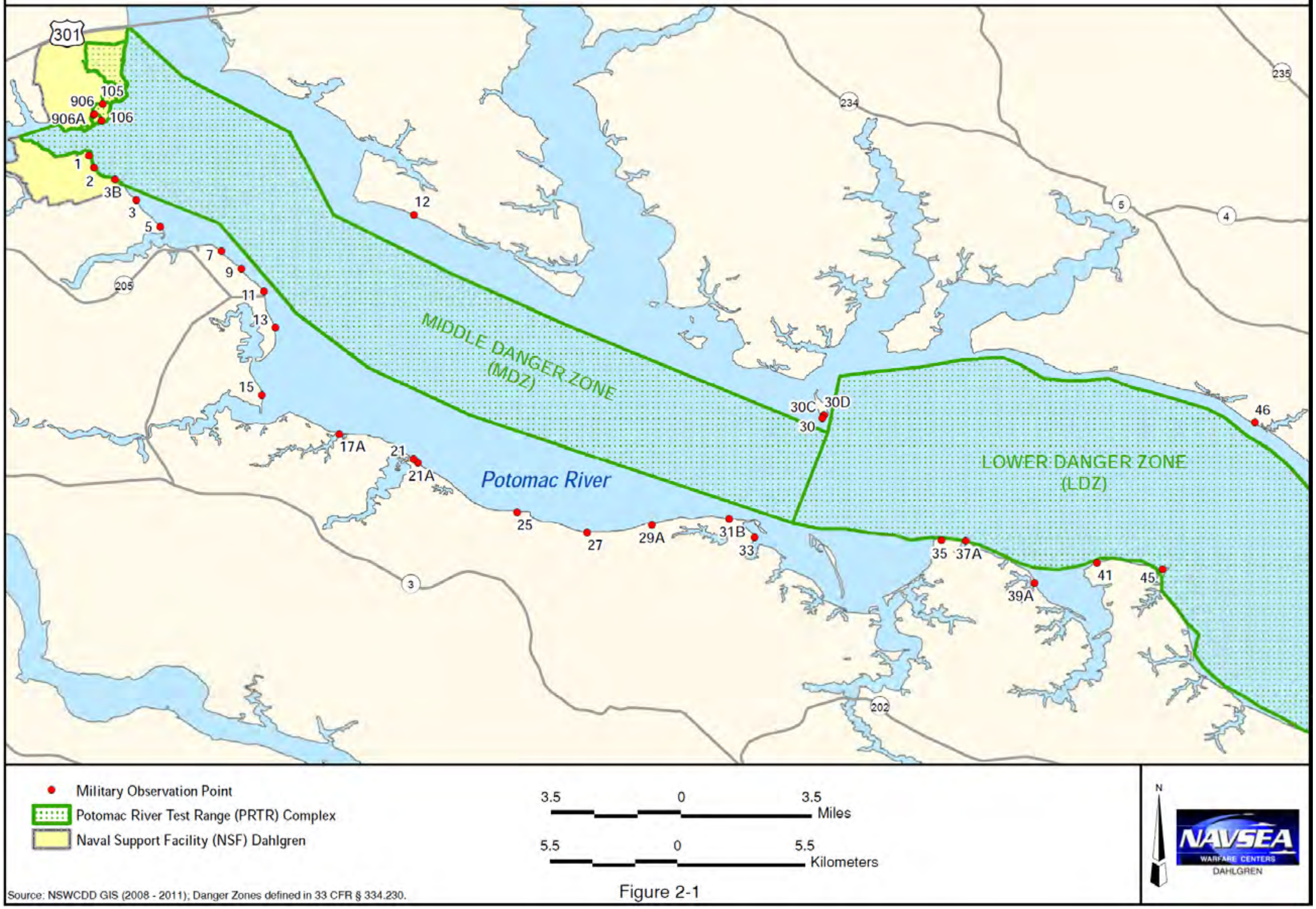


Figure 2-1

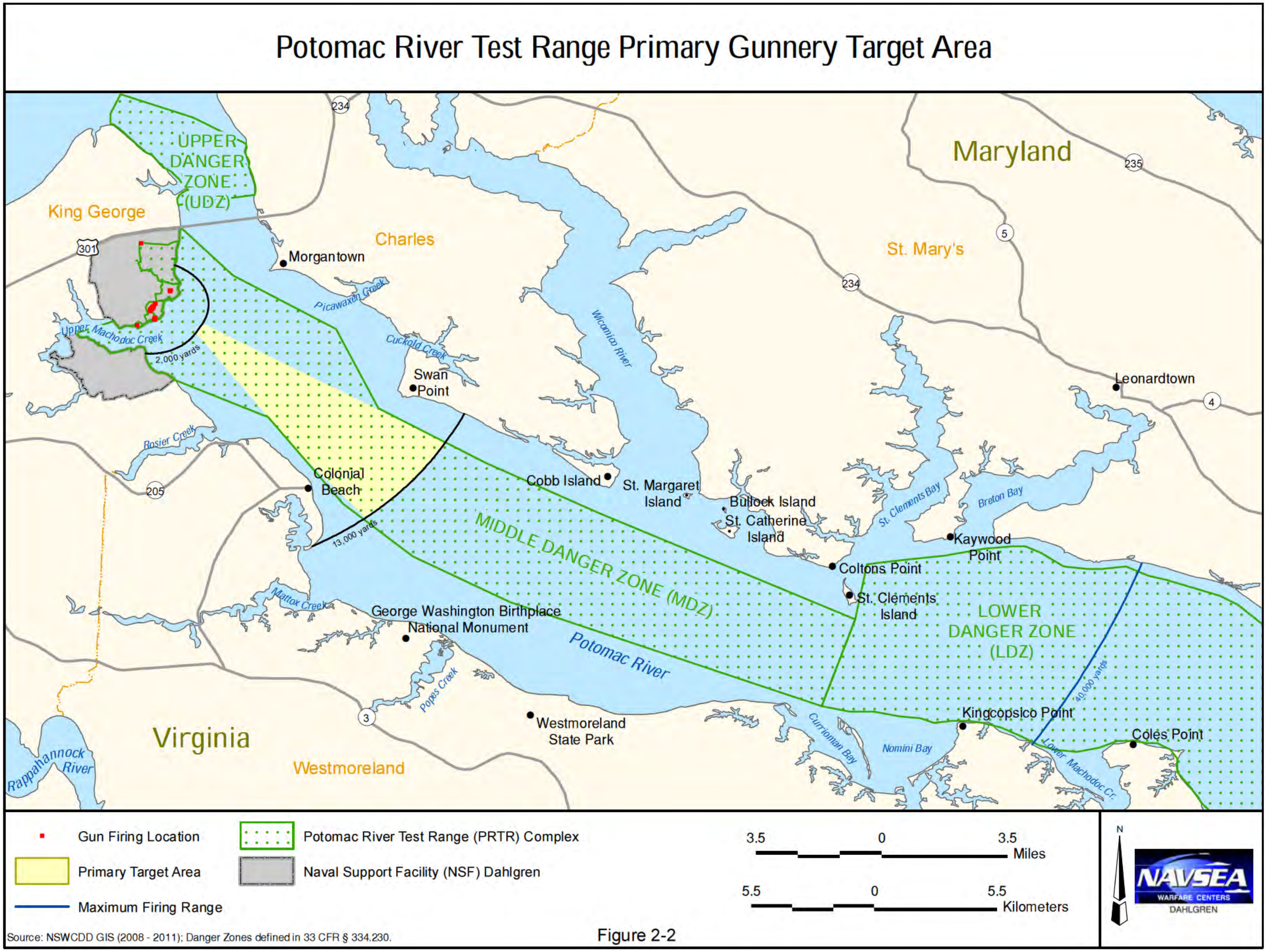


Figure 2-2

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

in or near restricted airspace to ensure effective communication in case of emergency. Points of contact for activities on the PRTR are provided in Table 2-1.

Table 2-1
PRTR Points of Contact

Point of Contact	Telephone or Website
NSWCDD Website	http://www.navsea.navy.mil/nswc/dahlgren/default.aspx
Range / Weapons Testing Hotline	877-845-5656(toll free)
Noise Questions and Comments	866-359-5540 (toll free)
NSWCDD Public Affairs Office	540-653-8152
Weekly Range Schedule	http://www.navsea.navy.mil/nswc/dahlgren/RANGE/rangeschedule.aspx
NSF Dahlgren	540-653-8502
NSF Dahlgren Base Operator (emergencies, suspected UXO)	540-653-8291
Note: Daily range schedules, types of tests (such as firing single or multiple shots or detonations), the use of substances (such as smoke for smokescreens), hours of testing, where on the PRTR the tests will take place, whether tests are on schedule, whether noise will be made, and contact numbers to obtain more information are included on the website and in the recorded message.	

2.1.3 PRTR Danger Zones

The PRTR is 51 NM (95 km) long, covers 169 square NM (sq NM) (580 square km [sq km]), and is divided into areas designated on nautical charts as the Upper, Middle, and Lower Danger Zones (UDZ, MDZ, and LDZ, respectively). The MDZ receives the heaviest use; it is 2.6 NM (4.8 km) wide, 15.4 NM (28.5 km) long, and covers 38.8 sq NM (133 sq km).

Surface Danger Zones and restricted areas are defined by the US Army Corps of Engineers (USACE) in 33 Code of Federal Regulations (CFR) § 334.2. Per these regulations, a danger zone is a "defined water area (or areas) used for target practice, bombing, rocket firing, or other especially hazardous operations, normally for the armed forces. The danger zones may be closed to the public on a full-time or intermittent basis, as stated in the regulations." No military warning areas or restricted areas other than special use airspace, described in Section 2.1.4, are associated with or located in the vicinity of the PRTR.

The boundaries of the PRTR's UDZ, MDZ, and LDZ are defined in 33 CFR § 334.230 and shown on Figure 1-3 and on National Oceanic and Atmospheric Administration (NOAA) nautical charts 12233, 12286, and 12288. Specific regulations applicable to the PRTR (33 CFR § 334.230 (a) (2)) include the following:

i) Firing normally takes place between the hours of 8 am and 5 pm daily except Saturdays, Sundays, and national holidays, with infrequent night firing between 5:00 pm and 10:30 pm. During a national emergency, firing will take place between the hours of 6:00 am and 10:30 pm daily except Sundays.

ii) When firing is in progress, no person, fishing, or oystering vessels shall operate within the danger zone affected unless so authorized by the Naval Surface Warfare Center's range control boats. Oystering and fishing boats or other craft may cross the river in the danger zone only after they have reported to the patrol boat and received instructions as to when and where to cross. Deep-draft vessels using dredged channels and propelled by mechanical power at a speed greater than five miles per hour may proceed directly

> through the danger zones without restriction except when especially notified to the contrary. Unless instructed to the contrary by the patrol boat, small craft navigating up or down the Potomac River during firing hours shall proceed outside of the northeastern boundary of the Middle Danger Zone. All craft desiring to enter the Middle Danger Zone when proceeding in or out of Upper Machodoc Creek during firing hours will be instructed by the patrol boat; for those craft which desire to proceed in or out of Upper Machodoc Creek on a course between the western shore of the Potomac River and a line from the Main Dock of the Naval Surface Weapons Center to Line of Fire Buoy P, clearance will be granted to proceed upon request directed to the range control boat.

Watercraft and deep-draft vessels are encouraged to communicate with NSWCDD's ROC via marine radio in order to minimize delays. NSWCDD's rigorous implementation of the regulations ensures that activities on the PRTR are conducted safely and with minimal adverse impacts to river users. During Navy activities on the river that could potentially endanger watercraft, a red flag is flown at the Yardcraft piers, near the mouth of Upper Machodoc Creek.

An NSWCDD Range Control Boat monitors the PRTR.

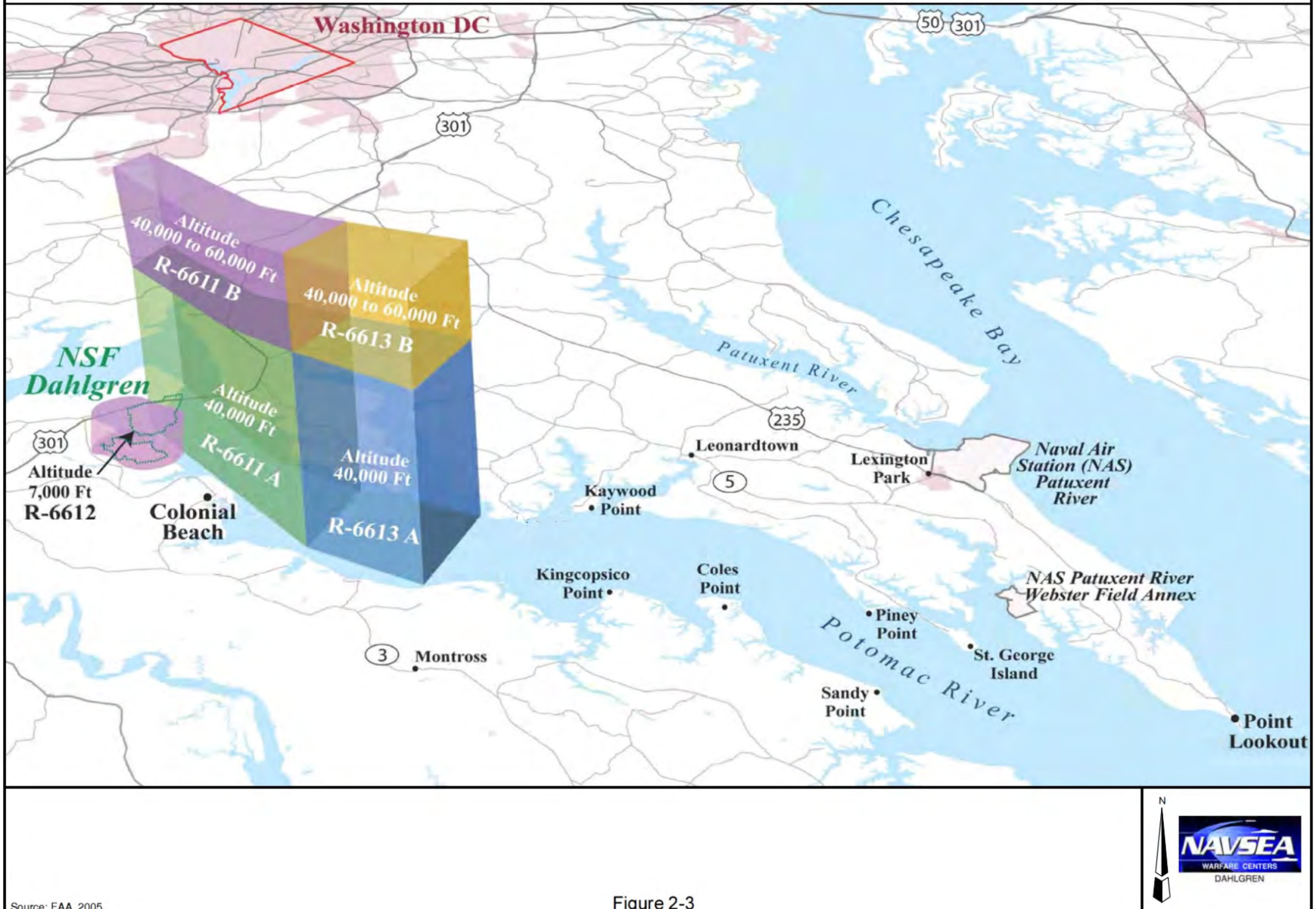
Range control boats (painted international orange with a white hull and normally stationed near Lower Cedar Point, Maryland; near Swan Point, Maryland; off Colonial Beach, Virginia; and at the mouth of Upper Machodoc Creek) patrol the active danger zone to ensure that no watercraft are present. To that end, the boats fly red flags warning watercraft not to enter the danger zone without having obtained permission from the nearest range patrol boat or from the ROC, which can be contacted by marine radio. If needed, range boats use a siren as a signal for a passing watercraft to come alongside for information and instructions on how to proceed, or they contact them by marine radio. Depending on the type of operation, traffic can frequently be safely rerouted around the operating area. When necessary, deep-draft vessels may be made to hold for a maximum of one hour, but more typically a half-hour.

To minimize any potential inconvenience, advanced notices of scheduled activities and danger-zone restrictions are provided on NSWCDD's website and via a toll-free number (see Table 2-1). Monitoring equipment, such as the cameras used to record projectile/water impact locations during ordnance activities, is also used for PRTR surveillance during periods of restricted access.

2.1.4 Restricted Airspace

Restricted, or special-use airspace, areas have been established by the Federal Aviation Administration (FAA) to prevent hazards to aircraft from NSWCDD's RDT&E activities (Figure 2-3, Special-Use Airspace). These restricted areas extend from the surface to their maximum altitudes of 40,000 ft for R-6611A and R-6613A, and 60,000 ft for R-6611B and R-6613B. For safety reasons, flying through the R-6611 and R-6613 areas by non-military aircraft is restricted

Special-Use Airspace



Source: FAA, 2005.

Figure 2-3

during testing. When testing is completed early or a scheduled test is cancelled, the airspace is returned to the control of the FAA for normal civilian air traffic use. Additionally, a small restricted airspace – R-6612 – lies directly over the EEA, and extends to 7,000 ft. R-6612, R-6611A, and R-6613A (surface to 7,000 or 40,000 ft) are automatically in effect (i.e., restricted to air traffic) from 8 am to 5 pm daily, excluding weekends and holidays. When NSWCDD does not plan to use the special-use airspace during these hours, it turns it back over to the FAA. Conversely, NSWCDD may need to use the airspace outside the normal weekday hours (i.e., at night or on weekends), in which case a Notice to Airmen is issued by the FAA 48 hours in advance. The same procedure is used for R-6611B and R-6613B (40,000 to 60,000 ft), which are not automatically in effect. When they are needed, the FAA, at the request of NSWCDD, issues a Notice to Airmen 48 hours in advance. These higher altitude zones are used only on rare occasions.

2.1.5 PRTR Operations Safety

The safety of civilian, military, and contractor personnel as well of visitors and the general public is paramount to NSWCDD. Safety is an integral part of all range activities and is emphasized in all aspects of NSWCDD's mission and decision-making.

NSWCDD has a well-established Risk Hazard Analysis (RHA) and Standard Operating Procedure (SOP) process. An RHA is part of the operating procedure for explosives use at NSWCDD and consists of an analysis for hazards. Risks addressed in an SOP for each operation, which include step-by-step procedures and responsibilities to mitigate the hazards associated with handling ordnance, unexploded ordnance (UXO), post-energetic remains, explosive hazardous waste, range clearance operations, and the processing/recycling of range residue. All risks that are identified by the RHA are mitigated through either administrative or engineering controls to ensure safe operations. The Safety and Environmental Office reviews all SOPs and the constituents contained in the ordnance to be tested on the PRTR.

Regular safety and awareness training occurs throughout the year, as well as an annual safety stand-down. Prior to the commencement of each range operation, all participating personnel must receive a hazard control brief. Each person is required to read, understand, and sign a statement for that operational SOP. All personnel working with explosives must be qualified and have an ordnance certification for the task involved.

For all range activities that may present a hazard off the operational range, installation personnel and the public are notified, as appropriate. In addition, appropriate safety and notification measures are addressed in each range operational SOP to ensure that personnel and property are protected both on and off the installation.

2.1.6 Location of Landmarks and Significant Resources

There are few recognized landmarks and significant resources, such as nearby major cities or island chains, offshore drilling rigs, offshore wind energy farms, protected underwater sanctuaries, rookeries, haul out areas and marine mammal migratory corridors within or adjacent to the PRTR. The Town of Colonial Beach, Virginia, located along the MDZ with a year-round population of about 3,500 and a summer population of over 10,000 (Town of Colonial Beach, 2011), is the only town of any size along the lower Potomac River. Substantial physical landmarks along the river include the US 301 Governor Harry W. Nice Memorial Bridge (commonly called Nice Bridge), located between NSWCDD's upper danger zone (UDZ) and the MDZ and the Morgantown Power Generating Plant, located just south of the bridge on the Maryland side of the river.

The PRTR has commercial fishing activity, with an estimated 800 commercial fisherman fishing the Potomac from its mouth to Mosspoint, Maryland, located upriver of the PRTR across from Quantico, Virginia (Cosby, Potomac River Fisheries Commission, pers. comm. October 7, 2008). The number of fishing permits issued has decreased over the last ten years from 2,531 in 1999 to 1,968 in 2008 (Cosby, Potomac River Fisheries Commission, pers. comm. February 26, 2010), suggesting a decline in commercial fishing in the Lower Potomac River. Reduced commercial landings of finfish, crabs, and oysters in the portion of the river that corresponds to the PRTR (Cosby, Potomac River Fisheries Commission, pers. comm., March 1, 2011) also evidence a decline in commercial fishing. Between 1997 and 2008, the reductions in landings of finfish and oysters were greatest in the section of the Potomac River than includes the LDZ, and the reduction in landings of crabs was greatest in the section that includes the UDZ—both areas where NSWCDD activities are limited.

The decline in the Lower Potomac River is symptomatic of the regional decline of commercial fisheries throughout the Chesapeake Bay and its tributaries. Noting that "[t]he bay's major commercial fisheries have collapsed or been sharply restricted," a recent Environment Maryland Research & Policy Center report (Dewar et al., 2009) cites fertilizer-laden runoff from farms and lawns, discharge from sewage treatment plants, and sediment from farms, roads, and construction sites—along with the resulting low dissolved oxygen levels and depleted submerged aquatic vegetation—as major causes for the decline of Chesapeake Bay's fisheries. Dissolved oxygen levels in Chesapeake Bay are worse than ten years ago, resulting in more dead zones, areas where dissolved oxygen levels are so low that aquatic life flees or dies (Dewar et al., 2009). The report also attributes the decline to other factors, including overfishing and competition from foreign imports.

Many migratory birds are found in the vicinity of the PRTR. The Potomac River is located off the main Atlantic flyway, which follows the Atlantic coast. Millions of migratory birds, including waterfowl, shorebirds, and songbirds, use the Atlantic flyway to travel between their summer breeding grounds and winter feeding grounds. Most species of waterfowl that use the flyway are from the northeastern United States and eastern Canada. Upriver of the PRTR in King George County, Virginia is the Caledon State Park, which extends over 2,579 acres (1,044 hectares) and is a designated National Natural Landmark.

The federal-listed endangered shortnose sturgeon (*Acipenser brevirostrum*) and Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) are found in the PRTR section of the Potomac River. A reward capture program operating for more than a decade has reported the capture of few shortnose sturgeon in the river, and the size of the population is thought to be very small. Shortnose sturgeon primarily transit through the PRTR; spending most of the warmer months in the freshwater portion of the river (NSWCDD, 2011). A total of 226 Atlantic sturgeon have been reported in the Potomac River from 1996 - 2010, primarily through the Sturgeon Reward Program (Eyler, pers. comm., January 11, 2011). Most Atlantic sturgeon have been captured below the Nice Bridge in the areas covered by the MDZ and LDZ.

The presence of three ESA-listed sea turtles – the loggerhead (*Caretta caretta*), Kemp's ridley (*Lepidochelys kempii*), and green (*Chelonia mydas*) sea turtles has been reported in the lower part of the PRTR LDZ (NSWCDD, 2011), near the mouth of the Potomac River where it meets the Chesapeake Bay. Although sea turtles may occur in the Lower Potomac River, their ranges do not extend upriver to the upper LDZ or the MDZ, the area of the PRTR where ordnance testing occurs.

2.1.7 Applicable Laws and Regulations

This section identifies the laws and regulations applicable to activities on the water range part of the PRTR Complex and the status of compliance with them. While this list is not exhaustive, it does include most of the major federal requirements to protect the environment and human health from the potential impacts of range activities. Relevant state laws and regulations also apply. Most of the PRTR's waters are within the State of Maryland, but some of the waters close to the Virginia side of the river are within the Commonwealth of Virginia.

Federal Munitions Rule (MR) (40 CFR § 266.202) and Resource Conservation and Recovery Act (RCRA) (42 United States Code [U.S.C] §§ 6901 to 6992k). The federal MR under RCRA defines when conventional and chemical military munitions become solid wastes and when they are potentially subject to hazardous waste regulations and establishes procedures and management standards for waste military munitions. The MR has been incorporated by the Virginia Department of Environmental Quality (VDEQ) (Title 9, Environment, Chapter 60 of the Virginia Administrative Code). Maryland has not adopted the federal MR and has not developed any state-specific military munitions regulations. The MR is implemented by the Navy through the DoD's Munitions Rule Implementation Policy (DoD, 1998).

Under the MR military munitions are not considered solid wastes when used for their intended purpose, which includes training and RDT&E activities, or when they are recovered and destroyed on-range during range clearance operations, repaired, or otherwise subjected to materials recovery. Under the MMR definition of wastes, used ordnance remaining on NSWCDD's land and water ranges is considered intended use and is not subject to hazardous waste regulations.

For purposes of RCRA (Section 1004(27)), a used or fired military munition is a solid waste, and, therefore, is potentially subject to RCRA corrective action if the munition lands off-range and is not promptly rendered safe and/or retrieved. Navy personnel and contractors conduct range clearance (including disposal of residue) and manage hazardous waste requirements for the NSWCDD ranges, so that used military munitions do not become solid waste.

As an operational range clearance best management practice, the explosive ordnance disposal unit sweeps the area periodically and after storm events, to prevent exposure of past buried items and remove any suspect munitions and explosives of concern. The Navy's *Operational Range Clearance Policy for Navy Ranges* (US Navy, 2004) includes requirements for activities such as the removal, disposal, and recycling of UXO, range scrap, and debris. NSWCDD procedures comply with the operational range clearance policy (NSWCDD, 2010).

National Environmental Policy Act (42 U.S.C. §§ 4321 to 4370e). The National Environmental Policy Act requires a detailed environmental analysis for major federal actions with the potential to significantly affect the quality of the human environment. An EIS is currently being prepared for outdoor RDT&E activities at NSWCDD, inclusive of the PRTR. Upon completion of this EIS, the Navy will satisfy the National Environmental Policy Act for those outdoor RDT&E activities that are included in the analysis of the preferred alternative, inclusive of the ordnance testing on the PRTR.

Clean Water Act (33 U.S.C. §§1251 to 1387). The Federal Water Pollution Control Act, as amended by the Clean Water Act of 1977, establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters. The Clean Water Act prohibits spills, leaks, or other discharges of oil or hazardous substances into the waters of the United States in quantities that may be harmful. USEPA's national recommended water quality criteria for the protection of aquatic life and human health in surface water, including about 150 pollutants, have been published pursuant to Section 304(a) of the Clean Water Act. The Maryland Department of the Environment (MDE) and the VDEQ administer the Clean Water Act and implement regulatory and planning programs to reduce the input of pollutants to the waters of the states. Chapter 6 of this WRSEPA compares munitions-related discharges to water quality standards. Based on these comparisons, the PRTR is in compliance with the Clean Water Act.

Rivers and Harbors Act (33 U.S.C. § 401 et seq.). The Rivers and Harbors Act regulates disposal of refuse and debris into the rivers and harbors of the United States and makes it illegal to create any obstruction to navigable waters without approval of the USACE. NSWCDD is in compliance with the Rivers and Harbors Act.

Clean Air Act (42 U.S.C. § 7401 et seq.). The Clean Air Act, as amended, is intended to protect and enhance the quality of the nation’s air resources so as to promote public health and welfare and the productive capacity of its population. NSF Dahlgren is not a major source for any Clean Air Act criteria or hazardous air pollutants. Because NSF Dahlgren’s annual emissions levels do not exceed the Title V major source threshold of 100 tons per year for any criteria pollutants, the installation is operating under a state minor synthetic operation permit issued by VDEQ.

Coastal Zone Management Act (16 U.S.C. § 1451 et seq.) The Coastal Zone Management Act provides assistance to states, in cooperation with federal and local agencies, for developing land and water use programs for the coastal zone. This includes the protection of natural resources and management of coastal development. The respective state coastal zone management program implements policy. The Coastal Zone Management Act requires that any federal agency activity that is reasonably foreseeable within or outside the coastal zone and affects any land or water use or natural resource of the coastal zone be carried out in a manner that is consistent, to the maximum extent practicable, with the enforceable policies of NOAA-approved state management programs.

The Navy has determined and documented in draft federal coastal consistency determinations that the Proposed Action, under any of the alternatives, is consistent to the maximum extent practicable with the enforceable policies of the coastal zone management programs of Virginia and Maryland, respectively and will submit determinations for review to VDEQ and the Maryland Department of Natural Resources in 2012.

Endangered Species Act (ESA) (15 U.S.C. §§ 1531 to 1544). Section 7 of the Endangered Species Act requires that federal agencies, in consultation with the responsible wildlife agency, ensure that Proposed Actions are not likely to jeopardize the continued existence of any endangered species or threatened species or result in the destruction or adverse modification of critical habitat (16 U.S.C. § 1536 (a)(2)]) Regulations implementing the Endangered Species Act expand the consultation requirement to include those actions that "may affect" a listed species or adversely modify critical habitat. On January 11, 2012 the Navy concluded consultation with NMFS. NMFS concurred with the Navy's determination that the Proposed Action is not likely to adversely affect any listed species under NMFS' jurisdiction (NMFS, 2012).

Migratory Bird Treaty Act (16 U.S.C. § 703). All migratory birds are protected under the Migratory Bird Treaty Act, which prohibits the taking, killing, or possessing of migratory birds, unless permitted by regulation. The National Defense Authorization Act of 2003 Section 315 provides that the Secretary of the Interior shall exercise his/her authority under the MBTA to prescribe regulations to exempt the Armed Forces from incidental taking of migratory birds during military readiness activities authorized by the Secretary of Defense. The final rule authorizing the DoD to take migratory birds during military readiness activities (50 CFR Part 21, published February 28, 2007) provides that the Armed Forces must confer and cooperate with the US Fish and Wildlife Service on the development and implementation of conservation measures to minimize or mitigate adverse effects of a military readiness activity if it determines that it may have a significant adverse effect on a population of a migratory bird species. Executive Order 13186, *Responsibilities of Federal Agencies to Protect Migratory Birds*, provides additional protection for migratory birds on federal properties and stresses incorporating bird conservation principles in agency management plans. NSWCDD is in compliance with the Migratory Bird Treaty Act.

National Historic Preservation Act (16 U.S.C. § 470). Section 106 of the National Historic Preservation Act provides that federally-funded agencies such as NSWCDD take into account the effects of their actions on any district, site, building, structure, or object included in, or eligible for inclusion in, the National Register of Historic Places. The locations near the PRTR that have been identified as included in or eligible for the National Register of Historic Places are all on land.

DoD Directive 3200.15 Sustainment of Ranges and Operating Areas. This directive establishes the policy that ranges must be managed and operated to support their long-term viability to meet the national defense mission. It also establishes responsibilities for the preparation of range sustainment programs within DoD components. NSWCDD adheres to this directive.

DoD Instruction 3200.16 Operational Range Clearance. This instruction provides procedures for all operational ranges requiring appropriate range clearance of used or fired military munitions, munitions debris, and range-related debris that may impair or inhibit the continued use of an operational range. NSWCDD has internal directives to ensure that this DoD instruction is carried out.

DoD Directive 4715.11 Environmental and Explosives Safety Management on Operational Ranges within the United States. This directive instructs the heads of DoD components to establish procedures for regular range clearance operations to permit the sustainable use of operational ranges for their intended purpose. These procedures need to determine the frequency and degree of range clearance operations, and consider the safety hazards of clearance and the quantities and types of munitions expended on that range. The Navy's response to DoD Directive 4715.11 is the Range Sustainment Program and the Operational Range Clearance Policy for

Navy Ranges, which is designed to ensure that Navy ranges are operated in an environmentally responsible manner that is protective of the public, while sustaining the highest levels of readiness to meet the Navy's mission requirements.

NSF Dahlgren and NSWCDD operate in compliance with applicable federal, state, and local regulations and guidelines for all areas, inclusive of the PRTR.

2.2 Description of the Lower Potomac River

2.2.1 Physical Characteristics

The Potomac River basin encompasses 14,670 square miles (sq mi) (37,995 sq km) in four states – West Virginia, Pennsylvania, Virginia, and Maryland – and the District of Columbia (Interstate Commission on the Potomac River Basin, 2011). Forests cover the majority (58 percent) of the basin's land area; agriculture covers 32 percent of the area; water/wetlands cover 5 percent, and developed lands cover 5 percent (Interstate Commission on the Potomac River Basin, 2011).

The Lower Potomac River basin drains 1,756 sq mi (4,548 sq km) (Irani, pers. comm., October 14, 2011). Approximately 26 percent of the basin is open water. The most extensive land use is forest, covering almost 38 percent of the basin; agriculture covers 16 percent, wetlands 10 percent, and urban land 4 percent (Irani, pers. comm., October 14, 2011). Impervious surfaces account for over 4 percent of the land area in the Lower Potomac River basin (Irani, pers. comm., October 14, 2011).

The Potomac River flows over 333 NM (616 km) from Fairfax Stone, West Virginia to the river mouth at Point Lookout, Maryland (Interstate Commission on the Potomac River Basin, 2011). The length of the tidal reach of the river is 99 NM (183 km) (Landwehr et al., 1999). The Potomac River flows into the Chesapeake Bay about 43 NM (80 km) south of NSF Dahlgren. Within the PRTR portion of the Potomac River, the river ranges in width from approximately 1.5 NM (2.7 km) at a narrow section within the UDZ to more than 9.7 NM (18 km) at the river's mouth at the southern end of the LDZ.

The bathymetry of the PRTR portion of the Potomac River is illustrated in Figure 2-4, Potomac River Test Range Bathymetry. The lower Potomac River trench extends from the level of Ragged Point in the LDZ to the mouth of the river (US Environmental Protection Agency [USEPA], 2003). The depth of the trench averages from 49 to 82 feet (ft) (15 to 25 m); a 33- to 49-ft- (10- to 15-m-) deep shelf extends from the sides of the trench (USEPA, 2003).

The PRTR portion of the Potomac River is tidal. It is an estuary, i.e., a partially enclosed body of water that has a free connection to the open sea and where saltwater from the sea mixes with freshwater from rivers, streams, and creeks (NOAA, 2011). This portion of the Potomac River exhibits features that are characteristic of a partially mixed estuary – specifically, strong tidal currents, moderate vertical stratification, and considerable longitudinal variation in salinity (Wilson, 1977). Moderate vertical stratification is characterized by the occurrence of two basic water layers: a less saline upper water provided by the river, and a deeper marine water, separated by a zone of mixing (Thurman, 1994). Within the PRTR, the mean salinity of the Potomac ranges from approximately 4 to 8 parts per thousand (ppt) in the vicinity of NSF Dahlgren, between the UDZ and the MDZ, to approximately 11 to 16 ppt around the downstream end of the LDZ, near the mouth of the river (based on Maryland Department of Natural Resources [MDNR], 2010).

Tidal-height data obtained from temporary tide gauges established between NSF Dahlgren and Lewisetta, Virginia, encompassing both the MDZ and the LDZ, indicate that the PRTR portion of the Potomac River has a semidiurnal tide period of 12.4 hours (Wilson, 1977). According to Wilson (1977), the tidal range decreases from about 2.17 ft (0.66 m) at NSF Dahlgren to about 1.57 ft (0.48 m) at Lewisetta, and the high tide at NSF Dahlgren occurs approximately 1.8 hours after that at Lewisetta. A permanent tide gauge (NOAA Station 8635750) was installed in July 1990 in Lewisetta (Figure 2-5, Water Quality Monitoring Stations). The mean tidal range at the Lewisetta station is 1.24 ft (0.38 m) and the diurnal range is 1.50 ft (0.46 m) (NOAA, 2011b). Current phases at NSF Dahlgren lag relative to those near Lewisetta by 1.5 to 2 hours (Wilson, 1977).

Because of the constriction in the Potomac River channel cross section above NSF Dahlgren at the Nice Bridge Station (US 301 Bridge, near the upper end of the MDZ), current velocities there are higher than downstream (Wilson, 1977). In the vicinity of the MDZ, the river makes a bend to the south and widens considerably. As this occurs, the water velocity decreases drastically, causing this part of the river to have a high potential for the rapid deposition of sediment.

2.2.2 Water Quality

MDNR has routinely sampled water quality year-round in the Chesapeake Bay and the Potomac River (as well as other tidal tributaries to the Chesapeake) since 1985 (MDNR, 2010). Five MDNR fixed monthly water quality monitoring stations are located in the general vicinity of NSF Dahlgren and the PRTR, as shown on Figure 2-5. MDNR collects data from 12 to 20 times a year at the four Potomac River stations (RET2.2, RET2.4, LE2.2, and LE2.3) and 16 times a year at Station CB5.3 in the Chesapeake Bay, near the mouth of the Potomac.

Salinity

Figure 2-6, Potomac River Salinity Levels (1985-2006), depicts surface water salinity levels in the Lower Potomac River. The figure shows the seasonal average salinity levels for the spring and the fall, based on monthly average salinities at the MDNR monitoring stations. Table 2-2 presents monthly surface water salinity data at the MDNR stations.

At all five stations, the mean salinity for each month is within the mixohaline or brackish range – between 0.5 and 30 ppt. Salinity levels increase in a downstream direction. At Station RET2.2, about 8 NM (14.8 km) upstream of the PRTR, mean salinities for each month are within the oligohaline range – 0.5 to 5 ppt. Between the UDZ and the MDZ, mean salinities vary between the oligohaline range and the mesohaline range – 5.0 to 18 ppt. In the LDZ and in the Chesapeake Bay, near the mouth of the Potomac River, mean salinities are within the mesohaline range.

Table 2-2
Surface Water Salinity (ppt)

Station ID	Range	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RET2.2	Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Mean	2.75	2.53	1.40	0.91	0.96	1.59	3.00	3.69	3.87	4.01	3.72	3.32
	Max	7.43	8.50	6.81	3.99	4.09	3.70	6.34	8.21	6.49	7.46	7.81	7.81
RET2.4	Min	0.00	0.32	0.00	0.04	0.34	0.49	1.98	2.37	1.09	2.74	1.51	0.26
	Mean	6.88	6.42	4.50	3.68	3.76	4.88	6.79	7.55	7.93	8.30	8.12	7.50
	Max	13.33	13.99	8.76	10.98	7.71	8.32	10.11	11.57	11.41	11.44	13.06	13.39
LE2.2	Min	5.10	4.00	2.98	3.36	3.10	4.20	7.26	6.11	7.12	7.01	7.26	5.02
	Mean	12.19	11.03	9.32	8.58	7.95	8.64	10.42	11.73	12.89	13.31	13.34	13.17
	Max	18.26	18.55	18.28	16.66	12.47	12.63	13.83	15.07	16.41	16.46	17.04	18.07
LE2.3	Min	7.74	9.40	7.18	6.71	6.06	7.30	9.11	9.28	10.37	7.87	9.59	8.25
	Mean	14.00	14.38	12.61	11.21	10.78	11.22	12.68	13.97	14.95	16.08	15.76	15.56
	Max	18.90	20.29	19.73	16.06	15.34	14.59	15.81	17.11	17.38	19.52	19.04	20.08
CB5.3	Min	7.81	8.89	8.73	7.34	7.50	8.12	10.04	10.47	11.87	11.02	10.95	9.91
	Mean	14.95	15.26	13.45	12.51	12.16	12.82	13.56	15.06	15.97	17.12	16.68	16.73
	Max	19.87	21.27	20.08	17.79	16.02	16.26	16.69	18.48	18.41	21.48	20.57	20.85

Notes: 1. Salinities are in parts per thousand (ppt).
2. Period of record is 1985 to 2008.
3. Min indicates minimum; Max indicates maximum.

Source: Based on MDNR, 2010.

At all five stations, salinity levels are seasonal, varying through the year depending on rainfall, freshwater runoff, and river flows. The relationship between river flows and salinity is strongest at the most upstream station – RET2.2 – and weakens in a downstream direction. The highest mean salinity levels occur in October and November. During the 1985 to 2008 period of record, polyhaline (18.0 to 30 ppt) water was recorded from October through March at Station LE2.3 in the LDZ, and from August through March in the Chesapeake Bay. Salinity levels decline from February through May, when snowmelt and increased seasonal rainfall produce elevated freshwater discharges from streams and groundwater. The lowest mean salinity levels occur in April and May. Between the UDZ and the MDZ (at Station RET2.4), fresh water was recorded during the months of December through June, as evidenced by minimum salinities (within the 0 to 0.5 ppt range). Salinity levels increase from the spring through the summer, when river flows are lowest.

Temperature

Table 2-3 shows monthly surface water temperature data at the monitoring stations. Temperatures are typically similar across the five monitoring stations, with only a 0.4- to 3.1-degree Fahrenheit (˚F) (-0.2- to 1.9-degree Celsius [˚C]) range of variation in monthly mean temperatures between the warmest station and the coolest station. The largest temperature variations between upstream and downstream stations occur in the spring, when the upstream stations are warmer, and in the fall, when the upstream stations are cooler. The mean temperatures at the five monitoring stations are most similar in September.

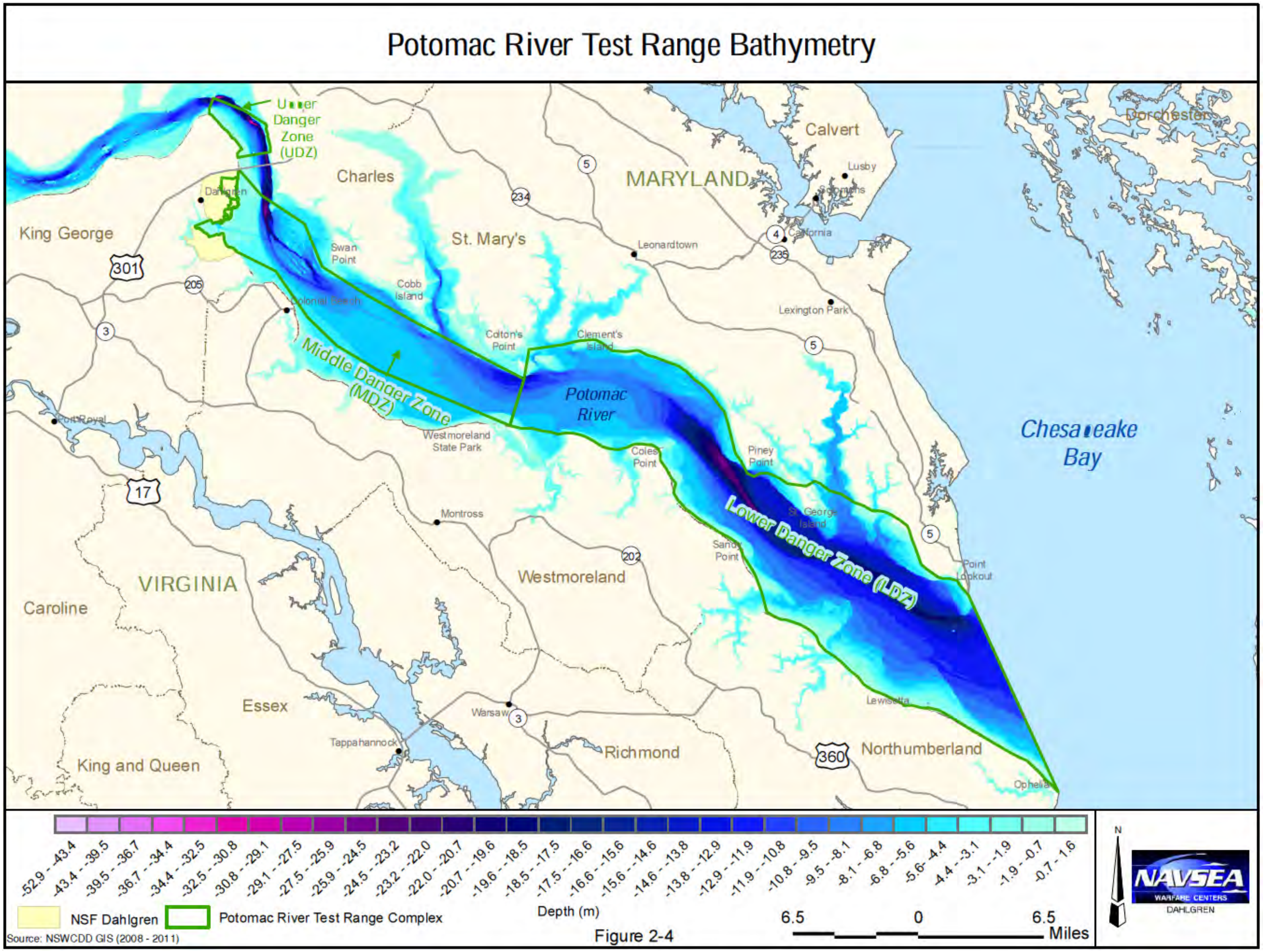


Figure 2-4

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

Water Quality Monitoring Stations

Source: NSWCDD GIS (2008 - 2011); Danger Zones defined in 33 CFR § 334.230.

Figure 2-5

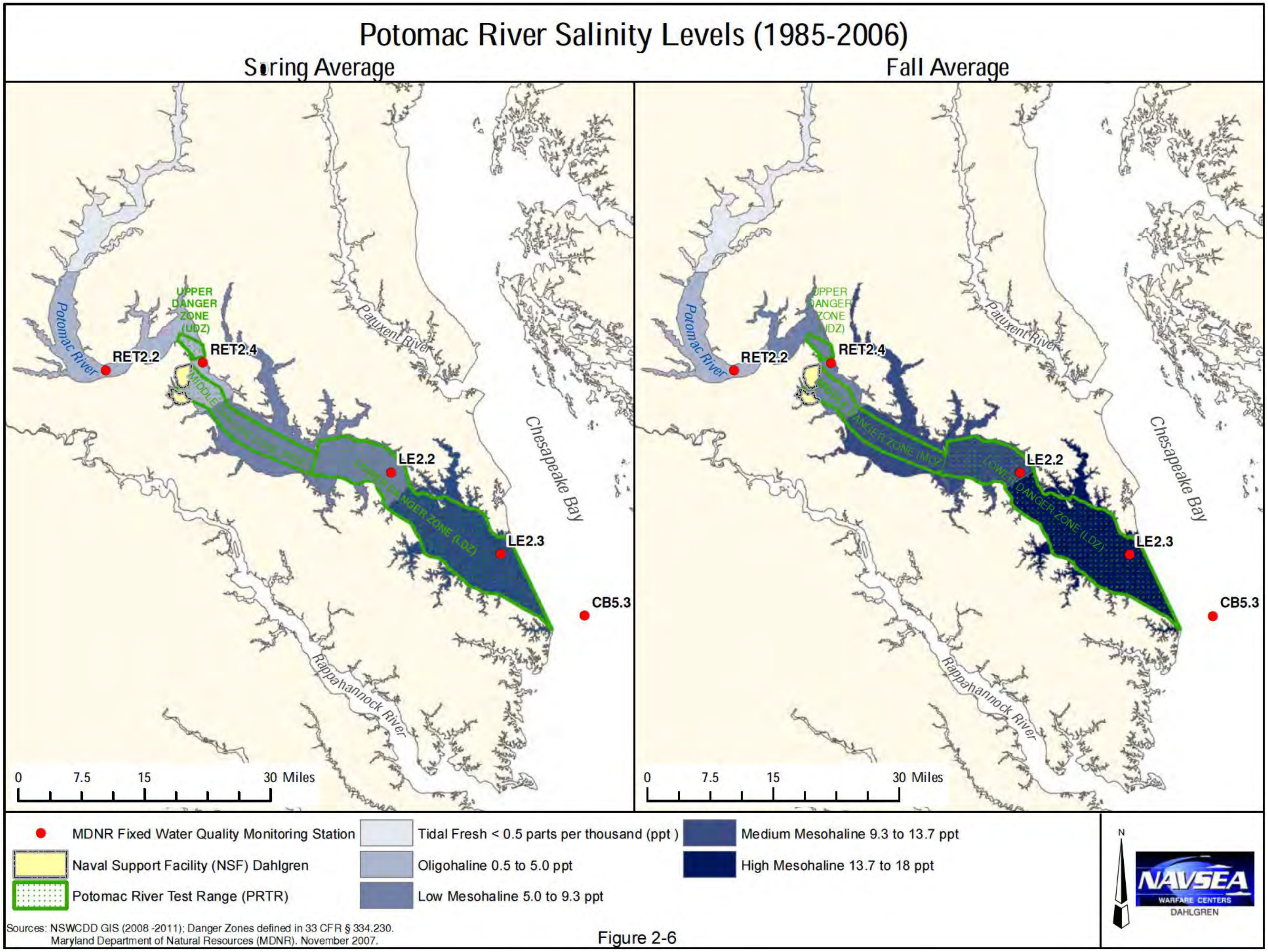

Potomac River Salinity Levels (1985-2006)
Spring Average
Fall Average
UPPER DANGER ZONE (UDZ)
MIDDLE DANGER ZONE (MDZ)
LOWER DANGER ZONE (LDZ)
Potomac River
Patuxent River
Chesapeake Bay
Rappahannock River
RET2.2
RET2.4
LE2.2
LE2.3
CB5.3
0 7.5 15 30 Miles
MDNR Fixed Water Quality Monitoring Station
Naval Support Facility (NSF) Dahlgren
Potomac River Test Range (PRTR)
Tidal Fresh < 0.5 parts per thousand (ppt)
Oligohaline 0.5 to 5.0 ppt
Low Mesohaline 5.0 to 9.3 ppt
Medium Mesohaline 9.3 to 13.7 ppt
High Mesohaline 13.7 to 18 ppt
N
NAVSEA
WARFARE CENTERS
DAHLGREN
Sources: NSWCDD GIS (2008 -2011); Danger Zones defined in 33 CFR § 334.230.
Maryland Department of Natural Resources (MDNR). November 2007.

Figure 2-6

Table 2-3
Surface Water Temperature (˚F)

Station ID	Range	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RET2.2	Min	33.62	33.62	37.04	50.81	60.44	68.90	79.16	77.99	71.69	57.02	46.40	37.22
	Mean	38.34	38.62	45.05	55.46	65.78	75.73	81.32	80.88	75.73	64.02	53.26	44.00
	Max	46.58	43.52	50.90	61.16	72.32	80.06	84.11	85.10	79.25	71.60	59.36	53.42
RET2.4	Min	34.70	33.44	36.50	48.56	60.71	67.64	78.26	77.72	72.86	57.20	47.84	39.02
	Mean	38.95	38.38	44.17	54.38	64.97	74.54	80.51	80.80	75.95	64.67	54.34	44.96
	Max	46.40	42.44	49.73	59.45	71.24	78.89	83.21	84.92	79.07	72.05	60.26	53.78
LE2.2	Min	35.06	35.96	36.86	50.54	60.71	68.18	77.18	76.46	72.86	60.35	48.74	39.02
	Mean	40.25	39.58	44.59	54.24	64.57	74.82	80.00	79.73	75.60	64.73	54.68	45.65
	Max	48.02	43.52	50.54	59.45	71.06	78.89	82.94	83.93	78.80	70.61	61.88	53.96
LE2.3	Min	33.98	31.82	36.32	49.37	59.18	64.76	77.18	77.54	71.24	62.87	50.90	40.64
	Mean	39.79	37.75	42.93	52.99	63.48	73.53	79.73	79.99	75.74	66.93	55.63	46.78
	Max	45.86	42.44	47.12	56.75	69.80	78.80	81.95	83.48	81.32	71.78	60.62	54.32
CB5.3	Min	34.34	31.46	36.68	49.46	58.64	63.32	77.27	76.82	71.60	62.78	50.90	40.64
	Mean	39.97	37.89	42.75	52.52	62.93	73.08	79.54	79.64	75.88	66.70	55.53	47.07
	Max	46.58	42.80	46.22	56.30	68.54	78.53	81.77	83.30	81.14	70.16	59.54	54.50

Notes: 1. Temperatures are in degrees Fahrenheit (˚F).
2. Period of record is 1985 to 2008.
3. Min indicates minimum; Max indicates maximum.
Source: Based on MDNR, 2010.

Over the year, the lowest mean temperatures occur in January and February and the highest mean temperatures occur in July and August. The slightly higher mean temperatures at Station LE2.2 in January and February may result from discharges from the Morgantown Generating Station – located across the Potomac River from NSF Dahlgren – of water that is warmer than the receiving river water during the winter. The generating station uses a once-through cooling system, circulating on average 1.0 million gallons (3.8 million liters [l]) of river water per minute (Mirant Mid-Atlantic, LLC, 2006). The system employs a 1,833-ft- (559-m-) long discharge canal to cool water from the condenser and mix the discharge with river water (Maryland Power Plant Research Program, 2001).

Dissolved Oxygen

Table 2-4 shows the monthly bottom-water dissolved oxygen (DO) concentrations – i.e., the amount of oxygen dissolved in the water – at the MDNR monitoring stations.

During all 12 months of the year except one, the highest mean DO concentrations occur at Station RET2.2, upstream of the PRTR. The highest mean DO concentration in March occurs at Station LE2.3 – in the LDZ near the mouth of the Potomac River – with Stations RET2.2 and LE2.2 having the second highest concentrations. From November through February, mean DO concentrations generally decrease in a downstream direction, with the highest concentrations at Station RET2.2 and the lowest concentrations at Station CB5.3 in the Chesapeake Bay. During the five-month period between May and September, however, the lowest mean DO concentrations occur in the LDZ at Stations LE2.2 and LE2.3.

Table 2-4
Bottom Water Dissolved Oxygen (mg/l)

Station ID	Range	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RET2.2	Min	10.00	9.90	7.25	7.35	5.45	3.80	3.55	4.25	4.60	5.25	7.40	8.60
	Mean	11.46	12.24	10.51	9.02	7.21	5.73	5.50	5.66	6.22	7.19	9.10	10.33
	Max	13.20	14.10	12.60	10.05	8.55	9.10	7.55	7.90	7.15	8.65	10.60	12.70
RET2.4	Min	7.80	7.60	6.10	4.85	1.95	0.35	1.70	1.45	2.02	4.25	4.97	7.50
	Mean	10.90	11.07	9.56	7.74	4.81	2.66	2.63	3.28	4.78	6.22	8.15	9.55
	Max	12.70	14.30	12.00	9.80	7.15	3.85	4.75	4.75	6.50	7.90	10.30	12.20
LE2.2	Min	8.60	8.80	8.10	4.40	0.09	0.05	0.05	0.00	0.03	2.55	5.00	6.90
	Mean	10.29	11.06	10.50	7.26	3.16	0.77	0.47	0.74	2.46	5.37	7.70	9.12
	Max	14.00	16.10	12.85	9.55	7.30	2.60	2.90	3.45	6.20	7.45	9.60	10.80
LE2.3	Min	8.90	9.00	8.10	5.45	0.90	0.10	0.07	0.08	0.10	2.60	5.80	7.80
	Mean	10.37	10.83	10.62	8.12	3.99	1.50	0.35	0.82	3.16	5.79	7.85	9.44
	Max	11.70	12.14	12.50	11.40	6.85	7.30	1.33	3.31	6.13	8.20	9.50	11.50
CB5.3	Min	8.10	9.20	8.60	4.80	2.15	0.90	0.25	0.50	0.50	3.10	4.70	6.50
	Mean	9.74	10.52	9.96	7.60	4.75	2.63	1.12	1.61	3.39	5.44	7.24	8.64
	Max	11.10	11.80	11.50	9.55	6.82	6.10	2.20	2.90	5.70	7.00	8.90	10.50

Notes: 1. Dissolved oxygen concentrations are in milligrams per liter (mg/l).
2. Period of record is 1985 to 2008.
3. Min indicates minimum; Max indicates maximum.
Source: Based on MDNR, 2010.

The mean DO concentrations for the months from May through September and for the two monitoring stations in the LDZ are more variable than the concentrations for the remaining months of the year and for the other stations. From May through September, there is a 3.8- to 5.2-milligrams per liter (mg/l) range of variation in monthly mean DO concentrations between the station with the highest concentration and the station with the lowest concentration. From October through April the ranges of variation are lower, with values between 1.1 and 1.9 mg/l. Over the course of a year, the ranges of variation for Stations LE2.2 and LE2.3 are 10.6 and 10.5 mg/l, respectively, whereas the other stations the ranges of variation are between 6.7 and 9.4 mg/l.

