Feasibility Study
for the Remediation of Sediments Adjacent to Lockheed Martin Middle River Complex Middle River, Maryland

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TABLE OF CONTENTS

Section **Page**

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

APPENDICES

LIST OF TABLES

Page

TABLE OF CONTENTS (continued)

LIST OF FIGURES

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

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ACRONYMS

AC	activated carbon
ANS	Applied NanoStructured Solutions, LLC
AOPC	area of potential concern
ARARs	applicable or relevant and appropriate requirements
As	arsenic
atm	atmosphere(s)
AVS	acid-volatile sulfides
AWQC	ambient water quality criteria
BaPEq	benzo(a)pyrene equivalents
bgs	below ground surface
CB-B-IBI	Chesapeake Bay Benthic Index of Biotic Integrity
CAD	confined aquatic disposal
Cd	cadmium
CDF	confined disposal facility
CDP	Criterium Decision Plus®
CERCLA	(federal) Comprehensive Environmental Resource, Compensation, and Liability Act
CFR	Code of Federal Regulations
cm	centimeter(s)
cm^2	square centimeter(s)
cm/year	centimeter(s) per year
CO_2	carbon dioxide
COC	chemical(s) of concern
COMAR	Code of Maryland Regulations
COPC	chemical(s) of potential concern
CRL	cancer risk level
Cs	cesium
CSF	cancer slope factor
CST	column settling test
Cu	copper
CWA	(federal) Clean Water Act
DMMP	dredged material management plan
DNR	Department of Natural Resources
DRET	dredge elutriate test

ENR	enhanced natural recovery
ERA	ecological risk assessment
ESA	environmental site assessment
FS	feasibility study
foc	fraction organic carbon
g	gravity
GAC	granular activated carbon
GE	General Electric
GHG	greenhouse gas
GPS	global positioning system
GRA	general response action
Hg	mercury
HHRA	human health risk assessment
HTTD	high-temperature thermal desorption
IC	institutional control
IRM	interim remedial measure
LEED	Leadership in Energy and Environmental Design
LMCPI	LMC Properties, Inc.
LTTD	low-temperature thermal desorption
Lockheed Martin	Lockheed Martin Corporation
MBE	multibeam echosounder
MCL	maximum contaminant level
MDE	Maryland Department of the Environment
MEC	midpoint effect concentration
mg/kg	milligram(s) per kilogram
mg/L	milligram(s) per liter
µg/kg	microgram(s) per kilogram
µg/L	microgram(s) per liter
µm	micrometer(s)
µmol/g	micromole(s) per gram
MLLW	mean lower-low water
MNR	monitored natural recovery
MRAS	Middle River Aircraft Systems
MRC	Middle River Complex
MS2	Maritime Systems & Sensors
MSA	Martin State Airport
MSL	mean sea level

N/m^2	Newton(s) per square meter
NAVFAC	Naval Facilities Engineering Command
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
NO_x	nitrous oxide
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NRC	National Research Council
O&M	operation and maintenance
OM&M	operation maintenance and monitoring
OMMP	operations, maintenance, and monitoring plan
OSWER	(USEPA) Office of Solid Waste and Emergency Response
PAH	polycyclic aromatic hydrocarbon
Pb	lead
PCB	polychlorinated biphenyl
PEC	probable effects concentration
PEL	probable effects level
PM_{10}	particulate matter
ppm	part(s) per million
ppt	part(s) per thousand
PRG	preliminary remediation goal
psf	pound(s) per square foot
QA/QC	quality assurance/quality control
RAL	remedial action level
RAO	remedial action objective
RBC	risk-based concentration
RCRA	(federal) Resource Conservation and Recovery Act
REC	Recognized Environmental Concern
RfD	reference dose
RME	reasonable maximum exposure
SEM	simultaneously extracted metals
(SEM-AVS)/f_{oc}	ratio of simultaneously extracted metals/acid-volatile sulfides to organic-content fraction
SO_x	sulfur oxides
SVOC	semivolatile organic compound
SWAC	site-wide area weighted-average concentration
TBC	(criteria) to be considered
TEQ	toxicity equivalents

Tetra Tech	Tetra Tech, Inc.
Tl	thallium
TOC	total organic carbon
TSCA	(federal) Toxic Substances Control Act
TSS	total suspended solids
UBC	Uniform Building Code
UCL	upper confidence level
UPL	upper prediction limit
USACE	United States Army Corps of Engineers
U.S.C.	United States Code
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UTL	upper tolerance limit
WDNR	Wisconsin Department of Natural Resources
Zn	zinc