DO concentrations are influenced by temperature and salinity, as the solubility of oxygen in water decreases with increasing temperature and salinity (NOAA, 2011). Over the year, the highest mean DO concentrations in the vicinity of the PRTR occur in February, the month with the lowest mean surface water temperatures at four of the five stations – at Station RET2.2, the lowest mean surface water temperature occurs one month earlier, in January. The lowest mean DO concentrations occur in July, with the highest mean surface water temperatures occurring in July and August.

May through September, the mean monthly DO concentrations for Stations RET2.4, LE2.2, LE2.3, and CB5.3 are all below 5 mg/l, with only Station RET2.2 maintaining mean monthly concentrations above this threshold. DO concentrations below 5 mg/l can stress certain aquatic organisms, such as certain fish species, especially when the organism is exposed to these conditions for prolonged periods (MDNR, 2010). Although some bottom-dwelling organisms, such as worms, can survive at DO concentrations as low as 1 mg/l, many will not survive exposure to concentrations below 1 mg/l for more than a few hours (MDNR, 2010). The June mean DO concentration for Station LE2.2 is below the 1-mg/l threshold, as are the July and August mean concentrations for both Station LE2.2 and Station LE2.3.

It is likely that low DO conditions are a natural feature of the lower Potomac River trench (USEPA, 2003), which extends from near Station LE2.2 to the mouth of the river, near Station LE2.3. The Potomac River trench is not connected to the mainstem Chesapeake Bay trench. Strong water-column stratification effectively isolates the trench waters from the surface waters, preventing the mixing of surface and bottom waters. Given the large size of the Potomac River basin, large amounts of organic matter may be transported from upriver to the waters of the trench. Decomposition of this organic matter could depress oxygen levels that are not readily replenished due to the presence of a pycnocline (the zone between waters with different densities). The high mean DO concentration in the LDZ, at Stations LE2.2 and LE2.3, in March – the month with the highest freshwater discharges – may result from high river flows rejuvenating the below-pycnocline waters of the Potomac River trench.

Turbidity

Water turbidity is a state of reduced clarity caused by the presence of suspended matter. The greater the amount of total suspended solids in the water, the higher the turbidity and the less light penetrates through the water. Increased turbidity can lead to reduced growth of submerged aquatic vegetation, reduced fish health, and, typically in association with dredging operations, burial of benthic organisms.

Excessive algal growth, runoff, shoreline erosion, pollution, resuspension of bottom sediments, and the mixing of fresh and salt water can increase turbidity. Analysis of river discharge and turbidity data for the five monitoring stations in the vicinity of the PRTR indicates high correlation between the two parameters for Station RET2.2 ($r^2 = 0.7555$) and moderate to high correlation for Station RET2.4 ($r^2 = 0.5583$).[5] As river discharge data for the Potomac River is not available for a gauge in the vicinity of the PRTR, data from a US Geological Survey (USGS) monitoring station near Washington, DC (Station 01646502) was used in the analysis. The analysis indicated negligible correlations (r^2 between 0.0 and 0.2) for the three downstream stations – LE2.2, LE2.3, and CB5.3.

Table 2-5 shows the monthly turbidity – measured as Secchi depth[6] – of the water at the MDNR monitoring stations. Throughout the year, mean water turbidity generally decreases in a downstream direction, with the highest turbidity (or lowest clarity) at Station RET2.2, and the lowest turbidity at Stations LE2.3 and CB5.3.

At all five stations, turbidity is seasonal. The highest mean turbidity levels occur in April for the three upstream stations and in June or July for the downstream stations. For Stations RET2.2 and RET2.4, the lowest turbidity levels occur in October; whereas for the three stations downstream of RET2.4, the lowest turbidity levels occur in November or December.

[5] r^2 is the square of the Pearson product-moment correlation coefficient. The r^2 value can be interpreted as the proportion of the variance in y attributable to the variance in x.
[6] Secchi depth is measured using a Secchi disk, a circular plate that is divided into quarters, painted alternately black and white. The disk is lowered into the water and the Secchi depth – the depth at which the disk is no longer visible – is recorded. Low Secchi depth indicates high turbidity.

Table 2-5
Water Clarity or Turbidity (Secchi Depth) (m)

Station ID	Range	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RET2.2	Min	0.10	0.20	0.20	0.25	0.25	0.35	0.35	0.45	0.15	0.30	0.05	0.10
	Mean	0.43	0.53	0.43	0.40	0.42	0.53	0.65	0.66	0.74	0.76	0.61	0.49
	Max	0.80	1.20	0.70	0.65	0.60	0.85	0.95	1.05	1.10	1.40	1.80	0.90
RET2.4	Min	0.10	0.30	0.30	0.20	0.40	0.35	0.50	0.60	0.35	0.50	0.21	0.20
	Mean	0.69	0.71	0.59	0.46	0.58	0.65	0.77	0.84	0.93	1.09	1.08	0.80
	Max	1.50	1.10	1.00	0.85	0.80	1.15	1.15	1.10	1.35	1.70	2.60	1.20
LE2.2	Min	1.00	0.70	0.70	0.40	0.35	0.60	0.70	0.95	0.95	0.95	1.10	0.50
	Mean	1.55	1.58	1.32	1.03	1.08	1.11	1.24	1.33	1.32	1.57	1.72	1.50
	Max	2.60	3.40	2.30	1.80	2.70	1.95	2.00	1.70	1.70	2.10	3.40	2.80
LE2.3	Min	1.10	1.40	1.10	0.85	1.00	1.00	0.85	1.20	1.00	1.30	1.30	1.10
	Mean	2.01	2.07	1.84	1.52	1.67	1.47	1.44	1.61	1.67	1.88	2.17	2.25
	Max	2.80	3.10	3.00	2.40	2.90	2.20	1.85	2.30	2.30	2.50	3.80	6.00
CB5.3	Min	1.50	1.00	0.80	0.70	1.00	0.85	0.90	1.20	1.30	1.00	1.20	1.20
	Mean	2.03	2.00	1.80	1.62	1.65	1.46	1.47	1.68	1.76	1.82	2.17	2.14
	Max	3.00	3.20	2.70	2.75	2.95	2.30	2.10	2.60	2.70	2.50	3.80	3.80

Notes: 1. As a measure of water clarity or turbidity, Secchi depths are in m.
2. Period of record is 1985 to 2008.
3. Min indicates minimum; Max indicates maximum.

Source: Based on MDNR, 2010.

pH

Table 2-6 shows the monthly surface water pH[7] at the monitoring stations. pH is variable across the five monitoring stations, with a 0.28 to 0.88 range of variation in monthly mean pH between stations. The largest variations between upstream and downstream stations occur in the spring and summer. The mean pH values at the five monitoring stations are most similar during the winter.

In the vicinity of the PRTR, pH generally increases in a downstream direction. Throughout the year, pH at the two upstream stations (RET2.2 and RET2.4) tends to be lower than that at the three downstream stations (LE2.2, LE2.3, and CB5.3). Counter to this tendency toward increasing pH downstream, Station LE2.2, in the upper portion of the LDZ, has the highest mean pH for eight months throughout the year. The annual range of variation of pH at the stations generally decreases in a downstream direction, likely as a result of buffering by seawater. However, Station RET2.4, between the UDZ and the MDZ, has the largest annual range of variation. The high mean monthly pH values for Station LE2.2 and the large range of variation at Station RET2.4 may result from discharges from the Morgantown Generating Station.

[7] pH – potential of hydrogen – is a measure of the acidity or alkalinity of a solution. The pH scale ranges from 0 to 14. A pH of 7 is neutral; below 7 is acidic; above 7 is alkaline or basic. The pH of water determines the amount that can be dissolved in the water (solubility) and the amount that can be utilized by aquatic life (biological availability) of chemical constituents, such as minerals and heavy metals.

Table 2-6
Surface Water pH

Station ID	Range	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RET2.2	Min	7.40	7.50	7.60	7.45	7.05	6.95	7.10	7.07	6.80	6.90	6.80	6.90
	Mean	7.92	7.94	7.89	7.73	7.60	7.56	7.49	7.52	7.56	7.61	7.73	7.80
	Max	8.30	8.30	8.35	8.05	7.90	8.00	7.70	8.30	8.60	7.90	8.20	8.20
RET2.4	Min	7.60	7.70	7.50	7.40	7.30	7.40	7.15	7.20	7.15	7.45	7.00	6.90
	Mean	7.99	8.08	7.91	7.78	7.75	7.59	7.57	7.54	7.59	7.69	7.75	7.90
	Max	8.40	8.50	8.40	8.30	8.20	7.85	7.75	7.95	7.90	7.95	8.10	8.40
LE2.2	Min	7.80	7.80	7.65	7.55	8.05	8.05	7.75	7.80	7.60	7.60	7.60	7.80
	Mean	8.35	8.24	8.17	8.32	8.48	8.32	8.27	8.22	8.06	8.06	8.13	8.24
	Max	9.40	8.70	8.85	9.00	9.00	8.60	8.65	8.75	8.35	8.45	8.60	8.70
LE2.3	Min	7.71	7.50	7.79	7.95	8.10	7.95	8.05	7.66	7.71	7.90	7.69	7.80
	Mean	8.12	8.08	8.16	8.37	8.45	8.38	8.28	8.17	8.08	8.04	8.06	8.13
	Max	8.70	8.40	8.44	8.84	8.80	8.60	8.45	8.60	8.30	8.50	8.30	8.40
CB5.3	Min	7.67	7.50	7.79	7.90	7.95	7.97	8.01	7.69	7.67	7.90	7.73	7.80
	Mean	8.09	8.08	8.15	8.37	8.37	8.35	8.27	8.15	8.09	8.02	8.05	8.10
	Max	8.60	8.40	8.50	8.78	8.75	8.60	8.60	8.55	8.40	8.30	8.30	8.50

Notes: 1. pH denotes 'potential of hydrogen' and is a measure of the acidity or alkalinity of a solution.
2. Period of record is 1985 to 2008.
3. Min indicates minimum; Max indicates maximum.
Source: Based on MDNR, 2010.

Stormwater Management

The average annual precipitation at NSF Dahlgren is 41 inches (in) (104 centimeters [cm]), based on rainfall data collected at Fredericksburg National Park in Virginia (Southeast Regional Climate Center, 2012). Rainfall is distributed uniformly throughout the year, except for an increase in July and August, with average rainfalls of 4.5 and 4.1 in (11 and 10 cm), respectively. Periods of drought lasting several weeks may occur, especially in the fall (NSF Dahlgren, 2007). In the summer and fall, extremely high precipitation events may occur as a result of hurricanes.

NSF Dahlgren is in compliance with three regulatory programs that are intended to protect water resources from degradation caused by stormwater runoff. The programs are the Virginia Stormwater Management Regulations (4VAC 3-20), the Virginia Erosion and Sediment Control Regulations (4VAC50-30), and the Chesapeake Bay Preservation Act and Regulations (VR 173-02-01).

The Commonwealth of Virginia passed the Chesapeake Bay Preservation Act in 1988 to improve water quality in the bay. The regulations apply to 14 tidewater counties and promote wise resource-management practices in the use and development of environmentally-sensitive land features. Although federal landowners are exempt from the provisions of the Chesapeake Bay Preservation Act, NSF Dahlgren complies with this regulation to the greatest extent practicable.

The quantity and quality of stormwater leaving the installation is controlled by a stormwater management system. The system consists of water retention ponds, gravity storm mains, laterals, drainage ditches, culverts, inlets, and catch basins. Most of the lines and culverts are reinforced concrete or corrugated metal, ranging in diameter from 4 to 60 in (0.1 to 1.5 m) (NSF Dahlgren, 2006). Natural features such as streams, wetlands, and floodplains also are part of the stormwater management system at NSF Dahlgren (US Navy, 1993, as cited in US Navy, 2006b). A Virginia Pollutant Discharge Elimination System permit covers small quantities of stormwater discharges into receiving water bodies.

2.3 Sediments

2.3.1 Source Sediments

The PRTR is located in the Maryland Potomac Estuary Lowlands District, within the Western Shore Lowlands Region of the Embayed Section of the Atlantic Coastal Plain Province (Maryland Geological Survey, 2008). The Potomac Estuary Lowlands District consists of the Potomac River, surrounding terraced lowlands, and associated estuaries extending from the western physiographic boundary (Fall Zone) of the Atlantic Coastal Plain to Point Lookout, Maryland.

The sedimentary framework of the PRTR was described in a comprehensive five-year study of the tidal Potomac River and estuary conducted by the USGS (Knebel et al., 1981). The tidal portion of the Potomac River begins at Little Falls, about 1 mi (1.6 km) below the Washington, DC and Montgomery County, Maryland border. Based on salinity (see Section 2.2.2 and Figure 2-6), the estuary covers the portion of the Potomac River from around the Nice Bridge at Route 301 to the Chesapeake Bay.

The Potomac River was a single-channel tributary of the Susquehanna River prior to the Holocene epoch (beginning about 10,000 years ago). It flowed in a wide, flat-bottomed valley, carved into the sandy sediments of the Chesapeake Group (Knebel et al., 1981). As sea levels increased with glacial melting, several layers of marine sediments were deposited on the valley floor – in layers as thick as 131 ft (40 m) – from brackish or shallow-estuarine waters. The estuarine environment became deeper as the sea level continued to rise and the river channel maintained its depositional nature. Sediments deposited in the river channel transitioned from sands to finer clay and silty-clay (Knebel et al., 1981).

The terraced lowlands surrounding the PRTR are comprised of “lowland deposits” consisting of coarse (sandy) and fine (clayey or silty) sediments with cobbles and boulders. These lowland deposits commonly contain reworked glauconite, varicolored silts and clays, brown to dark gray lignitic silty clay, and remnants of marine fauna (Maryland Geological Survey, 2008).

The bottom sediments present in the Potomac River in the region of the PRTR are derived from the following sources (USGS, 2003):

- Erosion from surrounding lowland deposits
- Transport by tributaries
- Transport downriver from upstream locations
- Transport from the Chesapeake Bay by tidal action
- Introduction from the atmosphere
- Generation by biological activity.

2.3.2 Bottom Sediments

Three geomorphic features generally define the cross-section of the PRTR: shoreline flats, transitional slopes, and the channel bottom, as shown in Figure 2-4. The shoreline flats are relatively level areas typically covered by shallow water that can extend up to 1,000 yds (914 m) offshore. The flats parallel the shoreline and are interrupted off tributaries and peninsulas. The transitional slopes between the flats and river-channel bottom are typically smooth and appear asymmetrical with slightly increasing slope gradients toward the Maryland shoreline.

The shoreline flats and smooth transitional slopes of the river channel are interspersed with mound-like features and small ridges identified as oyster bars, particularly in the area of the MDZ known as Kettle Bottom Shoals. Figure 2-7, Potomac River Oyster Bars, shows the locations and boundaries of the natural and historical oyster bars identified by MDNR in the PRTR area.

Particle-size analyses of 37 sediment samples taken from the PRTR indicated a correlation between the geomorphic features of the PRTR and the texture of the bottom sediments (Knebel et al., 1981). Eight sediment samples taken from the shoreline flats at various locations were composed of 94 to 100 percent sand. The sands were generally brown, included a few coarse shell fragments, and usually lacked woody matter. Nineteen samples from the main channel of the PRTR were predominantly gray to black clay or silty clay. Ten sediment samples obtained from the transitional slopes were texturally diverse, ranging from sand to silty-clay, varying in color from brown to gray-black, with a few coarse oyster and clam shells (Knebel et al., 1981).

The current PRTR bottom sediments are the result of the deposition in different proportions of sand-, silt-, and clay-sized particles suspended in the water. Sands are generally deposited along the shallow margins of the PRTR, adjacent to the shoreline, on the shoreline flats, and around peninsulas. Sands typically accumulate in higher-energy environments near shore, as stronger waves and currents near shore typically remove, or prevent the deposition of, finer-grained sediments, leaving the larger-grained sands behind. In contrast, silts and clays – "mud" – are deposited in low-energy environments, such as the PRTR river channel. USGS core samples of the mud in the PRTR river channel show that it is predominantly a homogeneous, gray to black, clay or silty-clay. It appears to be continuous with the muddy sediments that also cover the main body of the Chesapeake Bay. Figure 2-8, Sediments – Lower Potomac River, illustrates the deposition pattern of sand and silts/clays (mud) on the bottom of the PRTR and Chesapeake Bay.

Deposition of fine-grained particles in the MDZ is enhanced by processes that are associated with estuarine circulation. In a partially mixed estuary, less-dense fresh river water flows downstream in the upper layer, whereas denser, saltier seawater flows upstream in the lower layer. Fine suspended particles that settle into or are carried by the lower layer are transported upstream by its landward flow, leading to rapid accumulation of sediments on the bottom and a turbidity maximum within the overlying water column (Knebel et al., 1981). Sediment core measurements indicate that sediments have a high water content (58 to 73 percent) and are soft or semi-liquid. In the Potomac River estuary, the downstream limit of the turbidity maximum encompasses the broad expanse of the MDZ above Nomini Cliffs, near the boundary between the MDZ and LDZ (Figure 2-9, Potomac River Sediment Sample Locations). The estimated upper limit of the turbidity maximum is within the UDZ, above the Nice Bridge.

The magnitude and trend of sedimentation rates within the PRTR are similar to those observed for muddy sediments within the main channel of the Chesapeake Bay. Sediment accumulation rates range from 0.50 to 0.75 in (1.3 to 2.0 cm) per year, with higher rates within the tidal portion of the Potomac River and lower rates in the estuary near the river's mouth.

2.3.3 Shoreline Sediments

The shoreline of the tidal Potomac River achieved its present form during the Holocene sea-level rise, with more recent modifications from wind and wave activity in the shore zone and slope processes on the banks. Shore erosion leaves residual sand and gravel in shallow water and transports silt and clay offshore, contributing to the suspended sediment load of the tidal Potomac River (USGS, 1985). Wind-driven waves break down and remove accumulated debris in the shore zone and abrade and undercut the base of the bank. Slope processes, including surficial erosion and mass movement, play an important role in mobilizing and depositing debris at the base of the bank. These processes are most active in areas with high bank relief or that are marked by seepage or zones of concentrated groundwater flow from the face of the bank (USGS, 1985).

Shoreline erosion rates were estimated along the Potomac River by the USGS by comparing historical shoreline maps and aerial photographs (USGS, 1985). Cartographic comparisons spanned periods of 38 to 109 years and photogrammetric comparisons spanned 16 to 40 years. Field monitoring of erosion rates and processes spanning periods of 10 to 18 months was also conducted at two sites – Swan Point Neck, Maryland in the MDZ, and Mason Neck, Virginia, south of Washington, DC.

The USGS estimated average recession rates of shoreline in the estuary, based on cartographic and photogrammetric measurements, ranging from 1.4 to 1.7 ft (0.4 to 0.5 m) per year on the Virginia shore and 1.0 to 1.3 ft (0.3 to 0.4 m) per year on the Maryland shore. The average recession rates of the shoreline in the tidal portion of the river and the transition zone were close to 0.5 ft (0.2 m) per year. The estimated average volume-erosion rates along the shores of the tidal river and the transition zone were 0.55 to 0.74 cubic feet per foot of shoreline per year (USGS, 1985). Significant variability was seen in the field monitoring results, due to the influence of local factors (USGS, 1985).

2.3.4 Sediment Quality

Human activities in the Potomac River watershed have affected sedimentation rates and sediment quality in the Potomac estuary, including the area of the PRTR (Knebel et al., 1981). To characterize the sediments in the Potomac River, the USGS collected and analyzed sediment core samples for particle size and nutrient and trace-metal concentrations; sediment accumulation rates were estimated by radiocarbon dating techniques (Knebel et al., 1981). The analytical results indicate increased concentrations of trace metals and nutrient content related to human activities in the watershed starting at 3.3 ft (1.0 m) below the sediment surface. Radiocarbon dating of the sediment cores indicated that average sediment accumulation rates range from 0.8 in (2 cm) per year within the tidal portion of the Potomac River to 0.5 in (1.3 cm) per year in the lower portion of the estuary. Based on these rates, increases in concentrations of trace metals began 50 to 70 years ago (Knebel et al., 1981).

Potomac River Oyster Bars

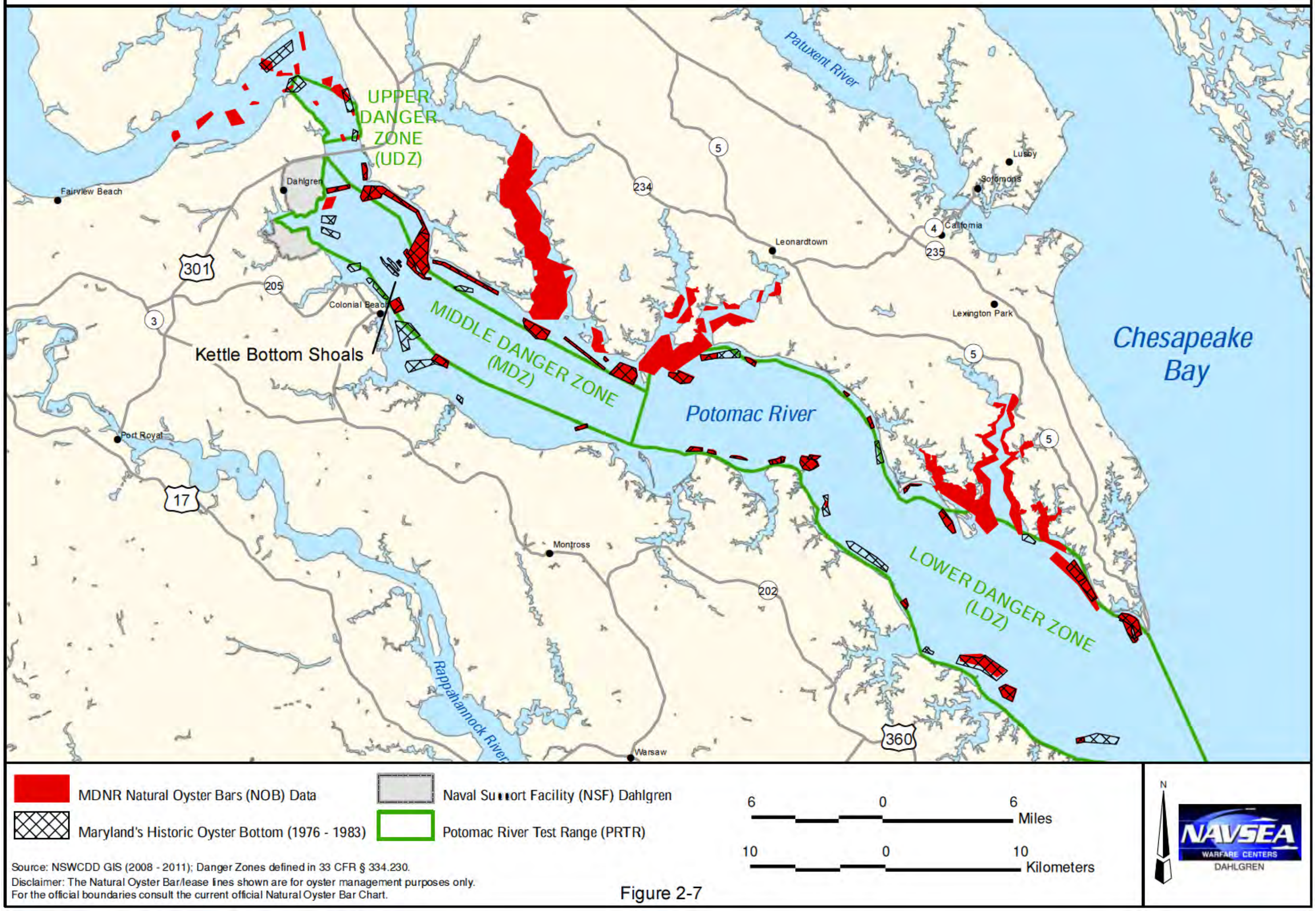


Figure 2-7

Sediments - Lower Potomac River

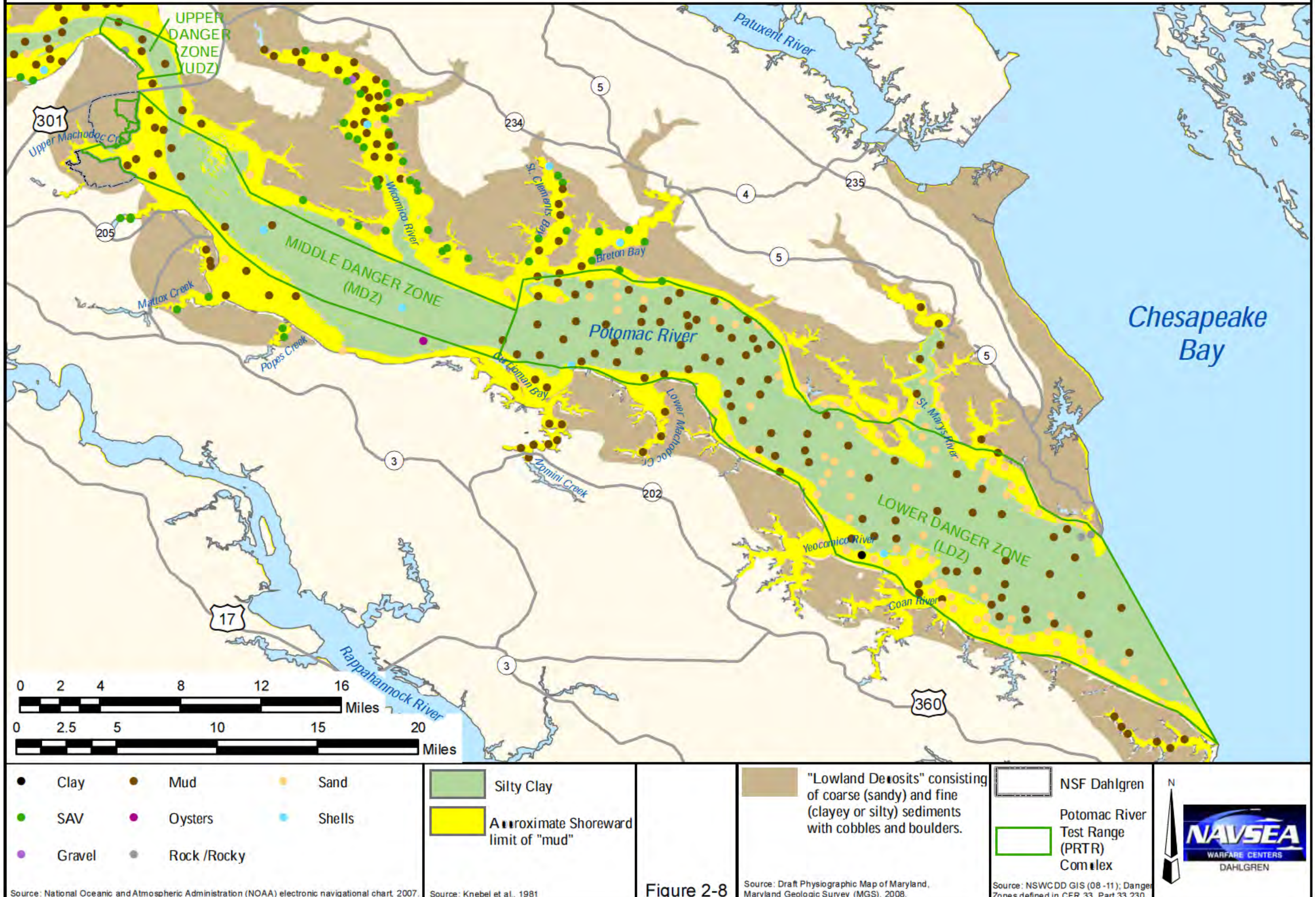


Figure 2-8

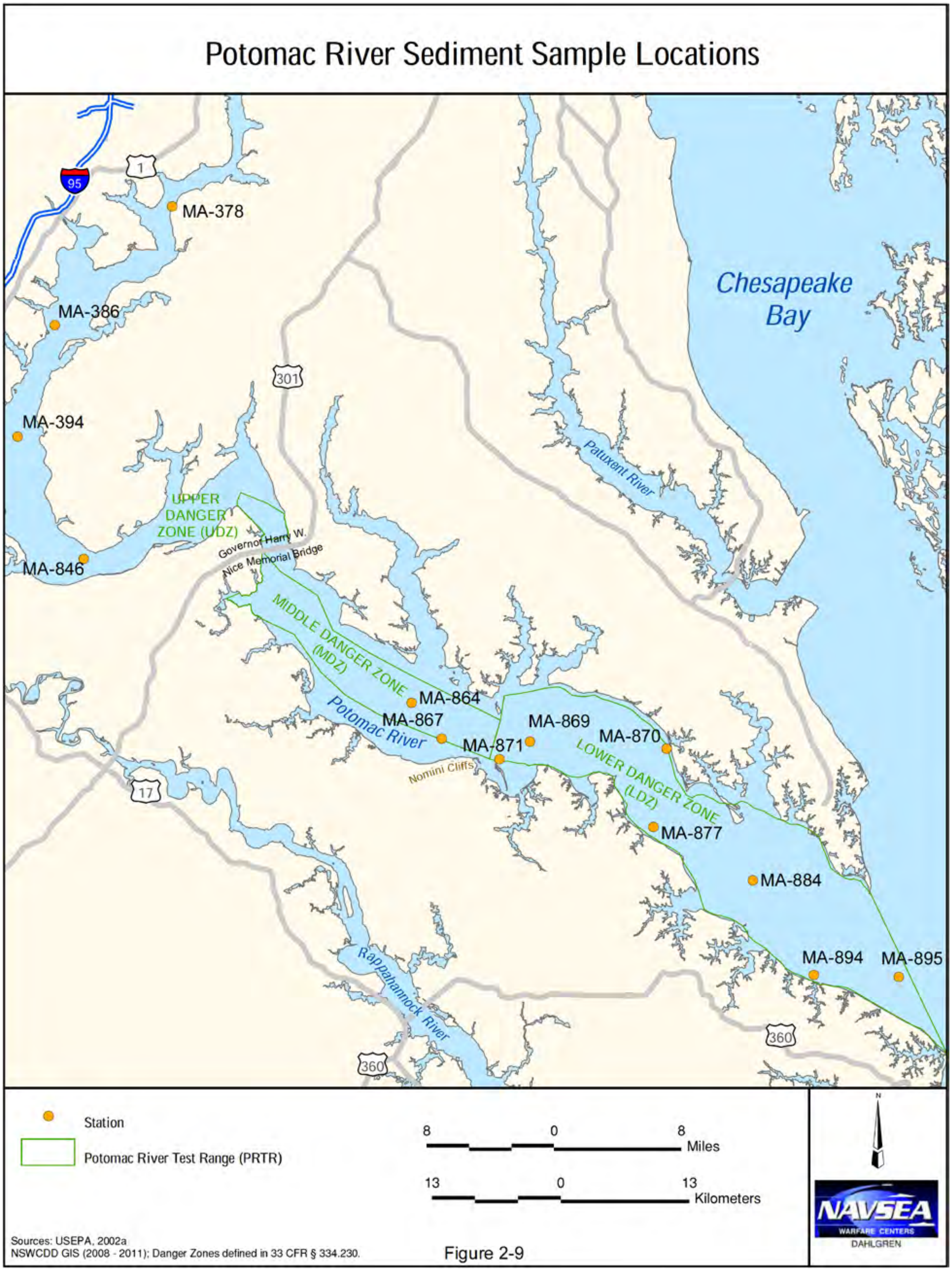


Figure 2-9

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

Analytical data for metal concentrations in the Potomac River sediments are also available from a sediment study performed by the US Navy in 1972 (Houser and Fauth, 1972) and data collected in 1997 by the USEPA for the Mid-Atlantic Integrated Assessment (MAIA) (USEPA, 2007).

The findings of the 1972 sediment study (Houser and Fauth, 1972) indicated that:

- Lead content was highest at the Woodrow Wilson Bridge and the Nice Bridge. The lead content was thought to be associated with heavy traffic loads on the bridges. Leaded fuel was still commonly used in 1972, with the USEPA issuing the first reduction standards in 1973. In 1996, the Clean Air Act banned the sale of leaded fuel.
- Copper, chromium, and nickel concentrations at the Woodrow Wilson Bridge and Piscataway Creek appeared to be associated with major wastewater treatment facilities, the outfalls of which are in the vicinity. (Upgrades have been made to wastewater treatment in this area since 1972.)
- There were significant increases in lead, cobalt, chromium, cadmium, zinc, nickel, barium, aluminum, iron, and lithium in the area near the Woodrow Wilson Bridge in comparison with levels measured above and below this area.

The 1972 report concluded that most of the metals present in the sediments were chemically bound and would require both heat and low pH to be converted to soluble form. However, disturbing the sediments (by, e.g., turbulence, dredging, changes in physical or chemical environment, or biological activity) may cause redistribution and partial solution of some of the metals. A recommendation was made for further studies, particularly on lead, manganese, and other heavy metals.

The USEPA MAIA program sampled Potomac River sediments as part of the Chesapeake Bay watershed study (USEPA, 2002a). The MAIA study determined that the Potomac River had especially high levels of nearly all metals tested in the program. Based on comparisons of Potomac River sediments to sediment-toxicity screening levels from Long et al. (1995), the sediment quality of the freshwater Potomac was generally classified as “poor;” the brackish area (where the PRTR is located) was characterized as “intermediate” and “good,” with one station characterized as “poor;” and the Chesapeake Bay area below the Potomac River was generally “good,” with some “intermediate” stations.

Available metals concentrations from the MAIA study for sediment samples collected within the boundary of the PRTR are presented in Table 2-7. Concentrations for samples collected within 18 NM (33 km) upstream of the PRTR are shown in Table 2-8. The sample locations are shown on Figure 2-9. Of the nine sample locations within the PRTR, two are in the lower portion of the MDZ and seven are in the LDZ.

The MAIA sediment-sample results support previous findings indicating that the highest concentrations of metals occur in the Upper Potomac River with concentrations decreasing downriver (Velinsky, 2004). Within the PRTR, concentrations of metals at upstream sediment-sample locations, in the MDZ, and in the upper portion of the LDZ are higher than at downstream sediment-sample locations. The sediment samples in the MDZ, closest to areas of heaviest RDT&E activities (sample locations MA-864 and MA-867; see Section 3.3 for a discussion of munitions testing), do not show an increase in overall metal concentrations when compared to other locations. Although limited, the available metals-concentration data for sediments in the area of the PRTR suggest that munitions RDT&E activities have not impacted sediment quality based on measured concentrations of the metals in sediments relative to upstream areas (see also Table 5-13 for more upstream sediment concentrations).

Table 2-7
Potomac River Sediment Sample Results - Stations within the PRTR

Potomac River Sediment Sample Analysis									
Compound	Sample Stations Located within the PRTR								
	864 (MDZ)	867 (MDZ)	869 (LDZ)	870 (LDZ)	871 (LDZ)	877 (LDZ)	884 (LDZ)	894 (LDZ)	895 (LDZ)
Total Metals Analysis (µg/g, or ppm)									
Cadmium	0.703	0.764	0.848	0.105	0.219	0.823	0.865	0.0517	0.736
Chromium	90.5	88.1	85.9	9.92	18.2	70.9	85.8	17.6	81.5
Copper	46.6	49.1	48.5	3.46	3.52	37	43.3	3.88	34.3
Lead	40.5	42.8	39.8	5.17	5.24	30.7	37.5	6.68	29
Manganese	648	735	669	158	150	528	452	188	422
Nickel	51.8	52.3	48.4	8.66	6.75	37.9	45.6	7.74	41.7
Zinc	206	215	205	19.4	17	167	186	21.3	152
Simultaneously Extracted Metals Analysis (micromoles/g)									
Cadmium	0.00732	0.00822	0.00627	0.000838	0.00189	0.00699	0.00678	0.00041	0.00532
Copper	0,404	0.397	0.283	0.0442	0.0189	0.272	0.258	0.0266	0.165
Nickel	0.223	0.269	0.168	0.0247	0.0186	0.151	0.166	0.0137	0.136
Lead	0.175	0.188	0.117	0.00936	0.0097	0.107	0.104	0.00758	0.0748
Zinc	1.90	2.13	1.48	0.181	0.118	1.45	1.42	0.0918	1.05
Source: USEPA (2002a).									

Table 2-8
Potomac River Sediment Sample Results - Stations Upstream from the PRTR

Potomac River Sediment Sample Analysis				
Compound	Sample Stations Located Upstream			
	378	386	394	846
Total Metals Analysis (µg/g, or ppm)				
Cadmium	0.395	0.569	0.571	0.56
Chromium	63.4	83.7	84.2	83.1
Copper	32.5	49	48.3	46.2
Lead	33.9	44.1	45.1	45.3
Manganese	1120	2520	1490	2320
Nickel	38.2	53.7	54.9	54
Zinc	156	215	219	215
Simultaneously Extracted Metals Analysis (micromoles/g)				
Cadmium	0.0015	0.0017	0	0.0011
Copper	0.252	0.2	0.053	0.148
Nickel	0.228	0.213	0.048	0.189
Lead	0.0956	0.114	0.022	0.101
Zinc	1.44	1.43	0.304	1.21
Source: USEPA (2002a).				

THIS PAGE INTENTIONALLY LEFT BLANK

3 MUNITIONS USE ON THE POTOMAC RIVER TEST RANGE

This chapter provides a detailed description of the use of munitions on the PRTR from its establishment in 1918 to the present time. Section 3.1 provides a history of munitions use on the range. Over the years, munitions or ordnance RDT&E activities on the PRTR have involved not only gun firing, but also aircraft bombing, the firing of rockets, mortars, and grenades, the deployment of anti-submarine devices such as depth charges and mines as well as gun testing against armor plate, among many other kinds of activities. Section 3.2 describes current munitions activities on the PRTR as well as NSWCDD's proposed future activity levels. Section 3.3 describes the number, type, and targets of the projectiles fired on the PRTR between 1918 and 2007 as recorded in available firing logbooks as well as the munitions constituents contained in the projectiles recorded.

3.1 Historical Munitions Use on the PRTR

The US Navy established the Naval Proving Ground at Dahlgren, Virginia during World War I "to obtain the long ballistic water range (40,000 yds) [36,576 m] required for testing modern, high-power guns" (Rife and Carlyle, 2006). The rural site selected provided a straight, almost unimpeded, over-water range of nearly 90,000 yds (82,296 m) towards the Chesapeake Bay (approximately 43 NM or 80 km downriver). The site was selected when the 13,000-yd (11,887-m) Naval Proving Ground at Indian Head, Maryland, 22 mi (34 km) to the north, reached the breaking point from the exponential increase in gun testing during the war. Also, full elevation testing and accurate ranging of the powerful 16" battleship gun developed in 1914 could not be achieved within the confines of the small river range at Indian Head. On the 16th of October, 1918, US Marines fired the first shot from a 7"/45 tractor-mounted Army gun down the Potomac River on the new proving ground (Rife and Carlyle, 2006).

First gun about to be fired at the US Naval Proving Ground, Dahlgren, Virginia on October 16, 1918

Since 1918, the Navy has used the PRTR continuously for ranging and proving naval guns. The river range has also been used for testing many types of ordnance, including all types of ordnance used by the US Navy and US Marine Corps on ships, aircraft, or land. From its beginnings, Dahlgren was also involved in the development and testing of new weapons. Over time, this work came to dominate RDT&E activities at the installation.

The tempo of testing and operations and, therefore, the rate at which ordnance and other materials has been deposited in the PRTR, has varied through the more than 90 years the range has been in operation. Testing and operations increased during war years – World War II (1939-1945), the Korean War (1950-1953), the Vietnam War (circa 1964-1975), the Persian Gulf War (1991-1992), the Iraq War (2003- 2011), and the ongoing war in Afghanistan (2001-). During war years, the need to ensure that ordnance items received from manufacturers met military specifications before being delivered to ships resulted in the exponential growth of lot acceptance and proof testing activities.

The tempo of operations is also influenced by the development of new weapons and weapon systems requiring RDT&E. RDT&E activities are cyclical by nature, and tests on a particular type of weapon, weapon component, or weapon system may take place once every three, five, or even ten years. When the weapon or system is being tested, it may be tested daily for weeks or months. Hence, firing levels may be higher in a particular year because a new gun or a new type of ammunition is being tested. Warfare spurs the development of new technology, which contributes to the increased amount of RDT&E activity taking place during wartime.

After World War II, Dahlgren Naval Proving Ground continued testing gun components, projectiles, and fuzes. However, this role gradually became a smaller portion of its work, as the installation built upon its early use of simple computers in developing new technologies, such as ballistic missile systems and warheads, and evolved into one of the Navy's primary research centers. In 1959, the Navy officially recognized the change in the installation's mission from traditional proving ground to research and development facility by changing its name from the Naval Proving Ground to the Naval Weapons Laboratory (Rife and Carlyle, 2006).

At the beginning of the 1970s, with the Vietnam War still underway, the Navy designated Dahlgren as its lead laboratory for surface weapons, with a particular focus on surface gunnery systems. In 1974, the Navy consolidated the Dahlgren Naval Weapons Laboratory with the White Oak Naval Ordnance Laboratory, located in Silver Spring, Maryland. This created the Naval Surface Weapons Center (NSWC), Dahlgren Division. The two sites were identified as the Dahlgren Laboratory (NSWCDL) and White Oak, respectively (Rife and Carlyle, 2006).

In 1976, the Navy chose NSWCDD to develop the Aegis Combat System, designed to use powerful computers and radars to track and destroy enemy targets and to defend against air, surface, and subsurface threats. This brought NSWCDD into the emerging field of systems engineering. Recognition of the expanded areas of interest at NSWC resulted in a name change in 1989 to NSWCDD (Rife and Carlyle, 2006). Today, NSWCDD is one of several tenants on NSF Dahlgren.

Thus, from 1918 to the present day, four organizations have fired/dropped/detonated ordnance in the PRTR. For the purposes of this historical review, however, "Dahlgren" is used to refer to all four.

3.1.1 Types of Ordnance Deposited in the PRTR

Many of Dahlgren's past activities have resulted in the deposition of ordnance in the waters of the PRTR. Based on histories of Dahlgren and UXO that has washed up along the shore, the principal contributions to this process have come from the proof testing and RDT&E of:

- Guns (small- and large-caliber)
- Aircraft bombs and guns
- Rockets
- Anti-submarine warfare devices
- Mortars and grenades
- Metal plate

However, a myriad of other types of ordnance has gone into the river as well, although in lesser quantities. With the exception of gun firing logs, which form the basis of the analysis presented later in this report, NSWCDD has virtually no records of the quantities of ordnance expended or of exactly where they were deposited in the river. General histories of Dahlgren, however, provide some clues, as described below.

A Range Survey Form prepared by NSWCDL in 1976 (NSWCDL, 1976) summarized the use of the river range to that date:

> The river range…has been receiving ordnance items for the past 58 years [in 1976] on an almost daily basis. Almost every type of naval ordnance is probably at rest here, as well as many Army and Air Force items. Although the heaviest projectile concentrations probably lie in the vicinity of 10,000 (9.144 km) and 25,000 (22.86 km) yards from the Station, there is probably no range at which some type of firing has not been done over the years. Stations records show that since 1960 as many as 57,000 rounds (1969) of projectiles and rockets per year were fired into the Potomac River Range (exclusive of machine gun fire). During WW II the quantity of these items was probably greater, plus thousands of bombs and mines. Many are fuzed and explosive loaded and would detonate if handled or impacted.

The ordnance and materials in the river include not only domestic products, but also foreign ones. Indeed, during World War II, when enemy guns and other ordnance were captured, they were fired/detonated/dropped into the river range to better understand their capabilities and to improve ways to defend against them. Ordnance developed by our allies was also tested. For example, a list of guns in World War II gun batteries at Dahlgren includes a number of British naval and army guns (Hedrick, 1947).

Possibly the largest object deposited in the river by Dahlgren – and an example of the many one-of-a-kind research projects for which no records remain as well as an example of research on foreign weapons – was the rubber-sheathed World War II German submarine U-1105. This submarine was one of fewer than ten produced during the war that was outfitted with an experimental synthetic rubber skin designed to counter Allied sonar devices. Its black rubber coating earned it the nickname "Black Panther" (Maryland Historical Trust, 2009). The wreck is located off Piney Point in the LDZ and was included in the charter list of Marine Protected Areas (MPAs) by the National Oceanographic and Atmospheric Administration (NOAA) in April 2009 (Maryland Historical Trust, 2009).

The Naval History and Heritage Command, which is responsible for US Naval shipwrecks, has identified a small number of other shipwrecks and a few aircraft wrecks within the PRTR. Within the lower Potomac River, approximately half of the known naval shipwrecks date from the Civil War, having often been lost during combat; the rest date to the first half of the 20th

century and mostly appear to have been sunk for test practice or fleet reduction (Naval Historical Center, 2008).

Table 3-1 summarizes the major types of ordnance known to have been deposited in the PRTR. Figure 3-1, Historical Ordnance Deposition in the PRTR, illustrates the locations described. As previously noted, NSWCDD no longer has any records that detail the quantities of most types of munitions expended or the exact location of the target areas. The exception is gun firing log books, which are available for most years since the range began operations. The number of projectiles fired into the PRTR over time, as listed in the firing log books, is described in Section 3.3.

3.1.2 Gun Projectiles

Less than a month after the first gun was fired at Dahlgren in 1918, World War I ended. By August 1921, construction at Dahlgren was largely complete and most of Indian Head's ordnance work had been transferred to the new site. The end of World War I led to a sharp decrease in ordnance testing, but by 1923, Dahlgren's work along developmental and experimental lines was increasing rather than decreasing (Rife and Carlyle, 2006).

From 1919 to 1945, the Ordnance Division was divided into two parts: routine proof and test of production ordnance material, and experimental tests or original investigations (Hedrick, 1947). Some of the most notable work done in the 1920s included: studies of the thermodynamics of guns; fuel oil ignition by projectile bursts; tracer shells; mechanically-timed fuzes; illuminating and marker projectiles; anti-submarine ordnance fuzes; and aerial bomb tests (Rife and Carlyle, 2006).

A ten-year post-World War I slowdown in capital ship building came to an end in 1932 with the election to the US presidency of Franklin D. Roosevelt, former Assistant Secretary of the Navy, and the initiation of the New Deal in 1933. By the end of 1934, 150 new ships were under construction or in planning. Dahlgren's proving work boomed. The pace of experimental research also quickened. Projects included the determination of ballistic qualities of all types of guns and shells; research to improve armor plates; the development of improved 8" armor piercing projectiles; and the development of new fuzes (Rife and Carlyle, 2006).

Live and Inert Projectiles

Projectiles used at Dahlgren can be live (explosive) or inert (non-explosive). Live projectiles are composed of energetic material (the explosive core or the propellant for a projectile), plus an outer casing, fragmentation material, a fuze (a detonating device), sensors, timers, or other items. Inert projectiles have a core composed of sand or concrete with no energetic material – no explosive core – but could have a fuze with a small amount of explosive material, a sensor, or other items for testing.

Table 3-1
Major Types of Munitions Used on the PRTR from 1918 to Present

Type of Munitions	Target Area in PRTR	Time Range
Large-Caliber Guns (more than 20 mm)	Projectiles fired primarily from the Main Range gun line, but also from the AA Fuze Range, Terminal Range, and Missile Test Range. Historically, projectiles mainly fired into the MDZ; rarely into the LDZ. In the last two decades, projectiles fired only into the MDZ.	1918-Present
Small-Caliber Guns (less than or equal to 20 mm)	Bullets fired primarily from the Machine Gun Range, but also from other land ranges and historically from the EEA machine gun range from 1941 to 1960. Bullets generally land within 1,000 ft[1] (historically) (305 m) to 2,000 ft (currently) (610 m) of the shoreline in Upper Machodoc Creek or the Potomac River.	1918-Present
Aircraft Bombs and Projectiles	Wooden platform bombing targets were located in the MDZ prior to World War II. Wooden platform target(s) were added in the UDZ early in World War II. Targets in the EEA and Upper Machodoc Creek were added in 1944.	1919-1957/1958
Rockets	From 1944 until 1965, rockets were launched into the MDZ from the Missile Test Range. Smaller rockets generally landed within 1,000 ft[1] (305 m) of the shoreline. Larger rockets and missiles were fired at unknown target areas in the deeper waters of the MDZ. From 1964 to 1974, rockets were fired from the Main Range 2,000 yards (1,829 m) into the MDZ.	1944-1974
Anti-Submarine Warfare Devices (mines, depth charges, torpedoes, bombs)	Depth charges during World War II were concentrated near the shoreline of the Missile Test Range. Fuze work was concentrated near the shoreline of the AA Fuze Range. Locations where mines and torpedoes were tested and target areas for aircraft-dropped items are unknown.	1919-1970s
Mortars and Grenades	Shells and grenades were fired from the Terminal Range, Main Range, AA Fuze Range and Machine Gun Range into the river, generally within 1,000 ft[1] (305 m) of the shoreline. Mortar shells were fired more to the north and grenades were fired more to the south.	?-Present
Armor Plate and Impact Fuze Testing	Projectiles were fired from the Missile Test Range towards hanging armor plate or into the river. The projectiles generally landed within 1,000 ft[1] (305 m) of the shoreline but some likely landed in the deeper waters of the MDZ.	1921-Present (Recent armor plate testing on land only)

Notes: Based on records that are not continuous or complete.

[1] The 1976 Range Survey Form (NSWCDL, 1976) shows rockets, machine gun bullets, mortars, and grenades landing in a band within 1,000 ft (305 m) of the shoreline, but this distance may have been merely illustrative since the survey was focused on the land ranges. Ordnance – especially rockets – may have been fired farther.

Sources: Hedrick, 1947; McCollum, 1976; NSWCDL, 1976; Rife & Carlyle, 2006

According to a 1977 history entitled *Dahlgren*, "All projectiles fired at the Proving Ground before World War II were inert" (McCollum, 1977). Similarly, Captain Hedrick, in charge of Dahlgren during World War II, commented in his history (1947) that "Prior to the war, nearly all projectiles fired at the Proving Ground were inert loaded."

Beginning with mobilization in 1940 and escalating when America entered World War II in December 1941, Dahlgren's programs underwent massive expansion. Land was added, many new facilities were built, and the configuration of today's land ranges was set.

As World War II began, Captain Hedrick (1947) noted that:

> When it became apparent, after considerable shooting, that inert loaded projectiles did not give consistent results, the duties of the Ammunition Department shifted from inert ammunition to a higher percentage of loaded ammunition. Also, the emphasis of fuze testing, which developed from war-time use of high explosive loaded projectiles, shifted the duties of the Ammunition Department from inert loading and target practice ammunition to live loaded war-time ammunition.
>
> During the pre-war years the quantity of work at the Proving Ground increased with the general Naval Building Program. Just prior to 1940 the development of the 1.1" machine gun and the 5"/38 gun had produced a relatively large amount of work. In general, there was no more than one major caliber firing per week involving, at the most, ten rounds. Those powders which were proved or re-proved from time to time required less than ten projectiles and, in many cases, major caliber guns were proved with only five rounds of firing, there being no powder or master powder to test. The quantity of medium caliber projectiles fired probably averaged under 50 rounds per day from 1930 to 1940. In July 1945 this had risen to approximately five thousand rounds of loaded ammunition, 3" and larger, per week.

Naval Guns

Naval gun designations generally include the: (1) model or reference designation; (2) modification designation to indicate a change from the original design; (3) caliber (diameter of the bore); and (4) barrel length, which is described in multiples of the diameter of the bore.

For example, the description **MK 45 Mod 1/2 5"/54** means that it is the 45th version of the 5" gun; has the first and second modifications to the Mark (MK) 45 design; has a 5"-diameter bore; and has a barrel 5" x 54" = 270" long.

The gun firing logs that are the basis of the analysis in this report (see Appendix A) do not reflect the intense gun firing tempo described in Captain Hedrick's history of Dahlgren during World War II. Some of the discrepancy may be due to the extensive testing of new anti-aircraft artillery guns, which fired up to 5" projectiles, and do not appear to be accounted for in the gun firing logs. Projectiles fired at the Plate Batteries (Figure 3-1) to test metal plate bound for Navy ships also do not appear to have been accounted for in the gun logs. Fuze testing for bombs, projectiles, and rockets at the Anti-Aircraft Fuze Battery as well as at other batteries also may not have been included in the gun firing logs. Indeed, the logs appear to focus primarily on medium- and large-caliber guns fired from the main gun batteries. In any case, large quantities of many types of ordnance were fired or dropped into the PRTR during World War II for which NSWCDD has no records.

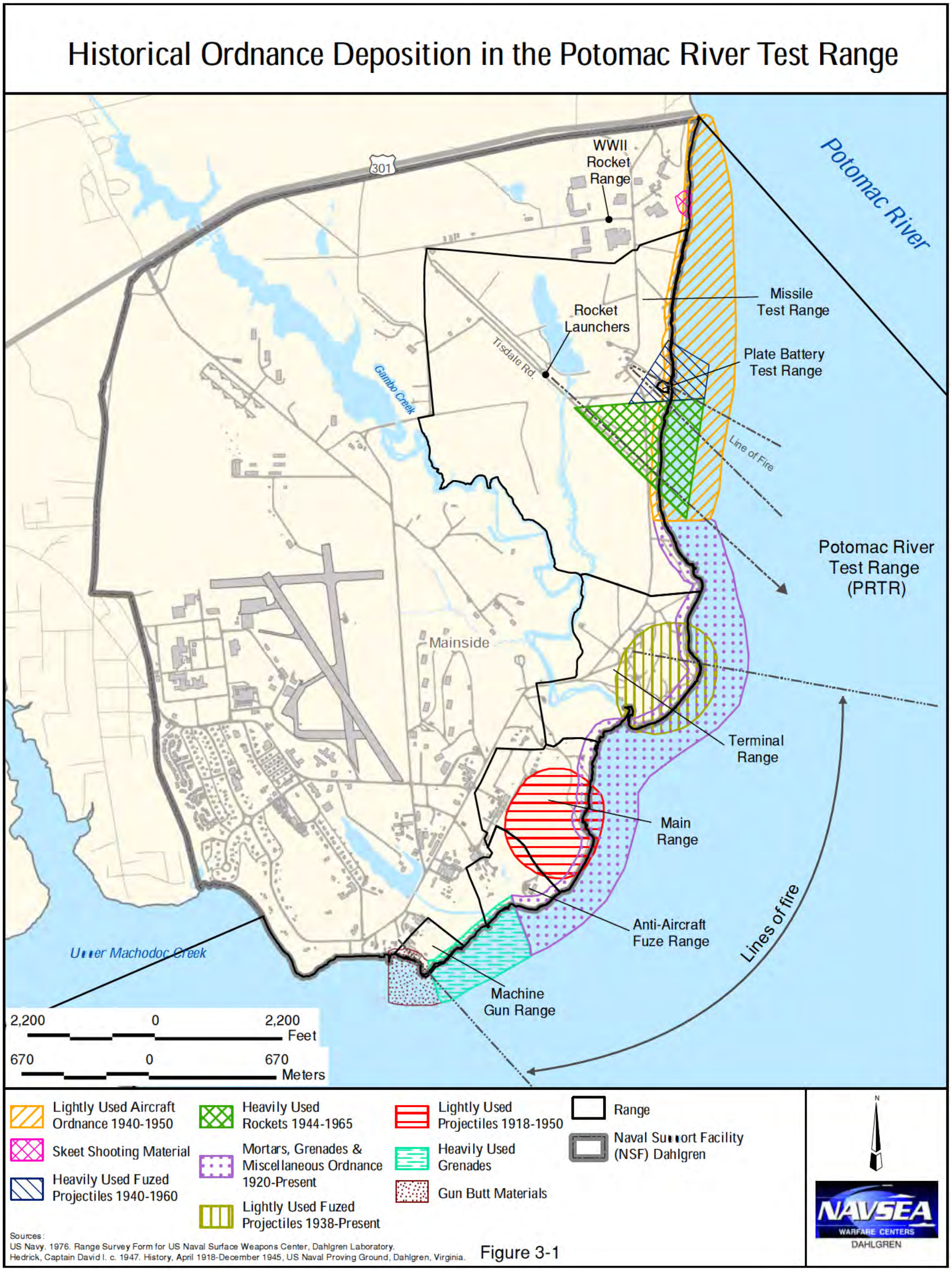

Historical Ordnance Deposition in the Potomac River Test Range
301
WWII Rocket Range
Potomac River
Missile Test Range
Rocket Launchers
Tisdale Rd.
Plate Battery Test Range
Gambo Creek
Line of Fire
Potomac River Test Range (PRTR)
Mainside
Terminal Range
Main Range
Anti-Aircraft Fuze Range
Lines of fire
Upper Machodoc Creek
Machine Gun Range
2,200 0 2,200 Feet
670 0 670 Meters
Lightly Used Aircraft Ordnance 1940-1950
Skeet Shooting Material
Heavily Used Fuzed Projectiles 1940-1960
Heavily Used Rockets 1944-1965
Mortars, Grenades & Miscellaneous Ordnance 1920-Present
Lightly Used Fuzed Projectiles 1938-Present
Lightly Used Projectiles 1918-1950
Heavily Used Grenades
Gun Butt Materials
Range
Naval Support Facility (NSF) Dahlgren
N
NAVSEA WARFARE CENTERS DAHLGREN
Sources:
US Navy. 1976. Range Survey Form for US Naval Surface Weapons Center, Dahlgren Laboratory.
Hedrick, Captain David I. c. 1947. History, April 1918-December 1945, US Naval Proving Ground, Dahlgren, Virginia.

Figure 3-1

Captain Hedrick reported (1947) that during World War II, proof testing accounted for approximately 50 percent of the volume of work; experimental testing for 25 percent (new type of materials, including foreign ones; materials with design changes or composition or unknown composition); and RDT&E for 25 percent (effects of abnormal conditions on materials and causes of failure). A notable amount of RDT&E effort went into developing the variable time (VT) fuze, to which at least 50 percent of the Ammunition Department's work was devoted. By June 1941, personnel were working six days a week, two shifts a day, and firing "until late at night" (Hedrick, 1947).

Also during World War II, millions of small-caliber gun rounds were fired on land into gun butts and into the river for proof testing as well as experimental and research work. The Machine Gun Range was set up early in the war, followed by a second range on today's EEA that fired overland north into Upper Machodoc Creek (Hedrick, 1947). The machine gun range on the EEA (Figure 3-2, Historical Aircraft Bombing Ranges and Target Areas) operated from 1941 until 1960 (NSWCDL, 1976). The Machine Gun Range is still the site of most smaller-caliber firing, but today most firing takes place either indoors or outdoors, into gun butts.

After World War II, as noted above, gun proof testing and experimental work soared during wars and continued at lower levels during peacetime. Gradually, as computers became more proficient, computer programs were able to simulate many of the gun ranging, proof testing, and RDT&E operations, greatly reducing the number of projectiles that needed to be fired. As a result, the number of projectiles fired annually has fallen dramatically since the 1960s and 1970s.

3.1.3 Aviation Ordnance

It became apparent during World War I that aircraft would play a significant role in future conflicts, and aviation ordnance was tested at Dahlgren almost as soon as the first gun was fired. A seaplane hangar was built in 1919 and soon after, a land plane hangar and landing strip were added. During the 1920s, when funds for guns dried up, some of the most notable work done at Dahlgren consisted of aerial bomb tests. During the 1920s and 1930s, Dahlgren's work included RDT&E and proofing of dive bombers, aerial bombs, aerial machine guns, and bombsights (a device used to accurately drop bombs). Every naval airplane that had a machine gun or drop bomb was sent to Dahlgren for testing. High altitude bombing tests were conducted to determine if bombs would penetrate metal plate. Low-altitude bombing of submarines was also part of Dahlgren's RDT&E work at that time (Rife and Carlyle, 2006).

Prescient and decades ahead of their time were studies conducted from 1919 to 1925 of automatically piloted ("flying bombs") and radio-controlled aircraft, much like today's unmanned aerial vehicles. Carl L. Norden worked with Dahlgren's scientists and engineers on these projects as well as on improving bombsights (Rife and Carlyle, 2006). During the 1920s, aircraft made many flights to support RDT&E of Norden's first bombsights for horizontal bombing and dive bombing (McCollum, 1976). Beginning in the 1920s, aviators practiced both horizontal and dive bombing, and often experimented with high-altitude horizontal bombing. The increased number of high-altitude bombing experiments prompted the Secretary of the Navy to restrict air space north and south of the installation in the early 1940s (Rife and Carlyle, 2006).

In 1931, Dahlgren began flight testing of Norden's Mark XV bombsight, a form of analog computer and a vast improvement over earlier models. Considered one of the most effective weapon systems of World War II, it saw heavy action over the skies of Nazi Germany and Japan. Dahlgren's role in the development of the Norden Mark XV bombsight rooted Dahlgren firmly within the field of mechanical computational technology (Rife and Carlyle, 2006).

During World War II, the Aviation Ordnance Department performed a considerable amount of acceptance testing and RDT&E work on aircraft armament, aircraft ordnance equipment (bombsights and aircraft bombs), and aviation special projects involving rockets, fuzes, explosives, bombs, mines, and pyrotechnics. The Dahlgren airfield was expanded and an Aviation Experimental Laboratory was established to develop and test rocket-propelled armor-piercing bombs, incendiary bomb clusters, and experimental target-identification bombs (Hedrick, 1947). A bombsight school operated at Dahlgren from March 1938 until early 1943, when it moved to Naval Air Station (NAS) Jacksonville, Florida. Aircraft used to perform tests were based at the Dahlgren airfield, as well as at NAS Patuxent River, Maryland and Chambers Field, NAS Norfolk, Virginia. During this time, assigned flights from Dahlgren's Naval Air Facility were mostly in conjunction with or assisting in the testing of naval ordnance (Rife and Carlyle, 2006).

In the years following World War II and through the Korean War, jet propulsion technology changed airborne weapons development and flight testing. Dahlgren worked on problems associated with bombing from new high speed jets and ways for jet fighter pilots to avoid running into their own decelerating 20 mm projectiles seconds after firing them. However, Dahlgren could not host jet aircraft because its airfield runways were too short, and flight operations were transferred to the Naval Aviation Test Center at Patuxent River, Maryland in 1957 (Rife and Carlyle, 2006). (Note that a 1976 Range Survey Form map [NSWCDL, 1976] indicates that bombing stopped at Dahlgren in 1958; therefore, Table 3-1 lists bombing through 1957/1958.)

While no records remain at Dahlgren, if any were kept, of the number of bombs and other types of ordnance dropped or bullets fired from aircraft from 1919 to 1957, the number of personnel involved and the levels of activity reported through the years suggests that a considerable number of pieces of ordnance (and at least a few aircraft) ended up in the river. In the 1930s, targets were added in the river off the seaplane hangar (possibly the Mussolini target on Figure 3-2), and later another one was set upriver (possibly the Hitler target shown on Figure 3-2). Activity increased because "bombsights [were] coming through in such numbers we had to have several planes testing at one time dropping bombs" and "we had to drop eight bombs with every bombsight that came through" (McCollum, 1976). Anecdotal evidence from the installation histories suggests that at least some of the bombs dropped were live, and the 1976 Range Survey (NSWCDL, 1976) noted that many bombs that had been discovered (on land ranges) in recent years were filled with explosives and fuzed.

Pumpkin Neck, now the EEA, was purchased in 1944 to expand the number of bombing target areas because of the heavy demand for proof testing during wartime (Rife and Carlyle, 2006). The UDZ was the location of a bombing range (around the Hitler Target shown on Figure 3-2) that the 1976 Range Survey (NSWCDL, 1976) noted was "heavily used" and in 1976, bombs were being found along the Mainside shoreline, presumably having washed down from the bombing range north of the Nice Bridge:

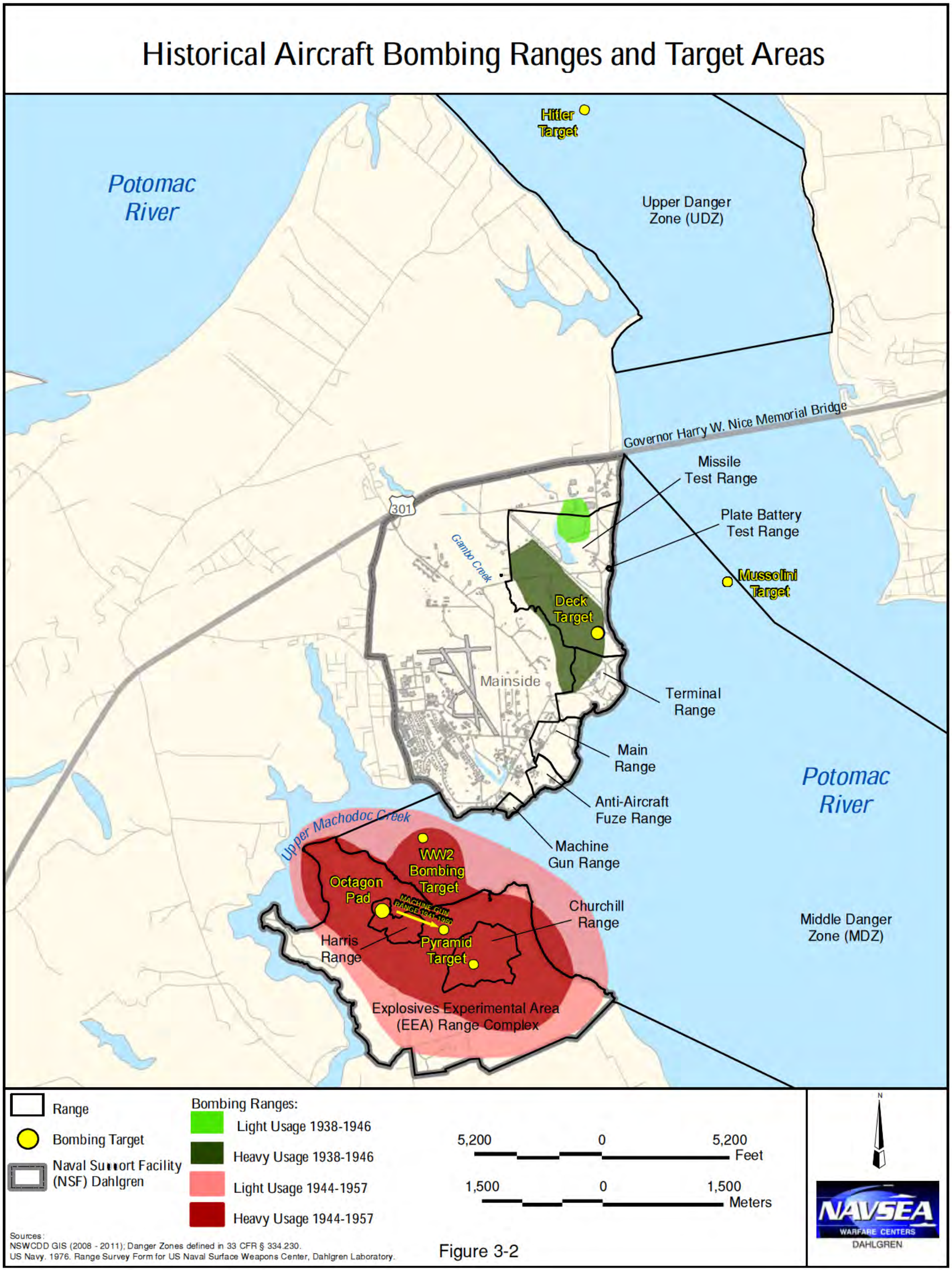

Historical Aircraft Bombing Ranges and Target Areas
Hitler Target
Potomac River
Upper Danger Zone (UDZ)
Governor Harry W. Nice Memorial Bridge
301
Missile Test Range
Plate Battery Test Range
Gambo Creek
Mussolini Target
Deck Target
Mainside
Terminal Range
Main Range
Potomac River
Anti-Aircraft Fuze Range
Upper Machodoc Creek
Machine Gun Range
WW2 Bombing Target
Octagon Pad
MACHINE GUN RANGE 1941-1960
Churchill Range
Middle Danger Zone (MDZ)
Harris Range
Pyramid Target
Explosives Experimental Area (EEA) Range Complex
Range
Bombing Target
Naval Support Facility (NSF) Dahlgren
Bombing Ranges:
Light Usage 1938-1946
Heavy Usage 1938-1946
Light Usage 1944-1957
Heavy Usage 1944-1957
5,200 0 5,200 Feet
1,500 0 1,500 Meters
N
NAVSEA WARFARE CENTERS DAHLGREN
Sources:
NSWCDD GIS (2008 - 2011); Danger Zones defined in 33 CFR § 334.230.
US Navy. 1976. Range Survey Form for US Naval Surface Weapons Center, Dahlgren Laboratory.

Figure 3-2

> The waters bordering the Explosive Experimental Area are continually revealing old bombs and mines. This is true not only of the Potomac River but also in Machodoc Creek, since there were several targets for aircraft bombing located in the creek. One in particular is recalled as being in section c-18. The soft creek bottom makes it difficult to locate any of those underwater (NSWCDL, 1976).

While Figure 3-2 shows two aircraft bombing targets on the EEA and one in Upper Machodoc Creek, the 1976 Range Survey indicated that there were several targets in the creek and that a number of targets were used on the EEA.

3.1.4 Rockets

Although primitive rockets had been used in warfare for centuries, it was during World War II that new technological developments led to their becoming a major weapon, as illustrated by Germany's V-2 rocket program. American military rocket programs began in the mid-1940s. The total production of US military rockets went from zero in 1940 to a billion rounds per year by 1945. Dahlgren participated in rocket RDT&E in 1940 and 1941, working on rocket propulsion for armor-piercing bombs (Pearson, 1995).

By June 1944, heavy rocket testing led to the establishment of a separate rocket battery on Tisdale Road (Figure 3-1) (NSWCDL, 1976). The battery, aimed southeast towards the river, had a down-river range and two land ranges with 16 rocket launchers. The land ranges were used for ranging beach barrage rockets as well as mousetrap and hedgehog ammunition (see Section 3.1.5). The down-river range was used for ranging all types of rockets and launchers, for water impact tests of rocket fuzes, and for experimental tests of rocket fuzes, ammunition, and launchers. Rockets fired monthly were 1,252 in January, 1945 and 1,677 in July, 1945 (note, a breakdown between the water and land ranges was not provided) (Hedrick, 1947).

During World War II, rocket fuzes were also tested at the AA Fuze Battery with much firing into the water. VT rocket fuzes were tested in aircraft as well. The World War II Aviation Experimental Laboratory developed and tested rocket-propelled armor-piercing bombs (Hedrick, 1947). Near the end of the war, the pace of rocket firing was so intense that a Women Accepted for Volunteer Emergency Service (WAVES) officer stationed at Dahlgren, writing to friends, was bothered more by the noise of rocket firings than by that of guns or bombs:

> The rockets are difficult to not hear. We all try to build up resistance to hearing the firing. A recently developed rocket sounds like galloping horses. Of course the sound is magnified many times, and the rhythm is very fast. They are too fast to be counted part of the time. Once we counted 96 in about 20 seconds. (Unidentified Author, 1945)

Following World War II, two long horizontal rocket launchers located on Tisdale Road fired rounds by the uncounted thousands down Tisdale Road into heavy targets on the Potomac River shoreline:

> In the adjacent open field, rockets were fired from short, shipboard-type launchers with poor accuracy characteristics…That the area just off shore is similarly populated [with 5" and smaller rocket duds] was indicated a number of years ago when an oysterman dredged up a 5" (127 mm) rocket and later attempted to convert it to a lamp base – with fatal results. (NSWCDL, 1976).

By 1950, rockets as large as 800 lbs (363 kg) and 12.75” (0.32 m) were being fired from Dahlgren’s rocket battery, furthering the development of guided ballistic missiles (Rife and Carlyle, 2006).

From 1964 to 1974, 73,882 2.75” folding-fin aircraft rockets (FFAR) (also known as Mighty Mouse rockets) and 13,817 5” rockets (Zuni rockets) were fired to proof test rockets and rocket launchers. Rockets were fired from the Main Range into the MDZ to a distance of approximately 2,000 yards. Almost all of these rockets were inert and made mainly of steel. The peak firing years were 1967, 1968, 1969, and 1970 – during the Vietnam War – when, respectively, 15,634, 18,053, 14,456, and 15,477 rockets were fired. The number of rockets fired fell precipitously in 1971 and ended in 1974 (Patteson, 2009).

While the location of rocket target areas in the river is unknown, Figure 3-1 shows the nearshore area in the river where rockets are known to have been fired. The location of the rocket target area in the river established during World War II is not known.

Firing of rockets from the rocket battery on Tisdale Road ended by 1965 (NSWCDL, 1976). The location of the rocket target area in the river established during World War II is not known.

3.1.5 Anti-Submarine Warfare Ordnance

During the 1920s, “in light of Germany’s stunning U-boat successes” during World War I, the Navy “became extremely interested in developing countermeasures against submarine threats of the future” (Rife and Carlyle, 2006). As a result, the development of anti-submarine ordnance fuzes was an important field of research at Dahlgren in the years leading up to and during World War II. Whether anti-submarine warfare ordnance was to be dropped from a plane (bombs), launched from a ship (depth charges), or placed in the water (mines), fuzes, sensors, and timing devices were critically important to achieving maximum effect (Rife and Carlyle, 2006). During World War II, different types of fuzes were developed, particularly at the AA Fuze Battery, including delay fuzes, proximity fuzes, magnetic noise fuzes, and hydrostatic fuzes (Hedrick, 1947).

During World War II, Dahlgren fired depth charges and anti-submarine rockets from launchers in the rocket battery area into the river. Hedgehogs were a British depth charge fired from launchers with such powerful recoil that they could only be used on larger ships, such as destroyers. Using the Hedgehog as a prototype, the Navy developed the lighter Mousetrap anti-submarine rocket launcher for smaller ships. Mousetrap rounds were 7.2” (18 cm) in diameter, weighed 65 lbs (29 kg), and carried a 33-lb (15-kg) warhead. Dahlgren tested mines, Hedgehogs, and Mousetraps. Dahlgren also worked on shaped-charge weapons, such as antisubmarine scatter bombs, which were tested underwater. The aviation group tested anti-submarine bombs, aircraft-dropped mines, and torpedoes (Hedrick, 1947).

The use of underwater explosives continued at Dahlgren until the 1970s, when this type of work was transferred to NSWC Panama City, Florida and its large Gulf of Mexico ranges.

3.1.6 Mortars and Grenades

During World War II, short-range mortars and grenade rounds were fired into the river from the Terminal Range, Main Range, AA Fuze Range, and the Machine Gun Range for water impact testing (Hedrick, 1947). Mortars are still tested at Dahlgren. The concentrations of mortar rounds buried in river sediments are heavier to the north, while grenades are heavier to the south (Figure 3-1). Duds still posed sufficient danger in 1976 that recreational use of the shoreline was restricted following two incidents with oyster/crabbing boats (NSWCDL, 1976).

3.1.7 Armor Plate and Impact Fuze Testing

Armor plate testing began at Dahlgren in 1921. It was conducted not only to determine how effective weapons were at piercing the types of armor plate used to fortify ships and submarines, but also to test whether the plate itself could withstand attack. During 1940 and 1941, one program dropped 1,000- and 1,600-lb (454- and 726-kg) bombs from aircraft on horizontal armor plate targets (presumably on land) to determine whether the bombs were capable of piercing the decks of heavily armored vessels. In 1941, a plate battery was established (Figure 3-1) and guns were fired towards the river within the firing lines shown on Figure 3-1 at vertical sheets of plate backed by sand-filled butts. Lot acceptance testing of armor bound for Navy ships also took place. Up to 16" projectiles were fired at heavy plate. Some projectiles were fired into the river in the area that is indicated as "heavy used fuzed projectiles" in Figure 3-1, and perhaps beyond, given that large-caliber guns were used (Hedrick, 1947). Armor penetration tests continue to this day.

During World War II and the Korean War, thousands of live, fuzed projectiles (up to 152 mm [6"] caliber) were fired in this same area for impact fuze testing on a two-shift per day, six-day-a-week basis. Duds were often not recovered because of time constraints, and it is known that many have buried themselves on the Missile Test Range and off shore (NSWCDL, 1976).

3.2 Current and Future Munitions Use on the PRTR

3.2.1 Current Munitions Use on the PRTR

3.2.1.1 Large-Caliber Gun Firing

Over the last 15 years (1995-2009), NSWCDD has fired an average of 2,900 large-caliber (20 mm [0.8"] or larger in diameter[8]) projectiles annually into the river, ranging from a low of 900 fired in the year with the smallest number of firings (2005) to 5,050 in the year with the highest

[8] Early in the WRSEPA and EIS process, large-caliber projectiles were defined as 30 mm or larger in diameter. However, only a few types of projectiles in the 21 mm to 29 mm diameter size range were found in the firing logs with limited numbers of rounds fired. Therefore, when the EIS moved to a large-caliber gun definition that included munitions above 20 mm, munitions between 21 and 29 mm were not added to the WRSEPA assessment because of their minimal contribution to munitions input to the water range.

number of firings (2009). The average for particularly active years is approximately 4,700 large-caliber projectiles fired. The number of projectiles fired annually from large-caliber guns varies based on the types of tests being conducted in a given year. RDT&E testing is cyclical by nature and tests on a particular type of weapon, weapon component, or weapon system may take place once every three, five, or even ten years. When a weapon or system is being tested, it may be tested daily for weeks or months. Therefore, firing levels may be higher than average in a particular year because a new gun or a new type of ammunition is being tested.

Through the decades, NSWCDD's ordnance RDT&E has evolved from single-component testing to warfare systems integration testing with networks connected to most shipboard combat-system elements (such as gun fire control, sensors, radars, and the Naval Fire Control System). The largest gun fired at NSWCDD today is a 155 mm howitzer used by the US Marine Corps and US Army. An 8" gun is fired rarely to launch a canister filled with electronics in order to test the capability of the electronics to withstand high G forces, but the canisters are recovered. The large-caliber guns fired most frequently are 5" guns. The MK 45 Mod 1/2 5"/54, a gun commonly found on ships in the Fleet, has a maximum sustained firing rate of 20 projectiles per minute and a maximum firing range of 13 NM (24 km).

For the years 1995 through 2009, 74 percent of the projectiles fired from the PRTR land ranges into the Potomac River were inert, and 26 percent were live explosive projectiles. The component most often tested on inert projectiles is the fuze or detonator. A fuze or detonator typically contains less than 0.004 lbs (2 grams [g]) of explosive material. A fuze usually also contains a few ounces of non-explosive talcum-like powder to produce a puff of smoke to indicate to observers that the fuze has been successfully triggered. Guns can shoot multiple bursts or intermittent single rounds.

The largest explosive rounds usually fired today are 5" projectiles (155 mm projectiles are fired occasionally), which contain approximately 6 to 10 lbs (2.7 to 4.5 kg) of explosive. For comparison purposes, while the Navy no longer fires large 16" projectiles into the PRTR, the 16" projectiles fired until the early 1990s each contained over 150 lbs (68 kg) of explosives.

The types of operations conducted at NSWCDD today that use large-caliber guns include:

- **Lot acceptance and proof testing.** NSWCDD conducts tests to ensure the safety and effectiveness of newly-delivered weapons and ammunition for most types of naval weapons, such as land attack systems, anti-aircraft guns, missiles, and projectiles, as part of Naval Surface Fire Support, a central mission of the Navy. NSWCDD serves as the final inspection and acceptance point for most naval gun barrels, ammunition, and all associated components, including fuzes, primers and propellants, to ensure that sailors and marines are provided with safe, accurate, and reliable weapons. While missile components are tested at NSWCDD, no missiles are physically launched from the range complexes or the Mission Area. Lot acceptance and proof testing, once a major portion of NSWCDD's ordnance operations, represents now only about 10 percent of the workload.

- **Projectile and fuze testing.** NSWCDD tests projectiles and their fuzes by firing them from actual Navy guns over the PRTR's combined water and land range, which accurately replicates real wartime (at-sea and littoral) environments and their associated "background clutter." Background clutter includes such things as surface reflectivity, optical glint, and EM interference. Because radio frequency, infrared, and other sensor characteristics are affected by water surfaces and moist atmospheric conditions differently from what occurs over land, testing on a water range is necessary to realistically assess munitions and fuzes to be against sea-based targets.

MK 45 Mod 1/2 5"/54 Gun

- **Development and certification of integrated targeting and fire control systems.** Today, a sensor such as radar or a laser not only detects a target, but must also transmit the information to one or more platforms, such as ships and aircraft, simultaneously. NSWCDD is working to enable almost immediate communication among sensors and platforms in order to make it possible to instantly engage a detected target with the most appropriate weapon from each platform.
- **Reactive materials.** Reactive materials are inert under normal conditions, but when they impact a target at very high speeds, they "react" with a high level of explosive force. The performance and effectiveness of reactive materials are being studied at NSWCDD.
- **Missiles, rockets, and launcher components.** This work focuses not on launches and flights of fully-operational missiles and rockets, but rather on the operation of some of their components, such as sensors and telemetry systems.
- **Operational improvements in reliability, accuracy and safety of weapons and ammunition.** One example of such work is RDT&E to produce longer-lasting, lighter weapons by using light composite materials in gun barrels.
- **Long-range guns that can fire accurate and reliable projectiles at distances in excess of 50 NM (93 km).** While NSWCDD is developing and testing the capabilities of these new guns and projectiles, they would not be tested at full range at the PRTR.
- **High-speed penetrating projectiles.** NSWCDD is working on developing new forms of high-speed penetrating weapons to serve as "bunker busters."

3.2.1.2 Small-Caliber Gun Firing

Firing of small-caliber guns (defined here as having a projectile diameter of less than or equal to 20 mm) can take place on any of the ranges, but primarily occur on the Machine Gun Range, AA Fuze Range, and Main Range. In addition, penetration testing of light armor materials and testing of primers (caps or tubes containing a small amount of explosive used to detonate the main explosive charge of a firearm) of all sizes occurs at the Machine Gun Range. Active gun mounts are available for firing hundreds of types of small-caliber handguns, machine guns, and rifles.

Usually, the projectile of a gun smaller than 20 mm is referred to as a "bullet." Approximately 6,000 bullets are fired on the ranges annually. Most bullets fired are inert – made of solid metal with no explosive filler – but some are explosive. The bullets used on land-based operational ranges are fired from the Machine Gun Range either at a target on land that traps the projectiles or at a target in the water up to 4,000 yards out, in which case they would clear the range up to 6,000 yards. Approximately 90 percent of small arm firings take place entirely on the land ranges with the remaining 10 percent of the bullets (about 600 bullets) fired into the river. Most bullets fired in the river decelerate rapidly and are immediately buried intact in the soft bottom sediments. Burial isolates these munitions from movement and potential exposure pathways, thereby limiting contaminant release into surface water and surficial sediments.

3.2.2 Future Munitions Use on the PRTR

3.2.2.1 Large-Caliber Gun Firing

As described in Section 3.1, the Navy established Dahlgren to test ordnance in 1918, and testing ordnance will remain a primary part of NSWCDD's mission into the future. Testing and improving ordnance reliability, safety, lethality, accuracy, fuzing, and range for small- and large-caliber guns and assessing explosive compounds remain basic Navy requirements. This is because these weapons remain core components of Navy ships.

However, ordnance technology has reached the point where fundamental changes in ordnance are now possible. The Navy's goals are to develop guns and projectiles that are more effective or lethal when they reach their target, can reach targets farther away, are integrated into warfare systems, and are safer to handle so that they do not explode inadvertently. The use of reactive materials in projectiles is an example of current work – projectiles carrying reactive materials will only be capable of exploding when hitting a target. When sufficiently developed, projectiles with reactive materials will begin to replace current explosive projectiles.

NSWCDD has been and will continue to be the primary Navy RDT&E facility for improving existing ordnance and developing new types of ordnance. However, in the coming years, RDT&E to improve existing types of ordnance will decline while RDT&E for newer types of ordnance will increase. As a result, the tempo of large-caliber gun testing is expected to remain relatively constant for the foreseeable future.

Additionally, the use of sophisticated computer modeling and simulation to predict some aspects of ordnance behavior in place of actual live firing is contributing to keeping gun use from increasing. Modeling has played a substantial role in reducing the number of rounds fired into the PRTR. In the 1970s, from 15,000 to 18,000 rounds were fired in a year; since 1995, the number of rounds fired per year has averaged 2,900. However, as each new conflict demonstrates, no amount of modeling can completely replicate real-world environments, and, therefore, firing guns and projectiles will continue to be needed as a real-world test of what modeling has indicated should happen.

NSWCDD estimates that for the foreseeable future, particularly active years will average a high of 4,700 projectiles fired based on the last 15 years of firing data (1995-2009). In other words, large-caliber gun firing in the foreseeable future is not expected to increase beyond the levels typical of the last 15 years. In an average year, the number of projectiles fired is expected to be less than 3,000. Because of the cyclical nature of ordnance RDT&E, the actual number fired annually and the proportions of each type of gun will vary from year to year. As is the case now, large guns would only be fired typically from 8 am to 5 pm, Monday through Friday into the MDZ.

3.2.2.2 Small-Caliber Gun Firing

The number of bullets fired outdoors from small-caliber guns (defined as those having a projectile diameter of 20 mm or less) is expected to increase in the foreseeable future from the current 6,000 up to 30,000 per year to support potential Marine Corps requirements for the evaluation and development of small-caliber guns and related systems. The evaluation of a Marine Corps squad assault rifle could require the test-firing of between 10,000 and 30,000 rounds outdoors per year. Future firing would continue to occur from the Machine Gun Range either at a target on land that traps the projectiles or at a target in the water up to 4,000 yards out, in which case they would clear the range up to 6,000 yards, While most bullets will be fired into gun butts on land, approximately 10 percent of the bullets are expected to be fired into the waters of the PRTR, so that an estimated 1,000 to 3,000 bullets would enter the Potomac River each year. Most bullets fired in the river decelerate rapidly and would immediately be buried intact in the soft bottom sediments, thereby limiting contaminant release into surface water and surficial sediments. The contaminant input from the additional number of bullets settling near the surface of the sediments (about 26 bullets) would be too small to warrant consideration.

3.3 Records of Projectiles Fired on the PRTR

As described in Section 3.1, NSWCDD possesses only fragmentary records and historical accounts of the past use of munitions on the PRTR. The one exception is a series of firing logbooks that NSWCDD and its predecessor organizations have kept since the beginning of 1919 to the current day. These records are complete, with the exception of firing data from 1926 to 1935. For purposes of this WRSEPA process,

Munitions Considered in the WRSEPA

Included:
- Projectile firings recorded in the firing logbooks and with a diameter larger than 20 mm
- Projectile firings extrapolated for years with no log records (1926-1934)

Not Included:
- Firings not recorded in the firing logbooks
- Projectile with a diameter less than or equal to 20 mm
- Guns with limited usage
- Bombs, rockets, missiles, depth charges, mines, mortars, grenades

the missing data have been extrapolated. The data considered here include only large-caliber projectiles (defined as larger than 20 mm in diameter). For each projectile, the firing logs record:

- The type of gun fired
- The range or distance fired
- The date
- Whether the projectile was inert (non-explosive) or live (filled with explosives).

This section summarizes the available current and historical information regarding the types and approximate quantities of projectiles fired on the PRTR, in accordance with WRSEPA policy (US Navy, 2008). The comprehensiveness of record-keeping has improved over time, and, therefore, recent records provide a fuller picture of munitions usage than do older records.

3.3.1 Firing Log Data Compilation

For the WRSEPA analysis, NSWCDD provided firing logbooks covering 73 years of activity, from 1935 through 2007. Firing records for the first 17 years of activity – from 1918 to 1934 – were not available at NSWCDD. To fill this gap, research was conducted at the National Archives and Records Administration in Washington, DC and the Mid-Atlantic Region Archives Facility in Philadelphia, Pennsylvania (Philadelphia National Archives Branch). Other sources of information included archivists at the National Archives and Records Administration in College Park, Maryland; the Naval History and Heritage Command at the Washington Navy Yard, Washington, DC; James Rife and Rodney Carlisle, authors of *The Sound of Freedom – Naval Weapons Technology at Dahlgren, Virginia 1918-2006* (Rife and Carlyle, 2006); and the Technical Library at NSWCDD. Appendix A describes the efforts to locate ordnance activity data for the years from 1918 to 1934.

Data for munitions testing at Dahlgren from 1918 to 1925 were found at the Philadelphia National Archives Branch. However, data for the nine-year period from 1926 to 1934 could not be located. Therefore, munitions use records for two proximate, seven-year periods – 1919 to 1925 and 1935 to 1941 – were used to recreate data for the nine-year gap from 1926 to 1934 (see Appendix A). The United States was not at war during the two seven-year periods or during the data-gap years; so it was assumed that firing activity during the gap year would be commensurate to firing activity during the two proximate periods. Table 3-2 presents the data that were used to estimate munitions usage for the 1926-1934 period.

The average yearly number of projectiles tested during the 14-year, non-war period – 1919 to 1925 and 1935 to 1941 combined – was 1,134 projectiles. During the 14-year period, 99.4 percent of the projectiles tested were inert and 0.6 percent were live. The average number of projectiles and the percentage of live and inert projectiles from the 14-year, non-war period was applied to the nine years with no data available. Based on this information it was estimated that from 1926 to 1934 about 1,134 projectiles were tested per year, consisting of 1,128 inert (99.4 percent) and 6 live (0.6 percent) projectiles.

The available records referenced a total of 66 different types of guns or munitions. However, nine munitions types (Table 3-3) were small-caliber rounds with limited usage and were not included in the assessment due to their minimal contribution.

Table 3-2
Data Used to Estimate Numbers of Large-Caliber Projectiles Tested from 1926 to 1934

Year	Number of Projectiles* Tested		
	Inert	Live	Total
1919	3,466	20	3,486
1920	2,790	16	2,806
1921	291	2	293
1922	1,269	7	1,276
1923	2,668	15	2,683
1924	2,117	12	2,129
1925	357	2	359
1935	33	0	33
1936	606	0	606
1937	419	0	419
1938	411	0	411
1939	437	11	448
1940	361	5	366
1941	560	0	560
Average per year	**1,128**	**6**	**1,134**
Percentage	**99.4**	**0.6**	**100.0**

Note: * Only projectiles larger than 20 mm are included in this table.

3.3.2 Firing Log Data for Large-caliber Guns Tested on the PRTR

A detailed report on projectile firing associated with all documented large-caliber guns from 1918-2007 at Dahlgren is presented in Appendix A. This appendix contains information from the original data sheets, reorganized and compiled into an electronic database.

The total number of inert and live projectiles tested each year over the 90-year period from 1918 to 2007 is presented in Figure 3-3, Total Number of Projectiles Tested on the PRTR (1918 - 2007). Firing records from 1918 to 2007[9] are detailed in Appendix A. Based on the available records, from 1918 to 2007, Dahlgren tested 291,971 inert large-caliber projectiles and 51,844 live large-caliber projectiles on the PRTR, for a total of 343,815 projectiles. Inert projectiles accounted for 84.9 percent of the total and live projectiles accounted for 15.1 percent. Over the 90 years under consideration, an average of 3,820 projectiles – comprising an estimated 3,244 inert projectiles and 576 live projectiles – were tested each year.

Table 3-4 lists the 57 types of large-caliber guns documented in the firing logbooks and the years during which they were tested. The 5”/54, 5”/38, and 76 mm guns were the most heavily tested, with 58, 45, and 35 years of testing recorded, respectively. The 5”/54 gun is estimated to have been tested a total of 100,528 times over 58 years, accounting for over 29 percent of all

[9] The 2008 firing data were received after the analyses presented in this report were completed. However, as the level of firing was close to the 90-year average – 3,877 projectiles fired in 2008 versus an average of 3,820 projectiles per year – the results presented in this report are considered to be representative of RDT&E through 2008 and into the future.

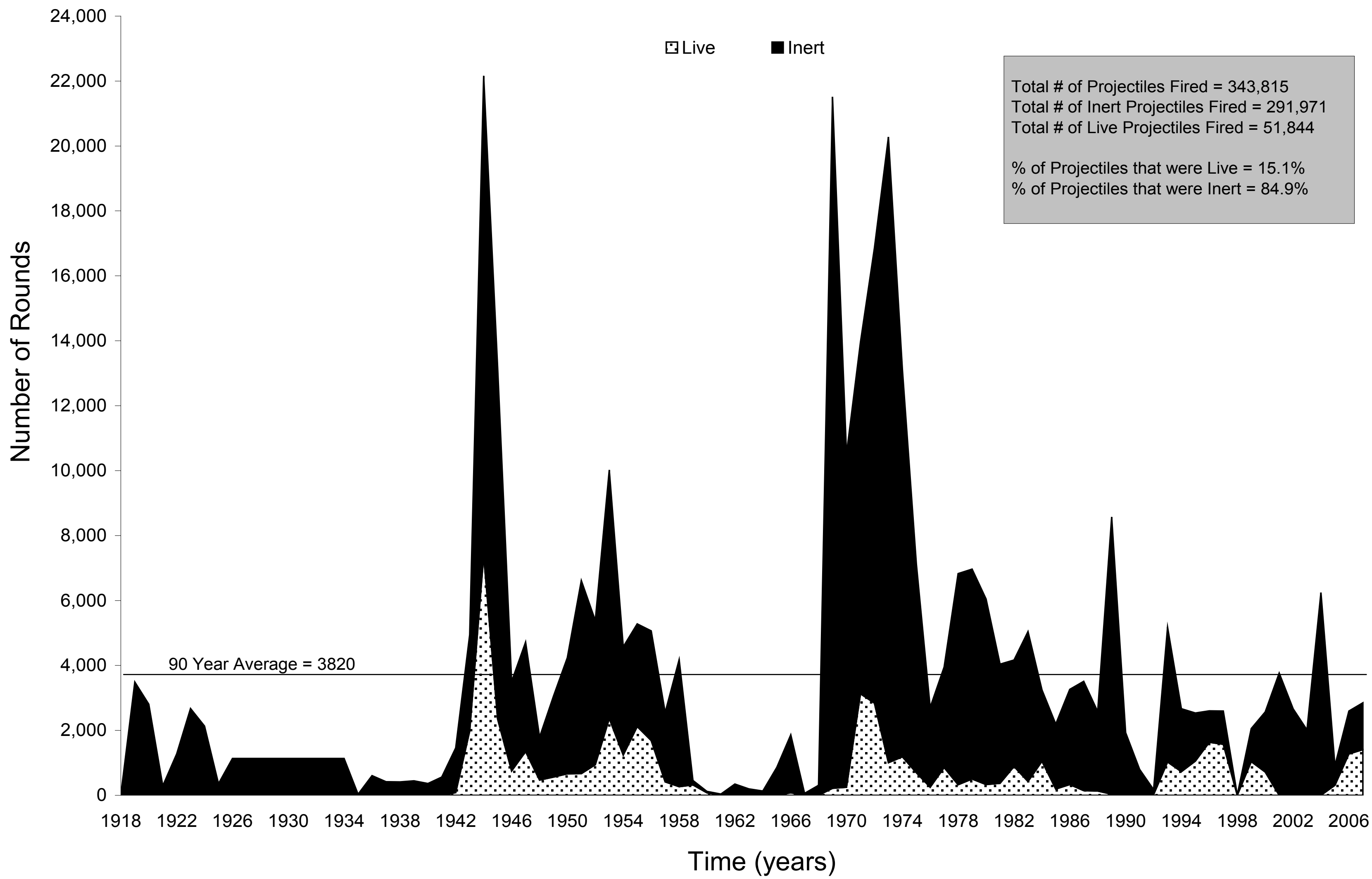
projectiles tested. Approximately 86 percent (86,118) of the estimated 100,528 projectiles were inert and 14 percent were live (14,410). The 5”/38 gun is estimated to have been tested a total of 92,084 times over 45 years; 81,335 (88 percent) were inert projectiles and 10,749 (12 percent) were live projectiles. Table 3-5 presents a summary of the estimated quantity of testing for each munitions type, and Appendix A reports the number of tests by year for each munition type.

Table 3-3
Small-caliber Munitions Excluded from Further Analysis

Munition	Years of Testing and Data Collection	Years Tested	Inert	Live	Total
.50 caliber	2002-2004	3	346	0	346
12 gauge	2004	1	54	0	54
.22-250 Remington	2001	1	470	0	470
Launcher	1970	1	62	0	62
Remington 700	2002	1	247	0	247
5.56 mm	1989, 2002	2	853	0	853
7.62 mm	2002, 2004	2	408	0	408
9 mm	1987, 1989, 1991	3	330	0	330
20 mm	2001-2004	4	1,326	0	1,326

Note: mm indicates millimeter(s).

Figure 3-3
Total Number of Projectiles Tested on the Potomac River Test Range (1918 - 2007)



DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

Table 3-4
Large-caliber Guns Tested on the PRTR from 1918 to 2007

Gun	Years of Testing and Data Collection	Total Number of Years Tested
30 mm	2000-2002, 2004, 2006-2007	6
35 mm	2007	1
1-pounder	1919-1920, 1924	3
40 mm	1970-1976, 1982, 1986-1989, 1993, 1996, 2003-2004	16
57 mm	1980-1981, 2003-2006	6
6-pounder	1919-1920	2
60 mm	1986, 1991, 1993, 1994	4
75 mm	1985-1987	3
76 mm	1972-1997, 1999-2007	35
81 mm	1972, 1985-1987, 2006-2007	6
83 mm	1986-1988, 1991-1992	5
90 mm	1982, 1986	2
105 mm	1971-1972, 1978-1984, 1986, 1992, 2004	12
120 mm	1987, 1998, 2003, 2006, 2007	5
122 mm	1989-1990	2
155 mm	1971-1976, 1978-1979, 1995-1996, 2003-2007	15
3"	1919-1924, 1926-1934, 1984	16
3” 15 caliber	1923-1924, 1971-1972	4
3" 20 caliber	1971-1979, 1981-1987, 1989, 1991	18
3" 23 caliber	1923-1925	3
3" 50 caliber	1944-1945, 1947-1953, 1969-1975, 1977-1978, 1980, 1982-1983, 1987, 1990	36
3" 70 caliber	1946-1959, 1970, 1971	16
4"	1919-1923, 1926-1934	14
4" 50 caliber	1922-1934, 1944-1945	15
5"	1919-1924, 1926-1934, 1997	16
5" 15 caliber	1993	1
5" 25 caliber	1923-1925	3
5" 38 caliber	1942, 1944-1967, 1969-1981, 1983-1985, 1988-1989, 1991, 1993	45
5" 40 caliber	1922-1934	13
5" 51 caliber	1922-1934	13
5" 54 caliber	1941-1959, 1966, 1969-1997, 1999, 2000-2007	58
5" 62 caliber	1996-1997, 1999-2007	11
5” 70 caliber	1947-1949	3
6"	1919-1921	3
6" 23 caliber	1923	1
6” 25 caliber	1971, 1973	2
6" 40 caliber	1923, 1944-1953	11
6" 45 caliber	1922	1
6" 47 caliber	1926-1934, 1936-1948, 1952, 1972-1973	25
6" 53 caliber	1922-1934	13

Table 3-4 cont'd
Large-caliber Guns Tested on the PRTR from 1918 to 2007

Gun	Years of Testing and Data Collection	Total Number of Years Tested
7"	1919-1920, 1924	3
7" 45 caliber	1918, 1923-1934	13
8"	1919-1920, 1922-1923, 1926-1934, 1971-1973, 1997	17
8" 35 caliber	1944-1948, 1953, 1972	7
8" 51 caliber	1971-1978, 1983, 1986-1988	12
8" 55 caliber	1925, 1941-1942, 1969-1988, 1995-1997, 1999-2007	35
12"	1919-1920, 1923-1924	4
12" 40 caliber	1923-1925	3
12" 45 caliber	1923-1924	2
12" 50 caliber	1923-1925	3
14"	1919-1920, 1922, 1924-1934	14
14" 33 caliber	1923, 1925	2
14" 45 caliber	1922-1934	13
14" 50 caliber	1923-1924	2
16"	1919-1920, 1922-1924, 1926-1934	14
16" 45 caliber	1923-1945	23
16" 50 caliber	1923-1924, 1967-1969, 1971, 1974, 1976, 1979-1991	21

Notes: mm indicates millimeter(s)
This table includes munitions with a diameter greater than 20 mm.
Only munitions testing activities that have taken place at Dahlgren are included in this table.
See Appendix A.IV for information on data treatment from 1926-1934.

Table 3-5
Estimated Quantity of Large-caliber Projectiles Fired on the PRTR from 1918 to 2007

Gun	# Inert	# Live	Total
30 mm	3,984	165	**4,149**
35 mm	0	358	**358**
1-pounder	729	4	**733**
40 mm	6,917	7,491	**14,408**
57 mm	4,384	240	**4,624**
6-pounder	171	2	**173**
60 mm	85	34	**119**
75 mm	65	36	**101**
76 mm	36,627	6,112	**42,739**
81 mm	37	23	**60**
83 mm	198	15	**213**
90 mm	334	42	**376**
105 mm	766	693	**1,459**
120 mm	252	105	**357**
122 mm	45	0	**45**
155 mm	524	151	**675**
3"	3,452	27	**3,479**
3” 15 caliber	154	1	**155**
3" 20 caliber	437	581	**1,018**
3" 23 caliber	72	0	**72**
3" 50 caliber	5,334	1,976	**7,310**
3" 70 caliber	15,861	954	**16,815**
4"	2,766	11	**2,777**
4" 50 caliber	1,841	75	**1,916**
5"	1,605	60	**1,665**
5" 15 caliber	7	45	**52**
5" 25 caliber	320	2	**322**
5" 38 caliber	81,335	10,749	**92,084**
5" 40 caliber	770	10	**780**
5" 51 caliber	1,778	15	**1,793**
5" 54 caliber	86,118	14,410	**100,528**
5" 62 caliber	5,110	959	**6,069**
5” 70 caliber	445	0	**445**
6"	114	0	**114**
6" 23 caliber	10	0	**10**
6” 25 caliber	12	0	**12**
6" 40 caliber	1,029	8	**1,037**
6" 45 caliber	970	5	**975**
6" 47 caliber	8,221	4,724	**12,945**
6" 53 caliber	1,525	4	**1,529**
7"	35	0	**35**
7" 45 caliber	809	1	**810**
8"	883	25	**908**
8" 35 caliber	134	2	**136**
8" 51 caliber	336	0	**336**
8" 55 caliber	6,900	79	**6,979**
12"	47	0	**47**
12" 40 caliber	41	0	**41**
12" 45 caliber	35	0	**35**
12" 50 caliber	38	0	**38**
14"	756	0	**756**
14" 33 caliber	11	0	**11**
14" 45 caliber	879	1	**880**
14" 50 caliber	166	1	**167**
16"	740	0	**740**
16" 45 caliber	4,506	1,610	**6,116**
16" 50 caliber	1,251	38	**1,289**

3.3.3 Projectile Target Areas

Based on available records, 343,815 large-caliber projectiles have been fired into the PRTR since 1918. Most of the projectiles (99.7 percent) have been fired into the MDZ, with a small number of projectiles (0.3 percent) tested in the LDZ, as shown in Table 3-6 and Figure 3-4, Distribution of Large-caliber Projectiles in the Potomac River Test Range. The UDZ was primarily used as a bombing target area and there are no records of projectiles fired into the UDZ.

Table 3-6
Usage of the Danger Zones in the PRTR

Danger Zone	Surface Area (sq NM)	Number of Large-caliber Projectiles	Density (projectiles per sq NM)
UDZ	3.79	NA	NA
MDZ	38.77	342,756	8,841
LDZ	126.58	1,059	8.37
PRTR Total	169.14	343,815	2,033
Notes: NA = not available, as there are no records of projectiles fired into the UDZ.			

Although an overall density of 8,841 projectiles per sq NM (2,574 projectiles per sq km) can be estimated for the MDZ, the projectiles were not evenly distributed throughout the danger zone, as shown in Table 3-7 and Figure 3-5, Distribution of Large-caliber Projectiles in the Middle Danger Zone and Lower Danger Zone. Rather, there are zones within the MDZ that have higher or lower densities of projectiles. The zone between the Gun Firing Line (0 yd[10]) and 25,000 yds (22,860 m) accounts for 341,706 projectiles, or 99.4 percent of all munitions tested in the PRTR (Table 3-7). This zone has a surface area of 31.19 sq NM (107 sq km). Assuming an even distribution of projectiles throughout this zone, there are approximately 10,956 projectiles per sq NM (3,190 projectiles per sq km).

Table 3-7
Heavily-used Target Areas in the MDZ

Target Area	Surface Area (sq NM)	Number of Large-caliber Projectiles	Density (projectiles per sq NM)
11,000 yards to 13,000 yards	2.29	159,580	69,686
10,000 yards to 17,000 yards	8.50	248,798	29,270
15,000 yards to 17,000 yards	2.67	59,029	22,108
0 yards to 25,000 yards	31.19	341,706	10,956
0 yards to 3,000 yards	3.43	30,778	8,973
24,000 yards to 25,000 yards	1.24	7,662	6,179

[10] Although 0 (zero) yd is used here, the gun firing line is actually about 150 yds (137 m) from the Potomac River.

Distribution of Large-caliber Projectiles in the Potomac River Test Range

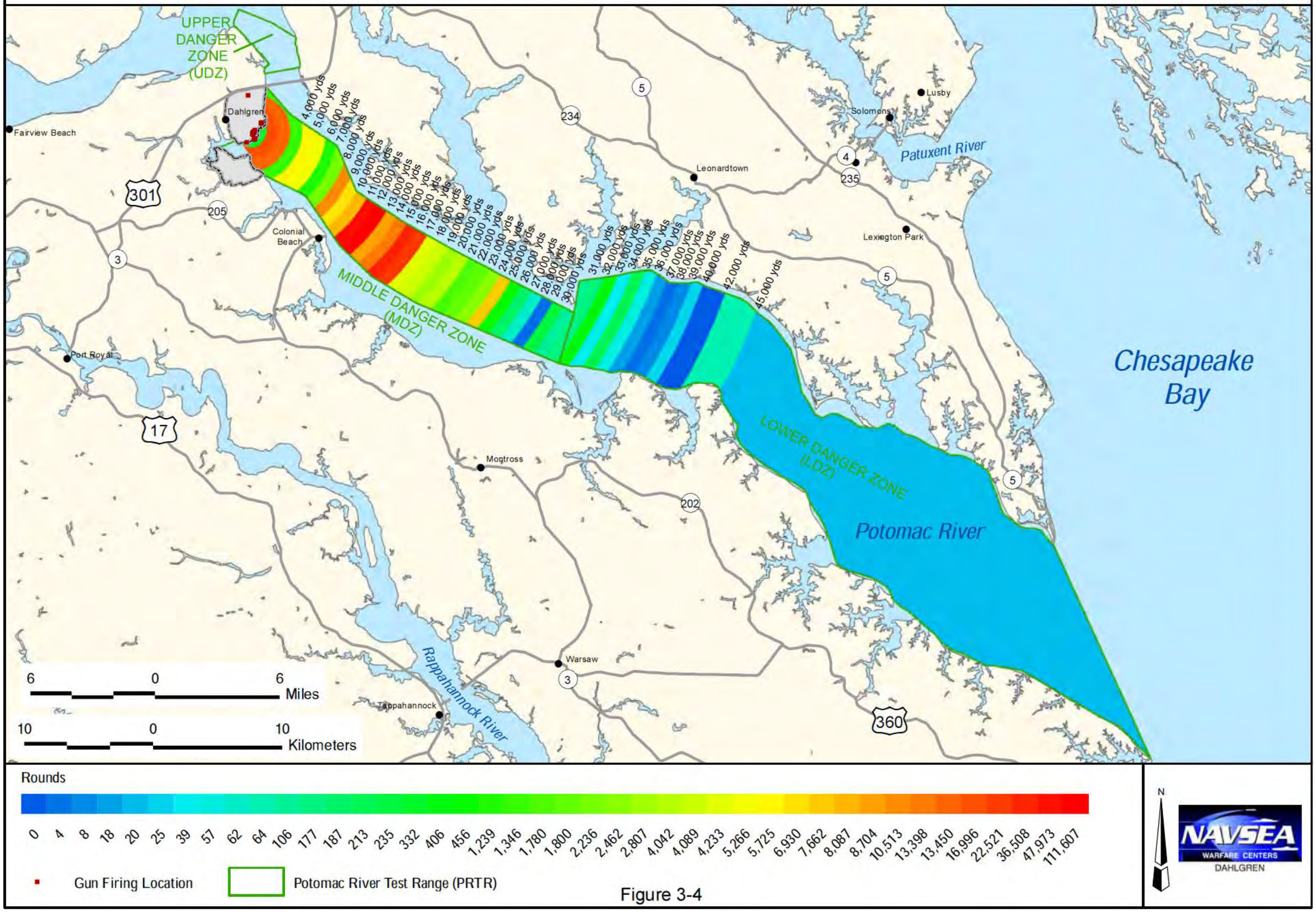


Figure 3-4

Distribution of Large-caliber Projectiles in the Middle Danger Zone and Lower Danger Zone

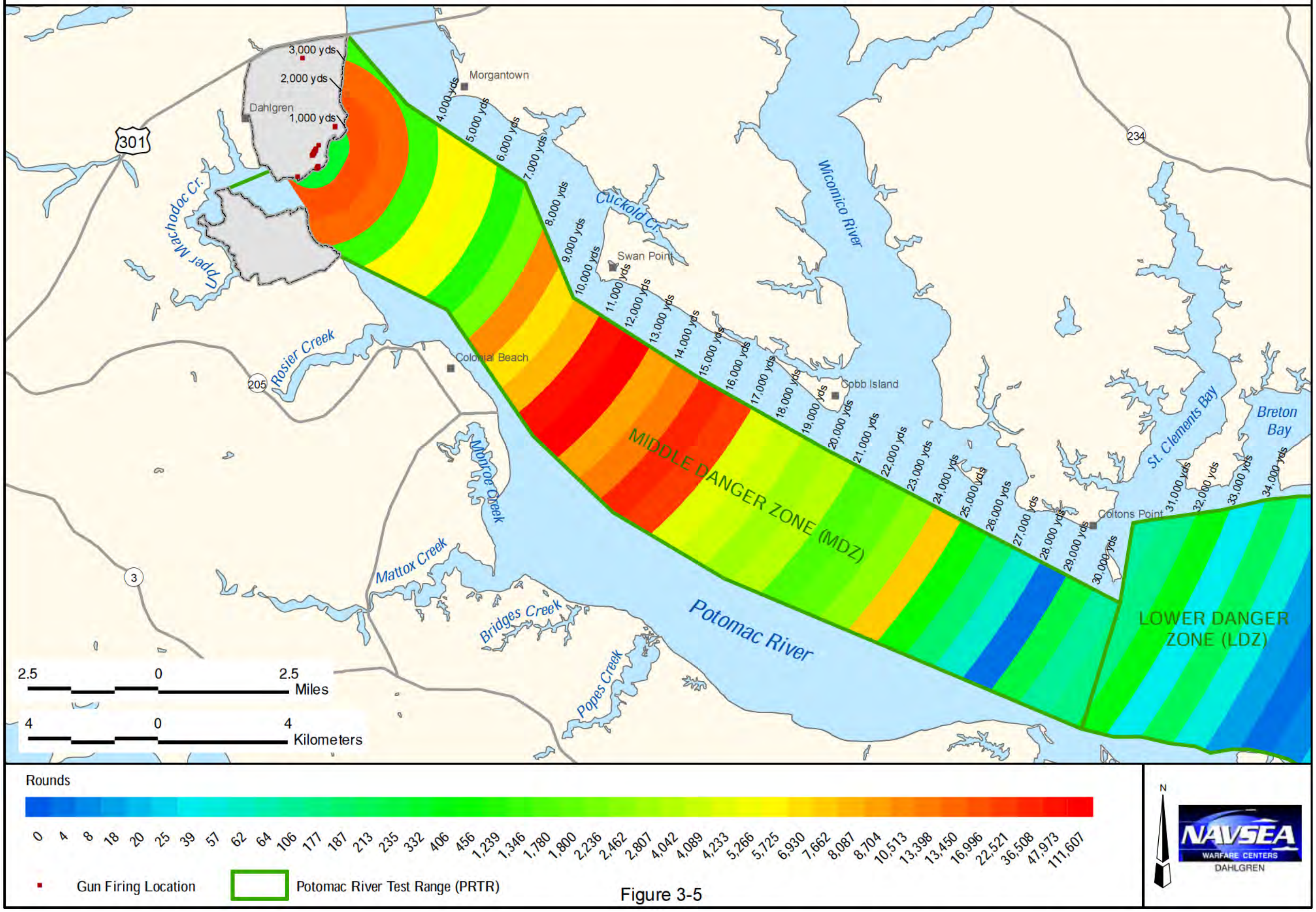


Figure 3-5

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

Another heavily used target area within the MDZ is the zone from 10,000 to 17,000 yds (9,144 to 15,545 m). This zone covers approximately 8.5 sq NM (29 sq km), and was the target area for 248,798 projectiles from the last 90 years, yielding a density of approximately 29,270 projectiles per sq NM (8,579 projectiles per sq km). Within the 10,000- to 17,000-yd (9,144- to 15,545-m) zone, the zone from 11,000 to 13,000 yds (10,058 to 11,887 m) has the highest density of projectiles. This zone has a surface area of approximately 2.29 sq NM (7.86 sq km) and approximately 159,580 projectiles were fired into it, yielding a density of 69,686 projectiles per sq NM (20,303 projectiles per sq km).