GLOSSARY

absorption—The process in which a substance is taken into the volume of another substance.

acute risk—Acute risks can affect a person's health immediately.

adsorption—The process in which a substance adheres to the surface of a solid material.

advection—The transport of matter by a mass of flowing fluid (e.g., a river).

alluvium—Unconsolidated sediment derived from the land composed of sorted or unsorted sand, gravel, and clay that has been deposited by water.

amalgamated—A mix of different elements.

analyte—A compound or property that is to be determined, detected, and/or analyzed.

anoxic—An environment lacking oxygen.

anthropogenic—Resulting from human activity; e.g., natural and human-made substances may be in the environment due to human activities.

applicable or relevant and appropriate requirement (ARAR)—Any state or federal statute or regulation that pertains to protection of human life and the environment in addressing specific conditions or use of a particular cleanup technology at a site.

aqueous—Something made from, with, or by water.

aquifer—An underground geologic formation (or group of formations) containing water that can be readily transmitted and that is a source of groundwater for wells and springs.

aroclor—Trade name of mixtures of polychlorinated biphenyls (PCBs). Except for Aroclor-1016, the last two numbers in the trade-name designation correspond to the percentage of chlorine by weight.

assessment endpoint—In an ecological risk assessment, an expression of the environmental value to be protected; it includes both an ecological entity and specific attributes thereof. For example, crab (i.e., the valued ecological entity) reproduction and population maintenance (i.e., attributes) is an assessment endpoint.

attenuation—The process by which a chemical is reduced in concentration over time, through absorption, adsorption, degradation, dilution, and/or transformation.

Atterberg Limits—A basic measure of the nature of a fine-grained soil. Depending on the water content of the soil, it may appear in four states: solid, semi-solid, plastic, and liquid. In each state, the consistency and behavior of a soil is different and thus so too its engineering properties. Thus, the boundary between each state can be defined based on a change in the behavior of the soil. Atterberg Limits can be used to distinguish between silt and clay and between different types of silts and clays.

background (background level)—As defined by USEPA, substances in the environment that are not influenced by releases from a site and usually described as naturally occurring or anthropogenic. *Naturally occurring* is defined as substances in the environment in forms that have not been influenced by human activity. *Anthropogenic* is defined as natural and human-made substances in the environment because of human activities, but not specifically related to the site in question.

bathymetry—The measurement of depths of water in rivers, lakes, oceans, and other water bodies or the information derived from such measurements. Bathymetry is expressed relative to a reference elevation or datum.

bedload—Sediment particles resting on or near the channel bottom that are pushed or rolled along by the flow of water.

benthic/benthos—Relating to or characteristic of the bottom of an aquatic body or the organisms and plants that live there.

benthic organisms—Those creatures that live in the benthic zone of a body of water, which includes the sediment surface and shallow subsurface. Benthic organisms may include worms and mollusks.

bioaccumulation—The accumulation of contaminants in the tissue of organisms through either direct exposure to a contaminated medium, through respiration, or through its diet.

bioassay test—A test to determine the relative strength of a substance by comparing its effect on a test organism with that of a standard preparation.

bioavailability—For chemicals, the state of being potentially available for biological uptake by an organism when exposed to a chemical present in environmental media.

biomagnification—The process in which the concentrations of certain bioaccumulative chemicals such as PCBs increase in organism tissue with increase in trophic level (i.e., moving up the food chain). The substances become increasingly concentrated in tissues or internal organs as they move up the food chain.

biota—The types of plant and animal life found in specific regions at specific times.

biota-sediment accumulation factor (BSAF)—The concentration of a chemical in tissue divided by a concentration in sediment.

bioturbation—Mixing of sediment caused by benthic organism activities such as burrowing. Generally occurs in the top 10 centimeters of sediment.

cadmium—Cadmium is an element found naturally in soil and rocks. It is also found in some foods, and in manmade consumer products such as batteries, plastics, pigments, paints, and metal coatings. Cadmium does not break down in the environment and generally does not dissolve in water. It typically adsorbs to soil and sediment. Exposure to cadmium may adversely affect human and ecological receptors.

capping—A process in which a layer of sand or other material (typically 3-feet thick) is applied to the top of a contaminated medium such as soil or sediment.

carcinogen—Any substance that can cause cancer.

central tendency—When referring to the exposure of organisms to a chemical, an estimate of the average exposure that may potentially be experienced by the population.

chemical(s) of concern (COC)—Chemicals identified through the baseline risk assessment that may potentially cause unacceptable adverse effects to human health and/or ecological receptors.

chemical(s) of interest (COI)—Chemicals that have been detected at a site but have not been screened yet in the risk assessment process or have been screened and are not COPC (see below).

chemical(s) of potential concern (COPC)—Chemicals of interest that have been retained (following screening) for evaluation in later analyses during the risk assessment.