3.3.4 Heaviest Years of Firing Activity

Firing has been highest during time periods when the United States was at war, and specifically during war periods prior to 1980 – i.e., World War II, the Korean War, and the Vietnam War, as described in Section 3.1. The nine most active years in Dahlgren's 90-year history (Table 3-8) occurred during wartime periods prior to 1980 and account for more than 40 percent of all munitions tested – 40 percent of all live projectiles tested and 41 percent of inert projectiles. By comparison, war periods after 1980 (i.e., Persian Gulf, Operation Enduring Freedom, and Operation Iraqi Freedom) comprise approximately 12 years, and account for 10 percent of all inert and 7.3 percent of all live munitions tested.

On average, Dahlgren tested 15,731 projectiles per year during the nine years of heaviest activity, or more than four times the annual testing average (3,820 projectiles per year) of all 90 years combined. During the remaining 81 years of testing on the PRTR, an average of 2,496 projectiles per year were tested, composed of 2,112 inert and 384 live projectiles per year.

The heaviest year of firing during Dahlgren's 90-year history was 1944 (22,159 projectiles tested) at the height of World War II, followed by 1969 (21,516 projectiles tested) at the height of the Vietnam War. In 1944 more than a third (7,386) of the 22,159 projectiles tested were live projectiles. The 9,733 live projectiles fired during the World War II years 1944 and 1945 account for almost 19 percent of the total number of live munitions (51,844) ever tested at the PRTR.

Table 3-8
Heaviest Years of Firing Activity on the PRTR from 1918 to 2007

Year	Total Inert Large-caliber Projectiles	Total Live Large-caliber Projectiles*	Total
1944	14,773	7,386	22,159
1945	10,819	2,347	13,166
1953	7,658	2,364	10,022
1969	21,303	213	21,516
1970	10,259	249	10,508
1971	10,831	3,124	13,955
1972	14,021	2,838	16,859
1973	19,274	1,005	20,279
1974	11,929	1,184	13,113
Total	**120,867**	**20,710**	**141,577**

3.3.5 Munitions Constituents

Raw firing activity data obtained from NSWCDD and Philadelphia National Archives Branch were sorted, compiled, and cross-referenced with common MCs and the uniquely military property constituents (hereafter "constituents") information that was obtained from the Munitions Items Disposition Action System (MIDAS) database. The MIDAS database (https://midas.dac.army.mil) is a program developed by the US Army for storing, searching, processing, and retrieving data. MIDAS contains detailed technical data for a wide range of munitions, including the weight and material specifications for individual munitions. These specifications were entered into the NSWCDD WRSEPA database and were used to determine the constituents associated with each munitions type (in this case, large-caliber projectile) used on the PRTR (see Appendix A).

The primary MIDAS database reports that were used for this study were the Toxic Release Inventory (TRI) and the Propellants, Explosives, and Pyrotechnics (PEP) reports. For a given munitions type (projectile), the TRI report lists the toxic compounds it contains and the PEP report lists the propellants, explosives, and pyrotechnics associated with it. Both the TRI and the PEP reports include a Chemical Abstract Service registry number (CAS#) for each compound, the weight of the compound, and the percentage of total projectile weight represented by the compound. The TRI report also includes a TRI code. All munitions listed in the TRI and the PEP reports are also found in a separate report called the "Summary of Compounds in an Item" report, which lists every compound associated with each specific munitions type. The Summary of Compounds in an Item report was obtained to gather information on the quantity of iron in each munitions type.

Separate reports were obtained for all live and inert projectiles. Data were gathered on each projectile, excluding the cartridge (when appropriate), because the cartridge casing usually stays in the vicinity of the gun and does not enter the water range. In many cases the PEP and TRI reports contained duplicative information concerning the weight of a specific constituent. Under these circumstances, the two reports were compared and duplicative data were excluded. The reports gathered for the WRSEPA analysis captured nearly all of the constituents associated with each munitions type. Those constituents not included were insignificant in weight – e.g., constituents used for labeling a munition. Together, the PEP, the TRI, and the iron data account for approximately 99.5 percent of the total weight of each munitions type.

The MCs from the MIDAS database, combined with the firing activity data, provided information on the type of munitions used on the PRTR, the number of times that each type was tested, the year it was tested, the distance it was fired, whether it was live or inert, and the constituents associated with each type. The total weight for each constituent associated with each munitions type was calculated by multiplying the number of times a munitions type was tested by the weight of the constituent in each type. Summing those data across munitions types provided the total amount of each constituent associated with live and inert testing.

Several types of projectiles were not contained in MIDAS database, so their constituents had to be estimated using the constituents of similar munitions types as surrogates. For example, several of the 3" projectiles (i.e., 3", 3" 15 caliber, 3" 20 caliber, and 3" 23 caliber) were not in MIDAS; therefore, their constituents were estimated based on those of the 3" 50 caliber projectile, which was available in the database. Appendix A provides a complete list of the inert and live munitions for which constituents were estimated. For each type, the list identifies its Department of Defense Identification Code or, if applicable, which other munitions type was used as a surrogate.

Overall, 110 constituents were identified in the 57 different munition types tested at the PRTR. A total of approximately 33 million lbs (15 million kg) of constituents are associated with the 343,815 total projectiles fired into the PRTR.

Table 3-9 lists the top 50 constituents, sorted by their total weight. These top 50 constituents make up 99.9 percent of the total constituent weight. Information on the remaining 61 constituents and their total weights is provided in Appendix A.

The constituents comprising the majority of the total weight are metals in the projectile's casing, which are common to both live and inert projectiles. The predominant constituent is iron, contributing 31 million lbs (14 million kg), or 93.2 percent of the total constituent weight. The second largest contributor is copper, at 958,087 lbs (434,580 kg), followed by manganese at 463,239 lbs (197,874 kg), contributing 2.9 percent and 1.4 percent of the total amount of constituent weight, respectively. Combined, iron, copper, and manganese account for 97.5 percent of the total constituent weight of munitions over the 90 years of testing. Figure 3-6, Total Constituent Weight Associated with Munitions (1918 - 2007), shows the annual usage of constituents.

3.3.5.1 Constituents of the Inert Munitions (Projectiles)

In 90 years, Dahlgren tested approximately 291,971 inert projectiles, which account for nearly 85 percent of all munitions tested at the PRTR. Based on the MIDAS reports analyzed for this WRSEPA, cumulatively, inert munitions contain 64 different constituents weighing a total of 27,919,624 lbs (12,664,102 kg), and accounting for almost 84 percent of the total constituent weight (i.e., 33 million lbs [15 million kg]) of all munitions. Table 3-10 lists the top 30 constituents by weight, which together account for 99.99 percent of the total weight associated with inert munitions. The remaining 34 constituents are listed in Appendix A.

Iron contributed the most weight, constituting 94.7 percent of the total inert constituent weight. Following iron, copper contributed 2.9 percent of the total inert weight, manganese 1.4 percent, and aluminum 0.5 percent. Taken together, these four metals account for 99.6 percent of the total constituent weight associated with inert munitions.

3.3.5.2 Constituents of the Live Munitions (Projectiles)

Approximately 15 percent of all munitions tested over the 90 years under consideration were live projectiles. Based on the MIDAS reports used for this WRSEPA, a total of 103 constituents associated with live projectiles were identified, including metals used in the projectile casing and explosives. Live projectiles constituted approximately 16 percent (i.e., 5,324,748 lbs [2,415,260 kg]) of the total constituent weight of all projectiles (live and inert). Table 3-11 lists the top 30 constituents, which comprise 99.99 percent of the total weight associated with live munitions. Appendix A contains a list of the remaining 73 constituents associated with live munitions, which cumulatively comprise less than 7 lbs (3.18 kg) in total weight.

Out of all 103 constituents, iron contributed the greatest weight to the total, with 85 percent of the total. The next largest contributor was ammonium picrate (8.2 percent), followed by copper

Table 3-9
Top 50 Constituents in Live and Inert Projectiles Fired on the PRTR from 1918-2007 by Total Weight

Rank	Constituent	Total Sum of Weight (lbs)	Rank	Constituent	Total Sum of Weight (lbs)
1	IRON	30,980,921.82	26	COBALT	67.84
2	COPPER	958,087.21	27	CALCIUM SILICIDE	56.99
3	MANGANESE	463,238.57	28	LEAD AZIDE	55.43
4	AMMONIUM PICRATE	436,228.55	29	STRONTIUM NITRATE	44.72
5	ALUMINUM	148,631.69	30	CHARCOAL	39.54
6	RDX	85,165.59	31	ZINC CHROMATE	37.56
7	ZINC	61,467.90	32	HMX	36.38
8	NICKEL	47,957.43	33	SULFUR	26.36
9	PHOSPHORUS	13,862.73	34	CALCIUM STEARATE	21.67
10	TNT	12,524.58	35	LEAD STYPHNATE	16.27
11	ETHYLBENZENE	9,158.53	36	STEARIC ACID	15.24
12	LEAD	8,417.13	37	BERYLLIUM	14.83
13	WAX	7,719.48	38	CHARCOAL PWDR	14.29
14	METHYL ALCOHOL	4,948.83	39	LINSEED OIL	14.12
15	TETRYL	1,858.29	40	VANADIUM	12.55
16	ZINC PHOSPHATE	1,777.80	41	GRAPHITE	10.68
17	CHROMIUM	442.15	42	ISOPROPYL ALCOHOL	8.23
18	XYLENE	315.84	43	NITROCELLULOSE	8.08
19	POTASSIUM NITRATE	285.68	44	BARIUM STEARATE	7.82
20	SODIUM NITRATE	199.68	45	SHELLAC	7.45
21	CADMIUM	186.94	46	ANTIMONY	6.71
22	TOLUENE	144.33	47	PARAFFIN WAX	6.21
23	LEAD NAPHTHENATE 36%	103.52	48	POLYISOBUTYLENE	5.94
24	MAGNESIUM PWDR	77.08	49	NITROGLYCERIN	5.90
25	BARIUM PEROXIDE	76.63	50	N-BUTYL ALCOHOL	5.15

Table 3-10
Top 30 Constituents by Weight in Inert Projectiles Fired on the PRTR from 1918-2007

Rank	Constituent	Total Sum of Weight (lbs)	Rank	Constituent	Total Sum of Weight (lbs)
1	IRON	26,443,881.79	16	TOLUENE	107.49
2	COPPER	813,968.75	17	LEAD NAPHTHENATE 36%	103.31
3	MANGANESE	395,424.29	18	BARIUM PEROXIDE	76.15
4	ALUMINUM	144,800.26	19	CALCIUM SILICIDE	56.99
5	ZINC	46,121.66	20	COBALT	42.74
6	NICKEL	40,887.17	21	CADMIUM	17.93
7	PHOSPHORUS	11,989.30	22	MAGNESIUM PWDR	14.83
8	ETHYLBENZENE	9,141.53	23	BERYLLIUM	14.62
9	LEAD	6,283.26	24	CHARCOAL PWDR	14.29
10	METHYL ALCOHOL	4,947.67	25	LINSEED OIL	14.12
11	ZINC PHOSPHATE	729.11	26	VANADIUM	8.38
12	CHROMIUM	340.38	27	ISOPROPYL ALCOHOL	8.01
13	XYLENE	270.73	28	POTASSIUM NITRATE	4.70
14	SODIUM NITRATE	199.47	29	STRONTIUM NITRATE	3.52
15	TETRYL	141.14	30	LEAD AZIDE	2.74

Figure 3-6
Total Constituent Weight Associated with Munitions (1918 - 2007)

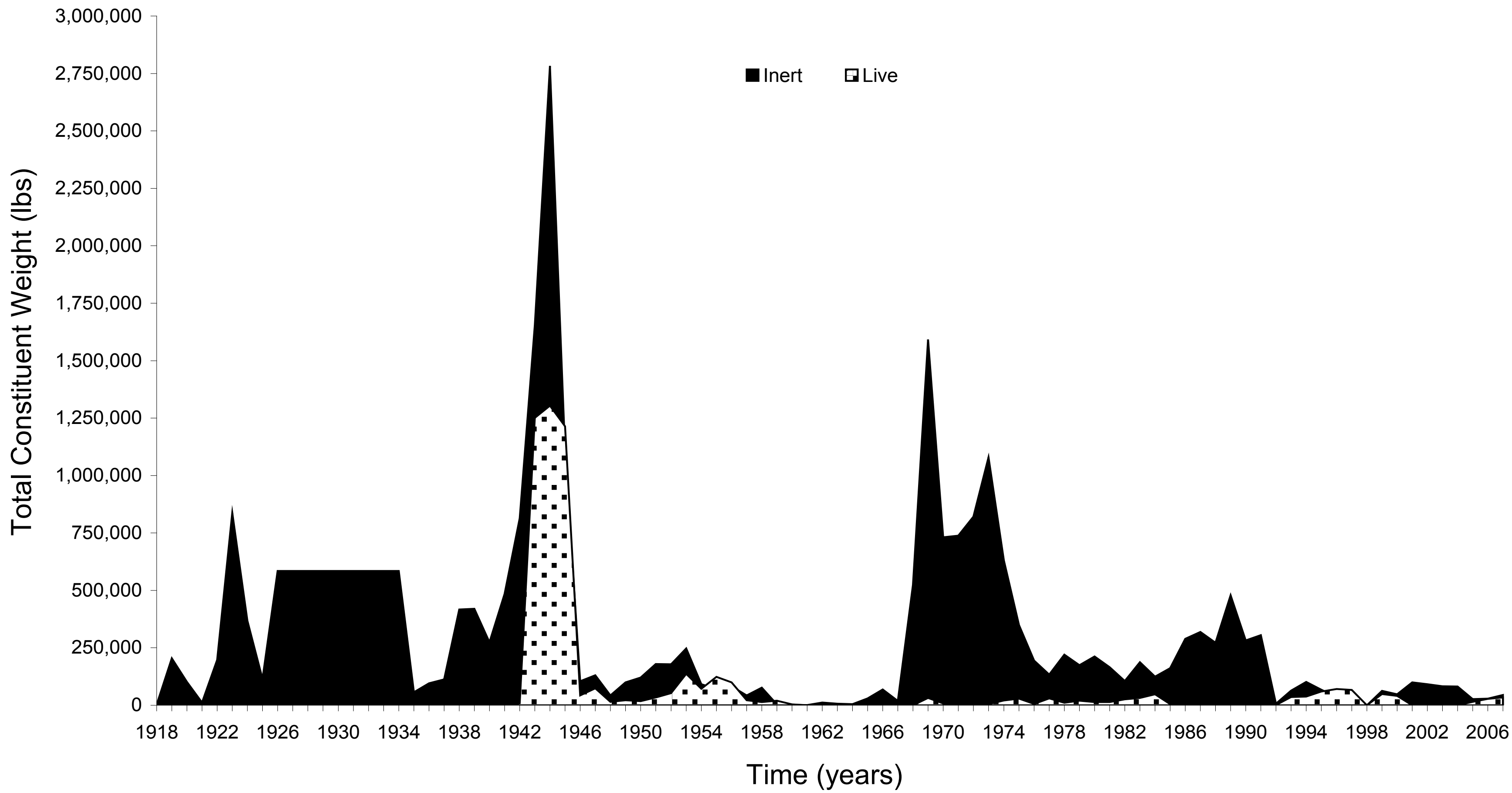


Table 3-11
Top 30 Constituents by Weight in Live Projectiles Fired on the PRTR from 1918-2007

Rank	Constituent	Total Sum of Weight (lbs)
1	IRON	4,537,040.02
2	AMMONIUM PICRATE	436,228.55
3	COPPER	144,118.46
4	RDX	85,165.59
5	MANGANESE	67,814.29
6	ZINC	15,346.24
7	TNT	12,524.58
8	WAX	7,719.48
9	NICKEL	7,070.26
10	ALUMINUM	3,831.43
11	LEAD	2,133.87
12	PHOSPHORUS	1,873.42
13	TETRYL	1,717.15
14	ZINC PHOSPHATE	1,048.69
15	POTASSIUM NITRATE	280.97

Rank	Constituent	Total Sum of Weight (lbs)
16	CADMIUM	169.01
17	CHROMIUM	101.77
18	MAGNESIUM PWDR	62.25
19	LEAD AZIDE	52.69
20	XYLENE	45.11
21	STRONTIUM NITRATE	41.19
22	CHARCOAL	39.54
23	ZINC CHROMATE	37.10
24	TOLUENE	36.83
25	HMX	36.38
26	SULFUR	26.36
27	COBALT	25.10
28	CALCIUM STEARATE	20.53
29	ETHYLBENZENE	17.00
30	LEAD STYPHNATE	16.27

(2.7 percent). Together, these three constituents account for about 96 percent of the total weight of live projectiles fired on the PRTR. Ammonium picrate (also known as Explosive D), 1,3,5-trinitro-1,3,5-triazine (RDX), and 2,4,6-trinitrotoluene (TNT) are the most common explosives that were used in testing at the PRTR and are among the top ten constituents by weight associated with live munitions (Table 3-11).

3.3.5.3 Total Constituent Contribution by Time Period

The top ten years of constituent contribution into the PRTR by inert and live projectiles are listed in Table 3-12. As mentioned in Section 3.3.4, the year of greatest testing activity was 1944, which is also the year in which the greatest amount of constituent weight entered the PRTR – 4,087,385 lbs (1,854,003 kg), 68 percent of which was associated with inert munitions (Figure 3-6, Table 3-12).

Of the ten years with the highest constituent inputs from inert munitions, five occurred prior to 1945 and the remaining five were the years from 1969 to 1973. The heaviest constituent inputs from live munitions occurred during the 1940s and 1950s – eight of the ten heaviest years occurred prior to 1956 while the remaining two years were 1996 and 1997.

Through the years of testing on the PRTR since 1918 – all 90 years involving tests of inert munitions and the 66 years from 1942 through 2007 involving tests of live munitions as well – approximately 33 million lbs (15 million kg) of constituents landed in the PRTR. By 1945, 57 percent – 19,128,507 lbs (8,676,530 kg) – of the cumulative total weight of constituents had been deposited. By 1975, 84 percent – 28,071,538 lbs (12,733,010 kg) – of the total weight had been dropped, and by 1987, the total had reached 92 percent. Appendix A provides the contribution of constituents associated with live and inert munitions by year.

The release of these constituents and their potential migration and exposure pathways are discussed in the subsequent chapters.

Table 3-12
Top 10 Years of Constituent Contribution into the PRTR

Year	Total Constituent Weight for INERT Munitions (lbs)
1944	2,782,982
1943	1,654,874
1969	1,592,302
1945	1,107,118
1973	1,079,020
1923	838,474
1972	821,132
1942	814,464
1971	738,530
1970	731,242

Year	Total Constituent Weight for LIVE Munitions (lbs)
1944	1,304,403
1943	1,250,864
1945	1,213,753
1953	137,006
1955	123,766
1956	100,057
1947	73,970
1954	71,771
1996	70,727
1997	66,753

4 OPERATIONAL RANGE SITE MODEL

An Operational Range Site Model (ORSM) was prepared to provide an overview of the operational usage of the PRTR, the release of constituents, potential migration and exposure pathways, and the links among potential sources of munitions constituents (MCs) and human and ecological receptors. The components of the ORSM are diagrammed in Figure 4-1, PRTR Operational Range Site Model.

4.1 Operational Profile

4.1.1 Facility Profile

NSWCDD's PRTR Complex (Figure 1-3) is the nation's largest fully-instrumented, over-the-water gun-firing range. It is located in a shallow-water coastal, or littoral, environment bounded by land. This WRSEPA focuses on the water portion of the PRTR Complex, the PRTR described in Section 2.1, which lies entirely within the Potomac River. There are no permanent manmade features on the PRTR. The land portion of the PRTR Complex has permanent manmade structures that have been addressed under an RCA prepared by NSWCDD (NSWCDD, 2010).

The PRTR has been used as a testing range since 1918, although according to available records, live munitions were not fired or were very rarely fired from gun batteries on land into the PRTR before World War II (see Figure 3-1). The majority (85 percent) of munitions tested in the PRTR over the life of the range have been inert. As described in Chapter 3, projectiles, aerial bombs, rockets, and other munitions have been tested on the PRTR in the past. The use of most ordnance types other than projectiles ended by 1965. Quantitative records are only available for projectiles, which, therefore, are the focus of this WRSEPA. More specifically, the term munitions as used here refers to large-caliber (greater than 20 mm) projectiles recorded in the firing log books, for which detailed information was available. Metal and explosive components associated with these munitions or ordnance are considered to be MCs, as defined in US Navy (2008). Although only projectiles are quantitatively evaluated here, other munitions used prior to 1965 generally contained the same MCs as are present in projectiles. Therefore, the list of MCs evaluated here is considered to be representative of the full range of munitions used at the PRTR.

4.1.2 Unexploded Ordnance

The Agency for Toxic Substances and Disease Registry (ATSDR) performed a public health assessment for NSF Dahlgren (ATSDR, 2006). One of the exposure issues evaluated included potential river safety concerns for recreational users due to UXOs. The number of tests where the fuze may have failed to detonate, or function as designed, resulting in unexploded ordnance (UXO) falling in the river and landing in the sediment is considered to be very small (ATSDR, 2006). In regard to potential river safety concerns for recreational users due to UXOs, the public health assessment (ATSDR, 2006) concluded that:

> Boaters who follow normal safe boating practices, consult the navigational charts prior to entering unfamiliar territory, and follow the directions of the range control boats, will not be exposed to safety hazards from range operations. In addition, people who follow base procedures for reporting found projectiles and unexploded ordnance are unlikely to be harmed by them. ATSDR supports NSF Dahlgren's public relations and community outreach efforts to ensure that people know how to respond if they find UXO or projectiles. ATSDR categorized this as *no apparent public health hazard*.

Estimates of unexploded rounds from projectiles are discussed in Section 5.2.2 and releases of MCs from those UXOs are included in fate and transport modeling estimates.

4.1.3 Physical Profile

The Potomac River is the fourth largest river on the Atlantic coast of the United States. The characteristics of the water column (see Section 2.2) and bottom sediments (see Section 2.3) influence the fate and transport of MCs entering the river. As the majority of munitions fired have been inert, most projectiles fired in the river are immediately buried intact in the soft bottom sediments. Burial isolates these munitions from potential exposure pathways, thereby limiting contaminant release into surface water and surficial sediments (see Figure 4-1). Munitions that are not buried, however, have the potential to release MCs into the water column and/or surficial sediments.

Human receptors include recreational users of, and consumers of fish from, the Potomac River. Ecological receptors include plants and animals living in the river and semi-aquatic and terrestrial animals that use the river as a food source.

4.1.4 Release Profile

MCs can enter the PRTR from gun-firing operations conducted on the complex. These operations are typically conducted from the Main Range gun line, but may also take place on other land ranges (Terminal, Missile Test, AA Fuze, or Machine Gun) (see Figure 2-1). The Main Range gun line includes 42 gun emplacements that are used to fire 20-mm to 8" projectiles as well as test stands for proof-firing gun-mount oscillating assemblies and gun barrels (NSWCDD, 2010). There are four firing bridges that are located approximately 1,500 ft (457 m) from the Potomac River. Residues from the land-based firing of munitions remain on land and would only enter the PRTR indirectly via surface water or soil runoff, or via groundwater discharge to the river. Pathways originating from munitions on land have been covered in a Range Condition Assessment as part of the Range Sustainability Environmental Program Assessment (RSEPA) requirements (NSWCDD, 2010). The Range Condition Assessment found RDT&E activities at NSWCDD land-based ranges to generally be in compliance with all applicable environmental regulations and program requirements (NSWCDD, 2010).

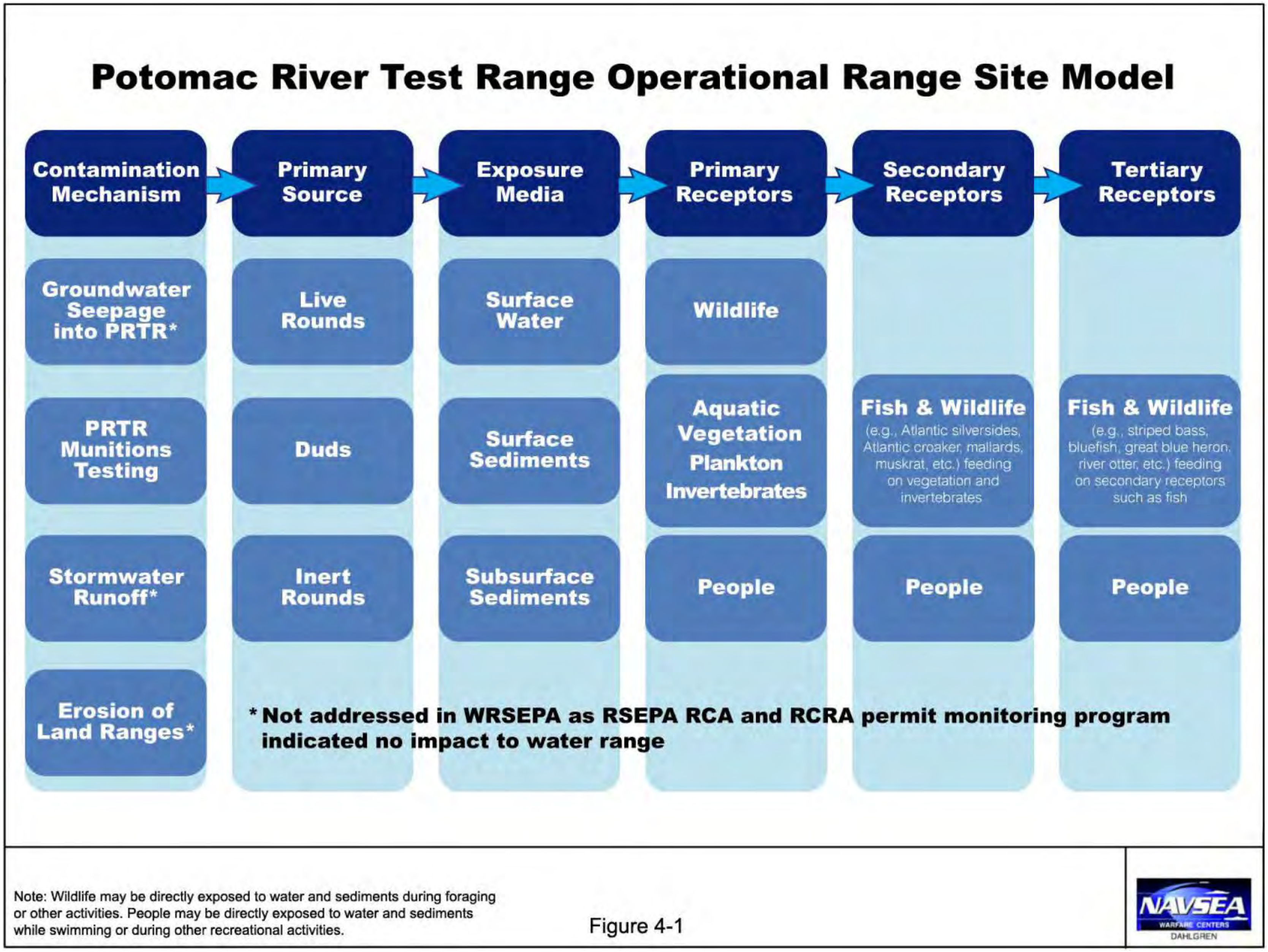


Figure 4-1

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

The type of MCs that may be introduced into the environment depends on whether a projectile is inert or live. Inert munitions contain propellants (deflagrating explosive used for propulsion or for reducing the drag of projectiles) that are expended during firing; concrete or other materials; and casing components. The casings of inert munitions remain intact during firing.

Inert projectiles enter the Potomac River with enough momentum to bury themselves in the bottom sediments. Although it is possible for damage to occur if the munitions hit a rock or another projectile, the sediments of the PRTR are soft or semi-liquid (see Section 2.3) and most munitions tested within the PRTR can be assumed to remain intact as they are buried in the liquefied silt and clay substrate. Once buried, the projectile is subject to slow corrosion of the shell casing. A small percentage of these buried munitions can be expected to work their way up to the surface during storm events, high flows, and other extreme weather conditions.

Live munitions contain propellants, explosives, and casing components. Like inert munitions, live projectiles also expend propellants during usage. Live munitions can be divided into those undergoing high-order detonations and those undergoing low-order detonations. During a high-order detonation, almost all the explosives a projectile contains are burned and, therefore, only minimal amounts of these explosives enter the water range. The casing is shattered into small pieces and fragments, which sink to the bottom of the river and may be carried downstream by the current until they settle out. The metal components of the casing then slowly dissolve or corrode into the water until they are buried by sediments.

A small percentage of the live munitions fired into the PRTR experience low-order detonation. In this case, the explosives in the projectile are only partially expended and what is left enters the water directly and is carried downstream with the river current or sinks to the bottom of the river, accumulating in the sediments.

If the ordnance fails to detonate altogether, it is considered a dud. It then enters the water with the original amount of explosives still fully contained within the intact shell. Like an inert projectile, the dud generally penetrates the river with enough momentum to become buried in bottom sediments.

After MCs have been introduced in the river, fate and transport processes result in them becoming chemically bound, diluted, buried, or available to potential receptors such as aquatic organisms or people. A full discussion of fate and transport processes is provided in Chapter 5.

4.1.5 Land Use and Exposure Profile

Three Virginia counties – King George, Westmoreland, and Northumberland – one Virginia incorporated town – Colonial Beach – and two Maryland counties – Charles and St. Mary's – border the portion of the Potomac River that contains the PRTR. The shores of the river at this location consist of forested lands, agricultural fields, and parkland alternating with areas characterized by waterside homes, loosely-woven residential communities, and denser villages or subdivisions. Shoreline development along the PRTR is primarily residential, with commercial uses mostly being water-dependent businesses such as charter boat operations, marinas, or seafood eateries. Colonial Beach (Figure 1-2) is the only substantial town along the shoreline. There are no manmade structures within the PRTR proper (the US Route 301 Governor Harry

Nice Memorial Bridge crosses the river between the UDZ and the MDZ but is not within the PRTR.)

People using the riverside parks (Table 4-1) and other recreation and leisure-oriented areas such as Colonial Beach may be exposed to potentially contaminated sediments and surface water while boating, swimming, jet-skiing, water-skiing, or taking part in any other aquatic sports.

Table 4-1
Public Parkland Adjacent to the PRTR

Jurisdiction	Public Parkland
Charles County, Maryland	Mallows Bay Natural Resources Management Area US Bureau of Land Management's Douglas Point property Douglas Point State Natural Resources Management Area Purse State Park Friendship Farm Park Chapel Point State Park
St. Mary's County, Maryland	St. Clement's Island State Park Point Lookout State Park
Westmoreland County, Virginia	Westmoreland State Park George Washington Birthplace National Monument
King George County, Virginia	Dahlgren Wayside Park Caledon State Park
Northumberland County, Virginia	No public parklands

However, the main pathway of exposure to MCs for people is through the consumption of locally-caught fish and shellfish obtained through recreational fishing or by purchase from commercial fishermen. Indeed, many individuals and charter fishing companies use the Potomac River for recreational fishing (from boats or from the piers attached to many riverside homes) while commercial fishing plays a significant role in the local economy, with the main target species consisting of menhaden, striped bass, croaker, blue crabs, and oysters. Data from the Potomac River Fisheries Commission indicate that 85 percent of finfish and 60 percent of crabs are harvested in the lower reaches of the Potomac – from Coltons Point, the lower boundary of the MDZ, down to the mouth of the river. While most oysters are harvested within or downstream of the MDZ, the volumes obtained are relatively small – an average of 4,654 bushels a year, ranging from 33,037 bushels in the 1997-98 season to 66 bushels in the 2001-02 season (Cosby, Potomac River Fisheries Commission, pers. comm., October 7, 2008).The Potomac River Fisheries Commission issues about 2,000 commercial finfish licenses annually, but many fishermen hold multiple licenses so that it is estimated that about 800 commercial fisherman fish the Potomac from its mouth to Mosspoint, Maryland (Cosby, Potomac River Fisheries Commission, pers. comm., October 7, 2008). The number of fishing permits issued for the Potomac River has consistently decreased over the last ten years from 2,531 permits in 1999 to 1,968 permits in 2008 (Cosby, Potomac River Fisheries Commission, pers. comm. February 26, 2010).

Table 4-2 summarizes the pathways by which people may be exposed to MCs in surface water, surficial sediments, and seafood. Based on these potential exposure routes, a range-specific screening-level human health risk assessment was performed and is presented in Chapter 7.

Table 4-2
Exposure Routes and Receptors

Potential Exposure Route	Human Receptors	Ecological Receptors
Ingestion of surface water	●	●
Dermal contact with surface water	●[1]	●
Incidental ingestion of surface sediment	●	●
Dermal contact with surface sediment	●[1]	●
Dermal contact with subsurface sediment	-	-[2]
Ingestion of subsurface sediment	-	-[2]
Ingestion of contaminated food	●	●

Notes:
● Indicates a complete pathway exists.
[1] The exposure to this pathway is not evaluated due to its low contribution.
[2] The benthic invertebrate community at the burial depth of munitions is considered to be minimal, as there is a general pattern of decreasing activity of benthic organisms with increasing depth down to 4-16 in (10-40 cm) (Clarke et al., 2001) and few, if any, ecological receptors would be present at the depth of munitions burial.

4.1.6 Ecological Profile

The Potomac River supports a rich diversity of aquatic life, including aquatic vegetation, invertebrates, and fish. Aquatic plants and animals are potentially exposed to metal and explosive constituents in the water column and sediments. Additionally, the shores of the Potomac River adjacent to the PRTR provide habitat for many terrestrial receptors, including a wide range of bird species and other wildlife. These animals may be exposed to MCs in the river through the consumption of aquatic vegetation and/or prey, but may also be directly exposed to MCs in surface water and sediments during foraging and other activities. Based on the complete exposure pathways for ecological receptors (summarized in Table 4-2), a range-specific screening-level ecological risk assessment is presented in Chapter 6.

5 FATE AND TRANSPORT ANALYSIS

This chapter discusses the fate and transport processes affecting MCs from projectiles fired into the PRTR. As described in Section 3.3, the quantification of munitions in this report is based on available records and focuses on large-caliber projectiles. In this chapter, a subset of the MCs is selected for modeling based on the total mass of MCs fired into the river and the potential for toxic effects on human health and the environment (Section 5.1). The concentrations of these MCs in sediments and water are then estimated using geochemical modeling (Section 5.2). Finally, a hydrodynamic model is applied to evaluate the overall impact of the MCs on the PRTR, which is briefly described in Section 5.3 and detailed in Appendix B.

The remainder of this report examines potential negative impacts associated with legacy munitions and ongoing munitions usage. Potential positive impacts associated with munitions usage beyond the RDT&E benefits (e.g., advances in technology, increased security) include the preservation of natural areas. The DoD has shown increasing dedication to protect the natural environment, including endangered species (Kaufman, 2010). The PRTR is located off the main Atlantic Flyway, which is used by millions of migratory birds and other wildlife (see Section 2.1.5). By limiting the development of the NSF Dahlgren natural areas around the PRTR, wildlife are able to use these habitats.

5.1 Selection of Munitions Constituents of Potential Concern

MCs are any materials originating from UXO, discarded military munitions, or other military ordnance and munitions, including explosive and non-explosive materials, and the emission, degradation, or breakdown products of such ordnance and munitions (US Navy, 2008). The MCs evaluated in this WRSEPA are those associated with projectiles from large-caliber guns fired into the PRTR during RDT&E activities.

Military Expended Material Constituents (MEMC) are any materials originating or released into the environment from the use of Military Expended Material (MEM). MEM include munitions as well as items, devices, equipment, and materials such as sonobuoys, flares, chaff, drones, targets, bathymetry measuring devices, communications devices, items used as training substitutes, and other instrumentation, that are uniquely military in nature and are used and expended in the conduct of military training and testing missions (US Navy, 2008). MEMC include constituents from explosive and non-explosive materials as well as the emission, degradation, or breakdown products from MEM. MEMC also include materials expended (such as propellants, weights, guidance wires) from items that typically are recovered (such as aerial target drones and practice torpedoes).

Targets used during activities on the PRTR today are virtual (i.e., locations defined by coordinates rather than physical targets), which minimizes the quantity of MEMCs generated during testing. Historically when the Mussolini, Hitler, and Upper Machodoc Creek bombing targets were in use from 1938-1957 (see Figure 3-2 in Section 3.1.3), wooden platforms on pilings with bull's eyes painted on them were used as bombing targets. Platforms were rebuilt when inert bombs hit the target. Pieces of the wooden pilings are likely to have entered the PRTR during this time period. However, as these materials are not toxic and constitute a small proportion of the material used on the PRTR, only MCs were considered for this assessment.

5.1.1 Selection of Metal Munitions Constituents of Potential Concern

To focus the study on those MCs most likely to contribute to human health and ecological risks, a subset of MCs –Munitions Constituents of Potential Concern (MCOPCs) – was identified by taking into account the total mass of constituents contained in the projectiles (cumulative over the 90 years under consideration), the toxicity of each constituent, and Navy RSEPA guidance (US Navy, 2006a).

For this purpose, MCs were divided into inorganics and organics. As discussed in Section 3.3.5, the constituents comprising the majority of the total constituent weight are metals from the projectile casing that is common to both live and inert projectiles. The combined weight of iron, copper, and manganese accounts for 97.5 percent of the total constituent weight. Table 5-1 provides a summary of the inorganic constituents by weight, obtained using information from the MIDAS database.

Table 5-1
Inorganic Constituents by Weight in Live and Inert Projectiles

Rank	Constituent	Total Sum of Weight (lbs)
1	Iron	30,980,922
2	Copper*	958,087
3	Manganese*	463,239
4	Aluminum	148,632
5	Zinc*	61,468
6	Nickel*	47,957
7	Lead*	8,417
8	Chromium*	442
9	Cadmium*	187
10	Cobalt	68
11	Beryllium	15
12	Vanadium	13
13	Antimony	6.7
14	Silver	2.6
15	Arsenic	0.33
16	Selenium	0.01

Notes: * Selected for further analysis.
Source: MIDAS database (see Appendix A for details)

Based on the overall mass introduced into the PRTR and potential toxicity, the following seven metals were selected for fate and transport modeling and for conducting the ecological and human health screening-level risk assessments presented in Chapters 6 and 7, respectively:

- Cadmium
- Chromium

- Copper
- Lead
- Manganese
- Nickel
- Zinc

These seven metals are among the top ten contributors of metals to the PRTR by weight. It should be noted that chromium occurs in the environment primarily in two valence states, trivalent chromium (III) and hexavalent chromium (VI). Chromium III occurs naturally in the environment and is an essential nutrient for the human body, whereas chromium (VI) is generally produced by industrial processes (National Library of Medicine, 2012). Chromium VI poses the largest health threat of the various forms of chromium and is much more toxic than chromium III.

The remaining three top-ten contributors, iron, aluminum, and cobalt, were not selected for further evaluation as described below.

Iron is an essential nutrient, that is, a nutrient required for normal body functioning that the body cannot produce itself. Monitoring data indicate that the general population is exposed to iron compounds via inhalation of ambient air, ingestion of food, vitamin supplements, and drinking water (Hazardous Substances Data Bank, 2011a). Although ingestion of large quantities of iron can be harmful, iron in the PRTR sediments and water is not expected to be readily bioavailable because it is not chelated (bound) to amino acids (e.g., chelated iron is contained in many iron supplements). Much of the iron entering the PRTR does not enter the ecosystem, as iron ions are retained on organic matter and are often bound with other elements. RSEPA guidance (US Navy, 2006a) provides direction that metals concentrations which are within the range of background levels are not considered site-related and should not be evaluated further. Although iron is the single greatest MC contributor, it was not selected because it is a common element that is ubiquitous in the environment and commonly used in everyday materials. Iron is one of the most abundant elements in the earth's crust, comprising 5.1 percent (by weight) of the earth's crust (Hazardous Substances Data Bank, 2011a). The iron introduced into the PRTR from RDT&E activities are well within background levels and therefore it was not evaluated further.

Aluminum is another major contributor (it ranks fourth by weight) that was also not selected because, like iron, it is an element used in everyday materials, common in the environment, and not bioavailable within the PRTR. The USEPA considers aluminum to be biologically available only when present in soils and waters of less than 5.5 pH. The Potomac River sediments and water are above 5.5 pH, indicating that aluminum would not be biologically available in the river.

A relatively small total quantity of cobalt has entered the river through projectile firing – about 68 lbs (31 kg) – over 90 years, making it the tenth-ranked metal. The small quantity combined with its low toxicity resulted in eliminating it from further consideration as well.

The six remaining metals in Table 5-1 – beryllium, vanadium, antimony, silver, arsenic, and selenium, in descending order of their total weights – were not selected because of the small amount of each of these metals introduced into the river by RDT&E activities on the PRTR.

5.1.2 Selection of Organic/Explosive Munitions Constituents of Potential Concern

Organic constituents used as explosives in munitions were also selected as MCOPCs. As was done for metals, the selection was based on the total mass of constituents contained in the projectiles (cumulative over the 90 years under consideration), the toxicity of each constituent, and Navy RSEPA guidance (US Navy, 2006a). The MIDAS database provided the total quantity of organics contained in the munitions (see Section 3.3.5 and Appendix A). The top ten organic constituents by weight contained in live and inert projectiles are listed in Table 5-2. The weight of the remaining organic compounds did not exceed 15.2 lbs (6.9 kg) for any individual compound. A complete list of organic constituents can be found in Appendix A. It is important to note that successfully detonated munitions (high-order detonations) consume almost all explosive material present in the round, leaving very little to enter the Potomac River. Thus, most of the organic explosive constituents are expended prior to entering the water, with only 0.001 percent of high-order detonation explosives entering the surface water/sediments of the PRTR (based on US Navy, 2006a). The incidence of unsuccessful live munitions (low-order detonations or duds), is discussed in Section 5.2.2.

Table 5-2
Top 10 Organic/Explosive Constituents by Weight in Live and Inert Projectiles

Rank	Organic/Explosive Constituent	Total Sum of Weight (lbs)
1	Ammonium picrate*	436,228.55
2	RDX*	85,165.59
3	Phosphorus[1]	13,862.73
4	TNT*	12,524.58
5	Ethylbenzene	9,158.53
6	Wax	7,719.48
7	Tetryl*	1,858.29
8	Xylene	315.84
9	Toluene	144.33
10	Charcoal	39.54
11	HMX*	36.38

Notes:
* Selected for further analysis.
[1] Phosphorus is a non-metal inorganic element, which is included here because it can be used as an explosive.
Source: MIDAS database (see Appendix A for details)

The following five explosives were selected as MCOPCs for this WRSEPA:

- Ammonium picrate
- HMX
- RDX
- Tetryl
- TNT

The top seven constituents – ammonium picrate, RDX, phosphorus, TNT, ethylbenzene, wax, and tetryl – comprise more than 99.9 percent of the weight of all organics/explosives.

The top-ranking explosive by weight, ammonium picrate, is a relatively insensitive[11] substance that was used widely during the First World War. It is used as a booster charge to set off secondary explosives, such as TNT. Due to the large total amount of ammonium picrate used, it was selected as an MCOPC.

RDX, TNT, tetryl, and HMX (11^{th} by weight) are listed as munitions constituents of potential concern (MCOPCs) in Navy RSEPA guidance (US Navy, 2006a). Previous work on Army ranges identified RDX, HMX, TNT, and perchlorate as the principal energetic compounds of concern (e.g., Pennington et al., 2006; Jenkins et al., 2005). Because the Marines train with the same weapon systems as the Army, with the exception of some small arms systems, the energetic compounds of concern are the same for both services (Clausen et al., 2007). TNT, RDX, and tetryl are also recommended for modeling in the Navy RSEPA guidance (US Navy, 2006a). Therefore, these four constituents – RDX, HMX, TNT, and tetryl –were selected as MCOPCs for this study.

Perchlorate (ClO_4) is a naturally occurring and man-made anion that consists of one chlorine atom bonded to four oxygen atoms (USEPA, 2010). Perchlorate is used as an energetics booster or oxidant in solid propellant in some rockets, missiles, explosives, and pyrotechnics (Xu et al., 2003). As discussed in Section 3.1.4, 2.75" FFAR and 5" Zuni rockets were tested on the PRTR from 1964 to 1974. A total of 34 Department of Defense Identification Codes were found in the Naval Ordnance Maintenance Management Program for the 2.75" FFAR and the 5" Zuni rockets. The summary of all compounds and the Toxic Release Inventory data sheets were pulled from MIDAS (see Section 3.3.5) for all 34 Department of Defense Identification Codes and checked for perchlorate. Of the 34 rockets examined, three 2.75" FFARs contained ammonium perchlorate and potassium perchlorate in their warheads. No 5" Zuni rockets contained perchlorate. As the rocket testing used almost exclusively inert rockets (Section 3.1.4), it is extremely unlikely that warheads were tested on the PRTR.

Virtually no large-caliber projectiles contain perchlorate. Potassium perchlorate was recorded as being used only once in large-caliber projectiles fired by NSWCDD – in 1986, a total of 1.15 lbs (0.52 kg) of potassium perchlorate were used as part of 83 mm munitions (see Appendix A.I-2, Table 4) and was probably used as a stab primer (a pyrotechnic initiator) or as a delay in this projectile, rather than as fuel. Almost all of this explosive – more than 99.99 percent – would have been expended during firing (US Navy, 2006a). Less than one thousandth of a gram is assumed to have entered the PRTR over twenty years ago, an amount considered too small to

[11] The sensitivity of an explosive refers to the ease with which it can be ignited or detonated.

have any impact on the system. Because of the presence of other DoD installations up river (Naval Surface Warfare Center Indian Head, Marine Corps Base Quantico, and US Army Garrison Fort Belvoir), and the naturally occurring perchlorate in Chilean saltpeter used to make fertilizer (mostly prior to 1950), perchlorate detected in the river is unlikely to be attributable to the 1986 NSWCDD munitions testing.

NSF Dahlgren has voluntarily tested for perchlorate in surface water, groundwater, soil, drinking water, and sediment across the facility to assess possible releases to the environment associated with range activities. Sampling for perchlorate was initiated in 2001 and is ongoing. Perchlorate concentrations have been detected in shallow groundwater predominantly at the open burning/open detonation unit in the EEA Range Complex, used for land-based ordnance RDT&E. Perchlorate is present in this area due to the testing of rocket motors, mortars, smoke pots, and grenades. The contaminated shallow groundwater at the open burning/open detonation unit on the EEA is being sampled and monitored in compliance with the open burning/open detonation Resource Conservation and Recovery Act (RCRA) Subpart X Permit requirements. The RCA report (NSWCDD, 2010) concluded that monitoring is currently in compliance with the permit requirements and that shallow groundwater contamination does not have the potential to migrate off-range. Therefore, no deficiencies in compliance were noted for the open burning/open detonation unit (NSWCDD, 2010).

There is no evidence from surface water sampling results that perchlorate is leaving the land ranges and entering the Potomac River, although the Potomac River has not been sampled for perchlorate (Lovejoy, pers. comm., 2010). Therefore, based upon the RCA findings and the lack of evidence that perchlorate is entering the Potomac River, perchlorate was not selected to be an MCOPC.

Phosphorus was used primarily in inert projectiles (over 86 percent), for which it likely served as a propellant. Almost all the phosphorus used in inert projectiles is assumed to be consumed prior to the projectile's entering the water. The phosphorus used in live projectiles is not white phosphorus (used for screening, spotting, and signaling purposes), which is listed separately on MIDAS chemical inventory sheets. Phosphorus, an essential element for plant life, is not included in the list of MCOPCs in Navy RSEPA guidance (US Navy, 2006a). Phosphorus is a common constituent of agricultural fertilizers, manure, and organic wastes in sewage and industrial effluent, and large quantities in water can speed up eutrophication (a reduction in dissolved oxygen in water bodies caused by an increase of mineral and organic nutrients) (USGS, 2011). Quantities of phosphorus entering the Potomac River from munitions are minuscule when considered against the 30 million pounds per year of phosphorus entering Chesapeake Bay, about 25 percent of which comes from the Potomac River (USGS, 1995). Therefore, phosphorus was not selected as a MCOPC.

Ethylbenzene was not selected because it is a compound that was used primarily in inert projectiles (99.8 percent), for which it likely served as a propellant; therefore, it can be assumed that it was consumed prior to the projectile's entering the water. Ethylbenzene is found in natural products, such as coal tar and petroleum, and in manufactured products, such as inks, insecticides, and paints; it is also used as a solvent, in fuels, and in the fabrication of other chemicals. Wax, which was used in live projectiles, was not selected for further evaluation, because waxes are generally non-toxic and the amount of wax used is not considered to pose potential risks to humans or the environment.

Conversely, although only about 36 lbs (16 kg) of HMX are recorded as having been used at the PRTR, this compound was selected as a MCOPC because of its potential toxicity and following recommendations provided in the Navy RSEPA guidance (US Navy, 2006a).

5.2 Mass Loading of Munitions Constituents in the PRTR

The munitions that have been fired at the PRTR, over the 90 years under consideration, include organic (e.g., explosives) and metal components. To help understand the potential accumulation of these constituents in the river's water and sediments, the ORSM presented in Chapter 4 was developed. It should be noted that the ORSM made use of conservative assumptions[12]. The two primary factors affecting the concentrations of explosives and metals in the environment of the PRTR are:

- The physical distribution of munitions in the PRTR.
- The geochemical factors that determine the distribution of explosives and metals in environmental media, such as sediments and water.

These two factors are described in the following sections.

5.2.1 Distribution of Munitions in the PRTR

As discussed in Section 3.3.3, most munitions fired on the PRTR landed in the MDZ (see Figures 3-4 and 3-5). After examination of the distribution of the projectiles, the following two areas within the MDZ (shown in Figure 5-1, Areas Used for Munitions Modeling) were selected for modeling:

- **Dense zone.** The area 11,000 to 13,000 yards (yds) (10,058 to 11,887 m) from the firing line, where the largest concentration of munitions fired into the PRTR landed (Table 3-7).
- **Diffuse zone.** The area 0[13] to 25,000 yds (0 to 22,860 m) from the firing line, where more than 99 percent of the munitions fired into the PRTR landed (Table 3-7). The diffuse zone includes the dense zone.

Based on the available records, 165,204[14] of the 342,756 projectiles fired in the MDZ, or approximately 48 percent, landed in or exploded over the dense zone, which covers 2.3 sq NM (7.8 sq km) of the river, about 6 percent of the MDZ surface area. This zone is used to represent the "worst case" exposure because of the dense concentration of munitions deposited here.

The diffuse zone, encompassing 31 sq NM (106 sq km), was also considered for the three following reasons. First, only 25 of the 57 documented munitions types fired into the Potomac River have been fired into the dense zone, while all 57 types have been fired into the larger

[12] Conservative assumptions are those that would result in greater impact to the environment if verified; therefore, their use in estimating impacts is considered to be protective of the environment.
[13] Although 0 yds is used here, projectiles land a minimum of 100 to 150 yds away from the gun emplacement area.
[14] The number of rounds included in the dense zone differs slightly from that listed in Table 3-7 for 11,000 to 13,000 yds, because the dense zone in this evaluation includes rounds assumed to have landed at 11,000 yds, whereas in Table 3.7, the 11,000 to 13,000 yds category includes rounds from about 11,001 to 13,000 yds. Using the larger number of rounds results in a more conservative evaluation of impacts to this zone.

diffuse zone. Thus, the evaluation of a greater area provides a more complete chemical inventory, as chemical composition varies by munitions type (see Section 3.3.5). Second, the chemical composition of river water and sediments is influenced by the river's flow and tidal movement, which have a larger impact on a smaller zone than on a larger zone. Finally, the larger area of the diffuse zone provides a larger potential exposure area for human and ecological receptors that move up and down the river.

The diffuse zone received 99.4 percent (341,706 projectiles) of all projectiles fired, as recorded in the log books (343,815 projectiles; see Tables 3-6 and 3-7). Given the surface area of 31 sq NM (106 sq km) and assuming an even distribution of projectiles throughout this zone, the density of projectiles in the diffuse zone is 10,956 projectiles per sq NM (3,190 projectiles per sq km).

5.2.2 Munitions Groups

Munitions fired into the PRTR were divided into three groups:

- Live projectiles
- Duds (no detonation)
- Inert projectiles

The percentage of live and inert projectiles tested at the PRTR by munitions type is provided in Table 5-3.

Constituents from each of these categories enter the water and sediments of the Potomac River in different ways, as described below.

Live Projectiles

Live projectiles fired on the PRTR generally explode above the surface of the water. The casing of live projectiles is fragmented during the detonation and metals enter the water as pieces or small particles. These pieces settle on bottom sediments with no loss of metal to the atmosphere. For this study, all live-round metal fragments were assumed to settle on the surface of sediments at the sediment/river water interface. These fragments were conservatively assumed to take 100 years for complete dissolution in the Potomac River. This is considered conservative based on the results of Chendorain et al. (2002), who studied corrosion rates in unexploded ordnance in soil and estimated perforation rates of ½" casings to range between 320 to 4,200 years. Therefore, the assumption that one percent of the metal remaining from live projectiles is completely dissolved each year is considered to be exceedingly conservative and actual rates could be 3 to more than 42 times slower.

Based on information in the literature (e.g., Walsh, 2007) and Navy RSEPA guidance (US Navy, 2006a), most of the organic (explosive) constituents from live projectiles can be assumed to be expended during detonation prior to entering the water. However, the percentage of organic constituents remaining in the projectile and entering the water depends on whether the detonation is complete (high- or low-order). As previously noted (Section 4.1.3), a low-order detonation will result in a greater amount of explosives remaining from the round than a high-order detonation. For this analysis, per Navy RSEPA guidance (US Navy, 2006a), it was assumed that one thousandth of one percent (0.0001 percent) of the energetic filler remains following high-order detonation (Hewitt et al., 2003; Jenkins et al., 2000), whereas 50 percent remain following a low-order detonation (Hewitt et al., 2003; Lewis et al., 2002).