Chesapeake Bay Benthic Index of Biotic Integrity (CB-B-IBI)—An index developed to assess benthic community health and environmental quality in Chesapeake Bay.

chromium—A metal found in the environment, including in rocks, soils, plants, animals and people. Chromium also is used for industrial purposes such as chrome plating, the manufacture of dyes and pigments, and the preservation of wood and leather. Exposure to chromium through skin contact, ingestion, or inhalation may adversely affect human and ecological receptors.

chronic risk—Chronic risks may be associated with exposures occurring over a long period, either continuously or intermittently; describes ongoing exposures and effects that develop only after a long exposure.

cleanup—Actions to deal with a release or threat of release of a hazardous substance that could affect humans and/or the environment. The term “cleanup” is sometimes used interchangeably with the terms remedial action, removal action, response action, or corrective action.

colloid(s)—Very small solids that do not dissolve and remain dispersed in a liquid for a long time due to their small size and electrical charge.

combined sewer overflow (CSO)—Discharge which occurs when system storage and conveyance capacity are exceeded during large wet-weather events, resulting in sanitary wastewater and storm-water overflow discharging directly to the receiving body of water.

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)—A 1980 federal law authorizing USEPA to respond to releases or threatened releases of hazardous substances that may endanger public health or the environment (also see Superfund).

conceptual site model (CSM)—A written and/or schematic representation of an environmental system and the physical, chemical, and biological processes that affect the transport of chemicals from sources through environmental media (i.e., air, soil, water, sediment or tissue) to humans and ecological receptors in the system. The CSM is often revised periodically as additional data become available at a site.

confined aquifer—An aquifer in which groundwater is confined under pressure which is significantly greater than atmospheric pressure.

congener—One of many related individual chemicals having similar chemical structure but different precise composition (e.g., PCB congeners each have two phenyl rings, but differ in the number and position of chlorine atoms).

copper—A metal found naturally in the ground and used extensively in household plumbing. High levels of copper may impact human and ecological receptors.

column settling test (CST)—Test designed to determine the settling behavior of suspended sediment.

degradation—A type of organic chemical reaction in which a compound is converted, in stages, into a simpler compound.

dense non-aqueous-phase liquid (DNAPL)—Chemicals in liquid form, such as chlorinated hydrocarbon solvents or petroleum fractions, with specific gravities greater than 1.0 that sink through the water column until they reach a confining layer.

dermal absorption/penetration—A route of chemical exposure whereby a chemical may be absorbed by or penetrate the skin and enter the body.

dermal exposure (contact)—Contact between a chemical and the skin.

desorption—The release of a chemical from the surface of a solid material (e.g., a sediment particle) to water (e.g., water in or overlying the sediment).

detection limit—The lowest concentration of a chemical that can reliably be distinguished from a zero concentration.

diffusion—The movement of particles or dissolved chemical-species from higher chemical potential to lower chemical potential (such as is represented by a difference in concentration).

dredging—The removal of sediment from the bottom of water bodies. Dredging may be subject to regulation under Section 404 of the Clean Water Act.

dredge elutriate test (DRET)—A laboratory test to predict the concentration of contaminants in the water column at the point of dredging. It involves mixing sediment and site water, allowing the heavier solid particles to settle, and analyzing for dissolved and particulate-bound contaminants.

dredge prism—Required dredge dimensions and zones.

ecological risk assessment (ERA)—The process of evaluating the likelihood that adverse ecological effects may occur or are occurring as a result of exposure of ecological receptors to environmental stressors, including chemicals.

ecosystem—The interacting system of interdependent biological organisms and their nonliving environmental surroundings.

effluent—Liquid waste (treated or untreated) that flows out of a treatment plant, sewer, or industrial outfall.

elutriate—To purify or separate a substance or mixture by washing and straining or decanting.

enhanced natural recovery—A process that adds non-contaminated material such as sand as a top layer to the sediment. The process reduces the contaminant concentration in the biologically active zone and speeds up the natural recovery process.

erosion—The wearing away of land surface by wind or water, intensified by land-clearing practices related to farming, residential or industrial development, road building, or logging.

estuary—A semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage.

exposure—Contact between an organism or biological system and a chemical, physical, or biological agent. Exposure may be expressed as the concentration in a given environmental medium (i.e., air, water, soil, sediment, or tissue) at the point of contact (see exposure point concentration) or as the concentration that is taken up by an organism (i.e., a dose).

exposure assessment—Measurement or estimation of the magnitude, frequency, duration, and route of exposure to stressors.

exposure pathway—The path from sources of chemicals to humans and ecological receptors from contaminated media including air, soil, sediment, water, or food.

exposure point concentration (EPC)—The concentration of a contaminant at the location where exposure occurs.

exposure route—The way a contaminant enters an organism after contact; i.e., by ingestion, inhalation, or dermal absorption.

exposure scenario—A tool to develop estimates of potential exposure, dose, and risk. An exposure scenario generally includes facts, data, assumptions, inferences, and sometimes professional judgment about how the exposure takes place.

***ex situ* treatment (sediment)—**The processing of dredged sediments to transform or destroy COC at a separate location from where they were collected. It often involves a combination of processes or treatment to address various contaminant problems, and includes pretreatment, operational treatment, and/or effluent treatment/residual handling.

flocculant—chemicals that promote flocculation by causing suspended particles in liquids to aggregate, forming a floc.

flux—The rate of flow of liquid or discharge, or the transfer of a chemical substance that is the product of the water flow and substance concentration.

food web model—A graphical and mathematical model that describes the feeding relationships by which energy and nutrients are transferred from one species to another.

Gastropods—Any mollusk of the class Gastropoda, such as snails, whelks, and slugs.

groundwater—Water beneath the surface of the Earth, usually in aquifers, which supplies wells and springs.

groundwater discharge—Groundwater entering a water body (e.g., lake, river, or coastal marine waters).

groundwater plume—An area of contaminated groundwater moving through the subsurface by advection and dispersion.

groundwater seep—Groundwater discharge that is visible at or above the ground surface.

habitat—The place where a population (e.g. human, animal, plant, microorganism) lives and its surroundings.

hazard index (HI)—An indication of the potential for non-cancer effects that is derived by summing the individual-chemical hazard quotients.

hazard quotient (HQ)—The ratio of estimated site-specific exposure to a single chemical to a selected toxicity threshold, which is either the level at which no adverse health effects are likely to occur (i.e., the no-observed-adverse-effect level) or at which effects are likely to occur (i.e., the lowest-observed-adverse-effect level).

hazardous substance—Substances identified as capable of posing "imminent and substantial danger to public health and welfare or the environment." CERCLA has identified more than 800 hazardous substances. The term does not include petroleum or natural gas.

hydraulic gradient—The slope of the groundwater potentiometric-surface expressed in feet of drop per foot of horizontal distance.

hydrodynamics—The study of liquids in motion.

hydrogeology—The study of the occurrence and movement of water below the surface of the Earth.

hydrograph—A record of the stage and/or discharge of a river as a function of time.

hydrophobic—Tending not to dissolve in, mix with, or be wetted by water.

infauna—The aggregate of organisms that burrow into and live in the bottom deposits of the ocean or other body of water.

infiltration—The penetration of water through the ground surface into subsurface soil or the penetration of water from the soil into sewer or other pipes through defective joints, connections, or manhole walls.

***in situ* treatment (sediment)—**Chemical, physical, or biological techniques for reducing COC concentrations while leaving the contaminated sediment mass in place.

intertidal—Relating to the region between the high tide mark and the low tide mark.

interstitial—Referring to the space between cells, atoms or molecules, or soil particles.

kriging—A method of statistical estimation which predicts unknown values from data observed at known locations.

leachate—Water that collects contaminants as it trickles through wastes or other materials, such as, pesticides, or fertilizers.

light non-aqueous-phase liquid (LNAPL)—A non-aqueous-phase liquid with a specific gravity less than 1.0. Because the specific gravity of water is 1.0, most LNAPLs float on top of the water table. Most common petroleum hydrocarbon fuels and lubricating oils are LNAPLs.

lowest observed adverse effect level (LOAEL)—The lowest level of a stressor that causes statistically and biologically significant differences between a test sample and a control sample (i.e., sample not subjected to a stressor).

matrix—The material in which the chemicals of interest are found (e.g., water, sediment, tissue).

media—Specific environmental materials—air, water, soil, and biological tissue.

mean higher-high-water—Average of the higher-high water height of each tidal day over a 19-year period.

mean lower-low-water (MLLW)—Average of the lower-low-water height of each tidal day over a 19-year period.

method detection limit (MDL)—The minimum concentration of a substance being analyzed that has a 99% probability of being identified.