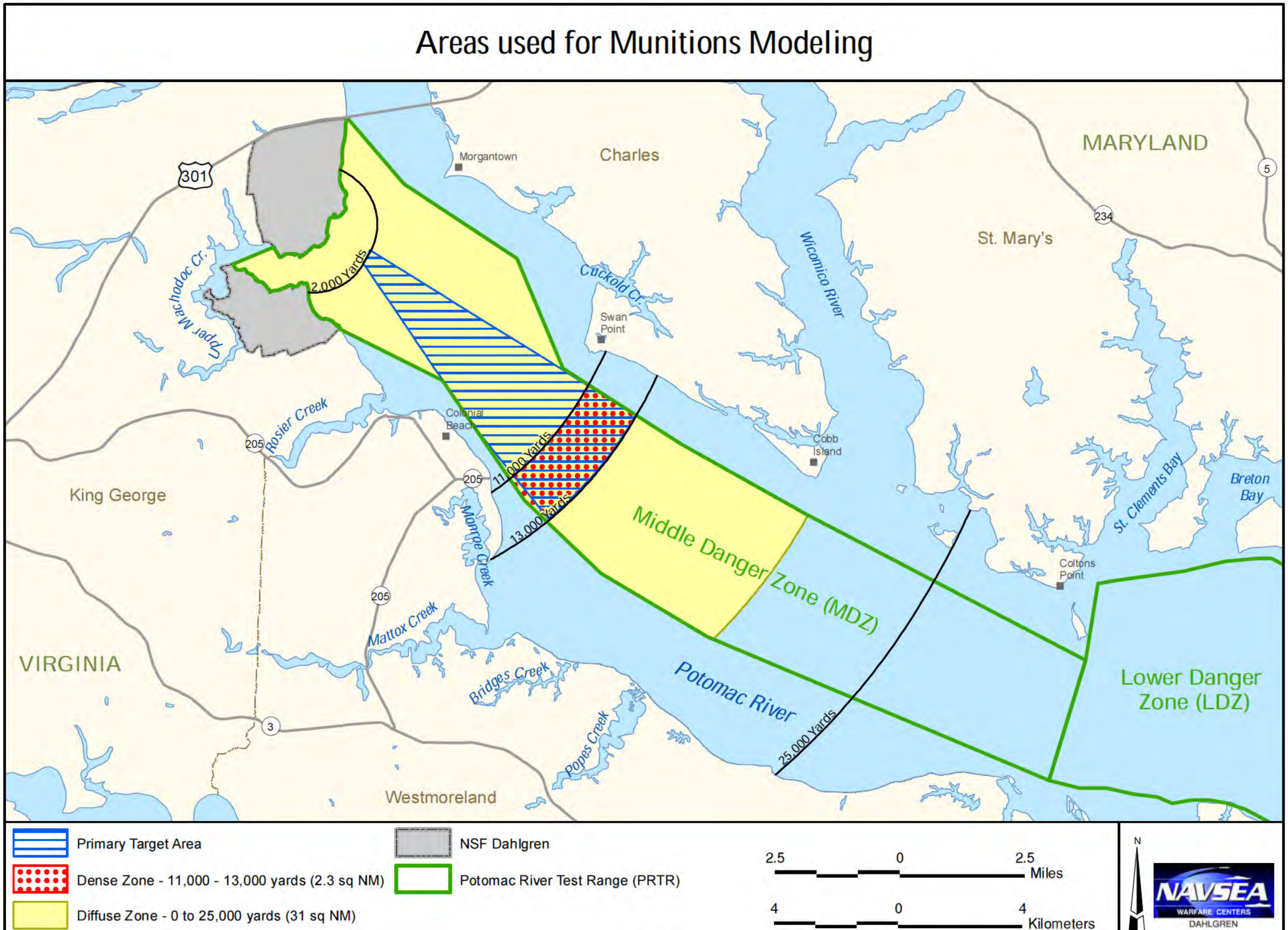


Figure 5-1

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

The US Army Defense Ammunition Center (USADAC, 2000, as cited in Clausen et al., 2006) calculated the average occurrence of low-order detonation for various munitions types, presented in Table 5-4. Twelve of these munitions types were used on the PRTR and the corresponding rate of low-detonation occurrence were applied to this analysis. For munitions not listed, a low-order detonation rate of 0.06 percent was applied, as directed in Navy RSEPA guidance (US Navy, 2006a).

Duds

Live projectiles that do not undergo low- or high-order detonation are duds. Duds have the same chemical content as live shells but their final location and weathering rate can be assumed to be similar to those of inert projectiles. Table 5-4 provides percentages of live projectiles that can be assumed to be duds for munitions types based on data from the US Army Defense Ammunition Center (USADAC, 2000; as cited in Clausen et al., 2006). Site-specific dud rates contained in records provided by NSWCDD are also provided in Table 5-4 and Appendix A. For the remainder of munitions types, for which neither site-specific nor munitions-specific data were available, a dud rate of 3.0 percent was used as directed in the Navy RSEPA guidance (US Navy, 2006a).

Inert Projectiles

Over 90 years of testing on the PRTR, 85 percent of all projectiles fired have been inert – that is, they do not detonate and, therefore, contain minimal quantities of explosives (see Figure 3-3). The small amounts of explosives used are generally expended as propellants or in fuzes. Table 5-3 provides a listing of the total number and percentage of inert projectiles used on the PRTR for each munitions type.

Inert projectiles and duds can be assumed to be buried in Potomac River sediments based on the force with which they are propelled into the river and hit the bottom and the results of retrieving canisters fired from guns (A. Swope, NSWCDD, pers. comm., October 22, 2008). In addition, as noted in Section 2.3.2, the upper layer of sediments has a water content of 90 percent or more (Goodwin et al., 1984). Such soft sediment would not support heavy projectiles, which would quickly sink and be buried in the sediment.

Inert projectiles and duds remain intact upon impact with the sediment because of their thick casings (Jenkins et al., 2001). Therefore, they are a potential source of metals as they corrode, and, in the case of duds, of explosives when corrosion breaches the casing[15]. However, most such munitions can be assumed to be buried deeply enough in the sediments – approximately 8 ft (2.4 m) below the surface (A. Swope, NSWCDD, pers. comm., October 22, 2008) – that the products of corrosion would not impact surface water or the upper sediment layers where most biota occur (see Chapter 6). In addition, the limited data available for metals in deeper sediments in the PRTR suggest that corrosion rates have been slow (e.g., Callender et al., 1984[16]).

[15] The explosives content of exposed inert shells, although small, was included in calculations (Section 5.2.4).

[16] Callender et al. (1984) provides a copper and zinc profile for sediments near the dense zone. There is no metals peak in the deeper sediments, where most munitions are expected to be located.

Table 5-3
Percentages of Live and Inert Projectiles by Type

Munition Type	Number of Inert Projectiles	Number of Live Projectiles	Total Projectiles	% Inert Projectiles	% Live Projectiles
105 mm	766	693	1,459	53%	47%
12"	47	0	47	100%	0%
12" 40 caliber	41	0	41	100%	0%
12" 45 caliber	35	0	35	100%	0%
12" 50 caliber	38	0	38	100%	0%
120-mm	252	105	357	71%	29%
122-mm	45	0	45	100%	0%
14"	756	0	756	100%	0%
14" 33 caliber	11	0	11	100%	0%
14" 45 caliber	879	1	880	100%	0%
14" 50 caliber	166	1	167	99%	1%
155 mm	524	151	675	78%	22%
16"	740	0	740	100%	0%
16" 45 caliber	4,506	1,610	6,116	74%	26%
16" 50 caliber	1,251	38	1,289	97%	3%
1-pounder (37-mm)	729	4	733	99%	1%
3" 15 caliber	154	1	155	99%	1%
3"	3,452	27	3,479	99%	1%
3" 20 caliber	437	581	1,018	43%	57%
3" 23 caliber	72	0	72	100%	0%
3" 50 caliber	5,334	1,976	7,310	73%	27%
3" 70 caliber	15,861	954	16,815	94%	6%
30 mm	3,984	165	4,149	96%	4%
35 mm	0	358	358	0%	100%
4"	2,766	11	2,777	100%	0%
4" 50 caliber	1,841	75	1,916	96%	4%
40 mm	6,917	7,491	14,408	48%	52%
5" 70 caliber	445	0	445	100%	0%
5"	1,605	60	1,665	96%	4%
5" 15 caliber	7	45	52	13%	87%
5" 25 caliber	320	2	322	99%	1%
5" 38 caliber	81,335	10,749	92,084	88%	12%
5" 40 caliber	770	10	780	99%	1%
5" 51 caliber	1,778	15	1,793	99%	1%
5" 54 caliber	86,118	14,410	100,528	86%	14%
5" 62 caliber	5,110	959	6,069	84%	16%
57 mm	4,384	240	4,624	95%	5%
6" 25 caliber	12	0	12	100%	0%
6"	114	0	114	100%	0%
6" 23 caliber	10	0	10	100%	0%
6" 40 caliber	1,029	8	1,037	99%	1%
6" 45 caliber	970	5	975	99%	1%
6" 47 caliber	8,221	4,724	12,945	64%	36%

Table 5-3 cont'd
Percentages of Live and Inert Projectiles by Type

Munition Type	Number of Inert Projectiles	Number of Live Projectiles	Total Projectiles	% Inert Projectiles	% Live Projectiles
6" 53 caliber	1,525	4	1,529	100%	0%
60 mm	85	34	119	71%	29%
6-pounder (57-mm)	171	2	173	99%	1%
7"	35	0	35	100%	0%
7" 45 caliber	809	1	810	100%	0%
75 mm	65	36	101	64%	36%
76 mm	36,627	6,112	42,739	86%	14%
8"	883	25	908	97%	3%
8" 35 caliber	134	2	136	99%	1%
8" 51 caliber	336	0	336	100%	0%
8" 55 caliber	6,900	79	6,979	99%	1%
81 mm	37	23	60	62%	38%
83 mm	198	15	213	93%	7%
90 mm	334	42	376	89%	11%

Table 5-4
Percentages of Low-order Detonations and Duds

Munition Type	Low-order Detonation	Dud
Percentages from USADAC[a]		
Fuze	0.02%	3.96%
105 mm	1.07%	4.65%
106 mm	0.20%	2.68%
120 mm	0.00%	2.59%
152 mm	0.00%	0.00%
155 mm	0.99%	2.26%
165 mm	1.09%	1.63%
2.75”	0.00%	11.70%
3.5”	0.00%	1.08%
4.2”	0.14%	5.13%
40 mm	0.15%	1.37%
57 mm	0.00%	0.53%
60 mm	0.02%	2.34%
66 mm	0.04%	4.52%
75 mm	0.20%	5.70%
76 mm	0.12%	8.72%
8”	0.00%	0.99%
81 mm	0.11%	2.33%
83 mm	1.25%	1.96%
84 mm	0.15%	0.00%
90 mm	0.40%	8.06%
Percentages based on count provided by NSWCDD[b]		
76 mm	--	0.6%
6" 47 caliber	--	6.4%
5" 62 caliber	--	1.4%
5" 54 caliber	--	1.3%
5" 38 caliber	--	6.7%
3" 70 caliber	--	3.6%
16" 45 caliber	--	5.2%
155 mm	--	13.9%
Average:	0.28%	3.8%

Note: For munitions not listed, a low-order detonation rate of 0.06 percent and a dud rate of 3 percent were applied, as directed in Navy RSEPA guidance (US Navy, 2006a).

Sources:

[a] US Army Defense Ammunition Center (USADAC), 2000, as cited in Clausen et al., 2006.

[b] As contained in available NSWCDD PRTR records (see Section 3.3).

There are occasional reports of UXO or inert ordnance washing up along the Potomac River shoreline following storms. NSWCDD conducts recovery operations when such finds are reported (R. Mason, US Navy, pers. comm., April 6, 2005, as cited in ATSDR, 2006). Based upon the limited number of projectiles reported, it is estimated that 0.1 percent of the duds and inert projectiles fired (i.e., one in a thousand) are present at the sediment/river water interface due to exposure by storms, extremely high water flows, or other factors.

The metals in the inert projectiles and duds were conservatively assumed to take at least 400 years for complete dissolution in the Potomac River (i.e., 0.25 percent of total metal is assumed to dissolve each year). This rate is slower than the rate assumed for live projectiles because the exposed area of a non-fragmented projectile is less than the remnants of an exploded live one, and the metal has not been similarly stressed.

5.2.3 Additional Modeling Assumptions

The assumed rates of dissolution of the metal casing into river water of 1 percent per year for live projectiles and 0.25 percent per year for duds and inert projectiles do not take into account the initial form of the metal or its location on or within the round. In nature, metals are often present as alloys and the form of the metal affects corrosion rates. For example, the corrosion rate of nickel alloyed with copper is less than that of pure nickel. Similarly, zinc corrodes relatively rapidly as a pure metal and can be used to protect other metals as a sacrificial anode where it is more easily oxidized than the protected metal. When zinc and copper are combined in brass, however, they have much lower corrosion rates than as pure metals.

Applying conservative assumptions, the casings of inert projectiles and duds were assumed to be breached after 50 years. This would allow the explosives contained in the duds and inert projectiles to enter the river water. It was assumed that the explosives in these projectiles entered river water over a one-year time period.

Explosives and metals were modeled using the averaged metals and explosives load and assuming 90 years of environmental exposure for corrosion. Concentrations of organic explosives and metals constituents were calculated based on the assumptions described above and following the steps described in the text boxes below. The constituent concentrations released to the environment over the 90-year time period, also referred to as the “source term” were then assigned to river water or sediments based on distribution or geochemical modeling, as described in the following section.

Quantitative Determination of the Distribution of Metals after Entering the Environment (Source Term): Stepwise Approach

1. Sum the number of rounds by type of munitions in each zone.
2. Separate the total rounds into live and inert rounds by type of munition.
3. Multiply the number of inert or live rounds by the metal content in pounds for each type of round to get the total weight in pounds of each type of metal.
4. For metal compounds (e.g., zinc potassium chromate), multiply the total weight of the compound by the ratio of molecular weight of each metal to the molecular weight of the compound.
5. Sum the weight of metals and metal compounds separately for live and inert rounds. Metals of potential concern are: cadmium, chromium, copper, lead, manganese, nickel, and zinc (see Section 5.1.1).
6. Determine the number of duds for each munitions type using (see Section 5.2.2 and Table 5-5):
    a. The known number of duds at the PRTR - applicable to eight munitions types.
    b. The known percentage of duds from the literature (USADAC, 2000 as cited in Clausen et al., 2006) - applicable to 10 munition types.
    c. The average dud rate of 3.0 percent (US Navy, 2006a) - applicable to 39 munitions types.
7. Subtract the metals in duds from the live rounds and add to the inert rounds.
8. Multiply the inert round and dud round metals by 0.001 to obtain the metals in rounds exposed at the river water/sediment interface.
9. Multiply the inert round and dud round metals by 0.0025 to obtain the annual dissolved metals from these rounds. Multiply the live round metals by 0.01 to obtain the annual dissolved metals for these rounds.
10. Add the metals from live and inert rounds and from duds to obtain total metals for each year.
11. The model assumes a 0.1 cm layer of sediment within a 1 liter volume of water (dimensions of 10 cm x 10 cm x 10 cm). Convert the pounds of metals in each zone to mg/l of metals in each zone using the area of water in the zone and weight conversion (multiply by 4.54e+6 mg per lb or 1 kg per liter of water).
12. Determine the distribution of metals between sediment and river water using the PHREEQC model, particularly adsorptive functions (see Section 5.2.4).

Quantitative Determination of the Distribution of Organic Explosives after Entering the Environment (Source Term): Stepwise Approach

1. Sum the number of rounds by type of munitions in each (dense and diffuse) zone.
2. Separate the total rounds into live and inert rounds by type of munitions.
3. Multiply the number of inert or live rounds by the explosives content in pounds for each type of round to get total pounds of each type of explosive. (Note: explosives compositions for live rounds include ammonium picrate, HMX, RDX, tetryl, and TNT and only tetryl and TNT for inert rounds.)
4. Determine the number of duds for each munitions type using (see Section 5.2.2 and Table 5-5):
    a. The known number of duds at the PRTR - applicable to eight munitions types.
    b. The known percent of duds from the literature (USADAC, 2000 as cited in Clausen et al., 2006) - applicable to 10 munition types.
    c. The average dud rate of 3.0 percent from the literature (US Navy, 2006a; USADAC, 2000 as cited in Clausen et al., 2006) -applicable to 39 munitions types.
5. Subtract the explosives in duds from the live rounds and add them to the inert rounds.
6. Multiply the inert round and dud round explosives by 0.001 to obtain the explosives in rounds exposed at the river water/sediment interface (see Section 5.2.2).
7. Separate the pounds of explosives from live rounds into high-order and low-order detonations by using (see Section 5.2.2 and Table 5-4):
    a. The percentage of low-order detonations - applicable to 12 munitions types.
    b. A low-order detonation rate of 0.06 percent (US Navy, 2006a) - applicable to 45 munitions types.
8. Multiply high-order explosives by 0.00001 and low-order explosives by 0.5 to determine the pounds of live explosives entering water. Explosives in inert rounds and duds are not multiplied by any factor because they have not exploded.
9. Divide the total explosives by the total number of years of record (90 years) to get an average annual input and convert from pounds of explosives to milligrams per liter of explosives using:
    a. For explosives from live rounds, the volume of river water in the applicable zone.
    b. For explosives from inert rounds and duds, the volume of water in 10 cm of water overlying the sediments extending across the area of the applicable zone.
10. Add explosives from live rounds, duds, and inert rounds to get total explosives in water in contact with the sediment surface.
11. Compare concentrations with water solubility to make sure these values are not exceeded (see Table 5-6).
12. Determine the distribution of explosives between sediment and river water using the adsorption distribution coefficient (see Section 5.2.4, Equation 5-1).
13. Divide the resulting concentration adsorbed by 12 to obtain monthly concentration adsorbed to sediment (mg/kg dry weight) due to sedimentation rates of greater than 1 mm per month.

5.2.4 Fate of Explosives and Metals in Sediments and River Water

The environmental fate of organics and metal constituents varies depending on environmental factors, geochemical conditions, and attenuation mechanisms that redistribute the constituents in the environment. Some natural attenuation mechanisms – such as advection, dispersion, dissolution, precipitation, and sorption – reduce concentrations in water and redistribute constituents between river water and sediments. Other processes – such as biodegradation, hydrolysis, and photolysis – may change or destroy the original explosive compound but are not applicable to metals. For this evaluation, adsorption – the adhesion of a chemical species onto the surface of particles – was the key process evaluated. Potential redistribution due to hydrodynamic processes is discussed briefly in Section 5.3 and detailed in Appendix B.

Environmental Distribution of Explosives

The adsorption of explosive constituents by sediment results in partitioning them between sediment and river water. There is evidence that explosives are adsorbed by organic carbon, clay, and minerals containing a large percentage of iron (e.g., Pennington and Brannon, 2002; Larson et al., 2008). The present evaluation considered adsorption of explosives by organic carbon only. The distribution of explosives between the organic fraction of the sediments and river water can be determined using the adsorption distribution coefficient:

$$K_d = K_{oc} \text{ x } f_{oc} \qquad \text{(Equation 5-1)}$$

where:

K_d = concentration adsorbed to soil / equilibrium concentration in water

K_{oc} = adsorption factor for organic carbon specific to the adsorbed constituent

f_{oc} = fraction of organic carbon in sediments at the river water-sediment interface

The K_{oc} values for this evaluation were obtained from the existing literature (Walsh et al., 1995; Talmage et al., 1999 as cited in US Navy, 2002) and are presented in Table 5-5. The fraction of organic carbon (f_{oc}) values of 0.016 (1.6 percent total organic carbon [TOC]) and 0.023 (2.3 percent TOC), for the dense and diffuse zones, respectively, were used. These TOC values are based on data from sediment cores collected within or close to the dense and diffuse zones (Goodwin et al., 1984; Glenn, 1988; Versar, 2008). Specific data used to determine TOC for the PRTR are provided in Table 5-6.

Table 5-5
Water Solubility and Organic Carbon Partitioning Factors

Explosive	Water Solubility[a] (mg/l)	Organic Carbon Partition Coefficient (K_{oc}) (l/kg)
Ammonium picrate	10,000	0.0214[b]
HMX	5.0	2.8[c]
RDX	42	0.88 - 2.4 (0.832[d])
Tetryl	80	2140[c]
TNT	130	1830[c]

Notes:
l/kg = liters per kilogram
[a] Walsh et al., 1995.
[b] Based on conversion from K_{ow} to K_{oc}: $\log10 K_{oc}$=0.00028 + 0.983 log10 (K_{ow}) from Talmage et. al., 1999 (as cited in US Navy, 2002). K_{ow} value from Walsh et al.,1985.
[c] Talmage et. al., 1999 as cited in US Navy, 2002.
[d] Data from Talmage et. al., 1999 (as cited in US Navy, 2002), who used conversion factor from K_{ow} to K_{oc} (see note b).

Table 5-6
Potomac River MDZ Total Organic Carbon

Total Organic Carbon g/kg (%)	Reference [a]	Sand (%)	Notes
1 (0.1%)	Versar (2008) (#51)	96	Lower end of the MDZ, surficial sediments
32 (3.2%)	Versar (2008) (#52)	11	Lower end of the MDZ, surficial sediments
32 (3.2%)	Goodwin et. al. (1984) (#7809-V6B Piney Pt)	NA	Average of 1- and 7-cm depth samples
31 (3.1%)	Goodwin et. al. (1984) (#7805-V6 Piney Pt)	NA	Average of 1-,3-,5-,7-, and 9- cm depth samples
16 (1.6%)	Glenn (1988) (#241)	3	From channel in dense zone
27 (2.7%)	Glenn (1988) (#277)	14	From channel near diffuse zone
Average = 23 (2.3%)	--	--	--

Notes:
g/kg = grams per kilogram.
NA = not available.
[a] The reference samples (numbers in parenthesis) were selected based on their location in relation to the zones modeled.

Table 5-7 presents calculated surface sediment and overlying water concentrations of explosives for the dense and diffuse zones. The first column for each zone lists the concentration of explosives in the water column resulting from the input from live projectiles, and the second column provides the concentration in river water near the sediment resulting from the explosives in inert projectiles and duds. The contributions from live projectiles are greater than those from duds and inert projectiles because of the low explosive content of inert projectiles and because most duds and inert projectiles are buried well below the sediment surface.

Table 5-7 also provides concentrations adsorbed to sediments on a monthly basis and concentrations in the river water column on a daily basis. Adsorption occurs near the river water-sediment interface and has a minimal effect on concentrations in most of the water column. Therefore, no adsorption is factored into water concentrations, and the daily concentrations of explosives in river water are calculated based on initial concentrations in the river water column.

Environmental Distribution of Metal Constituents

Metal mobility varies depending on geochemical conditions. Highly acidic or alkaline conditions may induce dissolution, and oxidation-reduction (redox) conditions impact mobility. Table 5-8 summarizes general metal mobility for different redox conditions, assuming a pH of 6.5 to 8.5. Based on available data, as shown in Table 2-5, the mean pH values for river water in the MDZ all fall within this range, although maximum values at downstream locations occasionally exceed 8.5.

Knowledge of the geochemical environment is important for understanding the distribution of metals between river water and sediment. Studies performed in the Chesapeake Bay system, which includes the Potomac River, have resulted in the collection of geochemical, chemical, and other environmental data. In particular, Martin et al. (1981) and Goodwin et al. (1984) provide comprehensive data for sediment and pore water[17] composition based on the analysis of sediment

[17] Pore water is the water filling the spaces between grains of sediment.

cores taken in the Potomac River in 1978-80. Information from these reports is used in the following discussion. A text box describing the stepwise procedure used to calculate metal concentrations in sediments and water is provided at the end of the previous section.

Table 5-7
Modeled Explosive Concentrations in Potomac River Sediment and Overlying Water

Explosive	Annual Input		Adsorption coefficient (Kd)[a] (l/kg)	Sediment Concentration Adsorbed (mg/kg dw)		Daily Concentration in Water Column [d] (mg/l)
	From Live Projectiles into Water Column (mg/l)	From Duds and Inert Projectiles Near Sediment Surface (mg/l)		Annual [b]	Monthly [c]	
Dense Zone						
Ammonium picrate	0.0189	8.80×10^{-5}	3.42×10^{-4}	6.49×10^{-6}	5.41×10^{-7}	5.17×10^{-5}
HMX	1.63×10^{-6}	1.06×10^{-8}	0.0448	7.34×10^{-8}	6.11×10^{-9}	4.46×10^{-9}
RDX	0.0123	1.71×10^{-4}	0.0133	1.66×10^{-4}	1.38×10^{-5}	3.37×10^{-5}
Tetryl	2.09×10^{-4}	1.81×10^{-6}	34.2	0.00723	6.03×10^{-4}	5.74×10^{-7}
TNT	0.00122	2.14×10^{-6}	29.3	0.0358	0.00298	3.34×10^{-6}
Diffuse Zone						
Ammonium picrate	9.81×10^{-4}	8.53×10^{-6}	4.92×10^{-4}	4.87×10^{-7}	4.06×10^{-8}	2.69×10^{-6}
HMX	9.49×10^{-7}	4.17×10^{-10}	0.0644	6.12×10^{-8}	5.10×10^{-9}	2.60×10^{-9}
RDX	2.09×10^{-4}	2.48×10^{-6}	0.0191	4.05×10^{-6}	3.37×10^{-7}	5.73×10^{-7}
Tetryl	6.00×10^{-6}	9.38×10^{-8}	49.2	3.00×10^{-4}	2.50×10^{-5}	1.64×10^{-8}
TNT	2.32×10^{-4}	2.71×10^{-7}	42.1	0.00977	8.14×10^{-4}	6.35×10^{-7}

Notes:

l/kg = liters per kilogram

mg/l = milligrams per liter or parts per million

mg/kg dw = milligrams per kilogram dry weight or parts per million

A concentration of 0.001 mg/kg is equal to 1 part per 1,000,000,000 (part per billion).

Scientific notation is used for small numbers; for example 1.0×10^{-6} is one millionth (0.000001).

[a] Kd = Koc x foc.

[b] Concentration adsorbed = concentration in river water near sediment river water interface x Kd.

[c] Sediment refreshed monthly due to sedimentation rate in dense zone of 1.8 cm per year and in diffuse zone of 1.3 cm per year (Knebel et. al, 1981).

[d] Adsorption is localized and has minimal impact on explosives concentrations in water column; therefore, daily concentrations are calculated from water-column concentrations.

Table 5-8
Metals Mobility under Different Redox Conditions

Metal	Oxidizing	Iron Reducing	Sulfate Reducing
Cadmium	Adsorbed	Mobile	Precipitate as sulfide
Chromium	Adsorbed or precipitate	Mobile or precipitate	Mobile
Copper	Adsorbed	Mobile	Precipitate as sulfide
Lead	Adsorbed	Mobile	Precipitate as sulfide
Manganese	Adsorbed or precipitates if carbonate present	Mobile	Mobile
Nickel	Adsorbed	Mobile	Precipitate as sulfide
Zinc	Adsorbed	Mobile	Precipitate as sulfide

Note: Adsorption assumes the presence of adsorbing iron minerals.
Source: Adapted from Smith and Huyck, 1999.

River water and sediments in the MDZ have neutral-to-slightly alkaline pH values. According to data collected by Goodwin et al. (1984), the pore water pH ranges from 6.9 to 7.9 in the upper sediments of the diffuse zone. Pore water Eh values (Eh – reduction potential or redox potential – is a measure of the tendency of a solution to donate or accept electrons; 1 Eh = redox in terms of standard hydrogen electrode units) vary from oxidizing to reducing at different locations. However, concentrations of organic carbon and sulfide indicate that sulfate-reducing conditions occur in deeper sediments, beginning at about 2 ft (0.6 m) below the sediment surface.

Another indication of redox conditions is the presence or absence of dissolved oxygen (DO). Measurements of DO in bottom water near Ragged Point Beach, Virginia (downstream of the MDZ, see Figure 1-3) from 1990 to 2005 demonstrated a cyclic pattern of oxygen depletion (Jaworski et al., 2007). This pattern has probably been occurring since the early 1900s and is likely due to the impact of sewage treatment plant discharges into the Potomac River (Jaworski et al., 2007). In winter, DO concentrations in bottom water increase to near saturation levels; they fall to 1.0 mg/l or less during the summer. At the Nice Bridge Station (near the upper end of the MDZ), a similar pattern was observed with seasonal drops in DO to about 2 mg/l (Jaworski et al., 2007).

Most inert munitions and duds can be assumed to be buried about 8 ft (2.4 m) deep in the sediments. This estimate is based on 8” canisters that Explosives Ordnance Disposal units have recovered from the river. The 8” canister is a blunt-nosed projectile, the descending velocity of which is greatly reduced by a deployed parachute. Recovery of these canisters ranged from 2 to 8 ft (0.6 to 2.4 m) below the river bottom (Goss, NSWCDD, pers. comm. October 19, 2009). As conventional pointed projectiles penetrates the sediment more easily than blunt projectiles and have no associated parachutes, their velocities when entering the sediments would be much higher and their burial depths would be deeper than those observed for the 8” canisters. Therefore, an 8-ft (2.4-m) burial depth can be considered conservative. The limited data for sediment at this depth indicate that conditions are sulfate reducing, which would result in most metals precipitating as sulfides (refer to Table 5-8). Data from a core at the mouth of the Potomac River indicate that sulfate-reducing conditions occur in sediments at a depth of about 1.6 ft (0.5 m). A deeper zone of oxidized conditions may exist, but the extent of such a zone is unknown (Pohlman, 2008). Total carbon data plotted for a sediment core to a depth of 27 ft (8.3 m) at 20-in (0.5-m) intervals indicate an abundant reserve of carbon in sediments that should be available to retain reducing conditions. This core was located near the dense zone (Callender et al., 1984).

In addition to the expected metal immobility due to sulfate-reducing conditions, most munitions can be assumed to be buried deeply enough in the sediments that the products of corrosion, if any, would not impact either the surface water or the upper sediment layers, where biota occur. Therefore, this evaluation focused on fragments and particles from live munitions and intact munitions casings that can be expected to be at or near the river water-sediment interface. DO is present at the sediment surface, although concentrations fluctuate seasonally (Jaworski et al., 2007). In this type of environment, adsorption is the dominant mechanism that removes dissolved metals from the water.

To determine metal partitioning between river water and sediment, the geochemical modeling program PHREEQC (Parkhurst and Appelo, 1999) was used for equilibrium modeling. PHREEQC distributes metals to different phases (dissolved, precipitated, or adsorbed) based on reactions and governing equilibrium constants. The USGS WATEQ4F database (Ball and Nordstrom, 1991; Parkhurst and Appelo, 1999 updates) includes these types of reactions for metals of interest, with the exception of chromium. The MINTEQ database[18] was used for modeling chromium; however, adsorption data for chromium are not part of the database. Therefore, to evaluate the possible impact of chromium adsorption to sediment, it was conservatively assumed that the concentration adsorbed to sediment was the same as the concentration in river water near the river water-sediment interface. Other metals were modeled together, to simulate the effects of competitive adsorption.

Geochemical modeling requires input data for water and the adsorptive solid. River water chemistry input was based on pore water data for the shallowest available pore water interval (1 cm [0.4 in] for most parameters) from sediment cores taken near or within the dense and diffuse zones (Goodwin et al., 1984). Input parameters used for the PHREEQC model are listed in Tables 5-9 and 5-10. Metals were added to the water based on the concentrations calculated using the method in the metals distribution textbox. Sodium hydroxide was used to maintain the solution charge balance and pH; DO was used to maintain redox conditions. These additions are needed because the river water provides a large buffer to pH and redox compared to the small volume assumed for modeling.

Other input to the model included reactions for aluminum, iron, manganese, and nickel dissolution (thermodynamic data from Woods and Garrels, 1987) and information about the adsorptive solid (i.e., the iron-containing mineral). The database includes surface-area parameters associated with amorphous ferric hydroxide. This noncrystalline iron mineral is often the first precipitate when conditions become favorable, for example, when pH increases from acidic conditions or redox becomes oxidizing. However, amorphous ferric hydroxide may alter over time to more stable, crystalline iron oxyhydroxide or iron hydroxide minerals. It is more likely that the dominant iron oxyhydroxide in the sediments is goethite (an iron-bearing oxide mineral) rather than amorphous iron oxyhydroxide (Luther et al., 1982; Dzombak and Morel, 1990).

[18] See PHREEQC FAQs for more information; available at: http://wwwbrr.cr.usgs.gov/projects/GWC_coupled/phreeqc/

Table 5-9
River Bottom Water - Input Parameters for the PHREEQC Model

Parameter	Unit	Pore Water [a]
Alkalinity as $CaCO_3$	mg/l	220
Ammonium as N	mg/l	0.84
Calcium	mg/l	133
Chloride	mg/l	2,308
Iron	mg/l	0.56
Magnesium	mg/l	343.6
Manganese[b]	mg/l	2.09
Phosphate as P	mg/l	0.16
Potassium	mg/l	144
Silica	mg/l	4.7
Sodium	mg/l	3,031
Sulfate as SO_4	mg/l	264
Total Organic Carbon	mg/l	103
pH	standard unit	7
Dissolved Oxygen[c]	mg/l	2 to 10
Temperature [d]	^{o}C	6
Eh[e]	millivolts	375
pe[f]	--	6.77

Notes:

[a] Pore water concentrations represent the average of locations 7805-V11 and 7805-V9, 1 cm deep in sediment, except for unreported major cations: calcium, magnesium, potassium, sodium from average of top 9 cm from boring 7908-VBB. Data from Goodwin et al. (1984).

[b] Manganese was used to model metal distributions other than manganese.

[c] Dissolved oxygen varies seasonally from about 2 to 10 mg/l according to Jaworski et al. (2007). Starting concentration of 10 mg/l used for most simulations, except to check the stability of goethite.

[d] Approximate bottom water temperature average at the Nice Bridge in 1999 (Jaworski et al., 2007).

[e] 1 Eh = redox in terms of the standard hydrogen electrode units. This is a measure of the tendency of a solution to donate or accept electrons.

[f] The pe is a log-converted form of the Eh measurement.

[e, f] Elevated values of Eh or pe correspond to oxidizing conditions; small (or negative) values of Eh or pe correspond to reducing conditions.

Table 5-10
Metals from Munitions in Upper Sediment - Input Parameters for the PHREEQC Model

Metal	Unit	Dense Zone	Diffuse Zone
Aluminum	mg/l	0.00691	0.00156
Cadmium	mg/l	0.000479	0.0000690
Chromium	mg/l	0.000185	0.0000426
Copper	mg/l	0.215	0.0565
Iron	mg/l	4.93	1.81
Lead	mg/l	0.00394	0.000866
Manganese	mg/l	0.0770	0.0264
Nickel	mg/l	0.00261	0.00269
Zinc	mg/l	0.0377	0.00632
Note: Concentrations calculated based on the assumptions described in Sections 5.2.1, 5.2.2, and 5.2.3.			

Modeling was used to ascertain the range of conditions under which goethite would be stable and therefore would likely occur in sediments. Goethite was stable under a broad range of conditions ranging from pH 6.5 to pH 8.0 and Eh -40 millivolts to 600 millivolts. Goethite has a smaller surface area than amorphous iron hydroxide, indicating that it has a smaller capacity to adsorb metals. Therefore, the surface area was changed from the default value of 600 square meters per gram (m^2/g) to 80 m^2/g (Swedlund, 2004).

The amount of adsorptive material (i.e., goethite) present (0.11 grams) was based on iron concentrations in the top 2 cm of sediment of about 4 percent (Martin et al., 1981), using a typical sediment density of 2.5 (such as used by Goodwin et al., 1984 and Defries, 1986) and reported porosity for upper sediments of 0.9 (Goodwin et al., 1984, based on the average porosity of the upper 1 cm of the two samples closest to the dense zone or the average upper 2 cm of the 4 samples closest to the diffuse zone). Other default surface-adsorption parameters in the WATEQ4F database were retained for modeling to assure consistency. Two adsorption site densities were modeled to determine sensitivity to whether a binding site was considered to be strong or weak[19]. To assure a conservative model outcome, the results for the higher site densities were used for sediment metals concentrations and the results for lower site densities were used for river water concentrations near the sediments. Higher site densities promote more adsorption and, therefore, higher sediment concentrations; lower site densities would promote less adsorption and, therefore, higher concentrations in river water.

5.2.5 Summary of the Geochemical Modeling Results

Munitions are a potential source of organic and metal constituents to river water and sediments. Using conservative assumptions, the expected concentrations of organic explosive compounds and metals were calculated. These concentrations were then distributed between river water and sediment using a simple adsorption-coefficient method for explosives and a geochemical

[19] Default values of 0.005 moles strong binding sites and 0.02 moles weak binding sites, as well as 0.00005 moles strong binding sites and 0.0002 moles weak binding sites were modeled.

equilibrium model for metals. As a conservative assumption, river-water concentrations of explosives are assumed not to be affected by adsorption.

Table 5-11 summarizes the modeling results for sediment and river water in the dense and diffuse zones, shown as annual concentrations. Sediment concentrations were divided by 12 to obtain the monthly exposure, as sedimentation rates of 1.8 centimeters (cm) per year in the dense zone and 1.3 cm per year in the diffuse zone have been reported (Knebel et al., 1981), indicating that the sediment surface is refreshed rapidly. This sediment renewal provides a new substrate for adsorption. Sedimentation also gradually buries exposed metal fragments and projectiles, thereby decreasing the source of metals available for concentration in river water and the upper portion of the sediment.

River-water concentrations were divided by 365 to obtain daily input to the water column. Metals are expected to dissolve and be adsorbed on a daily basis because the corrosion process, once started, would result in a slow but relatively continuous addition of metals. In the last column of the table, river-water concentrations are listed as concentrations for the volume of river water within the applicable zone (dense or diffuse); that is, diluted by the water column. The effects of river flow and tidal movement are discussed in Section 5.3 and Appendix B.

Table 5-12 summarizes the modeling results for explosives in the dense and diffuse zones of the PRTR. These concentrations indicate that the explosives from munitions may be estimated to result in MCOPC concentrations of 3 parts per billion (ppb) or less (on a dry weight basis) in the dense zone sediments where munitions are most concentrated. River-water concentrations are projected to be 0.05 ppb or less in the dense zone.

Table 5-13 summarizes the modeling results for metals adsorbed to sediments and dissolved in Potomac River water for the dense and diffuse zones. Metals are naturally occurring in sediments and river water and can also be present because of activities upstream of the PRTR. Therefore, the table also provides data from upstream samples of sediment and river water for comparative purposes. Based on this table, contributions of MCOPCs from RDT&E in the PRTR are orders of magnitude less than concentrations already present in the Potomac River. This indicates that munitions activities on the PRTR have not contributed significant concentrations of metals in river water and sediments. The explosives and sediment concentrations predicted from munitions usage in the PRTR are used for screening-level ecological and human health risk assessments in Chapters 6 and 7, respectively.

Table 5-11
Geochemical Modeling Results for Metals

Metal	Percent Adsorbed		Monthly Amount Adsorbed to Sediment		River Water Addition	
					Annual[a]	Daily[b]
	Large Sorptive Area	Small Sorptive Area	Large Sorptive Area (mg/kg)	Small Sorptive Area (mg/kg)	Small Sorptive Area (mg/l)	
Dense Zone: 11,000 - 13,000 yds						
Cadmium	100%	77%	**0.0145**	0.0112	1.10×10^{-4}	$\mathbf{5.04 \times 10^{-9}}$
Chromium[c]	na	na	**0.00561**	0.00561	1.85×10^{-4}	$\mathbf{8.45 \times 10^{-9}}$
Copper	100%	100%	**6.50**	6.50	1.29×10^{-4}	$\mathbf{5.91 \times 10^{-9}}$
Lead	100%	100%	**0.119**	0.119	1.26×10^{-7}	$\mathbf{5.77 \times 10^{-12}}$
Manganese	99%	70%	**2.32**	1.64	0.0227	$\mathbf{1.04 \times 10^{-6}}$
Nickel	100%	81%	**0.0787**	0.0641	4.84×10^{-4}	$\mathbf{2.21 \times 10^{-8}}$
Zinc	100%	97%	**1.14**	1.11	0.001	$\mathbf{4.58 \times 10^{-8}}$
Diffuse Zone: 0 – 25,000 yds						
Cadmium	100%	78%	**0.00209**	0.00163	1.52×10^{-5}	$\mathbf{6.94 \times 10^{-10}}$
Chromium[c]	na	na	**0.00129**	0.00129	4.26×10^{-5}	$\mathbf{1.94 \times 10^{-9}}$
Copper	100%	100%	**1.71**	1.71	3.29×10^{-5}	$\mathbf{1.50 \times 10^{-9}}$
Lead	100%	100%	**0.0262**	0.0262	2.61×10^{-8}	$\mathbf{1.19 \times 10^{-12}}$
Manganese	100%	61%	**0.797**	0.572	0.00749	$\mathbf{3.42 \times 10^{-7}}$
Nickel	100%	82%	**0.0815**	0.0671	4.81×10^{-4}	$\mathbf{2.20 \times 10^{-8}}$
Zinc	100%	98%	**0.192**	0.187	1.60×10^{-4}	$\mathbf{7.29 \times 10^{-9}}$

Notes:
mg/kg = milligrams per kilogram.
A concentration of 0.001 mg/kg or mg/l is equal to 1 part per 1,000,000,000 (part per billion).
Scientific notation is used for small numbers; for example 1.0×10^{-6} is one millionth (0.000001).
Bold results for sorbed metals using large sorptive site densities and for dissolved metals remaining after adsorption using small sorptive site densities.
Sedimentation rate in dense zone of 1.8 cm per year and 1.3 cm per year in diffuse zone, so one month was assumed for sediment adsorptive surface renewal.
[a] Annual addition of metal to bottom 10 cm of river water overlying sediments and not adsorbed by sediments.
[b] Daily concentration is for volume of water in zone listed; volume calculated using average depth for Potomac river of 6 m.
[c] Conservative assumption for sediment concentration used: all available chromium may adsorb.

Table 5-12
Summary of Modeled Explosives Concentrations

Explosive	Dry Sediment Concentration - Monthly Adsorption (mg/kg)		Daily Concentration in River Water Column (mg/l)	
	Dense Zone	*Diffuse Zone*	*Dense Zone*	*Diffuse Zone*
Ammonium picrate	5.41×10^{-7}	4.06×10^{-8}	5.17×10^{-5}	2.69×10^{-6}
HMX	6.11×10^{-9}	5.10×10^{-9}	4.46×10^{-9}	2.60×10^{-9}
RDX	1.38×10^{-5}	3.37×10^{-7}	3.37×10^{-5}	5.73×10^{-7}
Tetryl	6.03×10^{-4}	2.50×10^{-5}	5.74×10^{-7}	1.64×10^{-8}
TNT	2.98×10^{-3}	8.14×10^{-4}	3.34×10^{-6}	6.35×10^{-7}

Notes:
mg/kg = milligrams per kilogram.
mg/l = milligrams per liter.
A concentration of 0.001 mg/kg or mg/l is equal to 1 part per 1,000,000,000 (part per billion).
Scientific notation is used for small numbers; for example 1.0×10^{-6} is one millionth (0.000001).

Table 5-13
Summary of Modeled Metals Concentrations

Metal	Monthly Sediment Adsorption Due to Munitions (mg/kg)		Sediment Upstream [a]	Daily River Water Column Concentration Due to Munitions (mg/l)		River Water Upstream [b] (mg/l)
	Dense Zone	*Diffuse Zone*		*Dense Zone*	*Diffuse Zone*	
Cadmium	0.0145	0.00209	0.560	5.04×10^{-9}	6.94×10^{-10}	1.10×10^{-5}
Chromium	0.00561	0.00129	83.1	8.45×10^{-9}	1.94×10^{-9}	1.00×10^{-4}
Copper	6.50	1.71	46.2	5.91×10^{-9}	1.50×10^{-9}	0.00175
Lead	0.119	0.0262	45.3	5.77×10^{-12}	1.19×10^{-12}	1.37×10^{-4}
Manganese	2.32	0.797	2320	1.04×10^{-6}	3.42×10^{-7}	0.055
Nickel	0.0787	0.0815	54.0	2.21×10^{-8}	2.20×10^{-8}	0.001
Zinc	1.14	0.192	215	4.58×10^{-8}	7.29×10^{-9}	2.78×10^{-4}

Notes:

[a] Upstream sediment data from USEPA (undated).

[b] Upstream river water data from Maryland Department of the Environment (2006a) for cadmium, chromium, copper, lead; Maryland Department of the Environment (2006b) for manganese; Jaworski, et al., (2007) for nickel and zinc.

Metals from filtered samples except for manganese. Note that adsorbed chromium is based on the assumption that all available chromium may adsorb.

mg/kg = milligrams per kilogram.

mg/l = milligrams per liter.

A concentration of 0.001 mg/kg or mg/l is equal to 1 part per 1,000,000,000 (part per billion).

Scientific notation is used for small numbers; for example 1.0×10^{-6} is one millionth (0.000001).

5.3 Hydrodynamic Dispersion and Transport in the Potomac River

The modeling of metals and explosives performed in Section 5.2 provides estimates of water-column and sediment concentrations in segments of the PRTR where almost all munitions testing (99 percent) has occurred in the past 90 years and will continue to occur in the future. These estimates were based on the conservative assumption that there was no water or sediment movement in the MDZ – essentially, that munitions releases are contained within a limited area of the river. Because the Potomac River is a dynamic system that is influenced by flow from its watershed and the MDZ is in a tidal reach of the river, a hydrodynamic model was applied to predict constituent concentrations that take the dynamic river characteristics into account. Details of the hydrodynamic model are provided in Appendix B, this section summarizes the findings of the model.

The approach to the hydrodynamic dispersion and transport modeling effort was to model extreme flow and tidal conditions within the Potomac River, evaluating low- and high-energy scenarios for the magnitude of dilution as well as the fate and transport potential for both dissolved and sediment-bound constituents potentially present in the munitions deposited over time. This approach was developed to bracket the behavior of metals and explosives within the MDZ between two extremes: high-energy events (e.g., large storm events) and low-energy events (e.g., dry weather conditions). The objective was to understand the scale of dilution during different events and provide guidance for future data collection, if necessary. Scenarios within the extreme meteorological events were also modeled to simulate more common conditions and to verify that the extreme events were the bracketing scenarios.

A two-dimensional (2D) hydrodynamic model was chosen for the analysis because tides, which are very long waves and 2D in nature, dominate the hydrodynamics in the area. Freshwater-driven flows at NSF Dahlgren (adjusted by drainage area ratio to account for the ungauged drainage area) contribute only about 7 percent of the total flow (409 cubic meters per second [cms] of 5,737 cms), with tidal flow contributing the majority – 93 percent – of the flow.

The model consisted of one tidal boundary located near Lewisetta, Virginia (Figure 5-2, Location of Model Boundaries). There are two high tides in a day. In a diurnal system, such as the Potomac River, one of the high tides is higher than the other and hence is referred to as higher high tide; the other is referred to as lower high tide. The same is true for the low tides.

The mean tidal range looks at the arithmetic mean of both high tides for the tidal epoch[20] covering 1983 through 2001, whereas the diurnal tidal range only looks at the most significant value of the day and averages those values for that tidal epoch. According to the NOAA station information, the Lewisetta tide gauge has a mean range of 1.24 ft (0.38 m), which represents the difference between the mean high water level and the mean low water level. The diurnal range of the Lewisetta tide gauge is 1.51 ft (0.46 m), which represents the difference between the mean higher high water level and the mean lower low water level.

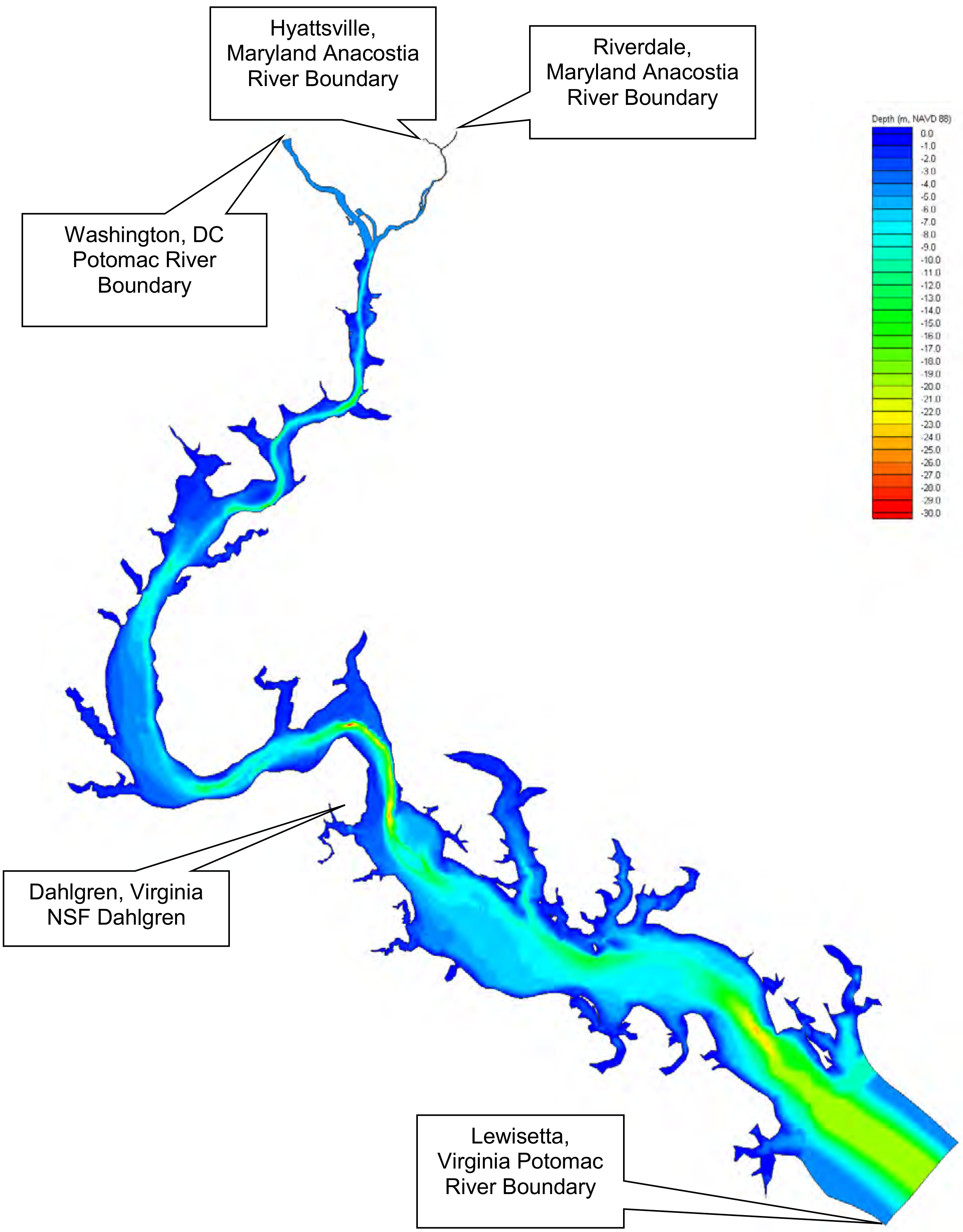
The hydrodynamic model was constructed within Surface-Water Modeling System (SMS) Version 8.1.20, a hydrodynamic modeling package developed by the Environmental Modeling Research Laboratory at Brigham Young University for the United States Army Corps of Engineers (USACE, 2008). A 2D finite element mesh (i.e., numerical model) was constructed in SMS for use with supported models, including RMA2 for hydrodynamic analysis (depth-averaged flow and water levels), RMA4 for dissolved constituent fate and transport analysis, and SED2D for sediment-bound constituent fate and transport analysis. RMA2, RMA4, and SED2D were all developed by USACE. The major components of the hydrodynamic model are described in detail in Appendix B.

Upon completion of the hydrodynamic model construction and verification, the 2D model was used to evaluate the fate and transport of both dissolved and sediment-bound constituents within the area of interest. The 2D hydrodynamic model was run for seven different meteorological events, listed in Table 5-14, ranging from dry periods to hurricane conditions.

The hydrodynamic simulation output files for the hydraulic events were input into the RMA4 model, which is a finite element water quality transport numerical model with a user interface contained within SMS (BYU, 2001). A constant mass-loading scenario was used to represent constituents released from sediments. This is consistent with the mass-loading modeling discussed in Section 5.2, in which a daily concentration of metal and explosive constituents is distributed uniformly into the complete water column.

[20] A tidal epoch is the specific 19-year period adopted by the National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values (e.g., mean lower low water, etc.) for tidal data and is actively considered for revision every 20 to 25 years. The present national tidal datum epoch is 1983 through 2001.

Figure 5-2. Location of Model Boundaries



Within RMA4, the constituent loading was tracked throughout the respective hydraulic event. The objectives were to determine the fate of the dissolved constituents as they move in the water column and to establish a relative dilution of the constituent concentration by the combination of river and tidal effects. The fate and transport scenario was modeled during several hydraulic events to bracket the response during a variety of conditions, as summarized in Table 5-14, and was applied to the dense zone and the diffuse zone in the MDZ of the PRTR.

Table 5-14
Hydrodynamic Model Runs

Event Description	Model		
	Hydrodynamic Analysis (RMA2)	Dissolved Constituent Fate and Transport Analysis (RMA4)	Sediment-Bound Constituent Fate and Transport Analysis (SED2D)
August 2002 Dry Period	●		
August 2006 Dry Period	●	●	
Hurricane Isabel	●	●	
Average Annual Peak River Discharge	●	●	
Average Monthly River Discharge	●	●	●
30-year River Discharge Event	●	●	
90-year River Discharge Event	●	●	●

It is important to note that no rate of decay was applied to any constituent as part of the modeling process. This assumption is suitable for metals, which are not likely to experience any change in state during transport in the river. However, organic compounds would likely decay and biodegrade over time in this reducing environment. SMS does not simulate dynamic decay, but the assumption that an organic particle does not change over time represents a conservative approach for these constituents.

The transport characteristics applicable to sediment-bound constituents within the PRTR were modeled using SED2D, a 2D numerical model for depth-averaged transport of sediments and their deposition, erosion, and formation of bed deposits, which has a user interface within SMS (USACE, 2008). This evaluation is most applicable to metals because, as discussed in Section 5.2, while some metals (such as manganese) may be dissolved in the river water column, most (such as zinc) will more readily adsorb to sediment than remain in dissolved form. Metals will experience little decay or biodegradation as sediments are transported within the river, and evaluation as sediment-bound constituents is, therefore, appropriate.

The SED2D analysis was performed for both sand and clay beds for several hydraulic events with the objective of determining whether conditions in the PRTR tend to be depositional (i.e., encourage the deposit of new sediment on the river floor) or removal (i.e., encourage the erosion of existing sediment from the river floor).

5.3.1 Fate and Transport of Dissolved Constituents in the Water Column

Within the PRTR, concentrations of explosives are best represented as dissolved constituents. As expected, the largest dilution was seen during the 90-year river discharge event, one of the extreme hydraulic events modeled in this analysis. During this event, constituents in the water column were swept further away from the PRTR towards the Chesapeake Bay than during any other modeled event.

In simulating an instantaneous release of constituent concentration within the dense zone, the August 2006 dry period achieved a 94 percent dilution after two weeks, whereas a dilution of 98.2 percent was achieved during the 90-year river discharge event over the same time. All other hydraulic events modeled fell within this dilution range. Within the diffuse zone, the August 2006 dry period achieved 51 percent dilution after two weeks, and the 90-year river discharge event achieved a dilution of 78 percent. The difference in dilution within the two zones results from a constituent concentration that was conservatively assumed to be uniform throughout the entire region. Using the same initial mass of constituent, the constituent concentration within the dense zone (with a volume of 2,239,880,196 cubic ft (ft^3) [63,426,338 cubic meters (m^3)]) is much greater than in the diffuse zone (with a much larger volume of 26,348,877,680 ft^3 [746,117,058 m^3]. The diffuse zone experiences a functional initial dilution of 91.5 percent because it is 11.8 times larger, which translates into a nearly 96 percent total dilution after accounting for the additional 51 percent dilution hydrodynamic fate and transport. This compares to a 94 percent dilution in the dense zone, where the mass is contained in a much smaller volume. In the 90-year river discharge event, the diffuse zone total dilution is 92 percent (based on size) and an additional 78 percent dilution, for a total dilution of 98 percent. The instantaneous-release simulation is helpful in understanding what happens to the accumulated dissolved constituents (due to gradual release) under various hydrodynamic conditions.