Middle River Complex—the site of the Lockheed Martin Mission Systems & Sensors (MS2) facility; Applied NanoStructured Solutions (ANS), which is a Lockheed Martin subsidiary; and the General Electric Middle River Aircraft Systems (MRAS); also known locally as Plant 1.

model forcing functions—important factors that drive model output such as physical or other environmental parameters.

monitored natural recovery—A remedy for contaminated media, such as sediment, that typically uses ongoing naturally occurring processes to contain, destroy, or reduce the bioavailability or toxicity of contaminants in sediment.

National Pollutant Discharge Elimination System (NPDES)—A regulatory program enacted under the Clean Water Act that prohibits discharge of pollutants into waters of the United States unless a special permit is issued by USEPA, a state, or, where delegated, a tribal government.

***National Priorities List* (NPL)—**The USEPA list of the most serious uncontrolled or abandoned hazardous waste sites identified for possible long-term remedial action under Superfund. The list is based primarily on the score a site receives from the Hazard Ranking System. USEPA is required to update the NPL at least once a year. A site must be on the NPL to receive money from the Superfund Trust Fund for remedial action.

natural recovery—The breakdown of contaminants due to physical, chemical, and biological processes which occur in the environment, and the ability of the environment to rebound from the injuries caused by the contamination.

no observed adverse effect level (NOAEL)—The highest exposure level at which no statistically or biologically significant increases are observed in the frequency or severity of adverse effects between the exposed population and its appropriate control; some effects may be produced at this level, but they are not considered adverse, or as precursors to adverse effects. In an experiment with several NOAELs, the regulatory focus is primarily on the highest one, leading to the common usage of the term NOAEL as the highest exposure without adverse effects.

non-aqueous-phase liquid (NAPL)—Non-aqueous-phase liquids are sparingly soluble in water. They do not mix with water, so they form a separate phase. For example, oil is an NAPL because it does not mix with water, and oil and water in a glass will separate into two separate phases. NAPLs can be lighter than water (LNAPL) or denser than water (DNAPL). Hydrocarbons, such as oil and gasoline, and chlorinated solvents, such as trichloroethylene, are examples of NAPLs.

non-detect—Data point for which the chemical of interest was not detected in an environmental sample.

non-point sources—Diffuse pollution sources (i.e., without a single point of origin or not introduced into a receiving stream from a specific outlet). Common non-point sources are agriculture, forestry, urban, mining, construction, dams, channels, land disposal, and industry.

operable unit (OU)—The USEPA defines an operable unit as each of a number of separate activities undertaken as part of a Superfund site cleanup but it is also used to define a portion of a site with which activities are associated.

organic carbon (OC) normalized—A chemical concentration in sediment adjusted for organic carbon content. The chemical concentration is divided by the fraction of sediment that is organic carbon.

overdredge allowance—A construction design method for dredging that occurs outside the required dredge dimensions to compensate for physical conditions, side slopes, and inaccuracies in the dredging process and allow for efficient dredging practices.

oxic—A term describing an environment, a condition, or a habitat in which oxygen is present.

oxidation-reduction potential—The electric potential required to transfer electrons from one compound or element (the oxicant) to another compound (the reductant); used as a qualitative measure of the state of oxidation in water treatment systems.

paint filter test—The purpose of the test is to determine if liquids will be released from containerized sorbed wastes. The Paint Filter Test has been used to determine the presence of free liquids in bulk or containerized waste since 1985. It consists of placing a sample (normally 100ml or 100g) into a conical paint filter (mesh number 60). The paint filter is suspended from a tripod or ringstand for five minutes. If any portion of the material passes through and drops from the filter, the material is deemed to contain free liquids and cannot be disposed of in a landfill.

partition coefficient—An expression of the amount of a chemical that is adsorbed to sediment versus the amount of chemical that goes into solution (at equilibrium) providing an indication of whether a chemical might be dissolved and bioavailable or bound and not bioavailable.

pathway—An exposure pathway is the physical course a chemical, particle, or microbe takes from its source to an exposed organism.

percent fines—The sum of all silt and clay fractions in sediment; sediment particles passing U.S. standard sieve #230 (0.0625-mm openings).

permeability—The rate at which a liquid or gas flows through soil or other materials.

plume—A contiguous visible or measurable discharge of a substance or contaminants emanating from a given point of origin. Can be visible as, for example, a plume of smoke, or simply measureable, as for example, elevated concentrations of contaminants in a discharge plume in a river.

point source—A stationary location or fixed facility from which contaminants are discharged; any single identifiable source of pollution; e.g., a pipe, ditch, ship, ore pit, or factory smokestack.

polycyclic aromatic hydrocarbons (PAHs)—A group of chemicals formed during the incomplete burning of coal, oil, gas, wood, garbage or other organic substances. There are more than 100 different PAHs. They are also commonly found in asphalt paving and roofing materials and urban environments.

polychlorinated biphenyls (PCBs)—Mixtures of up to 209 individual chlorinated compounds. There are no known natural sources of PCBs. PCBs are either oily liquids or solids that are colorless to light yellow. Trade name of mixtures of PCBs are also known as aroclors.

porewater—Water in the interstices (i.e., small spaces) between sediment particles.

preliminary remediation goal (PRG)—An acceptable contaminant level or range of levels for a given medium that can be used to support an evaluation of remedial alternatives. Although the preliminary remediation goals are established based on readily available information, the final acceptable exposure levels should be determined on the basis of the results of the baseline risk assessment and the evaluation of the expected exposures and associated risks for each alternative.

proximal—Near.

quality assurance/quality control (QA/QC)—A system of procedures, checks, audits, and corrective actions to ensure that all research design and performance, environmental monitoring and sampling, and other technical and reporting activities are of the highest achievable quality.

reactive media—Material that will eliminate or reduce the availability of chemicals through physical, chemical, or biological processes.

reasonable maximum exposure—The maximum exposure reasonably expected to occur in a population.

receptor—A human demographic group (e.g., people who fish in a river) or ecological entity (e.g., species or group of species) that is potentially exposed to a stressor.

record of decision—A public document that provides documentation regarding which cleanup alternative(s) will be used at *National Priorities List* sites.

remedial action—The construction or implementation phase of a Superfund site cleanup that follows a remedial design.

residuals—Contaminants left at a site after the risks posed by the site have been reduced and the site conditions no longer poses a threat to people or the environment.

rinsate—Water containing low concentrations of contaminants resulting from cleaning sampling containers.

riparian zone—A transition habitat between the upland (terrestrial) zone and a water body resulting from frequent but not constant inundation of water. For the MRC FS study area, the riparian zone was defined as the portion of riverbank between approximately +13 feet to +22 feet NAVD88 vertical elevation.

risk—An estimate of the likelihood of adverse effects on human health or ecological receptors associated with exposure to given stressors.

risk assessment—Qualitative and quantitative evaluation of the potential risk posed to human health and/or the ecosystem by the actual or potential presence of a stressor (e.g., a toxic chemical).

risk characterization—The last phase of the risk assessment that estimates the potential for adverse human health or ecological effects to occur from exposure to a stressor and evaluates the uncertainty involved.

risk drivers—A chemical that has a significant impact on risk estimates and requires a risk management recommendation or action.

risk management—The process of evaluating and selecting alternative regulatory and non-regulatory responses to risk.

risk reduction—Lessening the risks, for example, from chemicals by lowering concentrations, mobility, bioavailability, or toxicity, or reducing exposure of receptors.

saturated zone—The area below the water table where all open spaces are filled with water.

sediment—Refers to materials, such as sand, silts, and clays that settle at the bottom of the water body. They come from eroding soil and are washed from the land into water, usually after rain or snowmelt. Sediment is found underwater in storm drains, ponds, lakes, creeks, streams, rivers, and oceans.

sediment removal—Removal of sediment by hydraulic or mechanical dredging. Removal may also include near-shore excavation.

sediment quality guideline (SQG)—A sediment chemical-concentration threshold that represents a documented association with no effects or a specified level of effect on benthic invertebrates. SQGs may be presented as a pair, with the lower concentration indicating a threshold below which adverse biological effects rarely occurred, and the upper concentration indicating a threshold above which adverse biological effects frequently occurred in the data set used to derive the SQGs.