Relating the actual constituent concentrations to the unit concentration trend lines developed during the mass loading simulations (i.e. gradual release) will assist in evaluating the long-term mass accumulation of various constituents. Mass-loading simulations indicated that there will be about 71 percent hydrodynamic dilution within the first 24 hours within the dense and diffuse zones. This dilution factor may be applied to the daily values, shown in Table 5-13, to provide an estimate of MCOPCs concentrations in the PRTR. However, to provide a conservative estimate of MCOPC concentrations, a dilution factor was not applied to exposure concentrations.

Given the strong tidal nature of the hydrodynamics near the PRTR, during dry weather periods constituents monitored in the model were found to be transported upstream as well as downstream. The initial storm surge resulting from Hurricane Isabel carried constituents upstream of the PRTR; however, during the retreat of the storm surge, these constituents were carried past the PRTR and further down the Potomac River towards the Chesapeake Bay. The peak flow that occurred during the 90-year river discharge event transported the constituents towards the Chesapeake Bay while generating a strong dilution energy that resulted in a high dilution factor.

5.3.2 Fate and Transport of Sediment-Bound Constituents

Under average flow conditions, the Potomac River experiences deposition throughout the modeled area – in fact, no scouring conditions were observed in any hydraulic event modeled. The largest depths of deposition occur near, and directly downstream of, NSF Dahlgren, covering the PRTR area, where mid-channel velocities tend to be lower than the velocities upstream of the PRTR.

The diffuse zone was shown to be depositional for all hydraulic events modeled and all riverbed scenarios modeled. This region is ideal for deposition of sediments due to low velocity, which encourages rapid particle settling. When additional sediments are included, which would enter the Potomac River upstream, for instance during storm events, deposition would increase in the area of NSF Dahlgren and cause a "capping" effect of sediments in the river at this location. This is visually apparent on the velocity vector plots of the various hydrodynamic solutions from RMA2 that are provided in Appendix B.

5.3.3 Summary of Hydrodynamic Modeling

The hydrodynamic modeling described here and detailed in Appendix B indicates that the concentrations of MCOPCs used in this WRSEPA are conservative estimates of available explosives and metals. Concentrations of explosives in river water are likely to be diluted about 71 percent in the dense and diffuse zones. Concentrations of metals (adsorbed to sediments) are also likely to be lower due to deposition of upstream sediments on sediments in the PRTR. However, to provide a conservative estimate of MCOPC concentrations for use in the range-specific ecological and human health screening-level risk assessments, the higher MCOPC concentrations predicted from the geochemical modeling were used.

THIS PAGE INTENTIONALLY LEFT BLANK

6 SCREENING-LEVEL ECOLOGICAL RISK ASSESSMENT

As described in the ORSM in Chapter 4, ecological receptors in the Potomac River and the surrounding area, including aquatic plants and invertebrates, fish, and wildlife, may be exposed to metals and explosive constituents in the water column and sediments. Exposure may occur directly through contact with water and/or sediment or indirectly via consumption of previously contaminated prey or food. A screening-level ecological risk assessment was performed to evaluate the potential risk to ecological receptors from exposure to MCOPCs resulting from past, present, and future munitions testing in the PRTR and determine whether any additional analysis is necessary or whether the risks posed by the range are within acceptable limits, so that no further analysis is needed.

NSWCDD expects the number of large-caliber gun projectiles fired in the foreseeable future to remain at recent levels – approximately 4,700 projectiles fired per year in the most active years – which is the average of the three years in the period from 1994 through 2008 with the highest numbers of rounds fired. In normal years, the number of projectiles fired is expected to remain at current levels, which averages about 2,900 large-caliber projectiles annually. Therefore, the evaluation presented for current ecological exposure is also considered appropriate for future exposure.

Exposure was only modeled for the contribution of MCOPCs from RDT&E activities; the study does not take into account constituents that may enter the river upriver of the installation or natural background levels of metals. Contributions from other sources may or may not pose risks to the environment; however, the purpose of the WRSEPA is to determine whether the release or substantial threat of a release of MCs of potential concern and/or MEMCs from an operational range to an off-range area poses an unacceptable risk to human health or the environment (US Navy, 2008). To fulfill this purpose, this screening-level ecological risk assessment focuses solely on contributions from munitions testing in the PRTR.

This range-specific screening-level ecological risk assessment follows Navy policy for a Tier 1 screening-level risk assessment (US Navy, 1999) and is consistent with USEPA ecological risk-assessment guidance (USEPA, 1997).

6.1 Aquatic Receptors

Aquatic receptors in the PRTR include aquatic plants, water-column invertebrates, benthic invertebrates, and fish. Water and sediment quality criteria and guidelines recommended by federal and state agencies for metals were used as a screening tool to determine if modeled inputs of metals may adversely affect aquatic life, as described in Section 6.1.1. For MCOPCs without federal or state guidance (e.g., explosives), a literature search was performed and relevant studies and/or reviews were used to select adverse-effect levels. Potential impacts on fish were also evaluated by comparing predicted body burdens to tissue concentrations associated with adverse effects, as described in Section 6.1.2.

6.1.1 Toxicity-based Water and Sediment Criteria and Guidelines

The predicted concentrations of munitions-related constituents in water and sediments were compared to the federal and state criteria and guidelines for aquatic organisms described below. Tables 6-1 and 6-2 provide water-quality criteria for munitions-related metals in freshwater and saltwater, respectively. Both freshwater and saltwater criteria are provided so that predicted concentrations can be compared to the most stringent (protective) values. Sediment guidelines for munitions-related metals are provided in Table 6-3. The federal and state criteria and/or guidelines included in these tables are as follows:

Water Quality Criteria

- **US Environmental Protection Agency (USEPA). Current National Recommended Water Quality Criteria (USEPA, 2009).** USEPA's national recommended water-quality criteria for the protection of aquatic life and human health in surface water specify allowable concentration levels for about 150 pollutants. The ambient water quality criteria final chronic values (AWQC-FCVs) are published pursuant to Section 304(a) of the Clean Water Act and provide guidance for states and tribes to use in adopting water-quality criteria. The aquatic life criteria are intended to be protective of the vast majority of the aquatic communities in the United States. The criteria maximum concentration (CMC) is an estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed briefly without resulting in an unacceptable effect, while the criteria continuous concentration (CCC) is an estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect.
- **Virginia Department of Environmental Quality (VDEQ). Water Quality Standards (VDEQ, 2008).** These standards provide numerical water-quality criteria for acute and chronic toxicity. Acute toxicity refers to an adverse effect – typically, mortality – that usually occurs shortly after exposure to a pollutant. Chronic toxicity refers to an adverse effect that is progressive and irreversible, or occurs because the rate of injury is greater than the rate of repair during prolonged exposure to a pollutant. This includes low-level, long-term effects such as reduction in growth or reproduction rate.
- **Maryland Department of the Environment.** Water Quality Standards (MDE, 2009). These standards provide numeric acute and chronic toxic-substance criteria for fresh, estuarine, and salt water aquatic life protection and for human health protection.

Sediment Guidelines

- **NOAA Screening Quick Reference Tables (SQuiRTs) (NOAA, 2008).** These tables compiled by NOAA provide a range of screening concentrations for constituents found in sediments. For freshwater sediments, the following values are provided:
    - **Threshold Effects Level (TEL)** – The TEL is calculated as the geometric mean of the 15th-percentile concentration of the toxics-effects data set and the 50th percentile (the median) of the no-effect data set. It represents the concentration at which toxic effects are expected to occur only rarely.

Table 6-1
USEPA and State Freshwater Quality Criteria for Metals

Metal	USEPA (Aquatic Life)		MDE (Aquatic)		VDEQ (Aquatic)	
	AWQC-FCV (µg/l)	CCC (µg/l)	Acute (µg/l)	Chronic (µg/l)	Acute (µg/l)	Chronic (µg/l)
Cadmium	2	0.25	2	0.25	3.9	1.1
Chromium III	570	74	570	74	570	74
Chromium IV	16	11	16	11	16	11
Copper	13	9	13	9	13	9
Lead	65	2.5	65	2.5	120	14
Manganese	NA	NA	NA	NA	NA	NA
Nickel	470	52	470	52	180	20
Zinc	120	120	120	120	120	120

Notes:
USEPA = US Environmental Protection Agency.
MDE = Maryland Department of the Environment.
VDEQ = Virginia Department of Environmental Quality.
AWQC-FCV = ambient water quality criteria-final chronic value.
CCC = criteria continuous concentration.
µg/l = micrograms per liter.
NA = no criteria available.
Sources: USEPA, 2009; MDE, 2009; and VDEQ, 2008.

Table 6-2
USEPA and State Saltwater Quality Criteria for Metals

Metal	USEPA (Aquatic Life)		MDE (Aquatic)		VDEQ (Aquatic)	
	CCC (µg/l)	CMC (µg/l)	Acute (µg/l)	Chronic (µg/l)	Acute (µg/l)	Chronic (µg/l)
Cadmium	40	8.8	40	8.8	40	8.8
Chromium III	NA	NA	NA	NA	NA	NA
Chromium IV	1,100	50	1,100	50	1,100	50
Copper	4.8	3.1	4.8	3.1	9.3	6.0
Lead	210	8.1	210	8.1	240	9.3
Manganese	NA	NA	NA	NA	NA	NA
Nickel	74	8.2	74	8.2	74	8.2
Zinc	90	81	90	81	90	81

Notes:
USEPA = US Environmental Protection Agency.
MDE = Maryland Department of the Environment.
VDEQ = Virginia Department of Environmental Quality.
CCC = criteria continuous concentration.
CMC = criteria maximum concentration.
µg/l = micrograms per liter.
NA = no criteria available.
Sources: USEPA, 2009; MDE, 2009; and VDEQ, 2008.

Table 6-3
NOAA Sediment Quality Criteria for Metals

Metal	Benthos							
	NOAA Freshwater (µg/kg dw)			NOAA Saltwater (µg/kg dw)				
	TEL	PEL	UET	TEL	ER-L	PEL	ER-M	AET
Cadmium	596	3,530	3,000	680	1,200	4,210	9,600	3,000
Chromium	37,300	90,000	95,000	52,300	81,000	160,000	370,000	62,000
Copper	35,700	197,000	86,000	18,700	34,000	108,000	270,000	390,000
Lead	35,000	91,300	127,000	30,240	46,700	112,180	218,000	400,000
Manganese	630,000	NA	NA	1.10E+06	NA	NA	NA	260,000
Nickel	18,000	36,000	43,000	15,900	20,900	42,800	51,600	110,000
Zinc	123,000	315,000	520,000	124,000	150,000	271,000	410,000	410,000

Notes:
TEL= threshold effects limit; PEL = probable effects limit; UEL = upper effects limit.
ER-L = effects range-low; ER-M = effects range--medium; AET= apparent effects threshold.
µg/kg dw = micrograms per kilogram dry weight.
NA = no criteria available.
Source: NOAA, 2008.

- **Probable Effects Level (PEL)** – The PEL is calculated as the geometric mean of the median concentration of toxics-effects data set samples and the 85th percentile of the no-effect data set. It represents the concentration at which toxic effects are frequently expected.
- **Upper Effects Threshold (UET)** – The concentration at which biological indicators of adverse effects (e.g., sediment bioassay or reduced benthic infauna) are seen. At concentrations above the UET, adverse biological effects are expected.
- **Lowest Effect Level from the Assessment and Remediation of Contaminated Sediments (ARCS) Program** – The lowest concentration at which effects are seen in either of the two species tested, the amphipod *Hyalella azteca* and the midge *Chironomus riparius* (Ingersoll et al., 1996).

For saltwater sediment criteria, the TEL, PEL and the following values were used:

- **Effects Range-Low (ER-L)** – The concentration that represents the lowest 10th percentile of the concentrations at which toxic effects were observed. At concentrations below the ER-L, toxic effects are rarely expected (Long and Morgan, 1990).
- **Effects Range-Median (ER-M)** – The concentration that represents the 50th percentile (the median) at which toxic effects were observed. At concentrations above the ER-M, toxic effects are likely to occur (Long and Morgan, 1990).
- **Apparent Effects Threshold (AET)** – The concentration at which biological indicators of adverse effects (e.g., sediment bioassay or reduced benthic infauna) are seen, which is essentially equivalent to the concentration in the highest non-toxic sample. At concentrations above the AET, adverse biological effects are usually expected.

Munitions constituents from explosives are not listed on USEPA's Contract Laboratory Program Toxic Compound List (USEPA, 2011) and are generally not included in government criteria or guidelines. However, Talmage et al. (1999, as cited in US Navy, [2002]) developed water and sediment screening levels for explosives based on available data and using the standard USEPA methodology for the generation of water quality criteria. Freshwater (unless specified) and sediment criteria for explosives are presented in Table 6-4. No sediment criteria are available for ammonium picrate or tetryl.

Table 6-4
Freshwater and Sediment Criteria for Explosives

Constituent	Acute Water Quality Criteria[1] (mg/l)	Chronic Water Quality Criteria[1] (mg/l)	Sediment[1] (mg/kg)
Ammonium picrate	220 (Freshwater)[2]/ 66 (Saltwater)[2]	NA	NA
HMX	3.8	0.33	0.47
RDX	1.44	0.19	1.3
Tetryl	NA	NA	NA
TNT	0.57	0.09	9.2

Notes:
mg/l = milligrams per liter; mg/kg = milligrams per kilogram.
NA = criteria not available.
Sources:
[1] Talmage et al., 1999, as cited in US Navy, 2002. All values are for freshwater unless otherwise indicated.
[2] NOAA, 2008 – Freshwater based on LC50 for a 96-hour exposure of bluegill (*Lepomis macrochirus*); Saltwater based on LC50 for a 96-hour exposure of the inland silverside (*Menidia beryllina*).

Saltwater toxicity data were taken from the toxicity database for ordnance compounds developed by Nipper et al. (2001) and are presented in Table 6-5. Toxicity tests included fertilization success and embryological development of the sea urchin *Arbacia punctulata*; zoospore germination, germling length, and cell number of the green macroalga *Ulva fasciata*; survival and reproductive success of the polychaete *Dinophilus gyrociliatus*; larvae hatching and survival of the redfish *Sciaenops ocellatus*; and survival of juveniles of the mysid shrimp *Americamysis bahia* (formerly *Mysidopsis bahia*). Toxicity endpoints can be defined as the no-observed-effect concentration (NOEC) or lowest-observed-effect concentration (LOEC). The NOEC is the highest exposure concentration at which there are no biologically significant increases in the frequency or severity of adverse effects between the exposed population and an appropriate control group. The LOEC is the lowest exposure concentration at which there are biologically significant increases in the frequency or severity of adverse effects between the exposed population and an appropriate control group.

In general, the most sensitive toxicity test endpoints were the macroalga zoospore germination and the polychaete reproduction tests. The most toxic (i.e., lowest concentration resulting in adverse effects) of the constituents examined for this WRSEPA was tetryl. Tetryl is a highly degradable compound that was often reduced to very low or below-detection levels by the end of the maximum 96-hour test exposure period (Nipper et al., 2001). Picric acid is used to represent ammonium picrate, which is a salt formed by adding ammonia to picric acid. Saltwater toxicity data were not available for HMX and, therefore, only freshwater toxicity data were used for comparison in the following section.

Table 6-5
Saltwater NOEC and LOEC Data Toxicity Tests for Explosives

Organism	Endpoint	NOEC/LOEC			
		TNT (mg/l)	RDX (mg/l)	Tetryl (mg/l)	Picric Acid (mg/l)
Sea Urchin	Fertilization	28/103	75/>75	0.6/1.1	178/352
	Embryo development	9.1/19	75/>75	0.036/0.083	178/352
Algae	Germination	1.7/3.4 (1.4/2.9)	9.2/15.7	0.5/1.0 (0.31/0.67)	169/336
	Germling length & cell no.[a]	<0.21/0.21 (<0.18/0.18)	<5.0/5.0	0.098/0.25 (0.051/0.13)	<92/92
Polychaete	Survival	6.1/11.6 (4.3/9.6)	49/>49	0.026/0.056 (0.013/0.028)	199/379
	Eggs laid/female	1.4/2.8 (0.73/1.8)	11.9/23.7	0.015/0.026 (0.008/0.013)	108/198
Redfish	Larvae survival	6.3/10.8 (5.4/10.3)	68/>68	1.2/2.6 (0.79/1.6)	97/187
Mysid	Survival	0.65/1.34 (0.32/0.72)	47/>47	1.1/2.0 (0.54/1.0)	9.2/20.6

Notes:
Values are represented as initial measured concentrations, or as the mean of measured initial and final test concentrations (in parentheses) for tests in which losses ≥20% were observed.
NOEC = no-observed-effect concentration
LOEC = lowest-observed-effect concentration
[a] NOEC and LOEC values were the same for germling length and cell number.
HMX was not tested.
Source: Nipper et al., 2001.

6.1.2 Comparison of Modeled Water and Sediment Concentrations to Toxicity-based Criteria

The concentrations of metals and explosives in water and sediments in the two areas of the PRTR with the highest concentrations (the dense and diffuse zones) were modeled, as described in Section 5.2. The predicted metal and explosive concentrations, presented in Tables 5-12 and 5-13, were then compared to the water- and sediment-quality criteria and guidelines summarized in Tables 6-1 to 6-5 by dividing the predicted concentrations by criteria. Ratios of predicted concentrations to the associated criteria below 1 indicate that concentrations are below levels that could cause adverse effects to aquatic organisms, while ratios greater than 1 indicate the potential for adverse effects.

Metals

Tables 6-6 and 6-7 show the ratios of modeled metal concentrations to freshwater and saltwater criteria, respectively. All ratios are well below 1, indicating that there are no exceedances associated with metals in water or sediment with most concentrations many orders of magnitude (each order of magnitude is equal to 10 times) below criteria.

Modeled metal concentrations in sediment were compared to sediment quality guidelines to determine whether any concentrations are at or above guideline concentrations. As shown in Table 6-8, all ratios are well below guideline concentrations for all effect levels.

Table 6-6
Ratios of Predicted Metal Concentrations in Water to Freshwater Quality Criteria

Metal	USEPA (Aquatic Life)		MDE (Aquatic)		VDEQ (Aquatic)	
	CCC	CMC	Acute	Chronic	Acute	Chronic
Dense Zone						
Cadmium	2.50×10^{-6}	2.00×10^{-5}	2.50×10^{-6}	2.00×10^{-5}	2.50×10^{-6}	2.00×10^{-5}
Chromium III	1.50×10^{-8}	1.10×10^{-7}	1.50×10^{-8}	1.10×10^{-7}	1.50×10^{-8}	1.10×10^{-7}
Chromium IV	5.30×10^{-7}	7.70×10^{-7}	5.30×10^{-7}	7.70×10^{-7}	5.30×10^{-7}	7.70×10^{-7}
Copper	4.50×10^{-7}	6.60×10^{-7}	4.50×10^{-7}	6.60×10^{-7}	4.50×10^{-7}	6.60×10^{-7}
Lead	8.90×10^{-11}	2.30×10^{-9}	8.90×10^{-11}	2.30×10^{-9}	4.80×10^{-11}	4.10×10^{-10}
Manganese	NA	NA	NA	NA	NA	NA
Nickel	4.70×10^{-8}	4.30×10^{-7}	4.70×10^{-8}	4.30×10^{-7}	1.20×10^{-7}	1.10×10^{-6}
Zinc	3.80×10^{-7}	3.80×10^{-7}	3.80×10^{-7}	3.80×10^{-7}	3.80×10^{-7}	3.80×10^{-7}
Diffuse Zone						
Cadmium	3.50×10^{-7}	2.80×10^{-6}	3.50×10^{-7}	2.80×10^{-6}	3.50×10^{-7}	2.80×10^{-6}
Chromium III	3.40×10^{-9}	2.60×10^{-9}	3.40×10^{-9}	2.60×10^{-9}	3.40×10^{-9}	2.60×10^{-9}
Chromium IV	1.20×10^{-7}	1.80×10^{-7}	1.20×10^{-7}	1.80×10^{-7}	1.20×10^{-7}	1.80×10^{-7}
Copper	1.20×10^{-7}	1.70×10^{-7}	1.20×10^{-7}	1.70×10^{-7}	1.20×10^{-7}	1.70×10^{-7}
Lead	1.80×10^{-11}	4.80×10^{-10}	1.80×10^{-11}	4.80×10^{-10}	9.90×10^{-12}	8.50×10^{-11}
Manganese	NA	NA	NA	NA	NA	NA
Nickel	4.70×10^{-8}	4.20×10^{-7}	4.70×10^{-8}	4.20×10^{-7}	1.20×10^{-7}	1.10×10^{-6}
Zinc	6.10×10^{-8}	6.10×10^{-8}	6.10×10^{-8}	6.10×10^{-8}	6.10×10^{-8}	6.10×10^{-8}

Notes:
USEPA = US Environmental Protection Agency.
MDE = Maryland Department of the Environment.
VDEQ = Virginia Department of Environmental Quality.
CCC = criteria continuous concentration.
CMC = criteria maximum concentration.
NA = criteria not available to calculate ratios.

Ratios below 1 indicate that modeled concentrations are below water-quality criteria. All ratios shown here are orders of magnitude below 1 (each order of magnitude is equal to 10 times).
Scientific notation is used for small numbers; for example 1.0×10^{-6} is one millionth (0.000001).

Table 6-7
Ratios of Predicted Metal Concentrations in Water to Saltwater Quality Criteria

Metal	USEPA (Aquatic Life)		MDE (Aquatic)		VDEQ (Aquatic)	
	CCC	CMC	Acute	Chronic	Acute	Chronic
Dense Zone						
Cadmium	1.3×10^{-7}	5.7×10^{-7}	1.3×10^{-7}	5.7×10^{-7}	1.3×10^{-7}	5.7×10^{-7}
Chromium III	NA	NA	NA	NA	NA	NA
Chromium IV	7.7×10^{-9}	1.7×10^{-7}	7.7×10^{-9}	1.7×10^{-7}	7.7×10^{-9}	1.7×10^{-7}
Copper	1.2×10^{-6}	1.9×10^{-6}	1.2×10^{-6}	1.9×10^{-6}	6.4×10^{-7}	9.9×10^{-7}
Lead	2.7×10^{-11}	7.1×10^{-10}	2.7×10^{-11}	7.1×10^{-10}	2.40×10^{-11}	6.2×10^{-10}
Manganese	NA	NA	NA	NA	NA	NA
Nickel	3.0×10^{-7}	2.7×10^{-6}	3.0×10^{-7}	2.7×10^{-6}	3.0×10^{-7}	2.7×10^{-6}
Zinc	1.7×10^{-8}	7.9×10^{-8}	1.7×10^{-8}	7.9×10^{-8}	1.7×10^{-8}	7.9×10^{-8}
Diffuse Zone						
Cadmium	1.7×10^{-8}	7.9×10^{-8}	1.7×10^{-8}	7.9×10^{-8}	1.7×10^{-8}	7.9×10^{-8}
Chromium III	NA	NA	NA	NA	NA	NA
Chromium IV	1.8×10^{-9}	3.9×10^{-8}	1.8×10^{-9}	3.9×10^{-8}	1.8×10^{-9}	3.9×10^{-8}
Copper	3.1×10^{-7}	4.8×10^{-7}	3.1×10^{-7}	4.8×10^{-7}	1.6×10^{-7}	2.5×10^{-7}
Lead	5.7×10^{-11}	1.5×10^{-10}	5.7×10^{-11}	1.5×10^{-10}	5.0×10^{-12}	1.3×10^{-10}
Manganese	NA	NA	NA	NA	NA	NA
Nickel	3.0×10^{-7}	2.7×10^{-6}	3.0×10^{-7}	2.7×10^{-6}	3.0×10^{-7}	2.7×10^{-6}
Zinc	8.1×10^{-8}	9.0×10^{-8}	8.1×10^{-8}	9.0×10^{-8}	8.1×10^{-8}	9.0×10^{-8}

Notes:
USEPA = US Environmental Protection Agency.
MDE = Maryland Department of the Environment.
VDEQ = Virginia Department of Environmental Quality.
CCC = criteria continuous concentration.
CMC = criteria maximum concentration.
NA = criteria not available to calculate ratios.

Ratios below 1 indicate that modeled concentrations are below water-quality criteria. All ratios shown here are orders of magnitude below 1 (each order of magnitude is equal to 10 times).
Scientific notation is used for small numbers; for example 1.0×10^{-6} is one millionth (0.000001).

Table 6-8
Ratios of Modeled Concentrations of Metals in Sediment to NOAA Sediment Quality Criteria

Metal	Freshwater				Saltwater				
	Lowest ARCS	Threshold Effects Level	Probable Effects Level	Upper Effects Threshold	Threshold Effects Level	Effects Range-Low	Probable Effects Level	Effects Range-Median	Apparent Effects Threshold
Dense Zone									
Cadmium	0.025	0.024	0.0041	0.0048	0.021	0.012	0.0034	0.0015	0.0048
Chromium	0.00015	0.00015	6.2×10^{-6}	5.9×10^{-6}	0.00011	6.9×10^{-6}	3.5×10^{-6}	1.5×10^{-6}	9.0×10^{-6}
Copper	0.23	0.18	0.033	0.076	0.35	0.19	0.06	0.024	0.017
Lead	0.0032	0.0034	0.0013	0.00094	0.0039	0.0025	0.0011	0.00055	0.0003
Manganese	0.0058	0.0037	NA	NA	0.0021	NA	NA	NA	0.0089
Nickel	0.004	0.0044	0.0022	0.0018	0.0049	0.0038	0.0018	0.0015	0.00072
Zinc	0.012	0.0093	0.0036	0.0022	0.0092	0.0076	0.0042	0.028	0.028
Diffuse Zone									
Cadmium	0.0036	0.0035	0.00059	0.0007	0.0031	0.0017	0.0005	0.00022	0.0007
Chromium	3.6×10^{-5}	3.5×10^{-5}	1.4×10^{-5}	1.4×10^{-5}	2.5×10^{-5}	1.6×10^{-5}	8.0×10^{-6}	3.5×10^{-6}	2.1×10^{-5}
Copper	0.061	0.048	0.0087	0.02	0.091	0.05	0.016	0.0063	0.0044
Lead	0.00071	0.00075	0.00029	0.0021	0.00087	0.00056	0.00023	0.00012	6.6×10^{-5}
Manganese	0.002	0.0013	NA	NA	0.00072	NA	NA	NA	0.0031
Nickel	0.0042	0.0045	0.0023	0.0019	0.0051	0.0039	0.0019	0.0016	0.00074
Zinc	0.002	0.0016	0.00061	0.00037	0.0015	0.0013	0.00071	0.0047	0.0047

Notes:
ARCS = Assessment and Remediation of Contaminated Sediments Program.
NA = criteria not available.
Ratios below 1 indicate that concentrations are below sediment guidelines. All ratios shown here are orders of magnitude below 1 (each order of magnitude is equal to 10 times).
Scientific notation is used for small numbers; for example 1.0×10^{-6} is one millionth (0.000001).
Source: NOAA, 2008.

Explosives

Modeled concentrations of explosives in water and sediment, provided in Table 5-12, were compared to the freshwater and sediment criteria presented in Table 6-4 and are shown in Tables 6-9 and 6-10, respectively. As in the case of metal concentrations, the ratios were orders of magnitude below the target ratio of one, indicating that all concentrations are well below water and sediment quality criteria.

The ratios of modeled surface-water concentrations to saltwater toxicity values, shown in Table 6-11, also were orders of magnitude below concentrations at which adverse effects could occur. Ratios of tetryl, for which no freshwater criteria were available, were hundreds of thousands of times below no-effect concentrations. No HMX values were available for saltwater; however, since it is less toxic than RDX in freshwater and sediments (Table 6-5) and the saltwater ratios for RDX are roughly a million times lower than concentrations at which adverse effects may occur, HMX can be assumed to be at concentrations well below levels that could cause toxic effects in saltwater. As previously noted, there were no toxicity values available for ammonium picrate, so the closest available compound, picric acid was used for screening.

Table 6-9
Ratios of Modeled Explosive Freshwater Concentrations to Water Quality Criteria

Explosive	Ratios of Freshwater[1] Concentration: Acute Water Values		Ratios of Freshwater[1] Concentration: Chronic Water Values	
	Dense Zone	*Diffuse Zone*	*Dense Zone*	*Diffuse Zone*
Ammonium picrate	2.4×10^{-7} Freshwater 7.8×10^{-7} Saltwater	1.2×10^{-8} Freshwater 4.1×10^{-8} Saltwater	NA	NA
HMX	1.2×10^{-9}	6.8×10^{-10}	1.4×10^{-8}	7.9×10^{-9}
RDX	2.3×10^{-5}	4.0×10^{-7}	1.8×10^{-4}	3.0×10^{-6}
Tetryl	NA	NA	NA	NA
TNT	5.9×10^{-6}	1.1×10^{-6}	3.7×10^{-5}	7.1×10^{-6}

Notes:
mg/l = milligrams per liter; FW = freshwater; SW= saltwater.
NA = criteria not available.
[1] Values based on freshwater toxicity endpoint unless noted.
Ratios below 1 indicate that concentrations are below water quality values. All ratios shown here are orders of magnitude below 1 (each order of magnitude is equal to 10 times).
Scientific notation is used for small numbers; for example 1.0×10^{-6} is one millionth (0.000001).

Table 6-10
Ratios of Modeled Explosive Sediment Concentrations to Sediment Quality Criteria

Explosive	Ratios of Sediment Concentration: Sediment Values (mg/kg)	
	Dense Zone	*Diffuse Zone*
Ammonium picrate	NA	NA
HMX	1.3×10^{-8}	1.1×10^{-8}
RDX	1.1×10^{-5}	2.6×10^{-7}
Tetryl	NA	NA
TNT	3.2×10^{-4}	8.9×10^{-5}

Notes:
mg/kg = milligrams per kilogram.
NA = criteria not available.
Ratios below 1 indicate that concentrations are below sediment quality values. All ratios shown here are orders of magnitude below 1 (each order of magnitude is equal to 10 times).
Scientific notation is used for small numbers; for example 1.0×10^{-6} is one millionth (0.000001).

Table 6-11
Ratios of Modeled Explosive Water Concentrations to Saltwater Toxicity Values

Organism	Endpoint	TNT		RDX		Tetryl		Picric Acid	
		NOEC	LOEC	NOEC	LOEC	NOEC	LOEC	NOEC	LOEC
Dense Zone									
Sea Urchin	Fertilization	1.2×10^{-7}	3.2×10^{-8}	4.5×10^{-7}	$>4.5 \times 10^{-7}$	9.6×10^{-7}	5.2×10^{-7}	2.9×10^{-7}	1.5×10^{-7}
	Embryo development	3.7×10^{-7}	1.8×10^{-7}	4.5×10^{-7}	$> 4.5 \times 10^{-7}$	1.6E-05	6.9×10^{-6}	2.9×10^{-7}	1.5×10^{-7}
Algae	Germination	2.0×10^{-6}	9.8×10^{-7}	3.7×10^{-6}	2.1×10^{-6}	1.1×10^{-6}	5.7×10^{-7}	3.1×10^{-7}	1.5×10^{-7}
	Germling length & cell no.[a]	$<1.6 \times 10^{-5}$	1.6×10^{-5}	$<6.7 \times 10^{-6}$	6.7×10^{-6}	5.9×10^{-6}	2.3×10^{-6}	$<5.6 \times 10^{-7}$	5.6×10^{-7}
Polychaete	Survival	5.5×10^{-7}	2.9×10^{-7}	6.9×10^{-7}	$>6.9 \times 10^{-7}$	2.2×10^{-5}	1.0E-05	2.6×10^{-7}	1.4×10^{-7}
	Eggs laid/female	2.4×10^{-6}	1.2×10^{-6}	2.8×10^{-6}	1.4×10^{-6}	3.8×10^{-5}	2.2E-05	4.9×10^{-7}	2.6×10^{-7}
Redfish	Larvae survival	5.3×10^{-7}	3.1×10^{-7}	4.9×10^{-7}	$> 4.9 \times 10^{-7}$	4.8×10^{-7}	2.2×10^{-7}	5.3×10^{-7}	2.8×10^{-7}
Mysid	Survival	5.1×10^{-6}	2.5×10^{-6}	7.2×10^{-7}	$>7.2 \times 10^{-7}$	5.2×10^{-7}	2.9×10^{-7}	5.6×10^{-6}	2.5×10^{-6}
Diffuse Zone									
Sea Urchin	Fertilization	2.3×10^{-8}	6.2×10^{-9}	7.6×10^{-9}	$> 7.6 \times 10^{-9}$	2.7×10^{-8}	1.5×10^{-8}	1.5×10^{-8}	7.6×10^{-9}
	Embryo development	7.0×10^{-8}	3.3×10^{-8}	7.6×10^{-9}	$> 7.6 \times 10^{-9}$	4.6×10^{-7}	2.0×10^{-7}	1.5×10^{-8}	7.6×10^{-9}
Algae	Germination	3.7×10^{-7}	1.9×10^{-7}	6.2×10^{-8}	3.6×10^{-8}	3.3×10^{-8}	1.6×10^{-8}	1.6×10^{-8}	8.0×10^{-9}
	Germling length & cell no.[a]	$<3.0 \times 10^{-6}$	3.0×10^{-6}	$<1.1 \times 10^{-7}$	1.1×10^{-7}	1.7×10^{-7}	6.6×10^{-8}	$< 2.9 \times 10^{-8}$	2.9×10^{-8}
Polychaete	Survival	1.0×10^{-7}	5.5×10^{-8}	1.2×10^{-8}	$> 1.2 \times 10^{-8}$	6.3×10^{-7}	2.9×10^{-7}	1.4×10^{-8}	7.1×10^{-9}
	Eggs laid/female	4.5×10^{-7}	2.3×10^{-7}	4.8×10^{-8}	2.4×10^{-8}	1.1×10^{-6}	6.3×10^{-7}	2.5×10^{-8}	1.4×10^{-8}
Redfish	Larvae survival	1.0×10^{-7}	5.9×10^{-8}	8.4×10^{-9}	$> 8.4 \times 10^{-9}$	1.4×10^{-8}	6.3×10^{-9}	2.8×10^{-8}	1.4×10^{-8}
Mysid	Survival	9.8×10^{-7}	4.7×10^{-7}	1.2×10^{-8}	$> 1.2 \times 10^{-8}$	1.5×10^{-8}	8.2×10^{-9}	2.9×10^{-7}	1.3×10^{-7}

Notes:
NOEC = no-observed-effect concentration
LOEC = lowest-observed-effect concentration
[a] NOEC and LOEC values were the same for germling length and cell number.
Ratios below 1 indicate that modeled concentrations are below saltwater toxicity levels. All ratios shown here are orders of magnitude below 1 (each order of magnitude is equal to 10 times).
Scientific notation is used for small numbers; for example 1.0×10^{-6} is one millionth (0.000001).

Summary of Aquatic Toxicity

Munitions constituents released into the water column and sediments were compared to available water and sediment quality criteria and guidelines to determine whether they could adversely affect aquatic life. All modeled concentrations were well below freshwater, saltwater, and sediment criteria and guidelines – generally by many orders of magnitude – for both the dense zone and the larger diffuse zone. These areas contain the densest target areas for projectiles and thus represent the highest concentrations of munitions constituents in the PRTR. Based on these comparisons, no adverse effects to aquatic life are associated with metals or explosives released from munitions testing in the PRTR, as concentrations of MCOPCs outside these areas would be much lower due to dilution. As future RDT&E activities potentially releasing MCOPCs into the PRTR are expected to remain consistent with past usage, no adverse effects to aquatic life are predicted from future munitions testing in the PRTR.

6.1.3 Comparison of Modeled Fish Tissue Concentrations to Fish Toxicity Values

Sediment criteria and guidelines are generally based on benthic-community metrics and toxicity studies. As an additional comparison, fish-tissue concentrations (body burdens) were estimated based on the bioconcentration factors (BCFs) of the constituents in the water column. BCFs were used because of the lack of reliable biota-sediment accumulation factors (BSAFs) for metals or explosives. USEPA (1999) conducted a review of laboratory and field studies to derive BCFs for metals and other contaminants. The BCFs for the metals considered in this WRSEPA along with the basis for each value are provided in Table 6-12.

Table 6-12
Metal Bioconcentration Factors

Metal	BCF	Basis
Cadmium	907	Geometric mean of four field values.
Chromium (total)	19	Geometric mean of four laboratory values.
Copper	710	Geometric mean of four field values.
Lead	0.09	Based on one field value.
Manganese	633	Empirical data were not available. Based on the arithmetic mean of the recommended values for 14 inorganics with empirical data
Nickel	78	Geometric mean of three laboratory values.
Zinc	2,059	Geometric mean of four field values.
Source: USEPA, 1999.		

BCFs for explosives were obtained from US Navy (2002), with the exception of ammonium picrate, which was calculated using the following equation from Bintein et al. (1993, as cited in USEPA, 1999):

$$\log BCF = (0.910 \times K_{ow}) - (1.975 \times \log [6.8E\text{-}7 \times K_{ow} + 1]) - 0.786 \qquad \text{(Equation 6-1)}$$

The log octanol-water partition coefficient (K_{ow}) is the ratio of a chemical's concentration in the octanol phase to its concentration in the aqueous phase of a two-phase octanol/water system. Chemicals with low K_{ow} values (e.g., less than 10) are relatively hydrophilic and tend to have high water solubilities, small soil/sediment adsorption coefficients, and small BCFs. Conversely, chemicals with high Kow values (e.g., greater than 10^4) are very hydrophobic. Explosives generally have low K_{ow} values.

A range of BCFs was provided in US Navy (2002) and Bintein et al. (1993, as cited in USEPA, 1999), as shown in Table 6-13. To ensure a conservative risk estimate, the highest BCFs (shown in bold type in the table) were selected.

Table 6-13
Bioconcentration Factors for Explosives

Explosive	BCF	Source
Ammonium picrate	0.16	Equation 6-1
HMX	0.7 to **1.1**	US Navy (2002)
RDX	2.8 to **3.1**	US Navy (2002)
Tetryl	12 to **22.1**	US Navy (2002)
TNT	11 to **75.4**	US Navy (2002)
Note: When a range of BCFs was provided, the most conservative (highest) value was selected; this value is shown in **bold** type.		

To predict the concentration of a constituent in fish tissue, the following formula was used:

Conc. fish = BCF x Conc. surface water x FCM (Equation 6-2)

Where:

Conc. fish = the concentration of the constituent in a fish (mg/kg)

BCF = relevant fish bioconcentration factor (l/kg)

Conc. surface water = modeled surface water concentration (mg/l)

FCM = Trophic level 3 fish food chain multiplier

Food-chain multipliers (FCMs), derived by the USEPA (USEPA, 1995), are used to assess the possibility of constituent magnification through the food chain. FCMs are related to an organism's trophic status as predator/prey, producer/consumer, etc., and account for increases in tissue concentrations of chemicals as they pass through the food chain. The FCM for all metals evaluated in this assessment is 1, based on Sample et al. (1996). The FCM for explosives was also considered to be 1, as compounds with a log K_{ow} below 2 are considered to have an FCM of 1 (Sample et al., 1996). For the explosives considered here, the log K_{ow} ranges from 0.061 for HMX to 1.86 for TNT (Walsh et al., 1995).

For metals, calculated fish-tissue concentrations were compared to the lowest tissue-residue concentration levels known to have adverse effects. Jarvinen and Ankley's database linking effects to tissue residues of aquatic organisms (Jarvinen and Ankley, 1999) was used to locate relevant studies. Studies on both marine and freshwater fish were evaluated and those studies yielding the most conservative values were selected. The toxicity values selected, along with the level of confidence associated with them and the source, are shown in Table 6-14.

For cadmium, the lowest NOEC endpoint based on whole-body concentrations was for juvenile seabass, at 2.5 milligrams per kilogram whole body (mg/kg ww [wet weight]) (Shazili, 1995); however, the LOEC based on whole-body tissue concentrations was lower, at 0.9 mg/kg ww for adult three-spined stickleback (*Gasterosteus aculeatus*) (Pascoe and Mattey, 1977). The lowest value, a screening toxicity value for cadmium of 0.9 mg/kg ww, was selected.

For copper, the lowest effect level was seen in carp, which showed a reduced oxygen consumption when copper burdens were 0.4 mg/kg (Jezierska and Sarnowski, 2002). Although there was no decrease in mortality or growth, a copper screening toxicity value of 0.4 mg/kg was conservatively selected for screening. For lead, a value of 0.6 mg/kg was selected, based on a mortality NOEC in immature brook trout (*Salvelinus fontinalis*) (Holcombe et al., 1976, as cited in Jarvinen and Ankley, 1999). No studies on sub-adult estuarine or freshwater fish species were located for manganese; therefore, a screening value was not calculated for this metal. For nickel, a value of 0.8 mg/kg based on a mortality NOEC in the rainbow trout (*Oncorhynchus mykiss*) (Calamari et al., 1982) was chosen. For zinc, an Atlantic salmon (*Salmo salar*) growth NOEC for juveniles of 12 mg/kg was selected (Farmer et al., 1979).

Table 6-14
Tissue Residue-Based Toxicity Screening Values for Metals

Constituent	Screening Concentration	Level of Confidence	Source
Cadmium	0.9 mg/kg	Very low	Stickleback adult LOEC for mortality (Pascoe and Mattey, 1977)
Chromium	Not Available	Not Available	Insufficient fish ecotoxicity data
Copper	0.4 mg/kg	Very low to moderate	Reduced oxygen consumption in carp (Jezierska and Sarnowski, 2002)
Lead	0.6 mg/kg	Very low	Mortality NOEC in immature brook trout (Holcombe et al., 1976 as cited in Jarvinen and Ankley, 1999)
Manganese	Not Available	Not Available	Insufficient fish ecotoxicity data
Nickel	0.8 mg/kg	Very low	Rainbow trout survival NOEC, muscle tissue (Calamari et al., 1982)
Zinc	12 mg/kg	Very low to moderate	Atlantic salmon juvenile growth NOEC – whole tissue (Farmer et al., 1979)
Note: mg/kg = milligrams per kilogram.			

In general, the relationship between metal residues in tissues and toxicity is poor because metals may exist within an organism in several chemical forms and most, if not all, of the accumulated metal mass may be bound in a detoxified form or a relatively inert storage form. While free ions are the major toxicologically active form for most metals in organisms, total metal concentrations in tissue include non-toxic metal-protein complexes and selective sequestering of metals in metal-accumulating granules, tertiary lysosomes, and other structures. Thus, there is a low level of confidence in all metal-screening values, especially for essential elements such as copper and zinc. However, these values provide the best available screening comparison to determine whether concentrations of metals in fish due to RDT&E activities on the PRTR have the potential to cause adverse effects.

As shown in Table 6-15, all calculated metal concentrations in fish were orders of magnitude below the concentrations that could potentially result in adverse effects.

A comparison of explosives in fish tissue was not performed due to the lack of data on tissue concentrations and associated toxicity effects. However, as can be seen in Table 6-16, the predicted concentrations of explosives in fish tissue are low. In addition, the modeled concentrations of explosives in water and sediment are well below the relevant screening values (see Tables 6-9 to 6-11), and comparisons based on fish toxicity studies (see redfish in Table 6-11) are more than a million times below the target ratio of one. These results strongly suggest that the low levels of explosives in PRTR sediments and water would not result in adverse effects to fish.

Table 6-15
Modeled Fish Tissue Concentrations Compared to Metal Toxicity Screening Values

Metal	Concentration of Metals in Fish Tissues (mg/kg)		Ratio to Toxicity Screening Tissue Concentrations	
	Dense Zone	*Diffuse Zone*	*Dense Zone*	*Diffuse Zone*
Cadmium	4.6×10^{-6}	6.3×10^{-7}	5.1×10^{-6}	7.0×10^{-7}
Chromium	1.6×10^{-7}	3.7×10^{-8}	NA	NA
Copper	4.2×10^{-6}	1.1×10^{-6}	1.0×10^{-5}	2.7×10^{-6}
Lead	5.2×10^{-13}	1.1×10^{-13}	8.7×10^{-13}	1.8×10^{-13}
Manganese	6.6×10^{-4}	2.2×10^{-4}	NA	NA
Nickel	1.7×10^{-6}	1.7×10^{-6}	2.2×10^{-6}	2.1×10^{-6}
Zinc	9.4×10^{-5}	1.5×10^{-5}	7.9×10^{-6}	1.3×10^{-6}

Notes:
NA= not available (no toxicity data).
Ratios below 1 indicate that modeled concentrations are below target levels. All ratios shown here are orders of magnitude below 1 (each order of magnitude is equal to ten times).
Scientific notation is used for small numbers; for example 1.0×10^{-6} is one millionth (0.000001).

Table 6-16
Modeled Concentrations of Explosives in Fish Tissue

Ordnance	River Water Concentration from Munitions (Daily) (mg/l)		BCF (l/kg)	Food Chain Multiplier	Concentration of Explosives in Fish Tissues (mg/kg ww)	
	Dense Zone	*Diffuse Zone*			*Dense Zone*	*Diffuse Zone*
Ammonium Picrate	5.2×10^{-5}	2.7×10^{-6}	0.16	1	8.3×10^{-6}	4.3×10^{-7}
HMX	4.5×10^{-9}	2.6×10^{-9}	1.1	1	4.9×10^{-9}	2.9×10^{-9}
RDX	3.4×10^{-5}	5.7×10^{-7}	3.1	1	1.0×10^{-4}	1.8×10^{-6}
Tetryl	5.7×10^{-7}	1.6×10^{-8}	22.1	1	1.3×10^{-5}	3.6×10^{-7}
TNT	3.3×10^{-6}	6.4×10^{-7}	75.4	1	2.5×10^{-4}	4.8×10^{-5}

Notes:
mg/l = milligrams per liter; .l/kg – liters per kilogram; mg/kg ww = milligram per kilogram (parts per million) wet weight.
Fish Concentration= BCF x Conc. Water x FCM
All FCMs were 1 based on the log K_{ow} of all compounds being below 2 (Sample et al., 1996; Walsh et al., 1995).
BCFs were taken from US Navy, 2002, except for ammonium picrate which was calculated from Bintein et al., 1993 as cited in USEPA, 1999.
Maximum BCFs were used to estimate the upper bound of the range.
Scientific notation is used for small numbers; for example 1.0×10^{-6} is one millionth (0.000001).

Summary of Fish Exposure

Concentrations of metals and explosives in fish tissue were predicted using BCFs. The modeled metal concentrations were then compared to values associated with toxicological effects. All concentrations were well below the levels associated with adverse effects. There were insufficient studies associating toxicological effects with fish tissue concentrations for explosives. However, considering the extremely low concentrations of explosives in fish predicted together with the results of the aquatic toxicity screening, it is very unlikely that any adverse effects to fish would occur due to exposure to MCOPCs from RDT&E activities. As future munitions testing in the PRTR is expected to remain consistent with past usage, no adverse effects to fish are predicted from exposure to MCOPCs in the future.

6.2 Wildlife Exposure

As described in the ORSM (Chapter 4), wildlife living or foraging near the Potomac River may be exposed to munitions constituents through the consumption of contaminated prey, sediments, or water. Therefore, exposure to MCOPCs was modeled for birds and mammals using representative local species. Site-specific daily doses were estimated for wildlife considered to have the greatest potential for exposure to Potomac River sediments, surface water, and aquatic organisms. Maximum exposure scenarios were modeled to determine whether they would result in levels of exposure to MCOPCs that could have adverse effects, thus requiring further evaluation.

The potential exposure of wildlife to MCOPCs was determined through the summation of all pathways of exposure. The exposure rate was predicted based on the modeled concentrations of metals and explosives as provided in Tables 5-12 and 5-13, respectively. To provide a conservative estimate of the risk, it was assumed that the modeled animals spend their entire lives within the PRTR and obtain 100 percent of their food, drinking water, and incidental sediment ingestion from the area of the PRTR with the highest munitions densities (i.e., the dense zone and the diffuse zone) throughout their entire lifetime. As noted earlier, exposure was only modeled for the contribution of MCOPCs from RDT&E activities and the study does not take into account constituents that may enter the river upriver of the installation or natural background levels of metals, which is outside the scope of the WRSEPA (US Navy, 2008). As seen in Table 5-13, upstream concentrations of metals are orders of magnitude above the concentrations entering the river from RDT&E activities on the PRTR.

6.2.1 Food-web Modeling

Screening-level exposure estimates were calculated for avian and mammalian receptors using the conservative exposure assumptions, such as minimum body weights and using only the dense and diffuse zones for feeding. Wildlife life history parameters and exposure assumptions are listed in Table 6-17. Details on each wildlife receptor are provided in Section 6.2.2.

Food ingestion rates (FIRs) were calculated in grams of dry matter per day (g/day), using the following equations from Nagy (1987):

Birds: $\text{FIR (g/day)} = 0.648\ \text{Wt.}^{0.651}\ \text{(g)}$ (Equation 6-3)

Mammals: $\text{FIR (g/day)} = 0.235\ \text{Wt.}^{0.822}\ \text{(g)}$ (Equation 6-4)

For conversion from wet weight (ww) to dry weight (dw), fish tissue was considered to be 75 percent water, based on USEPA's *Wildlife Exposures Factors Handbook* (USEPA, 1993).

Water ingestion rates (WIRs) were calculated in liter per day (l/day) using the following equations from Calder and Braun (1983):

Birds: $\text{WIR (l/day)} = 0.059\ \text{Wt.}^{0.67}\ \text{(kg)}$ (Equation 6-5)

Mammals: $\text{WIR (l/day)} = 0.099\ \text{Wt.}^{0.90}\ \text{(kg)}$ (Equation 6-6)

Sediment ingestion rates (SIRs) expressed in g/day were based on professional judgment, as species-specific rates were not available. Ingestion rates for a range of wildlife species provided in Beyer et al. (1994) were considered when selecting SIRs.

Table 6-17
Wildlife Life History Parameters and Exposure Factors

Factor	Units	Wildlife Receptor		
		Belted Kingfisher	Great Blue Heron	River Otter
Body weight	grams	136 [c]	2.200 [e]	5.450 [f]
Food ingestion rate (FIR) (dw basis)[a]	kg/kg-day	0.117	0.044	0.051
Water ingestion rate (WIR)[b]	l/kg-day	0.114	0.056	0.105
Percent Diet Composition – Fish		100%	100%	100%
Sediment ingestion rate (SIR) (dw basis)[d]	% of FIR	1%	1%	1%
Residence time (maximum)	days/yr	365	365	365

Notes:
kg/kg-day = kilogram ingested per kilogram weight per day; l/kg-day = liter ingested per kilogram weight per day.
[a] Based on Nagy, 1987.
[b] Based on Calder and Braun, 1983.
[c] Brooks and Davis, 1987. Non-breeding range.
[d] Based on professional judgment.
[e] Dunning, 2008.
[f] Melquist and Dronkert, 1987.

The effects of exposure to MCOPCs by dose (e.g., mg/kg per day) are proportional to body weight and individuals with lower body weights have greater potential for adverse effects than ones with greater body weight when both are exposed to the same dose. As recommended by USEPA (1997), the minimum adult weight identified in the literature for each receptor species was used as the body weight for the purposes of the modeling. All ingestion rates were divided by receptor body weights to provide MCOPC intake rates per kilogram of body weight per day. Receptors were assumed to feed exclusively on fish to provide maximum exposure to PRTR MCOPCs. Concentrations of MCOPCs in fish were calculated as described in Section 6.1.3.

The general structure of the model used to estimate the exposure rate for a given contaminant by a wildlife receptor is as follows:

$$EED = \sum (IR_p \times [MCOPC]_p + IR_w \times [MCOPC]_w + IR_s \times [MCOPC]_s) \qquad \text{(Equation 6-7)}$$

where:

EED = estimated environmental dose (mg/kg body weight per day)

IR_p = receptor-specific prey intake rate (kg dry weight/kg body weight)

IR_w = receptor-specific water intake rate (l/kg body weight)

IR_s = receptor-specific incidental sediment intake rate (kg dry weight/kg body weight)

$[MCOPC]_p$ = MCOPC concentration in the receptors’ prey (mg/kg dry weight)

$[MCOPC]_w$ = MCOPC concentration in the receptors’ drinking water (mg/l)

$[MCOPC]_s$ = MCOPC concentration in the sediments or soils incidentally ingested (mg/kg dry weight)

Based on the chemical properties of the MCOPCs under consideration and the typical foraging behavior of the wildlife receptors, the primary routes of exposure of wildlife to MCOPCs are:

- Ingestion of prey items (e.g., benthic invertebrates/insects, fish, small mammals).
- Ingestion of drinking water.
- Incidental ingestion of sediment.

Therefore, for this assessment, exposure paths were considered to be ingestion of prey, water, and sediment, which are considered to account for the majority of exposure to MCOPCs.

6.2.2 Wildlife Receptors

Wildlife receptors were chosen to represent species documented at and near NSF Dahlgren (NSF Dahlgren, 2007). Because higher-trophic-level feeders (i.e., high in the food chain) are likely to have the greatest exposure to MCOPCs in the PRTR, piscivorous (fish eating) species were selected: the belted kingfisher (*Ceryle alcyon*) and great blue heron (*Ardea herodias*) as representative receptors for birds; and the river otter (*Lutra canadensis*) as representative receptor for mammals. While these receptors do not cover the entire range of species found around the PRTR, they include those with the highest risk of exposure. Receptors feeding on items with lower contaminant concentrations, such as herbivores (e.g., muskrat [*Ondatra zibethicus*] and mallard [*Anas platyrhynchos*]), are at lower risk than receptors feeding on higher-trophic-level prey; therefore, this risk assessment is considered to be protective of them. The assessed receptors serve as surrogates for all potential ecological receptors that may be exposed to site-related contamination.

6.2.2.1 Belted Kingfisher (*Ceryle alcyon*)

The belted kingfisher is found in much of North America (Bent, 1940). It is an aquatic feeder that requires clear water for spotting its prey (Davis, 1982). Kingfishers typically perch on a tree limb over a body of water while searching for prey and fish mainly at the surface of the water. The average body weight of an adult belted kingfisher used for this assessment is 136 g (0.30 lbs), based on a Pennsylvania population (Brooks and Davis, 1987).

Fish are the predominant prey of the belted kingfisher (Bent, 1940; USEPA, 1993); however, diets can vary with prey availability and kingfishers may supplement their diets with aquatic invertebrates, terrestrial prey, and/or plant material (Alexander, 1977). As a conservative assumption (i.e., fish is the most likely prey to have high concentrations of MCOPCs) fish are assumed to represent 100 percent of the diet in this screening-level assessment (Davis, 1982; Brooks and Davis, 1987).

Using the bioenergetic algorithm for birds of Nagy (1987) (see Equation 6-3), the daily food ingestion rate for the kingfisher was estimated to be 0.117 kg/kg body weight-day (dry-weight basis). The drinking water ingestion rate was estimated to be 0.144 l/kg body weight-day, based on the algorithm of Calder and Braun (1983) (Equation 6-5).

Incidental sediment ingestion was assumed to be 1 percent of the total prey intake. This is to account for incidental soil ingestion during nest construction and nesting, as belted kingfishers construct their nests by excavating tunnels in embankments (Levine, 1988). Although the kingfisher hunts almost exclusively within the pelagic zone, both the male and female dig the nesting burrow, using their bills as probes and their feet as shovels (Levine, 1988).

The home range is typically defined by the length of shoreline defended by a mated pair (breeding territory) or the feeding area defended by a solitary (non-breeding) adult. Generally, mated pairs defend a larger habitat than solitary individuals, although considerable overlap in size occurs. The foraging range of the kingfisher was reported to average between 0.2 and 1.4 mi (0.4 and 2.2 km) (Davis, 1982; Brooks and Davis, 1987). Based upon this foraging range, kingfishers evaluated in this screening assessment were considered to have a home range located completely within the dense zone of the PRTR.

The timing and extent of migration of belted kingfishers appear to be related to the severity of the weather (Davis, 1982). The belted kingfisher is a hardy bird that can remain far north in fall and winter as long as it is able to find open waters in which to catch a sufficient number of fish (Bent, 1940). As open water is present year-round at the PRTR and the belted kingfisher has been observed at NSF Dahlgren and at Audubon Christmas Counts in the region (Audubon Society, 2009), it was assumed to have year-round residency for the purposes of this study.

6.2.2.2 Great Blue Heron (*Ardea herodias*)

The great blue heron is a wading bird that occurs in a variety of freshwater and marine habitats and breeds in much of North America (Bent, 1926). It is the largest member of the heron family in North America. Great blue herons may inhabit lakes, rivers, brackish marshes, lagoons, coastal wetlands, tidal flats, and sandbars, as well as occasional wet meadows and pastures (USEPA, 1993). An average body weight for the female great blue heron of about 2,200 g (4.9 lbs) was selected based on Dunning (2008). Female body weights were used when available, as many of the most sensitive endpoints are related to reproductive functions and because female body weights are lower than male body weights thereby providing a more conservative estimate of risk (i.e., greater intake of MCOPC per unit body weight).

The principal food of the great blue heron is fish of various kinds, but amphibians (e.g., frogs), snakes, small birds and mammals, and aquatic and terrestrial invertebrates are also taken on occasion (Bent, 1926; USEPA, 1993). The great blue heron fishes by still hunting and stalking (Bent, 1926). Still hunting is the commonest method, where the heron stands motionless waiting for prey (primarily fish), which it captures striking swiftly with its bill (Eckert and Karalus, 1983). The great blue heron may also slowly wade in shallow water until it drives a fish out from a hiding place (Environment Canada, 2005). Fish make up 90 to 98 percent of the blue heron's diet (Alexander, 1977; USEPA, 1993). In this analysis, fish were conservatively assumed to make up 100 percent of the bird's dietary intake.

Using the bioenergetic algorithm for birds of Nagy (1987) (Equation 6-3), the daily food ingestion rate of the great blue heron was estimated to be 0.044 kg/kg body weight-day (dry-weight basis). The drinking water ingestion rate was estimated to be 0.056 l/kg body weight-day, based on the algorithm of Calder and Braun (1983) (Equation 6-5). The incidental sediment intake rate was assumed to be 1 percent to account for incidental intake during fishing.

The average foraging range for the great blue heron in South Dakota varies from an average of 1.9 mi (3.1 km) to a maximum distance flown of 15 mi (24 km). Foraging ranges of herons overlapped, with mean densities of 1.4 to 2.2 birds/mi (2.3 and 3.6 birds/km) observed at two separate locations (Dowd and Flake, 1985). These foraging ranges were used, as no data were available for foraging ranges in the eastern US. Based on these ranges, it was assumed that the

PRTR could support a great blue heron population, although it is unlikely that individual birds would obtain all their prey from the dense zone.

The great blue heron was assumed to be a year-round resident of the PRTR, as it has been observed at NSF Dahlgren (NSF Dahlgren, 2007) and has been documented in Audubon Christmas Counts in the area (Audubon Society, 2009).

6.2.2.3 River Otter (*Lutra canadensis*)

The river otter is one of the larger members of the Mustelidae family. It is found throughout most of North America. It is morphologically adapted for land and water, but feeds almost exclusively on aquatic prey. Females are smaller than males, with a weight ranging from 5 to 15 kg (11 to 33 lbs) at sexual maturity (Melquist and Dronkert, 1987). The lowest average weight found – 5.45 kg (12 lbs) (Connecticut Department of Environmental Conservation, 2011) – was selected for use in this assessment.

Fish comprise the majority of otter prey, but otter also commonly feed on crayfish. Aquatic invertebrates, amphibians, birds, mammals, and blueberries contribute a smaller percentage of the diet (USEPA, 1993). For the purposes of this study, a diet of 100 percent fish was conservatively used to estimate dietary exposure.

Using the bioenergetic algorithm for mammals of Nagy (1987) (Equation 6-4), the daily food ingestion rate of the river otter was estimated to be 0.051 kg/kg (dry-weight basis). The drinking water ingestion rate was estimated to be 0.105 l/kg body weight-day, based on the algorithm of Calder and Braun (1983) for mammals (Equation 6-6).

Incidental soil ingestion was assumed to be 1 percent of total daily food intake.

The typical home range of the river otter has been documented to vary from 0.6 to 48 mi (1 to 78 km) (Melquist and Dronkert, 1987). The home ranges of river otters have also been shown to overlap extensively, both within and between genders (Erickson and McCullough, 1987). Average densities range from one individual every 1.2 to 1.9 mi (2 to 3 km) (Erlinge, 1967) to one per 2.4 mi (3.9 km) of waterway (Melquist and Hornocker, 1983). The PRTR shoreline was considered adequate to support a small river-otter population, although it is unlikely that an individual otter would obtain all its prey from the dense zone. River otters have been observed at NSF Dahlgren and occur along the river (NSF Dahlgren, 2007).

River otters do not hibernate, nor do they migrate (USEPA, 1993). With the exception of local territorial movements by adults and dispersal of sub-adults from resident populations, river otters occupy and defend their resident territory throughout the year. Therefore, they were assumed to be year-round residents of the PRTR.

6.2.3 Toxicity

For wildlife receptors, a screening ecotoxicity value was selected for each complete exposure pathway, route, and contaminant. Consistent with screening guidance (USEPA, 1997), no-observed-adverse-effect-level (NOAEL) toxicity values were used for avian and mammalian receptors, when available, to provide a conservative estimate of risk. The NOAEL is the chemical dose at which no statistically or biologically significant increase in frequency (or severity) of adverse effects are seen between the exposed population and its appropriate control. Effects may be produced at this dose, but they are not considered to be adverse. Generally the NOAEL selected for a compound is the lowest (most conservative) value taken from appropriate studies.

Tables 6-18 and 6-19 present the toxicity values used to screen avian and mammalian receptors, respectively. The primary literature sources for these toxicity values were *Toxicological Benchmarks for Wildlife* by Sample et al. (1996) for metals and Agency for Toxic Substances and Disease Registry (ATSDR) reports (1995a, 1995b, 1997, 2010) for explosives. The original studies cited in Sample et al. (1996) and the ATDSR reports are listed in the tables.

The most conservative appropriate toxicity value available for each class of wildlife (e.g., avian, mammal) was selected for use as the NOAEL. When possible, studies based on reproductive endpoints, generally considered to be the most sensitive population-level endpoint, were selected. However, as there are few studies on the toxicity of explosives to wildlife, all studies with chronic NOAELs were considered. Mammalian explosive NOAELs were used for screening potential effects on birds, as insufficient avian data were available. Chronic (long-term) studies were preferred to acute (short-term) studies. If a study covered a sensitive life stage, such as reproduction, it was considered chronic.

Table 6-18
Avian Toxicity Values

Constituent	Avian NOAEL (mg/kg-day)	Test Species	Study Type	Reference[a]
Metals				
Cadmium	1.45	Mallard Duck	Chronic (90 days)	White and Finley (1978)[a]
Chromium[+III]	1.0	Black duck	Chronic (10 months)	Haseltine et al. (1985)[a]
Copper	47	1-day old chicks	Chronic (10 weeks)	Mehring et al. (1960)[a]
Lead	1.13	Japanese quail	Chronic (12 weeks)	Edens et al. (1976)[a]
Manganese	977	Japanese quail	Chronic (75 days)	Laskey and Edens (1985)[a]
Nickel	77.4	Mallard duckling	Chronic (90 days)	Cain and Pafford (1981)[a]
Zinc	14.5	White leghorn hens	Chronic (24 weeks)	Stahl et al. (1990)[a]
Explosives				
Ammonium picrate	NA			
HMX	50	Rat*	Chronic (13 weeks)	Everett et al. (1985)[b]*
RDX	8.0	Rat*	Chronic (6 months)	Levine et al. (1983)[c]*
Tetryl	13	Rat*	Chronic (90 days)	Reddy et al. (1991)[d]*
TNT	0.5	Beagle*	Chronic (6 months)	Levine et al. (1990)[e]*

Notes:
mg/kg-day = milligram ingested per kilogram weight per day.
*Mammalian value used, as no avian studies were available.
[a] As cited in Sample et al., 1996.
[b] As cited in ATSDR, 1997.
[c] As cited in ATSDR, 2010.
[d] As cited in ATSDR, 1995a.
[e] As cited in ATSDR, 1995b.
Trivalent chromium value was used as no hexavalent value was available.

Table 6-19
Mammalian Toxicity Values

Constituent	Mammalian NOAEL (mg/kg-day)	Test Species	Study Type	Reference
Metals				
Cadmium	1.0	Rat	Chronic (6 weeks through mating and gestation)	Sutou et al. (1980)[a]
Chromium^{+VI}	3.28	Rat	Chronic (1 year)	Mackenzie et al. (1958)[a]
Copper	11.7	Mink	Chronic (357 days)	Aulerich et al. (1982)[a]
Lead	8.0	Rat	Chronic (3 generations; > 1 year)	Azar et al. (1973)[a]
Manganese	88	Rat	Chronic (224 days)	Laskey et al. (1982)[a]
Nickel	40	Rat	Chronic (3 generations; > 1 year)	Ambrose et al. (1976)[a]
Zinc	160	Rat	Chronic (days 1-16 of gestation)	Schlicker and Cox (1968)[a]
Explosives				
Ammonium picrate	NA			
HMX	50	Rat	Chronic (13 weeks)	Everett et al. (1985)[b]
RDX	8	Rat	Chronic (6 months)	Levine et al. (1983)[c]
Tetryl	13	Rat	Chronic (90 days)	Reddy et al. (1999)[d]
TNT	0.5	Beagle	Chronic (6 months)	Levine et al. (1990)[e]

Notes:
mg/kg-day = milligram ingested per kilogram weight per day
[a] As cited in Sample et al., 1996.
[b] As cited in ATSDR, 1997.
[c] As cited in ATSDR, 2010.
[d] As cited in ATSDR, 1995a.
[e] As cited in ATSDR, 1995b.

6.2.4 Risk Characterization

To assess potential risks to wildlife, the modeled estimated exposure rate (EER) for each MCOPC was divided by the NOAEL toxicity value to derive the hazard quotient (HQ), as follows:

$$HQ = \frac{EER}{NOAEL} \qquad \text{(Equation 6-8)}$$

where:

HQ = hazard quotient or the ratio of the exposure and the NOAEL (no units)

EER = estimated exposure rate (mg/kg body weight-day)

NOAEL = toxicity reference value for the no-observed-adverse-effects level (mg/kg body weight-day)

HQs were calculated for each constituent for each wildlife receptor. If an HQ is greater than 1, the concentration of the MCOPC the receptor is exposed to is above the level at which no adverse effects are expected. Conversely, if an HQ is less than 1, the concentration of the MCOPC the receptor is exposed to is below the level at which no adverse effects are expected to occur.

A hazard index (HI) was also calculated by summing the hazard quotients for all the MCOPCs that an individual may be exposed to. The HIs presented here are considered conservative, as HIs are appropriate for substances that affect the same target organ or organ system. Ideally, HQs should be combined for MCOPCs that cause adverse effects by the same toxic mechanism. However, because detailed information on toxic mechanisms is not available for all of the MCOPCs in this assessment, the HI was derived by adding all HQs together, regardless of the mechanism. As with the HQ, aggregate exposures equal to or below an HI of 1.0 are unlikely to result in adverse effects and are considered acceptable. However, an HI greater than 1.0 does not necessarily suggest a likelihood of adverse effects due to the conservatism of the methodology.

HQs and HIs were calculated for the dense zone and the diffuse zone. If HQs and HIs for both zones are all well below the target of 1 – indicating that there are no risks to ecological receptors from MCOPCs – then it can be concluded that the areas outside these zones, with lower munitions-related constituent concentrations, are also below levels of concern. As shown in Tables 6-20 to 6-22, the HQs and HIs for all constituents for all three wildlife receptors are orders of magnitude below 1 – generally about ten thousand times lower (1×10^{-4}) for the effects of all MCOPCs – indicating that the MCOPCs released into the Potomac River by munitions testing are well below levels that may cause adverse effects in wildlife.

Summary of Wildlife Exposure

Wildlife exposure to MCOPCs in the PRTR was estimated using a food-web model. The concentrations of metals and explosives that wildlife would be exposed to through food, water, and sediment pathways were estimated using conservative screening assumptions. The modeled concentrations were compared to dose concentrations at which no adverse effects were seen in birds and mammals and were orders of magnitude below those levels. As discussed previously, future RDT&E munitions activities potentially releasing MCOPCs into the PRTR are expected to remain consistent with past usage. Therefore, wildlife exposure in the future is also predicted to be orders of magnitude below levels which could result in adverse effects. Uncertainties associated with the modeling (discussed in Section 6.2.5), such as time spent in the PRTR, were selected to be protective. Hence, the screening-level ecological risk assessment performed for the PRTR indicates that exposure to constituents from munitions will not result in adverse effects to wildlife in the area.

6.2.5 Uncertainty Analysis

The assumptions used in this screening-level ecological risk assessment were selected to yield conservative results in order to identify potential pathways of exposure that merit further evaluation. Sources of uncertainty include:

- Munitions-use quantification
- Selection of MCOPCs
- Fate and transport modeling
- The conceptual model (ORSM)
- Natural variation and parameter error
- Food and web model error
- Toxicological studies selected as measures of effect

Table 6-20
Screening Hazard Quotients for the Belted Kingfisher

Constituent	Fish Concentration[1] (mg/kg dw)	Sediment Concentration (mg/kg dw)	Water Concentration (mg/l)	Estimated Environmental Dose (mg/kg - day)	NOAEL (mg/kg-day)	Hazard Quotient
Dense Zone						
Metals						
Cadmium	1.1×10^{-6}	0.015	5.0×10^{-9}	1.7×10^{-5}	1.45	1.2×10^{-5}
Chromium	4.0×10^{-8}	0.0056	8.5×10^{-9}	6.6×10^{-6}	1.0	6.6×10^{-6}
Copper	1.0×10^{-6}	6.5	5.9×10^{-9}	0.0076	47	1.6×10^{-4}
Lead	1.3×10^{-13}	0.12	5.8×10^{-12}	1.4×10^{-4}	1.13	1.2×10^{-4}
Manganese	1.6×10^{-4}	2.3	1.0×10^{-6}	0.0027	977	2.8×10^{-6}
Nickel	4.3×10^{-7}	0.079	2.2×10^{-8}	9.2×10^{-5}	77.4	1.2×10^{-6}
Zinc	2.4×10^{-5}	1.1	4.6×10^{-8}	0.0013	14.5	9.2×10^{-5}
Explosives						
Ammonium picrate	2.1×10^{-6}	5.4×10^{-7}	5.2×10^{-5}	6.1×10^{-6}	NA	NA
HMX	1.2×10^{-9}	6.1×10^{-9}	4.5×10^{-9}	6.6×10^{-10}	50	1.3×10^{-11}
RDX	2.6×10^{-5}	1.4×10^{-5}	3.4×10^{-5}	6.9×10^{-6}	8.0	8.6×10^{-7}
Tetryl	3.2×10^{-6}	6.0×10^{-4}	5.7×10^{-7}	1.1×10^{-6}	13	8.8×10^{-8}
TNT	6.3×10^{-5}	0.003	3.3×10^{-6}	$1.12.5 \times 10^{-5}$	0.5	2.2×10^{-5}
Hazard Index (Metals + Explosives)						4.2×10^{-4}
Diffuse Zone						
Metals						
Cadmium	1.6×10^{-7}	0.0021	6.9×10^{-10}	2.5×10^{-6}	1.45	1.7×10^{-6}
Chromium	9.2×10^{-9}	0.0013	1.9×10^{-9}	1.5×10^{-6}	1	1.5×10^{-6}
Copper	2.7×10^{-7}	1.7	1.5×10^{-9}	0.002	47	4.3×10^{-5}
Lead	2.7×10^{-14}	0.026	1.2×10^{-12}	3.1×10^{-5}	1.13	2.7×10^{-5}
Manganese	5.4×10^{-5}	0.80	3.4×10^{-7}	9.4×10^{-4}	977	9.6×10^{-7}
Nickel	4.3×10^{-7}	0.082	2.2×10^{-8}	9.5×10^{-5}	77.4	1.2×10^{-6}
Zinc	3.8×10^{-6}	0.19	7.3×10^{-9}	2.3×10^{-4}	14.5	1.6×10^{-5}
Explosives						
Ammonium picrate	1.1×10^{-7}	4.1×10^{-8}	2.7×10^{-6}	3.2×10^{-7}	NA	NA
HMX	7.2×10^{-10}	5.1×10^{-9}	2.6×10^{-9}	3.9×10^{-10}	50	7.7×10^{-12}
RDX	4.4×10^{-7}	3.4×10^{-7}	5.7×10^{-7}	1.2×10^{-7}	8.0	1.5×10^{-8}
Tetryl	9.1×10^{-8}	2.5×10^{-5}	1.6×10^{-8}	4.2×10^{-8}	13	3.2×10^{-9}
TNT	1.2×10^{-5}	8.1×10^{-4}	6.4×10^{-7}	2.4×10^{-6}	0.5	4.9×10^{-6}
Hazard Index (Metals + Explosives)						9.6×10^{-5}

Notes:
mg/kg dw = milligram ingested per kilogram dry weight.
mg/l = milligram per liter.
mg/kg-day = milligram ingested per kilogram weight per day.
NA= No criteria available.
[1] Fish were assumed to be 75 percent water for conversion from wet to dry weight.
Hazard Quotients above 1 indicate the potential for adverse effects. All hazard quotients shown here are orders of magnitude below 1 (each order of magnitude is equal to 10 times).
Scientific notation is used for small numbers; for example 1.0×10^{-6} is one millionth (0.000001).

Table 6-21
Screening Hazard Quotients for the Great Blue Heron

Constituent	Fish Concentration[1] (mg/kg dw)	Sediment Concentration (mg/kg dw)	Water Concentration (mg/l)	Estimated Environmental Dose (mg/kg - day)	NOAEL (mg/kg - day)	Hazard Quotient
Dense Zone						
Metals						
Cadmium	1.1×10^{-6}	0.015	5.0×10^{-9}	6.4×10^{-6}	1.45	4.4×10^{-6}
Chromium	4.0×10^{-8}	0.0056	8.5×10^{-9}	2.5×10^{-6}	1.0	2.5×10^{-6}
Copper	1.0×10^{-6}	6.5	5.9×10^{-9}	0.0029	47	6.1×10^{-5}
Lead	1.3×10^{-13}	0.12	5.8×10^{-12}	5.2×10^{-5}	1.13	4.6×10^{-5}
Manganese	1.6×10^{-4}	2.3	1.0×10^{-6}	0.001	977	1.1×10^{-6}
Nickel	4.3×10^{-7}	0.079	2.2×10^{-8}	3.5×10^{-5}	77.4	4.5×10^{-7}
Zinc	2.4×10^{-5}	1.1	4.6×10^{-8}	5.0×10^{-4}	14.5	3.5×10^{-5}
Explosives						
Ammonium picrate	2.1×10^{-6}	5.4×10^{-7}	5.2×10^{-5}	3.0×10^{-6}	NA	NA
HMX	1.2×10^{-9}	6.1×10^{-9}	4.5×10^{-9}	3.1×10^{-10}	50	6.1×10^{-12}
RDX	2.6×10^{-5}	1.4×10^{-5}	3.4×10^{-5}	3.1×10^{-6}	8.0	3.8×10^{-7}
Tetryl	3.2×10^{-6}	6.0×10^{-4}	5.7×10^{-7}	4.5×10^{-7}	13	3.4×10^{-8}
TNT	6.3×10^{-5}	0.003	3.3×10^{-6}	4.3×10^{-6}	0.5	8.5×10^{-6}
Hazard Index (Metals + Explosives)						1.6×10^{-4}
Diffuse Zone						
Metals						
Cadmium	1.6×10^{-7}	0.0021	6.9×10^{-10}	9.5×10^{-7}	1.45	6.54×10^{-7}
Chromium	9.2×10^{-9}	0.0013	1.9×10^{-9}	5.8×10^{-7}	1	5.8×10^{-7}
Copper	2.7×10^{-7}	1.7	1.5×10^{-9}	7.7E-04	47	1.6×10^{-5}
Lead	2.7×10^{-14}	0.026	1.2×10^{-12}	1.2×10^{-5}	1.13	1.0×10^{-5}
Manganese	5.4×10^{-5}	0.80	3.4×10^{-7}	0.00036	977	3.7×10^{-7}
Nickel	4.3×10^{-7}	0.082	2.2×10^{-8}	3.7×10^{-5}	77.4	4.7×10^{-7}
Zinc	3.8×10^{-6}	0.19	7.3×10^{-9}	8.7×10^{-5}	14.5	6.0×10^{-6}
Explosives						
Ammonium picrate	1.1×10^{-7}	4.1×10^{-8}	2.7×10^{-6}	1.6×10^{-7}	NA	NA
HMX	7.2×10^{-10}	5.1×10^{-9}	2.6×10^{-9}	1.8×10^{-10}	50	3.6×10^{-12}
RDX	4.4×10^{-7}	3.4×10^{-7}	5.7×10^{-7}	5.2×10^{-8}	8.0	6.5×10^{-9}
Tetryl	9.1×10^{-8}	2.5×10^{-5}	1.6×10^{-8}	1.6×10^{-8}	13	1.3×10^{-5}
TNT	1.2×10^{-5}	8.1×10^{-4}	6.4×10^{-7}	9.4×10^{-7}	0.5	1.9×10^{-5}
Hazard Index (Metals + Explosives)						3.6×10^{-5}

Notes:

mg/kg dw = milligram ingested per kilogram dry weight.

mg/l = milligram per liter.

mg/kg-day = milligram ingested per kilogram weight per day.

NA = No criteria available.

[1] Fish were assumed to be 75 percent water for conversion from wet to dry weight.

Hazard Quotients above 1 indicate the potential for adverse effects. All hazard quotients shown here are orders of magnitude below 1 (each order of magnitude is equal to ten times).

Scientific notation is used for small numbers; for example 1.0×10^{-6} is one millionth (0.000001).

Table 6-22
Screening Hazard Quotients for the River Otter

Constituent	Fish Concentration[1] (mg/kg dw)	Sediment Concentration (mg/kg dw)	Water Concentration (mg/l)	Estimated Environmental Dose (mg/kg -day)	NOAEL (mg/kg -day)	Hazard Quotient
Dense Zone						
Metals						
Cadmium	1.1×10^{-6}	0.015	5.0×10^{-9}	7.5×10^{-6}	1.0	7.5×10^{-6}
Chromium	4.0×10^{-8}	0.0056	8.5×10^{-9}	2.9×10^{-6}	3.28	8.7×10^{-6}
Copper	1.0×10^{-6}	6.5	5.9×10^{-9}	0.0033	11.7	2.7×10^{-4}
Lead	1.3×10^{-13}	0.12	5.8×10^{-12}	6.1×10^{-5}	8.0	7.6×10^{-6}
Manganese	1.6×10^{-4}	2.3	1.0×10^{-6}	0.0012	88	1.4×10^{-5}
Nickel	4.3×10^{-7}	0.079	2.2×10^{-8}	4.0×10^{-5}	40	1.0×10^{-6}
Zinc	2.4×10^{-5}	1.1	4.6×10^{-8}	5.8×10^{-4}	160	3.6×10^{-6}
Explosives						
Ammonium picrate	2.1×10^{-6}	5.4×10^{-7}	5.2×10^{-5}	5.5×10^{-6}	NA	NA
HMX	1.2×10^{-9}	6.1×10^{-9}	4.5×10^{-9}	5.3×10^{-10}	50	1.1×10^{-11}
RDX	2.6×10^{-5}	1.4×10^{-5}	3.4×10^{-5}	4.9×10^{-6}	8.0	6.1×10^{-7}
Tetryl	3.2×10^{-6}	6.0×10^{-4}	5.7×10^{-7}	5.3×10^{-7}	13	4.1×10^{-8}
TNT	6.3×10^{-5}	0.003	3.3×10^{-6}	$5. \times 10^{-6}$	0.5	1.0×10^{-5}
Hazard Index (Metals + Explosives)						1.5×10^{-5}
Diffuse Zone						
Metals						
Cadmium	1.6×10^{-7}	0.0021	6.9×10^{-10}	1.1×10^{-6}	1	1.1×10^{-6}
Chromium	9.2×10^{-9}	0.0013	1.9×10^{-9}	6.6×10^{-7}	3.28	2.0×10^{-7}
Copper	2.7×10^{-7}	1.7	1.5×10^{-9}	8.7×10^{-4}	11.7	7.5×10^{-5}
Lead	2.7×10^{-14}	0.026	1.2×10^{-12}	1.3×10^{-5}	8	1.7×10^{-6}
Manganese	5.4×10^{-5}	0.80	3.4×10^{-7}	4.1×10^{-4}	88	4.7×10^{-6}
Nickel	4.3×10^{-7}	0.082	2.2×10^{-8}	4.2×10^{-5}	40	1.0×10^{-6}
Zinc	3.8×10^{-6}	0.19	7.3×10^{-9}	9.8×10^{-5}	160	6.1×10^{-7}
Explosives						
Ammonium picrate	1.1×10^{-7}	4.1×10^{-8}	2.7×10^{-6}	2.9×10^{-7}	NA	NA
HMX	7.2×10^{-10}	5.1×10^{-9}	2.6×10^{-9}	3.1×10^{-10}	50	6.2×10^{-12}
RDX	4.4×10^{-7}	3.4×10^{-7}	5.7×10^{-7}	8.3×10^{-8}	8.0	1.0×10^{-8}
Tetryl	9.1×10^{-8}	2.5×10^{-5}	1.6×10^{-8}	1.9×10^{-8}	13	1.5×10^{-9}
TNT	1.2×10^{-5}	8.1×10^{-4}	6.4×10^{-7}	1.1×10^{-6}	0.5	2.2×10^{-6}
Hazard Index (Metals + Explosives)						8.7×10^{-5}

Notes:
mg/kg dw = milligram ingested per kilogram dry weight.
mg/l = milligram per liter.
mg/kg-day = milligram ingested per kilogram weight per day.
NA = No criteria available.
[1] Fish were assumed to be 75 percent water for conversion from wet to dry weight.
Hazard Quotients above 1 indicate the potential for adverse effects.

The following paragraphs identify the strengths and limitations of the various components of this assessment.

The munitions-use quantitation described in Section 3.3 and Appendix A is based on an exhaustive search of available records. The number of large-caliber projectiles fired varies considerably from year to year depending on whether and how many new types of ordnance are being tested in a given year. Based on large-caliber gun-firing data from the years 1994 to 2008, an average of approximately 4,700 large-caliber projectiles are estimated to be fired in particularly active years. Some projectiles are fired at targets within the land ranges rather than into the river and do not enter the PRTR.

RDT&E for the other types of large ordnance fired into the PRTR ended more than 35 years ago – rockets were last fired in 1974, and bombs were last dropped in 1957-8. Therefore, given the high rate of sediment deposition in the river, which has been estimated to range from 1.8 cm/yr (0.7 in/yr) in the upper reaches to 0.16 cm/yr (0.06 in/yr) in the lower estuary (Knebel et al., 1981), there is considered to be little if any exposure to these historic munitions and the munitions quantitation contained in this assessment is considered to represent a conservative estimate of risk. In addition, this assessment considered the total input of projectiles since Dahlgren began operations in 1918, which likely overestimates the mass of MCOPCs for which complete exposure pathways exist.

The selection of MCOPCs, detailed in Section 5.1, was performed to include all major contributors in regard to both quantity and toxicity providing a high degree of confidence that risks are well represented by the MCOPCs. The fate and transport modeling used conservative assumptions to estimate MCOPC concentrations in surface water and sediments (Sections 5.2 and 5.3). For instance, it assumed no degradation of explosives and did not factor a dilution coefficient into water and sediment exposure concentrations.

The OSRM provides an overview of operational usage, constituent release information, potential migration and exposure pathways, and links between potential sources of MCOPCs and ecological receptors. It is intended to provide broad linkages from various receptor groups found in and around the PRTR to MCOPCs found in site water, sediments, soils, and prey. Since the conceptual model is a generalized model, it is not intended to represent specific individuals currently living in and around the PRTR, and actual linkages between the biotic levels depend on the seasonal availability of various prey and food items.

This screening-level evaluation does not consider existing concentrations of MCOPCs, in particular metals, that are present in the PRTR from natural and manmade sources. As shown in Table 5-13, concentrations of metals in the Potomac River sediments and water upriver of the PRTR are orders of magnitude – tens to millions of times – greater than the contributions from munitions. Therefore, potential risks that are present in the river from sources other than the PRTR RDT&E activities are not evaluated here as the scope of the WRSEPA is to determine whether the release or substantial threat of a release of MCs of potential concern and/or MEMCs from an operational range to an off-range area poses an unacceptable risk to human health or the environment (US Navy, 2008).

Natural variation represents known variation in parameters based on observed heterogeneity in the characteristics of a particular receptor species. In order to provide a conservative (protective) estimate of risk, the parameters resulting in the highest risks (e.g., lowest body weight, highest temporal, and spatial habitat use, etc.) were selected for each receptor. Therefore, calculated risks are expected to be at the upper end of the range.

A food-web model was used to approximate relationships between site-specific environmental conditions (i.e., exposure sources) and receptors. The simplistic model used for screening assumed that all exposure sources reflected the maximum exposure concentrations and complete uptake of constituents from all media, resulting in a conservative estimate of risk.

Toxicological studies used to select NOAELs have uncertainties associated with them and the parameters of these studies may not accurately reflect the PRTR-specific factors affecting toxicity of MCOPCs. Factors influencing toxicity include site-specific conditions; interspecies differences in sensitivity to contaminants; and actual bioavailability of contaminants. The range of toxicity thresholds reported in the literature is large, even among those studies deemed suitable. The range may be due to test species, life stage, exposure dosage and duration, the form of a contaminant, or other factors. Use of the lowest NOAEL values found in the literature for screening provides a conservative estimate of risk, as concentrations are being screened against the lowest values at which no adverse effects were seen.

It was also assumed that the form of the chemical present in the PRTR would be absorbed with the same efficiency as the chemical form used in the laboratory toxicity study. Chemical solubility is an important factor in absorption efficiency, and for many chemicals, laboratory toxicity studies are performed using the most soluble form. This is particularly true of the metal constituents, which are themselves natural but often biologically unavailable constituents of abiotic media such as soils and sediments. Many of the metals in munitions are likely to be biologically unavailable.

In general, the assumptions used in all components of this screening-level risk assessment provide a conservative bias and ensure that potential risks would be identified with a reasonable margin of certainty.

6.3 Conclusions

The range-specific screening-level ecological risk assessment showed that concentrations of the MCOPCs in Potomac River water and sediments, both in the dense and diffuse zones, are well below concentrations that may cause adverse effects to aquatic organisms (including fish) living in the Potomac River and to wildlife using the river for feeding, shelter, and/or reproduction. These results indicate that even if munitions RDT&E activities increased more than a hundredfold – which is not feasible given that existing operations hours already use 36 percent of all available operating hours within a year (i.e., typically from 8 am to 5 pm, Monday through Friday) – the MCOPCs entering the PRTR would still not pose unacceptable risks to aquatic life or wildlife, although other issues associated with testing activities, such as noise, could be a cause for concern. Based on this screening-level analysis, further evaluation of ecological risk from munitions use on the PRTR is not required, nor are protective measures warranted.

7 SCREENING-LEVEL HUMAN HEALTH RISK ASSESSMENT

7.1 Introduction

This range-specific screening-level Human Health Risk Assessment (HHRA) characterizes potential current and future health risks from modeled releases of munitions constituents of potential concern (MCOPCs) into the PRTR. As described in the ORSM in Chapter 4, people living or visiting the Potomac River in the vicinity of the PRTR may be exposed to metals and explosive constituents in the surface water, sediments, and fish and shellfish. This HHRA is being conducted pursuant to the Navy policy for conducting a WRSEPA (US Navy, 2008) and follows Navy policy for a Tier 1 screening-level risk assessment (US Navy, 2001).

The objective of this HHRA is to evaluate the potential risk to human health from exposure to MCOPCs in site media resulting from past, present, and future munitions testing on the Potomac River in order to determine whether an additional analysis is necessary and protective measures are warranted; or, conversely, whether the risks are within acceptable limits so that no further analysis is needed.

The modeling of concentrations of MCOPCs from projectiles fired in the PRTR is discussed in Chapter 5 of this report. Exposure pathways were identified based on the sources and locations of compounds in the PRTR, current and future land use along the shores of the Potomac River, the likely environmental fate of the compounds, and the location and activities of potentially exposed populations based on the ORSM described in Section 4.

The HHRA compares the predicted concentrations of MCOPCs from RDT&E activities in sediment, water, and fish tissue to risk-based screening levels for chemical contaminants at Superfund sites for those media. Screening levels were developed by USEPA for chemical screening during baseline risk assessment to determine whether levels of contamination found at the site may warrant further investigation or site cleanup, or whether no further investigation or action may be required (USEPA, 2012).

7.2 Munitions Constituents of Potential Concern

The first step in the HHRA process is the selection of MCOPCs. Chemicals in PRTR sediment may originate from present-day and historical Navy activities, local area non-Navy sources, or upstream sources. However, as required by Navy policy for conducting a WRSEPA (US Navy, 2008), the MCOPCs considered in this screening-level HHRA are exclusively from the munitions RDT&E activities conducted by the Navy in the PRTR. Therefore, the MCOPCs do not include input from upstream sources, as the purpose of the WRSEPA is to determine whether the release or substantial threat of a release of MCs of potential concern and/or MEMCs from an operational range to an off-range area poses an unacceptable risk to human health or the environment (US Navy, 2008).

Based on the materials known to make up munitions components and the toxicity of those constituents, the MCOPCs evaluated here consist of the metals and explosives selected in Section 5.1, namely:

- Metals: cadmium, chromium, copper, lead, manganese, nickel, and zinc.
- Explosives: ammonium picrate, HMX, RDX, tetryl, and TNT.

7.3 Exposure Assessment

After MCOPCs have been identified, the next step in the HHRA is the evaluation of potential exposure. Potential exposure is the process of identifying the human population that could come into contact with MCOPCs, and estimating the likely magnitude, frequency, duration, and route(s) of exposure under current and potential future land use scenarios.

7.3.1 Exposure Pathways and Receptor Populations

As described in the ORSM, complete exposure pathways exist for local residents of the Potomac River in and around the PRTR for recreational activities. This HHRA assumes that use of the PRTR area of the river by local residents will continue at the present rate and that additional development around the PRTR will not substantially change the residential land use patterns characteristic of current or future receptor populations. Therefore, the evaluation of exposures based on current land use is also considered applicable for future exposures.

7.3.1.1 Potential Exposure Pathways

An *exposure pathway* is the course a contaminant takes from a source to an exposed receptor. A complete exposure pathway consists of the following four elements:

- A source for the contaminant (e.g., munitions)
- A mechanism of release, retention, or transport of a contaminant in a given medium (e.g., water, sediment, tissue)
- A point of human contact with the medium (i.e., exposure point)
- A route of exposure at the point of contact (e.g., ingestion, dermal contact).

If any single element is missing, the pathway is considered incomplete and does not constitute a means of exposure. This screening-level HHRA quantifies the following exposure pathways (see Figure 4-1 and Table 4-2) in the absence of any institutional controls or other restrictions such as fish consumption advisories:

- Ingestion of fish from the PRTR
- Incidental ingestion of, or dermal contact with, surface water and sediments during recreational activities (e.g., wading, boating, or swimming).

7.3.1.2 Quantification of Exposure

Modeled concentrations of chemicals in sediment and the water column were developed based on the munitions tested at the PRTR since 1918, as detailed in Section 5.2. The predicted concentrations in the areas of the densest testing (dense and diffuse zones) are presented in Tables 5-12 and 5-13. Fish tissue concentrations were modeled using bioconcentration factors, as discussed in Section 6.1.3. The results of this modeling are presented in Tables 6-15 and 6-16 for metals and explosives, respectively.

For the fish ingestion pathway, modeled chemical concentrations in fish were compared to USEPA regional screening levels (USEPA, 2012). These equations assume 54 grams of fish a day (roughly two 6.7-ounce servings per week of fish) caught in the PRTR being eaten by a 154-lb (70-kg) adult year-round, considered to be 350 days a year (USEPA, 1991a). This consumption rate assumes that all fish consumed comes from the PRTR and by doing so provides a conservative estimate of risk.

Fish ingestion is considered to include both fish and shellfish (e.g., crabs, oysters, clams). In general, chemical contaminant concentrations are lower in shellfish than fish, so the screening levels are considered protective. For example, Maryland, which has jurisdiction over the Potomac River, includes only one type of shellfish (the blue crab) in its fish consumption advisory, whereas 20 species of fish are included in the advisory (MDE, 2011). The latest Maryland Fish Advisory (September 2011) lists only two fish species with consumption advisories in the tidal portion of the Potomac River below the Nice Bridge, the section of the river that includes the PRTR, the Atlantic croaker (*Micropogonias undulatus*) and the white perch (*Morone americana*), both because of polychlorinated biphenyl (PCB) contamination.

To evaluate incidental ingestion of water by recreational water users, the default USEPA residential tap-water ingestion rate of 2 liters/day, consumed 350 days/year for 30 years by a 154-lb (70-kg adult) was assumed (USEPA, 1991a). This results in a very conservative estimate that is only used for screening purposes, as incidental ingestion of water during recreational activities is assumed to be only 0.05 liters/day (USEPA, 2012).

Residential soil exposure screening levels were used to evaluate incidental exposure to sediment since levels for incidental exposure to sediment would require a more specific analysis that is not merited at this stage. Residential soil exposure is based on a 30-year residential exposure to soil and dust, divided into two parts (USEPA, 1991a). First, a six-year exposure duration is evaluated for young children for whom a higher rate of soil ingestion – 7.1 oz (200 mg/day) – and lower body weight – 33 lb (15 kg) – are assumed. Second, a 24-year exposure duration is assessed for older children and adults by using a lower soil ingestion rate of 3.5 oz (100 mg/day) and an adult body weight of 154 lb (70 kg). A constant year-round exposure is assumed. As is the case for the ingestion of water, this rate is extremely conservative when applied to recreational river users and is only used for screening purposes.

7.4 Toxicity Assessment

A toxicity assessment evaluates the potential for MCOPCs to cause adverse health effects in exposed persons and defines the relationship between the extent of exposure to a chemical and the likelihood and severity of any adverse health effects. The standard procedure for a toxicity assessment is to identify toxicity values for carcinogenic and non-carcinogenic effects and to summarize other relevant toxicity information. This section provides information on toxicity mechanisms as well as brief toxicity profiles of the MCOPCs evaluated.

7.4.1 Mechanisms of Toxicity

Contaminants are divided into carcinogens (i.e., causing cancer) and non-carcinogens (causing other systemic effects). Each of these two mechanisms of toxicity is briefly described below.

7.4.1.1 Carcinogenic Compounds

In the case of carcinogenic compounds, one or more molecular events can prompt changes in a single cell or a small number of cells that can lead to malignancy (USEPA, 1992). This non-threshold theory of carcinogenesis assumes that any level of exposure to a carcinogen results in some finite possibility of causing cancer. Regulatory agencies use the non-threshold approach for carcinogens in the absence of specific information concerning the mechanisms of carcinogenic action for a compound.

The USEPA develops dose-response values for estimating excess lifetime cancer risks associated with various levels of lifetime exposure to potential human carcinogens through development of a toxicological profile for each compound, peer review (both internal and external) of the profile, and inclusion of the compound in the integrated risk information system. The dose-response value, known as the cancer slope factor (CSF), is a number that, when multiplied by the lifetime average daily dose of a potential carcinogen, yields the upper-bound lifetime excess cancer risk associated with exposure at that dose (USEPA, 1992). Upper-bound is a term used by the USEPA to indicate the plausible upper limit of the true value. The CSF used to develop the screening values is based on a one-in-a-million (1×10^{-6}) excess lifetime cancer risk. Risks estimated using slope factors are considered unlikely to underestimate actual risks; they may overestimate risks for a given exposure over a 70-year lifetime, under specified exposure conditions (USEPA, 1992).

7.4.1.2 Non-Carcinogenic Compounds

For compounds that exhibit non-carcinogenic (e.g. systemic) effects, many authorities consider organisms to have repair and detoxification capabilities that must be exceeded by some critical concentration (threshold) before any health effect is manifested. This critical concentration is referred to as a reference dose (RfD). For example, an organ can have a large number of cells performing the same or similar functions that must be significantly depleted before the effect on the organ is seen. This threshold view holds that a range of exposures from just above zero to some finite value can be tolerated by the organism without an appreciable risk of adverse effects.

7.4.2 Regional Screening Levels

Risk-based screening levels developed by USEPA for chemical contaminants at Superfund sites are used in this step (USEPA, 2012). These screening levels are based on default exposure parameters and factors that represent reasonable maximum exposure conditions for long-term/chronic exposures and methods outlined in USEPA's Risk Assessment Guidance for Superfund, Part B Manual (USEPA, 1991a) and Soil Screening Guidance documents (USEPA, 1996; 2002b).

Regional screening levels for chemical contaminants are presented in Table 7-1. Chemical-specific screening levels are usually derived from two general sources: 1) concentrations based on potential Applicable or Relevant and Appropriate Requirements (ARARs) and 2) risk-based concentrations. ARARs include concentration limits set by other environmental regulations, such as the Safe Drinking Water Act maximum contaminant levels (MCLs). The second source is the focus of the USEPA regional screening levels: it consists of risk-based calculations that set concentration limits using carcinogenic or systemic toxicity values under specific exposure conditions.

Table 7-1
USEPA Regional Screening Levels

Constituent	Tap Water Screening Levels (µg/l)	Fish Tissue Screening Levels (mg/kg)	Residential Soil Screening Levels (mg/kg)
Metals			
Cadmium	6.91	1.35	70.2[2]
Chromium[3]	100[1]	2,030	0.29
Copper	622	54.1	3,130
Lead	15[1]	NA	400
Manganese	322	189	1,830
Nickel[4]	303	27	1,550[2]
Zinc	4,670	406	23,000
Explosives			
Ammonium Picrate	NA	NA	NA
HMX	781	67.6	3,800
RDX	0.61[2]	0.029[2]	5.56[2]
Tetryl	62.9	5.41	244
TNT	2.19[2]	0.105[2]	19.4[2]

Notes:
µg/l = microgram per liter; mg/kg = milligram per kilogram.
[1] Maximum contaminant level (MCL).
[2] Lower screening value (i.e., more conservative) of cancer and non-cancer values was selected.
[3] Total chromium (1:6 ratio Cr VI: Cr III) used for water, chromium VI used for residential soil, and chromium III used for fish.
[4] Value based on nickel soluble salts.
NA = not available (no criteria).
All levels presented are based on non-cancer values, with the exception of RDX and TNT.
Screening levels are based on all applicable exposure pathways (ingestion, dermal, inhalation)
Source: USEPA, 2012.

The screening-level concentrations correspond to either a 1×10^{-6} (one in a million) excess cancer risk for carcinogens or a hazard quotient (HQ) of 1 for non-carcinogens (USEPA, 2012). The HQ is the ratio of the exposure concentration over the non-cancer reference dose. Similar to the ecological risk screening, a value of 1.0 or higher indicates the potential for non-cancer effects from exposure to a compound. The residential soil criterion for lead, 400 mg/kg, was developed as a conservative residential screening criterion by USEPA for children (USEPA, 1991b.

The screening levels for fish tissue ingestion are used for the fish-ingestion pathway; screening concentrations for the ingestion of tap water are used for the surface water ingestion, and residential exposure screening levels for contaminated soil are used for sediment ingestion.

7.4.3 Toxicity Summaries

The potential toxic effects of the MCOPCs and associated water and sediment/soil screening levels for each MCOPC identified in this HHRA are summarized in this section. The Agency for Toxic Substances and Disease Registry (ATSDR) has published a series of summaries about hazardous substances known as ToxFAQs, based on their Toxicological Profiles and Public Health Statements. Appendix C contains the ToxFAQs sheets for all MCOPCs considered here, with the exception of ammonium picrate, for which no ToxFAQ sheet has been produced.

7.4.3.1 Metals

Cadmium

Cadmium is a soft, silvery-white, metal usually found in combination with other elements such as zinc, lead, and copper. Chronic inhalation or oral exposure in animals results in effects on the liver, lungs, bones, immune system, blood, and nervous system. Cadmium is a cumulative toxicant, with the kidney being a major target organ following chronic oral exposure. Animal studies have shown cadmium to be a developmental toxicant; data suggesting fetal malformations in humans due to chronic exposure to cadmium exist but are considered inadequate. The cadmium screening levels used in this assessment are: 1.35 mg/kg for fish tissue ingestion, 6.91 µg/l for tap water ingestion (used for incidental surface water ingestion), and 70.2 mg/kg for incidental soil ingestion (used for sediment).

Chromium

Chromium occurs in three main forms: chromium (0), chromium (III), and chromium (VI). Chromium (III) compounds are stable and occur naturally in the environment. Chromium (III) occurs naturally in the environment and is an essential nutrient for the human body. Chromium (0) and chromium (VI) are generally produced by industrial processes (National Library of Medicine, 2012). All forms of chromium can be toxic at high levels, but chromium (VI) is more toxic than chromium (III) (ATSDR, 1993). The major target organ for both chromium (VI) and chromium (III) toxicity is the respiratory tract. Chronic exposure to high levels of chromium (VI) through inhalation or ingestion may also cause effects on the liver, kidneys, the gastrointestinal and immune systems, and possibly the blood. Dermal exposure to chromium (VI) may cause dermatitis (skin rash), sensitivity, and ulceration of the skin. The chromium screening levels used in this assessment are: 2,030 mg/kg for fish tissue ingestion, 100 µg/l for tap water ingestion (used for incidental surface water ingestion), and 0.29 mg/kg for incidental soil ingestion (used for sediment).

Copper

Copper is a reddish-brown metal that is very prevalent in the environment. Long-term exposure to copper dust has been reported to irritate the nose, mouth, and eyes and to cause headaches, dizziness, nausea, and diarrhea. Ingestion of high doses of copper may cause gastrointestinal effects (vomiting, diarrhea, stomach cramps, and nausea), liver damage, and kidney damage. The copper screening levels used in this assessment are: 54.1 mg/kg for fish tissue ingestion, 622 µg/l for tap water ingestion (used for incidental surface water ingestion), and 3,130 mg/kg for incidental soil ingestion (used for sediment).

Lead

Lead is a naturally occurring metal found in small quantities in the earth's crust. It is persistent in the environment and has a potential to bioaccumulate. The main target for lead toxicity is the nervous system, but chronic exposure to lead has also been shown to cause effects on the blood, kidneys, and vitamin D metabolism. Children are particularly sensitive to the chronic effects of lead, with such effects as slow cognitive development, reduced growth, and other adverse health effects. The developing fetus is also sensitive to lead exposure, with low birth weight and slowed postnatal neurobehavioral development observed. Reproductive effects have been observed for both men and women. The lead screening levels used in this assessment are: 15 µg/l for tap water ingestion (used for incidental surface water ingestion) and 400 mg/kg for incidental soil ingestion (used for sediment). No screening level has been derived for lead in fish tissue.

Manganese

Manganese is a naturally occurring substance found in many types of rock; it is ubiquitous in the environment and found in low concentrations in air, water, soil, and food. Manganese is an essential nutrient for humans. The recommended daily intake of manganese is 2,500 to 5,000 µg/day (µg/d). Chronic exposure to high levels of manganese in animals has been associated with impaired growth, skeletal abnormalities, impaired reproductive functions in females, testicular degeneration in males, and ataxia. Chronic exposure to high levels of manganese by inhalation in humans results primarily in effects to the central nervous system. The manganese screening levels used in this assessment are: 189 mg/kg for fish tissue ingestion, 322 µg/l for tap water ingestion (used for incidental surface water ingestion), and 1,830 mg/kg for incidental soil ingestion (used for sediment).

Nickel

Nickel is a naturally occurring hard, silvery-white, metal that is used to make stainless steel and other metal alloys. Chronic exposure to nickel may result in contact dermatitis (skin rash). Respiratory effects have been reported from inhalation exposure. Animal studies have reported decreased body and organ weights, neonatal mortality, and dermatoxicity associated with oral exposure to nickel. Several animal studies have demonstrated fetotoxicity. Human and animal studies have shown an increased risk of lung and nasal cancers from exposure to nickel refinery dusts and to nickel subsulfide. Nickel carbonyl has been reported to cause lung tumors in animal studies. The nickel screening levels used in this assessment are: 27 mg/kg for fish tissue ingestion, 303 µg/l for tap water ingestion (used for incidental surface water ingestion), and 1,550 mg/kg for incidental soil ingestion (used for sediment).

Zinc

Zinc is an essential element in human diet and is found in many foods. Ingesting high levels of zinc for several months can decrease the levels of high-density lipoprotein cholesterol, cause anemia, and cause damage to the pancreas. The zinc screening levels used in this assessment are: 406 mg/kg for fish tissue ingestion, 4,670 µg/l for tap water ingestion (used for incidental surface water ingestion), and 23,000 mg/kg for incidental soil ingestion (used for sediment).

7.4.3.2 Explosives

Ammonium Picrate

Ammonium picrate in its pure form is a yellow, odorless, intensively bitter crystal. It is used as a reagent in explosive/rocket fuel; dye for silk and wool; germicides and fungicides; the leather industry; electric batteries and etching copper; and as chemical intermediate for metal picrates. Ammonium picrate is moderately irritating to the eyes, skin, and mucous membranes (Hazardous Substances Data Bank, 2011b). Other effects may include nausea, vomiting, diarrhea, staining of the skin, dermatitis (skin rash), circular eruptions of the skin, coma, and seizures. The most common occupational health problem seen in a study by the International Labour Office was dermatitis, thought to be due to sensitization rather than primary irritation by the picrate; there was no systemic toxicity seen among the workers and respiratory effects were of little consequence (Hazardous Substances Data Bank, 2011b). The USEPA has not derived oral or inhalation toxicity values for ammonium picrate; therefore, USEPA has not derived screening levels for fish-tissue ingestion, water ingestion, or soil.

HMX

HMX is a colorless solid that dissolves slightly in water. HMX is a solid high-energy explosive used in nuclear devices (to implode fissionable material), as a component of plastic-bonded explosives, as a component of rocket propellant, and as a high explosive burster charge. Studies in rats, mice, and rabbits indicate that HMX may be harmful to the liver and central nervous system. The HMX screening levels used in this assessment are: 67.6 mg/kg for fish tissue ingestion, 781 µg/l for tap water ingestion (used for incidental surface water ingestion), and 3,800 mg/kg for incidental soil ingestion (used for sediment).

RDX

RDX is one of the most powerful high explosives in use today. RDX is often mixed with TNT as a bursting charge for aerial bombs, mines, and torpedoes. Large amounts of RDX inhaled or eaten can cause seizures in humans. Decreased body weights and slight liver and kidney damage were seen in laboratory mice and rats that ingested RDX. The RDX screening levels used in this assessment are: 0.029 mg/kg for fish tissue ingestion, 0.61 µg/l for tap water ingestion (used for incidental surface water ingestion), and 5.56 mg/kg for incidental soil ingestion (used for sediment).

Tetryl

Tetryl is a powerful oxidant that is subject to fire and explosion. Tetryl is a yellow, crystal-like, solid that was frequently manufactured as pellets or powder and was commonly used to make explosives during World Wars I and II. In the United States today, it is only manufactured for limited military uses. Tetryl is an irritant, sensitizer, and allergen to humans. A rabbit study reported histological effects to the liver, kidneys, and spleen from oral exposure. The tetryl screening levels used in this assessment are: 5.41 mg/kg for fish tissue ingestion, 62.9 µg/l for tap water ingestion (used for incidental surface water ingestion), and 244 mg/kg for incidental soil ingestion (used for sediment).

TNT

TNT (2,4,6-trinitrotoluene) is a relatively stable explosive that will detonate under strong shock. It is a yellow, odorless, solid composed of the elements carbon, oxygen, nitrogen, and hydrogen. TNT is produced in the United States only at military arsenals; it is not produced commercially. Blood and liver effects were observed in animals fed TNT. The TNT screening levels used in this assessment are: 0.105 mg/kg for fish tissue ingestion, 2.19 µg/l for tap water ingestion (used for incidental surface water ingestion), and 19.4 mg/kg for incidental soil ingestion (used for sediment).

7.5 Risk Characterization

In risk characterization, exposure estimates and toxicity values are combined to evaluate the potential for health risks to occur. In this section, potential risks are estimated assuming long-term exposure to chemicals in site media. Risks are evaluated for each completed exposure pathway.

Tables 7-2 through 7-4 show the modeled concentrations of MCOPCs in each environmental medium and the applicable health-based screening level as noted above. These environmental media – fish (representing fish and shellfish), surface water, and sediments – cover the complete exposure pathways by which recreational receptors may be exposed to MCOPCs.

7.5.1 Ingestion of Fish

Modeled concentrations of munitions constituents in fish were compared to USEPA fish ingestion screening levels. As shown in Table 7-2, no exceedances of these concentrations are predicted for either metals or explosives. The ratios of the modeled concentrations to the screening level concentrations are orders of magnitude below the target ratio of one, indicating that the concentrations of MCOPCs in fish are well below the concentrations that could be expected to result in adverse effects to human health.

7.5.2 Ingestion and Dermal Contact with Surface Water

Modeled concentrations of munitions constituents in surface water were compared to USEPA tap water screening levels, as site-specific parameters would have to be modeled for incidental surface water ingestion. This step would have been completed in the event that ingestion of tap water posed a potential risk. As shown in Table 7-3, no exceedances of these concentrations are predicted for either metals or explosives. The ratios of the modeled concentrations to the screening level concentrations are well below the target ratio of one, indicating that the concentrations of MCOPCs in water are well below the concentrations that could be expected to result in adverse effects to human health.

Table 7-2
Risk Characterization of Modeled Constituents in Fish Tissue

MCOPC	Concentration in Fish Tissues (mg/kg ww)		Fish-Tissue Screening Level (mg/kg)	Hazard Quotient	
	Dense Zone	*Diffuse Zone*		*Dense Zone*	*Diffuse Zone*
Metals					
Cadmium	4.6×10^{-6}	6.3×10^{-7}	1.35	3.4×10^{-6}	4.7×10^{-7}
Chromium	1.6×10^{-7}	3.7×10^{-8}	2,030	7.9×10^{-11}	1.8×10^{-11}
Copper	4.2×10^{-6}	1.1×10^{-6}	54.1	7.8×10^{-8}	2.0×10^{-8}
Lead	5.2×10^{-13}	1.1×10^{-13}	NA	NA	NA
Manganese	6.6×10^{-4}	2.2×10^{-4}	189	3.5×10^{-6}	1.2×10^{-6}
Nickel	1.7×10^{-6}	1.7×10^{-6}	27	6.3×10^{-8}	6.3×10^{-8}
Zinc	9.4×10^{-5}	1.5×10^{-5}	406	2.3×10^{-7}	3.7×10^{-8}
Explosives					
Ammonium Picrate	8.3×10^{-6}	4.3×10^{-7}	NA	NA	NA
HMX	4.9×10^{-9}	2.9×10^{-9}	67.6	7.3×10^{-11}	4.3×10^{-11}
RDX	1.0×10^{-4}	1.8×10^{-6}	0.029	3.5×10^{-3}	6.3×10^{-5}
Tetryl	1.3×10^{-5}	3.6×10^{-7}	5.41	2.4×10^{-6}	6.7×10^{-8}
TNT	2.5×10^{-4}	4.8×10^{-5}	0.105	2.4×10^{-3}	4.6×10^{-4}
Hazard Index (Total HQs of Metals + Explosives)				5.9×10^{-3}	5.2×10^{-4}

Notes:
mg/kg = milligram per kilogram; ww = wet weight.
NA = not available (no criteria).

Hazard quotients are the modeled concentration divided by the screening level concentration.

Hazard quotients above 1 indicate the potential for adverse effects.

All hazard quotients and indices shown here are orders of magnitude below 1 (each order of magnitude is equal to ten times). Scientific notation is used for small numbers; for example 1.0×10^{-6} is one millionth (0.000001).

Table 7-3
Risk Characterization of Modeled Constituents in Surface Water

MCOPC	Modeled River Water Concentration from Munitions (Daily) (μg/l)		USEPA Tap Water Screening Levels (μg/l)	Hazard Quotient	
	Dense Zone	*Diffuse Zone*		*Dense Zone*	*Diffuse Zone*
Metals					
Cadmium	5.0×10^{-6}	6.9×10^{-7}	6.91	7.2×10^{-7}	1.0×10^{-7}
Chromium	8.5×10^{-6}	1.9×10^{-6}	1001	8.5×10^{-9}	1.9×10^{-9}
Copper	5.9×10^{-6}	1.5×10^{-6}	622	9.5×10^{-9}	2.4×10^{-9}
Lead	5.8×10^{-9}	1.2×10^{-9}	151	3.8×10^{-11}	7.9×10^{-12}
Manganese	1.0×10^{-5}	3.4×10^{-5}	322	3.1×10^{-8}	1.1×10^{-7}
Nickel	2.2×10^{-5}	2.2×10^{-5}	303	7.3×10^{-8}	7.3×10^{-8}
Zinc	4.6×10^{-5}	7.3×10^{-6}	4,670	9.9×10^{-9}	1.6×10^{-9}
Explosives					
Ammonium Picrate	5.2×10^{-5}	2.7×10^{-6}	NA	NA	NA
HMX	4.5×10^{-9}	2.6×10^{-9}	781	5.8×10^{-12}	3.3×10^{-12}
RDX	3.4×10^{-5}	5.7×10^{-7}	0.61	5.6×10^{-5}	9.4×10^{-7}
Tetryl	5.7×10^{-7}	1.6×10^{-8}	62.9	9.1×10^{-9}	2.5×10^{-10}
TNT	3.3×10^{-6}	6.4×10^{-7}	2.19	1.5×10^{-6}	2.9×10^{-7}
Hazard Index (Total HQs of Metals + Explosives)				5.85×10^{-5}	1.52×10^{-6}

Notes:
mg/kg = milligram per kilogram; ww = wet weight.
NA = not available (no criteria).
Hazard quotients are the modeled concentration divided by the screening level concentration.
Hazard quotients above 1 indicate the potential for adverse effects.
All hazard quotients and indices shown here are orders of magnitude below 1 (each order of magnitude is equal to ten times).
Scientific notation is used for small numbers; for example 1.0×10^{-6} is one millionth (0.000001).

7.5.3 Ingestion and Dermal Contact with Sediment

Modeled concentrations of munitions constituents in sediments were compared to USEPA residential screening levels for soil (, as site-specific parameters would have to be modeled for incidental sediment ingestion. This step would have been completed in the event that incidental ingestion of soil posed a potential risk. As seen in Table 7-4, no exceedances of these concentrations are predicted for either metals or explosives. The ratios of the modeled concentrations to the screening level concentrations are well below the target ratio of one, indicating that the concentrations of MCOPCs in sediments are well below the concentrations that could be expected to result in adverse effects to human health.

Table 7-4
Risk Characterization of Modeled Constituents in Sediments

MCOPC	Monthly Sediment Concentration from Munitions (mg/kg)		USEPA Residential Soil Screening Levels	Hazard Quotient	
	Dense Zone	*Diffuse Zone*		*Dense Zone*	*Diffuse Zone*
Metals					
Cadmium	0.015	0.0021	70.22	2.1×10^{-4}	3.0×10^{-5}
Chromium	0.0056	0.0013	0.29	0.019	0.004
Copper	6.5	1.7	3,130	0.002	5.4×10^{-4}
Lead	0.12	0.026	400	3.0×10^{-4}	6.5×10^{-5}
Manganese	2.3	0.8	1,830	0.001	4.4×10^{-4}
Nickel	0.079	0.082	15,502	5.1×10^{-6}	5.3×10^{-6}
Zinc	1.1	0.19	23,000	4.8×10^{-5}	8.3×10^{-6}
Explosives					
Ammonium Picrate	5.4×10^{-7}	4.1×10^{-8}	No Criteria	NA	NA
HMX	6.1×10^{-9}	5.1×10^{-9}	3,800	1.6×10^{-12}	1.3×10^{-12}
RDX	1.4×10^{-5}	3.4×10^{-7}	5.562	2.5×10^{-6}	6.1×10^{-8}
Tetryl	6.0×10^{-4}	2.5×10^{-5}	244	2.5×10^{-6}	1.0×10^{-7}
TNT	0.003	8.1×10^{-4}	19.42	1.5×10^{-4}	4.2×10^{-5}
Hazard Index (Metals + Explosives)				0.023	0.006

Notes:
NA = not available (no criteria).
Hazard quotients are the modeled concentration divided by the screening level concentration.
Hazard quotients above 1 indicate the potential for adverse effects.
All hazard quotients and indices shown here are orders of magnitude below 1 (each order of magnitude is equal to ten times).
Scientific notation is used for small numbers; for example 1.0×10^{-6} is one millionth (0.000001).

7.6 Conclusions

This screening-level HHRA examined risks from exposure to MCOPCs resulting from past, present, and future testing by the Navy in the PRTR. Exposure pathways evaluated included fish ingestion and dermal contact with, or incidental ingestion of, MCOPCs in surface water and sediments. None of the MCOPCs exceeded screening levels, even using extremely conservative assumptions that considerably overestimate the level of potential exposure to surface water and sediments. Exposure was evaluated in the areas of heaviest munitions testing, the dense and diffuse zones, and risks in other areas of the PRTR from munitions testing would be even lower. Although one explosive (ammonium picrate) lacks health-based screening concentrations, it should not pose a significant risk to human health, as it is not associated with significant toxicological effects in the small exposure quantities covered in this analysis.

The modeled concentrations of constituents in river sediments were compared to USEPA residential-soil screening levels (no sediment concentrations are available for human health screening). No exceedances of the residential-soil screening levels were identified; the ratios of modeled concentrations to the screening levels were orders of magnitude below the target ratio of one. As described in Section 7.3.1, the evaluation of exposures based on current land use is also considered applicable for future exposures. As future munitions testing in the PRTR is expected to remain consistent with past usage, no adverse effects to people are predicted from exposure to MCOPCs in the future. These results indicate that even if munitions RDT&E activities increased more than a hundred times – which is not feasible given that existing operations hours already use about a third of all available operating hours within a year (i.e., typically from 8 am to 5 pm, Monday through Friday) – the MCOPCs entering the PRTR would still not pose unacceptable risks to human health, although other issues associated with testing activities, such as noise, could be a cause for concern.

Therefore, based on the analysis of recreational exposure scenarios, exposure to RDT&E activities-related MCOPCs in the PRTR through the ingestion of fish and/or incidental ingestion of surface water and/or sediments does not pose unacceptable risks. No further evaluation of human health risks from munitions use on the PRTR is required, nor are protective measures warranted.

THIS PAGE INTENTIONALLY LEFT BLANK

8 SUMMARY AND RECOMMENDATIONS

The overall objective of the WRSEPA policy is to ensure range sustainability while protecting human health and the environment (US Navy, 2008). For Category 1 ranges, such as the PRTR, WRSEPA policy requires a determination of whether munitions constituents (MCs) and military expended material constituents (MEMCs) from RDT&E activities create an unacceptable risk to human health or the environment.

The PRTR Complex at NSF Dahlgren is the nation's largest fully-instrumented, over-the-water gun-firing range. It includes one of every type of gun currently used by the Navy as well as models that represent a new generation of guns. Nearly every ammunition lot and gun barrel that is fitted on a Navy ship is tested on the PRTR to ensure that performance is as specified. NSWCDD and its predecessor Navy organizations have been testing naval ordnance at Dahlgren since 1918 and there are records of approximately 33 million lbs (15 million kg) of constituents contained in either inert or live munitions being fired towards the PRTR. These data were considered with other parameters (e.g., percentage of burials, percentage of complete detonation) to estimate the quantity of munitions constituents of potential concern (MCOPCs) that have entered the PRTR over the years. A geochemical model was used to estimate concentrations of MCOPCs in the Potomac River water and sediments in the two areas of the PRTR where most testing has occurred.

As there is potential at the PRTR for interaction between the munitions (projectiles) fired into the Potomac River (the source) and human and ecological receptors, range-specific screening-level risk assessments (RSSRAs) were performed. A subset of MCs present in munitions were selected as MCOPCs based on the total mass of constituents contained in rounds (cumulative over the last 90 years), their toxicity, and RSEPA guidance (US Navy, 2006a).

The ecological and human health RSSRAs employed conservative (i.e., stringent/protective) assumptions to evaluate existing data and determine whether additional analysis is necessary and protective measures are warranted or whether the range poses acceptable risks, in which case, following Navy guidance (US Navy, 2008), no further analysis is needed.

The ecological and human health RSSRAs compared modeled MCOPC concentrations in water, sediment, and fish tissues to risk-based screening concentrations. Risk-based screening concentrations were available for ecological exposure to water and sediments and for human health exposure to fish, water, and sediments. The exposure of ecological avian and mammalian receptors to MCOPCs was modeled, as no screening values were available for wildlife. Piscivorous receptors were selected, as they were considered to have the highest potential exposure to MCOPCs in the PRTR.

The results of the ecological and human health RSSRAs indicate that MCOPCs from munitions testing in the PRTR are present in concentrations that are orders of magnitudes – hundreds to billions of times – below the concentrations that could cause adverse effects to human health or the environment. These results indicate that even if munitions RDT&E activities increased more than a hundredfold – which is unlikely to even be feasible given that existing operating hours already use about a third of all available hours within a year – the MCOPCs entering the PRTR still would not pose unacceptable risks to human health or the environment.

The MCOPCs considered here are exclusively from the munitions RDT&E activities conducted by the Navy in the PRTR and do not consider input from upstream sources, as the purpose of the WRSEPA is to determine whether the release or substantial threat of a release of MCOPCs or MEMCs from an operational range to an off-range area poses an unacceptable risk to human health or the environment (US Navy, 2008).

The PRTR is located in the lower portion of the Potomac River and receives storm water runoff from commercial, industrial, residential, and agricultural sites; point source pollutants from wastewater treatment plants and industrial discharges; and combined sewer overflows. Because upstream concentrations of metals in sediments and surface water are orders of magnitude greater than concentrations predicted from RDT&E activities at the PRTR, it is unlikely that the small contribution from NSWCDD could be easily discerned. Military installations above the PRTR may also contribute to concentrations of organic MCOPCs in the Potomac River. Given the low levels of input from NSWCDD RDT&E activities in the PRTR and higher concentrations of MCOPCs upstream, sediment and surface water sampling is likely to be inconclusive and is not recommended.

Based on the findings of this report, both ecological and human health risks are considered to be acceptable and no further risk assessments are required. Based on WRSEPA policy, a re-evaluation of the PRTR is required at least every five years from the completion of this WRSEPA or if significant changes (e.g., changes in range operations, site conditions, applicable statues, regulations, DoD issuances, or other policies) occur that affect the determination made during this assessment (US Navy, 2008).

9 REFERENCES

Agency for Toxic Substances and Disease Registry (ATSDR). 1995a. Toxicological Profile for Tetryl (2, 4, 6-Trinitrophenyl-N-methylnitramine). Atlanta, GA. US Department of Health and Human Services, Public Health Service. June 1995. Available from <http://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=1019&tid=216>.

Agency for Toxic Substances and Disease Registry (ATSDR). 1995b. Toxicological Profile for 2, 4, 6-trinitrotoluene (TNT). Atlanta, GA. US Department of Health and Human Services, Public Health Service. June 1995. Available from <http://www.atsdr.cdc.gov/ToxProfiles/TP.asp?id=677&tid=125>.

Agency for Toxic Substances and Disease Registry (ATSDR). 1997. Toxicological profile for HMX. Atlanta, GA. US Department of Health and Human Services, Public Health Service. September 1997. Available from <http://www.atsdr.cdc.gov/ToxProfiles/TP.asp?id=877&tid=171>.

Agency for Toxic Substances and Disease Registry (ATSDR). 2006. *Public Health Assessment Naval Support Facility (NSF) Dahlgren (A/K/A Naval Surface Warfare Center - Dahlgren) Dahlgren, Virginia EPA Facility ID: VA7170024684.* Federal Facilities Assessment Branch, Division of Health Assessment and Consultation, Agency for Toxic Substances and Disease Registry, Public Health Service, United States Department of Health and Human Services. Final Release. October 11, 2006. Available from <http://www.atsdr.cdc.gov/HAC/pha/NavalSupportFacility (NSF)Dahlgren/NavalSupportFacilityDahlgrenPHA10.11.06.pdf>.

Agency for Toxic Substances and Disease Registry (ATSDR). 2010. Toxicological profile for RDX. Atlanta, GA. US Department of Health and Human Services, Public Health Service. July 2010. Available from <http://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=412&tid=72>.

Alexander, G.R. 1977. Food of vertebrate predators in trout waters in north central lower Michigan. *Michigan* Academician 10:181-195.

Ambrose, A. M., P. S. Larson, J. F. Borzelleca, and G. R. Hennigar, Jr. 1976. Long-term toxicologic assessment of nickel in rats and dogs. *Journal of Food Science and Technology* 13: 181-187. As cited in Sample et al., 1996.

Audubon Society. 2009. Christmas Bird Count. 23 March 2009. Available from <http://www.audubon.org/Bird/cbc/ >.

Aulerich, R. J., R. K. Ringer, M. R. Bleavins, et al. 1982. Effects of supplemental dietary copper on growth, reproductive performance and kit survival of standard dark mink and the acute toxicity of copper to mink. *Journal of Animal Science* 55: 337-343. As cited in Sample et al., 1996.

Azar, A., H. J. Trochimowicz, and M. E. Maxwell. 1973. Review of lead studies in animals carried out at Haskell Laboratory: two-year feeding study and response to hemorrhage study. *In: Environmental Health Aspects of Lead: Proceedings, International Symposium*, D. Barth et al. eds. Commission of European Communities. pp. 199-210. As cited in Sample et al., 1996.

Ball, J.W. and Nordstrom, D.K. 1991. *User's Manual for WATEQ4F, with Revised Thermodynamic Data Base and Test Cases for Calculating Speciation of Major, Trace, and Redox Elements in Natural Waters.* US Geological Survey Open-File Report 91-183. Reprinted and Revised April, 2001.

Bent, A.C. 1926. Life histories of North American marsh birds. Smithsonian Institute, *US National Museum, Bulletin* 135. US Government Printing Office, Washington, DC.

Bent, A.C. 1940. Life histories of North American cuckoos, goatsuckers, hummingbirds, and their allies. *US National Museum Bulletin* 176.

Beyer, W.N., E. Conner, and S. Gerould. 1994. Survey of soil ingestion by wildlife. *Journal of Wildlife Management* 58(2):375-382.

Bintein, S., J. Devillers, and W. Karcher. 1993. "Nonlinear Dependence of Fish Bioconcentration on n-Octanol/Water Partition Coefficients." *SAR and QSAR Environmental Research* 1:29-39. As cited in USEPA, 1999, Appendix C.

Brooks, R.P. and W.J. Davis. 1987. Habitat selection by breeding belted kingfishers (*Ceryle alcyon*). *American Midland Naturalist* 117:63-70.

Cain, B.W. and E.A. Pafford. 1981. Effects of dietary nickel on survival and growth of Mallard ducklings. *Archives of Environmental Contamination and Toxicology* 10: 737-745. As cited in Sample et al., 1996.

Calamari**,** D., Gaggino, G.F. and Pacchetti, G. 1982. *Toxicokinetics* of *low* levels of Cd, Cr, Ni and their mixture in long-term treatment on *Salmo gairdneri* Rich. Chemosphere 11: 59-70.

Calder, III, W.A. and E.J. Braun. 1983. Scaling of osmotic regulation in mammals and birds. *American Journal of Physiology* 244:601.

Callender, E., Carter, V., Hahl, D. C., Hitt, K., Schultz, B.I. (eds.) 1984. A water-quality study of the Tidal Potomac River and Estuary; an Overview. US Geological Survey Water Supply Paper 2233.

Chendorain, M.D., C.D. Stewart, and B. Packer, B. 2002. *UXO Corrosion in Soil*. Presented at the Partners in Environmental Technology Technical Symposium & Workshop: Meeting DoD's Environmental Challenges, December 3-5, 2002. Marriott Wardman Park Hotel, Washington, DC.

Clarke, D.G., M.R. Palermo, and T.C. Sturgis. 2001. Subaqueous cap design: Selection of bioturbation profiles, depths, and rates. DOER Technical Notes Collection (ERDC TN-DOER-C21). US Army Engineer Research and Development Center, Vicksburg, MS.

Clausen, J.L., N.K., M. Dodson, J. Robb, and S. Rieven. 2006. Conceptual Model for the Transport of Energetic Residues from Surface Soil to Groundwater by Range Activities. Cold Regions Research and Engineering Laboratory US Army Engineer Research and Development Center. ERDC/CRREL TR-06-18. November 2006.

Clausen, J.L., C.L. Scott, R.J. Cramer. 2007. Development of Environmental Data for Navy, Air Force, and Marine Munitions. Strategic Environmental Research and Development Program: Report ER-1480 ERDC/CRREL TR-07-7. June.

Connecticut Department of Environmental Conservation. 2011. River Otter Fact Sheet. [website] Accessed 8 September 2011. Available from <http://www.ct.gov/dep/cwp/view.asp?A=2723&Q=345008>.

Cosby, E.B. 2008. Assistant Executive Secretary, Potomac River Fisheries Commission. October 7, 2008. Letter to A. Parker, AECOM.

Cosby, E.B. 2010. Assistant Executive Secretary, Potomac River Fisheries Commission. February 26, 2010. Email to V. Frankenthaler, AECOM.

Cosby, E.B. 2011. Assistant Executive Secretary, Potomac River Fisheries Commission. March 1, 2011. Email to V. Frankenthaler, AECOM.

Davis, W.J. 1982. Territory size in *Megaceryle alcyon* along a stream habitat. *Auk* 99:353-362.

Defries, R.S., 1986. Effects of Land-Use History on Sedimentation in the Potomac Estuary, Maryland; A Water-Quality Study of the Tidal Potomac River and Estuary. US Geological Survey Water-Supply Paper 2234-K.

Department of Defense (DoD). 2004. Directive Number 4715.11. Environmental and Explosives Safety Management on Operational Ranges within the United States. May 10, 2004. Certified Current as of April 24, 2007.

Department of Defense (DoD). 1998. Department of Defense Policy to Implement the EPA's Military Munitions Rule. 1 July 1998.

Dewar, H., T. Landers, and E. Ridlington. 2009. *Watermen Blues: Economic, Cultural and Community Impacts of Poor Water Quality in the Chesapeake Bay*. Environment Maryland Research & Policy Center. September 2009.

Dowd, E.M. and L.D. Flake. 1985. Foraging habitats and movements of nesting great blue herons in a prairie river ecosystem, South Dakota. *Journal of Field Ornithology* 56(4):379-387.

Dunning, Jr., J.B. (ed). 2008. CRC Handbook of Avian Body Masses. CRC Press, Boca Raton, Florida. Second edition.

Dzombak, D.A. and F.M. Morel. 1990. Surface Complexation Modeling: Hydrous Feric Oxide. Wiley-Interscience.

Eckert, A.W. and K.E. Karalus. 1983. The wading birds of North America: North of Mexico. Weathervane Books, New York, NY. 226 pp.

Edens, F., W.E. Benton, S.J. Bursian, and G.W. Morgan. 1976. Effect of Dietary Lead on Reproductive Performance in Japanese Quail, *Coturnix coturnix japonica*. *Toxicological and Applied Pharmacology* 38: 307-314. As cited in Sample et al., 1996.

Environment Canada. 2005. Canadian Wildlife Service, Hinterland's Who's Who, Great Blue Heron. [website] Accessed 1 September 2011. Available from <http://www.hww.ca/hww2.asp?id=43>.

Erickson, D.W. and C.R. McCullough. 1987. Fates of translocated river otters in Missouri. *Wildlife Society Bulletin* 15:511-517.

Erlinge, S. 1967. Home range of the otter (*Lutra lutra*) in southern Sweden. *Oikos* 18. 379-97.

Everett, D. J., I.P. Johnson, P. Hudson, and M. Jones. 1985. HMX: 13-week toxicity study in rats by dietary administration. AD-A171 601. U.S. Army Medical Research and Development Command, Fort Detrick, MD. As cited in ATSDR, 1997.

Farmer, G.J., D. Ashfield, and H.S. Samant, 1979. Effects of zinc on juvenile Atlantic salmon, *Salmo salar*: acute toxicity, food intake, growth and bioaccumulation. *Environmental Pollution* 19: 103-117.

Glenn, J.L., 1988. Bottom Sediments and Nutrients in the Tidal Potomac System, Maryland and Virginia. US Geological Survey Water-Supply Paper 2234-F.

Goodwin, S.D., Schultz, B.I., Parkhurst, D.L., Simon, N.S., Callender, E., 1984. *Methods for the Collection of Geochemical Data from the Sediments of the Tidal Potomac River and Estuary, and Data for 1978-1980*. U.S. Geological Survey Open-File Report 84-074.

Goss, William. 2009. Safety and Environmental Office, Naval Surface Warfare Center Dahlgren Division. Personal communication via e-mail to Penny Douglas, AECOM. October 19, 2009.

Haseltine, S.D., L. Sileo, D.J. Hoffman, and B.D. Mulhern. 1985. Effects of chromium on reproduction and growth in black ducks. USFWS unpublished manuscript. As cited in Sample et al., 1986.

Hazardous Substances Data Bank. 2011a. National Library of Medicine, Hazardous Substances Data Bank, Iron Compounds. [website] Accessed 24 October 2011. Available from <http://toxnet.nlm.nih.gov/cgi-bin/sis/search/f?./temp/~H7ehG4:1>.

Hazardous Substances Data Bank. 2011b. National Library of Medicine, Hazardous Substances Data Bank, Ammonium Picrate CASRN: 131-74-8. [website] Accessed 24 October 2011. Available from <http://toxnet.nlm.nih.gov/cgi-bin/sis/search/f?./temp/~z7iiS6:1>.

Hedrick, D.I. (Captain, US Navy). 1947. US Naval Proving Ground, Dahlgren, Virginia - History, April 1918-December 1945. Technical Library, Naval Proving Ground, Dahlgren, Virginia.

Hewitt, A.D., T.F. Jenkins, T.A. Ranney, J.A. Stark, M.E. Walsh. 2003. Estimates for Explosives Residue from the Detonation of Army Munitions. Engineer Research and Development Center Hanover NH, Cold Regions Research and Engineering Lab.

Holcombe, G.W., D.A. Benoit, E.N. Leonard, and J.M. McKim. 1976. Long-term effects of *lead* exposure on three generations of *brook trout* (*Salvelinus fontinalis*). *Journal of the Fisheries Research Board of Canada* 33(8):1731-1741. As cited in Jarvinen and Ankley, 1999.

Houser, M.E. and M.I. Fauth. 1972. Potomac River Sediment Study. Indian Head Technical Report 355. June 1972. Prepared for Naval Ordnance Station, Indian Head, Maryland.

Ingersoll, C.G., P.S. Haverland, E.L. Brunson, T.J. Canfield, F.J. Dwyer, C.E. Henke, and N.E. Kemble. 1996. Calculation and evaluation of sediment effect concentrations for the amphipod *Hyalella azteca* and the midge *Chironomus riparius*. *Journal of Great Lakes Research* 22:602-623.

Interstate Commission on the Potomac River Basin (ICPRB). 2011. ICPRB website. [website] Accessed 1 September 2011. Available from <http://www.potomacriver.org/index.htm>.

Irani, Frederick M. October 14, 2011. Landscape Analyst, United States Geological Survey and Chesapeake Bay Program. Email to V. Frankenthaler, AECOM. firani@chesapeakebay.net.

Jarvinen, A.W., and G. T. Ankley. 1999. Linkage of Effects to Tissue Residues: Development of a Comprehensive Database for Aquatic Organisms Exposed to Inorganic and Organic Chemicals. SETAC Press, Pensacola, Florida.

Jaworski, N.A., Romano, B., Buchanan, C. 2007. A Treatise: The Potomac River Basin and its Estuary: Landscape Loadings and Water Quality Trends, 1895-2005. Edition 1.0. March 1, 2007.

Jenkins, T.F., Miyares, P.H., Walsh, M.E., Collins, N.H. and Ranney, T.A. 2000. Evaluation of the Use of Snow Covered Ranges to Estimate the Explosives Residues that Result from Detonation of Army Munitions. ERDC/CRREL TR-00-15, US Army Engineer Research and Development Center, Hanover, New Hampshire.

Jenkins, T.F., J.C. Pennington, T.A. Ranney, T.E. Berry, P.H. Miyares, M.E. Walsh, A.D. Hewitt, N.M. Perron, L.V. Parker, C.A. Hayes, and E.G. Wahlgren. 2001. Characterization of Explosives Contamination at Military Firing Ranges. ERDC TR-01-5. US Army Corps of Engineers, Engineer Research and Development Center. Hanover, NH.

Jenkins, T. F., S. Thiboutot, G. Ampleman, A. D. Hewitt, M. E. Walsh, T. A. Ranney, C. A. Ramsey, C. L. Grant, C. M. Collins, S. Brochu, S. R. Bigl, and J. C. Pennington. 2005. Identity and Distribution of Residues of Energetic Compounds at Military Live-Fire Training Ranges. ERDC TR-05-10. US Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory. Hanover, NH. November.

Jezierska B. and Sarnowski P. 2002. The effect of mercury, copper and cadmium during single and combined exposure on oxygen consumption of *Oncorhynchus mykiss* Wal. and *Cyprinus carpio* L. larvae. *Archives of Polish Fisheries* 10(1): 15-22.

Kaufman, L. 2010. A Base for War Training, and Species Preservation. New York Times. February 21, 2010. [website] Accessed 3 March 2010. Available from <http://www.nytimes.com/2010/02/22/science/earth/22endangered.html?pagewanted=all>.

Knebel, H.J., Martin, E.A., Glenn, J.L., Needell, S.W. 1981. Sedimentary Framework of the Potomac River Estuary, Maryland. *Geological Society of America Bulletin* 92(1):578-589.

Landwehr, Jurate M., Justin T. Reel, Nancy B. Rybicki, Henry A. Ruhl, and Virginia Carter. 1999. Chesapeake Bay Habitat Criteria Scores and the Distribution of Submersed Aquatic Vegetation in the Tidal Potomac River and Potomac Estuary, 1983-1997. United States Geological Survey, Reston, Virginia, Open-File Report 99-219.

Larson, S.L., Martin, W.A., Escalon, B.L., Thompson, M. 2008. Dissolution, sorption, and kinetics involved in systems containing explosives, water, and soil. *Environmental Science and Technology* 42:786-792.

Laskey, J.W., G.L. Rehnberg, J.F. Hein, and S.D. Carter. 1982. Effects of chronic manganese (Mn_3O_4) exposure on selected reproductive parameters in rats. *Journal of Toxicology and Environmental Health* 9: 677-687. As cited in Sample et al., 1996.

Laskey, J.W., and F.W. Edens. 1985. Effects of chronic high-level manganese exposure on male behavior in the Japanese Quail (*Coturnix coturnix japonica*). *Poultry Science* 64: 579-584. As cited in Sample et al., 1996.

Levine, B.S., E.M. Furedi, V.S. Rac, D.E. Gordon, P.M. Lish. 1983. Determination of the chronic mammalian toxicological effects of RDX: Twenty-four month chronic toxicity/carcinogenicity study of hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) in the Fischer 344 rat: Phase V. Vol. 1. Contract no. DAMD17-C-9161. Frederick, MD: U.S. Army Medical Research and Development Command, Fort Detrick. Document no. AD A160774. As cited in ATSDR, 2010.

Levine, B.S., J.H. Rust, J.J. Barkley, E.M. Furedi EM, and P.M. Lish. 1990. Six month oral toxicity study of trinitrotoluene in beagle dogs. *Toxicology* 63(2):233-244. As cited in ASTDR, 1995b.

Levine, E. 1988. Belted kingfisher (*Ceryle alcyon*). pp. 224-225. In: The Atlas of Breeding Birds in New York State. R.F. Andrle and J.R. Carroll (eds). 1988. Cornell University Press, Ithaca, NY.

Lewis, A.M., P.S. Verlinde, M.P. Acheroy, A.J. Sieber. 2002. “Recent Progress in the Joint Multisensor Mine-Signatures Database Project,” in Detection and Remediation Technologies for Mines and Minelike Targets VII, J. T. Broach, R. S. Harmon, and G. J. Dobeck, eds., Seattle: International Society for Optical Engineering, 2002. As cited in US Navy 2006a.

Long, E.R. and L.G. Morgan. 1990. The potential for biological effects of sediment-sorbed contaminants tested in the National Status and Trends Program. NOAA Technical Memorandum, NOS OMA 64. National Oceanic and Atmospheric Administration, Seattle, WA.

Long, E.R., D.D. MacDonald, S.L. Smith, and F.D. Calder. 1995. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. *Environmental Management* 19:81-97.

Lovejoy, Vanessa. 2010. Naval Surface Warfare Center, Dahlgren Division, personal communication via e-mail to Helen Chernoff, AECOM, March 5, 2010.

Luther, G.W. III, Giblin, A., Howarth, R.W., Ryans, R.A., 1982. Pyrite and oxidized iron mineral phases formed from pyrite oxidation in salt marsh and estuarine sediments. *Geochimica et Cosmochimica Acta* 46:2665-2669.

Mackenzie, R.D., R.U. Byerrum, C.F. Decker, C. Hoppert, and R.F. Langham. 1958. Chronic toxicity studies, II. Hexavalent and trivalent chromium administered in drinking water to rats. *American Medical Association Archives of Industrial Health* 18: 232-234. As cited in Sample et al., 1996.

Martin, E.A., J.L. Glenn, C.A. Rice, G. Harrison, E. Gum, and M. Curington. 1981. Concentrations of Selected Trace Metals in Shallow Cores from the Tidal Potomac River and Estuary: 1978 and 1979. US Geological Survey Open-File Report 81-1175.

Maryland Department of Natural Resources (MDNR). 2010. *Fixed Station Monthly Monitoring*. [website] Accessed June 2010. Available from <http://mddnr.chesapeakebay.net/bay_cond/index.cfm>.

Maryland Department of the Environment (MDE). 2006a. Water Quality Analysis of Cadmium, Chromium, Copper, and Lead in the Potomac River Middle Tidal, Charles County, Maryland. February. Available from <http://www.mde.state.md.us/assets/document/Middle_potomac_tidal_02-01-06_wqa_final.pdf >.

Maryland Department of the Environment (MDE). 2006b. Water Quality Analysis of Metals in Upper North Branch Potomac River, Garrett County, Maryland. July. Available from <http://www.mde.state.md.us/assets/document/UNBPotomac_Metals_072806_final.pdf >.

Maryland Department of the Environment (MDE). 2009. Numerical Criteria for Toxic Substances in Surface Waters: COMAR 26.08.02.03-2. [website] Accessed 05 March 2009. Available from <http://www.dsd.state.md.us/comar/26/26.08.02.03-2.htm>.

Maryland Department of the Environment (MDE). 2011. Maryland Fish Consumption Advisories, Statewide Fresh Water, Estuarine, and Marine Waters. September 20, 2011. Available from <http://www.mde.state.md.us/programs/marylander/citizensinfocenterhome/pages/citizensinfocenter/fishandshellfish/index.aspx>.

Maryland Geological Survey (MGS). 2008. Draft Physiographic Map of Maryland. Open-file Report 08-03-1. September 2008

Maryland Historical Trust. 2009. Maryland's U-1105 Black Panther Historic Shipwreck Preserve Becomes a Charter Member of the National System of Marine Protected Areas. [website] Accessed 15 May 2009. Available from <http://mht.maryland.gov/documents/PDF/Press_Releases/2009_04_28_U1105_MPA.pdf>.

McCollum, K.G., editor. 1976. Dahlgren History: As Told by Those Who Saw it Happen. Naval Surface Weapons Center, Dahlgren Laboratory, Dahlgren, Virginia. NSWC/DL MP 8/76. October.

Mehring, A.L. Jr., J.H. Brumbaugh, A.J. Sutherland, and H.W. Titus. 1960. The tolerance of growing chickens for dietary copper. *Poultry Science* 39: 713-719. As cited in Sample et al., 1996.

Melquist, W. E. and M. G. Hornocker. 1983. Ecology of river otters in west central Idaho. *Wildlife Monographs* No. 83.

Melquist, W.E. and A.E. Dronkert. 1987. River otter. In : Novak, M., J.A. Baker, M.E. Obbarel, et al., eds. 1988. Wild furbearer management and conservation. University of Pittsburgh Press, Pittsburgh, PA.

Mirant Mid-Atlantic, LLC. 2006. Environmental Analysis, Application for CPCN Authorizing Modification of the Morgantown Generating Station. Prepared by Golder Associates Inc. for Mirant Mid-Atlantic, LLC. October 13, 2006.

Nagy, K.A. 1987. Field metabolic rate and food requirement scaling in mammals and birds. *Ecological Monographs* 57(2):111-128.

National Library of Medicine, 2012. Chromium, Tox Town. [website] Accessed 9 May 2012. Available from <http://toxtown.nlm.nih.gov/text_version/chemicals.php?id=10>.

National Marine Fisheries Service (NMFS). 2012. Letter from Daniel S. Morris, Acting Regional Administrator to Jeffery C. Bossart, Director, Environmental Division, Naval Support Activity South Potomac. Re: Naval Surface Warfare Center, Dahlgren Division, Research, Development, Test, and Evaluation. January 11, 2012.

National Oceanic and Atmospheric Administration (NOAA). 2002. National Oceanic and Atmospheric Administration's Nautical Charts of Potomac River: 12233, Chesapeake Bay to Piney Point; 12286, Piney Point to Lower Cedar Point; 12288, Lower Cedar Point to Mattawoman Creek.

National Oceanic and Atmospheric Administration (NOAA). 2007. Tides & Currents website [website] Accessed December 2007. Available from <http://tidesandcurrents.noaa.gov/index.shtml>.

National Oceanic and Atmospheric Administration (NOAA). 2008. Screening Quick Reference Tables. [website] Accessed 19 March 2009. Available from <http://response.restoration.noaa.gov/book_shelf/122_NEW-SQuiRTs.pdf>.

National Oceanic and Atmospheric Administration (NOAA). 2011. *estuaries.gov.* [website] Accessed October 10, 2011. Available from <http://www.estuaries.gov>. NOAA Office of Ocean and Coastal Resource Management.

Naval Historical Center (NHC). 2008. Partial List of Foundered US Navy Craft. Provided by Alexis Catsambis, Underwater Archaeologist, Naval Historical Center, Underwater Archaeology Branch, from evolving database for NHC, United States.

Naval Support Facility Dahlgren (NSF Dahlgren). 2006. Environmental Assessment, Electromagnetic Research and Engineering Facility (EMREF) and Counter Explosive Test Facility (CETFAC), Naval Support Facility Dahlgren, Dahlgren, Virginia.

Naval Support Facility Dahlgren (NSF Dahlgren). November 2007. *Integrated Natural Resources Management Plan, Naval Facility Support Dahlgren, Dahlgren, Virginia*. Prepared by Geo-Marine, Inc. for Naval Support Facility Dahlgren, Dahlgren, Virginia. Final. United States Navy, Naval Support Facility Dahlgren.

Naval Surface Warfare Center, Dahlgren Laboratory (NSWCDL). 1976. Range Survey Form, US Naval Surface Weapons Center, Dahlgren Laboratory.

Naval Surface Warfare Center, Dahlgren Division (NSWCDD). 2008-2011. Geographic Information System (GIS).

Naval Surface Warfare Center, Dahlgren Division (NSWCDD). 2010. *Final Range Condition Assessment Report for Naval Surface Warfare Center, Dahlgren Laboratory Ranges, Dahlgren, Virginia.* United States Navy, Naval Sea Systems Command. September 2010.

Naval Surface Warfare Center, Dahlgren Division (NSWCDD). 2011. Biological Assessment, Shortnose Sturgeon (*Acipenser brevirostrum*), Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*), Loggerhead Sea Turtle (*Caretta caretta*), Kemp's Ridley Sea Turtle (*Lepidochelys kempii*), Green Sea Turtle (*Chelonia mydas*). Naval Surface Warfare Center, Dahlgren Laboratory Dahlgren, Virginia. November 2011.

Nipper, M., R.S. Carr, J.M. Biedenbach, R.L. Hooten, K. Miller, and S. Saepoff. 2001. Development of Marine Toxicity Data for Ordnance Compounds. *Archives of Environmental Contamination and Toxicology* 41:308–318.

Parkhurst, D.L. and Appelo, C.A.J. 1999. User's Guide to PHREEQC (Version 2) – A Computer Program for Speciation, Batch-Reaction, One-Dimensional Transport, and Inverse Geochemical Calculations. U.S. Geological Survey Water-Resources Investigations Report 99-4259. Available from <http://wwwbrr.cr.usgs.gov/projects/GWC_coupled/phreeqc/>.

Pascoe, D. and M.L. Mattey. 1977. Studies on the toxicity of cadmium to the three-spined stickleback *Gasterosteus aculeatus* L. *Journal of Fish Biology* 11:207-215.

Patteson, M. 2009. Naval Surface Warfare Center, Dahlgren Division. Rocket motor firing data sent to William Goss, NSWCDD and then to Penny Douglas, AECOM. 14 October 2009.

Pearson, L.M. 1995. Technical Developments in World War II. Naval Aviation News, May-June 1995, pp. 30-35.

Pennington, J.C. and J.M. Brannon. 2002. Environmental fate of explosives. *Thermochimica Acta* 384:163-172.

Pennington, J. C., T. F. Jenkins, G. Ampleman, S. Thiboutot, J. M. Brannon, A. D. Hewitt, J. Lewis, S. Brochu, E. Diaz, M. R. Walsh, M. E. Walsh, S. Taylor, J. C. Lynch, J. Clausen, T. A. Ranney, C. A. Ramsey, C. A. Hayes, C. L. Grant, C. M. Collins, S. R. Bigl, S. Yost, and K. Dontsova. 2006. Distribution and Fate of Energetics on DoD Test and Training Ranges: Final Report. US Army Engineer Research and Development Center, Environmental Laboratory. Vicksburg, Mississippi. ERDC TR-06-13.

Pohlman, John. 2008. United States Geological Survey, personal communication with Anne Lewis-Russ, AECOM. September 2008.

Reddy, T.V., G.R. Olson, B. Wiechman, G. Reddy, J. Torsella, F.B. Daniel, and G.J. Leach. 1999. Toxicity of Tetryl (N-Methyl-N,2,4,6–Tetranitroaniline) in F344 Rats. *International Journal of Toxicology* 18(2): 97-107. As cited in ATSDR 1995a.

Rife, J.P. and R.P. Carlisle. 2006. The Sound of Freedom - Naval Weapons Technology at Dahlgren, Virginia 1918-2006. Navy Historical Center, US Government Printing Office.

Sample, B.E., D.M. Opresko, and G.W. Suter, II. 1996. Toxicological benchmarks for wildlife: 1996 revision. ES/ER/TM-86/RS. Prepared for the US Department of Energy, Office of Environmental Management. Oak Ridge National Laboratory, Risk Assessment Program, Health Sciences Research Division, Oak Ridge, TN.

Sanford, L. 2008. An Overview of Sediment Transport Model Applications in the Chesapeake Bay System. University of Maryland Center for Environmental Science, Horn Point Laboratory, Cambridge, Maryland. [website] Accessed 30 January 2009. Available from <www.chesapeakemeetings.com/CheMS2008/papers/W7_Sanford_Sediment-Transport-Overview.ppt>.

Schlicker, S.A. and D.H. Cox. 1968. Maternal dietary zinc, and development and zinc, iron, and copper content of the rat fetus. *Journal of Nutrition* 95: 287-294. As cited in Sample et al., 1996.

Shazili, N.A.M. 1995. Effects of salinity and pre-exposure on acute cadmium toxicity to seabass, *Lates calcarifer*. *Bulletin of Environmental Contamination and Toxicology* 54:22–28.

Smith, K.S. and Huyck, H.L.O. 1999. *An Overview of the Abundance, Relative Mobility, Bioavailability, and Human Toxicity of Metals.* In Plumlee, G.S. and Logsdon, J.J. (eds.), The Environmental Geochemistry of Mineral Deposits. Part A. Processes, Techniques, and Health Issues. Society of Economic Geologists, *Reviews in Economic Geology* 6A: 29-70.

Stahl, J.L., J.L. Greger, and M.E. Cook. 1990. Breeding-hen and progeny performance when hens are fed excessive dietary zinc. *Poultry Science* 69: 259-263. As cited in Sample et al., 1996.

Southeast Regional Climate Center. 2012. Fredericksburg Natl Pk, Virginia (443192), Period of Record Monthly Climate Summary, Period of Record: 4/17/1893 to 3/31/1997. [website] Accessed 23 May 2012. Available from <http://www.sercc.com/cgi-bin/sercc/cliMAIN.pl?va3192>.

Sutou, S., K. Yamamoto, H. Sendota, and M. Sugiyama. 1980. Toxicity, fertility, teratogenicity, and dominant lethal tests in rats administered cadmium subchronically. I. Fertility, teratogenicity, and dominant lethal tests. *Ecotoxicology and Environmental Safety* 4:51–56. As cited in Sample et al., 1996.

Swedlund, P., 2004. Modelling Cu, Zn, Cd and Pb Adsorption by Iron Oxyhydroxides in SO_4-rich Systems Simulating Acid Mine Drainage. Dissertation. University of Auckland, New Zealand**.**

Swope, Ann. 2008. Director, Safety and Environmental Office, Naval Surface Warfare Center, Dahlgren Division. Personal communication via e-mail to Penny Douglas, AECOM. October 22, 2008.

Talmage, S.S., Opresko, D.M., Maxwell, C.J., Welsh, C.J., Cretella, F.M., Reno, P.H., Daniel, E.B. 1999. Nitroaromatic munition compounds: environmental effects and screening values. *Reviews of Environmental Contamination and Toxicity* 161:1-156. As cited in US Navy, 2002.

Thurman, H.V. 1994. Introductory Oceanography, Seventh Edition. Macmillan Publishing Company, New York.

Town of Colonial Beach. 2011. The Town of Colonial Beach. [website] Accessed 8 September 2011. Available from <http://www.colonialbeachva.net/>.

Unidentified Author. 1945. Letter dated 13 March 45, Naval Proving Ground, Dahlgren, Virginia from WAVE officer (signed Gene) to friends.

United States Army Corps of Engineers (USACE). 2008. SMS – Surface Water Model System. Coastal and Hydraulics Laboratory - Engineer Research and Development Center Waterways Experiment Station - Vicksburg, Mississippi. Available from <http://chl.erdc.usace.army.mil/sms>.

United States Army Defense Ammunition Center (USADAC). 2000. Study of Ammunition Dud and Low Order Detonation Rates. Technical Center for Explosives Safety. July 2000. As cited in Clausen et al., 2006.

United States Environmental Protection Agency (USEPA). Undated. Environmental Monitoring & Assessment Program Mid-Atlantic Integrated Assessment, Estuaries 1997-1998. [website] Accessed 11 December 2008. Available from <http://www.epa.gov/emap/maia/html/data/estuary/9798/>.

United States Environmental Protection Agency (USEPA). 1989. Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part A), Interim Final. EPA/540/1-89/002. December 1989.

United States Environmental Protection Agency (USEPA). 1991a. Risk Assessment Guidance for Superfund. Volume I: Human Health Evaluation Manual Supplemental Guidance. Standard Default Exposure Factors. Interim Final. OSWER Directive 9285.6-03. US Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, DC.

United States Environmental Protection Agency (USEPA). 1991b. Lead; Identification of Dangerous Levels of Lead; Final Rule. 40 CFR Part 745. January 5, 2001.

United States Environmental Protection Agency (USEPA). 1992. Guidance on Risk Characterization for Risk Managers and Risk Assessors. F.H. Habicht II, Deputy Administrator. February 1992.

United States Environmental Protection Agency (USEPA). 1993. Wildlife exposures factors handbook. EPA/600/R-93/187a. US Environmental Protection Agency, Office of Research and Development, Washington, DC.

United States Environmental Protection Agency (USEPA). 1995. Final Water Quality Guidance for the Great Lakes Systems Final Rule.

United States Environmental Protection Agency (USEPA). 1997. Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments. Office of Solid Waste and Emergency Response. EPA-540-R-97-006. June 1997.

United States Environmental Protection Agency (USEPA). 1996. Soil Screening Guidance: User's Guide. Second Edition. Office of Emergency and remedial Response, Washington, D.C. Publication 9355.4-23. July 1996.

United States Environmental Protection Agency (USEPA). 1999. Screening Level Ecological Risk Assessment Protocol for Hazardous Waste Combustion Facilities. EPA/530/D-99/001A. Peer Review Draft. August 1999.

United States Environmental Protection Agency (USEPA). 2002a. Mid-Atlantic Integrated Assessment 1997-98, Summary Report, EPA/620/R-02/003. US Environmental Protection Agency, Atlantic Ecology Division, Narragansett, RI. Available from <http://www.epa.gov/emap/maia/html/docs/maiasr_9798.html>.

United States Environmental Protection Agency (USEPA). 2002b. Supplemental Guidance For Developing Soil Screening Levels For Superfund Sites. Office of Emergency and remedial Response, Washington, D.C. OSWER 9355.4-24. December 2002.

United States Environmental Protection Agency (USEPA). 2003. Technical Support Document for Identification of Chesapeake Bay Designated Uses and Attainability. USEPA Region III, Chesapeake Bay Program Office, EPA 903-R-03-004. October 2003.

United States Environmental Protection Agency (USEPA). 2007. MAIA Estuaries 1997-98. [website] Accessed 8 August 2008. Available from <http://www.epa.gov/emap/maia/html/data/estuary/9798/index.html>.

United States Environmental Protection Agency (USEPA). 2009. National Recommended Water Quality Criteria. Available from <http://water.epa.gov/scitech/swguidance/standards/current/>.

United States Environmental Protection Agency (USEPA). 2010. Emerging Contaminant - Perchlorate. December 2010. Available from <http://www.epa.gov/fedfac/documents/emerging_contaminants.htm>.

United States Environmental Protection Agency (USEPA). 2011. Target Compounds and Analytes. [website] Accessed on August 30, 2011. Available from <http://www.epa.gov/superfund/programs/clp/target.htm>.

United States Environmental Protection Agency (USEPA). 2012. Regional Screening Table. May 2012. [website] Accessed 16 May 2012. Available from <http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm>.

United States Geological Survey (USGS). 1985. A Water-Quality Study of the Tidal Potomac River and Estuary.

United States Geological Survey (USGS). 1995. Chesapeake Bay: Measuring Pollution Reduction. [website] Accessed 15 February 2010. Available from <http://water.usgs.gov/wid/html/chesbay.html>.

United States Geological Survey (USGS). 2003. A Summary Report of Sediment Processes in Chesapeake Bay and Watershed. Water-Resources Investigations Report 03-4123.

United States Geological Survey (USGS). 2011. The effects of urbanization on water quality: Phosphorus. [website] Accessed 30 August 2011. Available from <http://ga.water.usgs.gov/edu/urbanpho.html>.

United States Navy (US Navy). 1999. Navy Policy for Conducting Ecological Risk Assessments, CNO Ser N453E/9U593555. 5 April 1999.

United States Navy (US Navy). 2001. Navy Policy for Conducting Human Health Risk Assessments under the Installation Restoration Program, CNO Ser N453E/1U595168. 12 February 2001.

United States Navy (US Navy). 2002. Environmental Effects of Underwater Ordnance. Internal Draft. Naval Facilities Engineering Service Center. January 2002.

United States Navy (US Navy). 2004. Operational Range Clearance Policy for Navy Ranges. 3000 Series N43/4U741226. 2 April 2004.

United States Navy (US Navy). 2006a. US Navy Range Sustainability Environmental Program Assessment Policy Implementation Manual, Revision 1. Chief of Naval Operations Environmental Readiness Division (N45).

United States Navy (US Navy). 2006b. Environmental Assessment, Electromagnetic Research and Engineering Facility (EMREF) and Counter Explosive Test Facility (CETFAC), Naval Support Facility, Dahlgren, Dahlgren, Virginia.

United States Navy (US Navy). 2008. Draft Final Navy Policy for Conducting Operational Water Range Sustainability Environmental Program Assessments. July 14, 2008.

Velinsky, D. 2004. Review of Historical Data Concerning Chemical Contaminants in the Tidal Potomac River. Presented at the Interstate Commission on the Potomac River Basin (ICPRB) Regional Technical Workshop on Potomac Toxics Data held on January 29, 2004.

Virginia Department of Environmental Quality (VDEQ). 2008. State Water Control Board 9 VAC 25-260 Virginia Water Quality Standards. Statutory Authority: § 62.1-44.15 3a of the Code of Virginia with Amendments Effective October 2008. [website] Accessed 5 March 2009. Available from <http://www.deq.state.va.us/wqs/documents/WQS_eff_10_22_08.pdf>.

Versar, 2008. Chesapeake Bay Benthic Monitoring Program Web Site, Maryland 2007 Sediment Data. [website] Accessed 10 September 2011. Available from <http://www.esm.versar.com/vcb/benthos/data.htm>.

Walsh, M.R. 2007. Explosives Residues Resulting from the Detonation of Common Military Munitions: 2002-2006. Cold Regions Research and Engineering Laboratory. ERDC/CRREL TR-07-2. [website] Accessed 29 December 2008. Available from <http://www.dtic.mil/cgibin/GetTRDoc?AD=ADA465866&Location=U2&doc=GetTRDoc.pdf >.

Walsh, M.E., T.F. Jenkins, and P.G. Thorne. 1995. Laboratory and Field Analytical Methods for Explosives Residues in Soil. *Journal of Energetic Materials* 13:357-383.

White, D. H. and M. T. Finley. 1978. Uptake and retention of dietary cadmium in mallard ducks. *Environmental Research* 17: 53-59. As cited in Sample et al., 1996.

Wilson, Robert E. 1977. A model of dynamics in the Lower Potomac River Estuary. *Chesapeake Science* 18 (2):177-187. June 1977.

Woods, T.L. and Garrels, R.M. 1987. Thermodynamic Values at Low Temperature for Natural Inorganic Materials: An Uncritical Summary. Oxford University Press, New York.

Xu, J., Y. Song, B. Min, L. Steinberg, and B.E. Logan. 2003. Microbial Degradation of Perchlorate: Principles and Applications. *Environmental Engineering Science* 20(5): 405-422.

THIS PAGE INTENTIONALLY LEFT BLANK

10 PREPARERS

The Navy Technical Representative for the preparation of this document is:

Ms. Carolyn Woods
Naval Facilities Engineering Command, Washington
Washington Navy Yard
1314 Harwood Street, SE
Washington, DC 20374-5018

The contractor responsible for the preparation of this document for the US Navy is:

AECOM

675 North Washington Street, Suite 300
Alexandria, VA 22314

Key personnel who prepared or reviewed the document include:

Naval Surface Warfare Center, Dahlgren Division

Capt. Michael H. Smith, Commanding Officer

Ann Swope, Chief of Staff

Jennifer Boyd, EIS Project Manager, Safety and Environmental Director

Vanessa Lovejoy, Environmental Program Manager

Stacia Courtney, Public Affairs Office

Oscar Towler, Legal Counsel

Marguerite Dineen, Legal Counsel

Naval Support Activity South Potomac, Naval Support Facility Dahlgren

Walter Legg, Environmental Manager, Project Review

Mary Geil, NEPA/Cultural Resources Program Manager, Project Review

Thomas Wray, Natural Resources Manager, Project Review

Naval Surface Warfare Center Command, Washington, DC

Kimberley Cannon, Project Review

Tanya Robinson, Project Review

Stephen Wilson, Project Review

Naval Sea Systems Command, Washington, DC

Tina Serbanos, Legal Counsel, Project Review

Tuwana Cummings, Legal Counsel, Project Review

Deborah Verderame, NEPA Program Manager, Project Review

Vickie Writt, Environmental Program Manager, Project Review

Susan Levitt, Project Review

AECOM

Lane Willson, Environmental Program Manager (Captain, US Navy, Retired): 35 years of active duty experience afloat in cruisers and destroyers, and ashore in environmental compliance and program management. Auburn University, BS, Marketing and Transportation; Marymount University, MBA.

Penelope Douglas, EIS Project Manager: 40 years of experience in environmental and natural resource planning and environmental impact assessment. University of Michigan, BS, Natural Resource Planning; University of Maryland, MA, Geography/Environmental Analysis.

Craig Carver, Environmental Planner: 2 years of experience in environmental planning and impact assessment. Virginia Commonwealth University, BA, Music; Virginia Commonwealth University, Master of Urban and Regional Planning.

Helen Chernoff, WRSEPA Project Manager: 26 years of experience performing ecological and human health risk assessments and environmental impact analyses under NEPA, and various types of hazardous waste investigations (CERCLA/RCRA). State University of New York, Binghamton, BS, Biology; Florida State University, MS, Biology.

Andrew Foley, Ecologist/Environmental Planner: 10 years of experience in ecology; 2 years of experience in environmental planning. Eastern Michigan University, BS, Aquatic and Terrestrial Ecology; Eastern Michigan University, MS, Ecology and Organismal Biology.

Victor P. Frankenthaler, Senior Environmental Planner: 30 years of experience as an environmental planner specializing in the preparation of environmental impact studies, water and coastal resource planning, and field investigations. Cook College, Rutgers University, BS, Environmental Planning and Design; Rutgers University, MS, Geography.

Anne Lewis-Russ, PhD, Principal Geochemist: 27 years of experience in design and interpretation of geochemical, hydrogeological and geological studies, evaluation of contaminant fate and transport in soil, groundwater, and sediments; determination of background concentrations; evaluation of geochemical barriers and soil attenuation. South Dakota School of Mines and Technology, BS, Geological Engineering; Colorado School of Mines, PhD, Geochemistry.

Brendan V. McGuinness, Senior Geologist: 25 years of experience in environmental geological work, site assessment, remedial investigation, feasibility studies and risk assessment. Tennessee Registered Professional Geologist. State University of New York, BS, Geosciences.

Serkan Mahmutoglu, Water Resources Engineer: 15 years of experience in hydrologic, hydraulic, water-quality and sediment-transport modeling. Connecticut and Maine Registered Professional Engineer. Istanbul Technical University, BS, Environmental Engineering; University of New Hampshire, MS, Ocean Engineering.

Mark Moese, Principal Environmental Scientist: 30 years of experience specializing in environmental impact assessments and statements, environmental and social soundness assessments, EIS/EIA training seminars, hazardous materials investigations, dredging impact analyses, environmental permits, and site-selection studies. Fairleigh Dickinson University, BS, Biology; MS, Marine Biology; New York University, PhD, Environmental Toxicology/Biology.

Katherine Weber, GIS/Cartography: 10 years of experience in mapping using GIS, ArcView, ArcGIS, and PGS. Mary Washington College, BA, Geography.

Kratos Defense Engineering Solutions, DES Division

William Goss, NEPA Compliance, Project Review.

Richard Neil, NEPA Compliance, Project Review.

Bridget Petrucelli, NEPA Compliance, Project Review.

THIS PAGE INTENTIONALLY LEFT BLANK