semivolatile organic compound (SVOC)—Organic compounds that volatilize (i.e., vaporize) slowly at standard temperature (20 degrees Celsius and 1 atmosphere pressure).

shear stress—forces on the bottom sediments due to waves.

silt—Sediment composed of fine mineral particles that pass a #200 sieve.

site—Middle River Complex and associated environmentally impaired sediments.

solubility—A measure of how much a substance will dissolve in a liquid. Aqueous solubility is the maximum concentration of a chemical that will dissolve in pure water at a reference temperature.

sorption—A term describing adherence of chemical substances to particles. It includes either absorption or adsorption.

storm-water conveyance system—A system for the collection and transfer of storm water to a discharge point.

stressors—Physical, chemical, or biological conditions that can induce adverse effects on ecosystems or human health.

Superfund—The federal environmental cleanup program operated under the legislative authority of CERCLA and the 1984 Superfund Amendments and Reauthorization Act that addresses both emergency removal and long-term remedial activities. The Superfund program includes establishing the *National Priorities List*, investigating sites for inclusion on the list, determining their priority, and conducting and/or supervising cleanup and other remedial actions.

supernatant—the usually clear liquid overlying material deposited by settling, precipitation, or centrifugation

surface runoff—Precipitation, snow melt, or irrigation water in excess of what can infiltrate the soil surface and be stored in small surface depressions; it is a major mechanism for transport of non-point source contaminants to water bodies.

surface water—All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.).

surficial—Of or relating to a surface.

suspended loads (sediment)—Specific sediment particles maintained in the water column by turbulence and carried with the flow of water.

toxicity characteristic leaching procedure (TCLP)—Analytical procedure to simulate leaching from a soil or solid material.

threshold—The exposure level (concentration or dose) below which a significant adverse effect is not expected or above which a significant adverse effect is expected.

total petroleum hydrocarbons (TPH)—Measure of the concentration or mass of petroleum hydrocarbon constituents present in a given amount of soil or water.

toxic equivalent quotient (TEQ)—The sum of a series of multiplicative products, each consisting of the concentration of an individual carcinogenic polycyclic aromatic hydrocarbon, PCB, or dioxin/furan congener multiplied by its toxicity equivalency factor.

toxicity—The degree to which a chemical or mixture of chemicals can cause adverse effects to living organisms. *Acute toxicity* involves harmful effects in an organism through a single or short-term exposure. *Chronic toxicity* is the characteristic of a chemical or mixture of chemicals to cause adverse effects, usually upon repeated or continuous exposure over an extended period, sometimes the entire life of the exposed organism. *Subchronic toxicity* is the characteristic of the chemical or mixture to cause effects after exposure that is intermediate between acute and chronic.

toxicity reference value (TRV)—A chemical concentration (or dose) threshold that represents a level of documented effect on a particular organism from exposure to the chemical (i.e., the minimum concentration at which adverse effects have been observed, or the maximum concentration at which no adverse effects have been observed).

toxicity testing—Biological testing (usually with an invertebrate, fish, or small mammal) to measure the adverse effects of a chemical, effluent, or environmental sample.

transformation (chemical)—A process that converts one chemical to another chemical by any number of chemical reaction or biological pathways.

trophic level—Each of several hierarchical levels in an ecosystem, comprising organisms that share the same function in the food chain and the same nutritional relationship to the primary sources of energy.

unconfined aquifer—An aquifer that is not confined by an overlying aquitard.

unsaturated zone—The area above the water table where soil pores are not fully saturated, although some water may be present. Also referred to as the vadose zone.

urban runoff—Storm water from city streets and adjacent domestic or commercial properties that carries contaminants of various kinds into the sewer systems and receiving waters.

volatile—Any substance that evaporates readily.

volatile organic compound (VOC)—Organic compound that generally has a boiling point below 150 °C and a vapor pressure greater than 0.1 millimeter of mercury.

volatilization—The conversion of a chemical substance from a liquid or solid state to a gaseous or vapor state by the application of heat, by reducing pressure, or by a combination of these processes.

water quality criteria—Chemical concentrations in surface water specified by environmental regulation and expected to render a body of water suitable for its designated use. Criteria are based on specific levels of chemicals that would make the water safe for aquatic life or safe for human use for drinking, swimming, farming, fish production, or industrial processes.

weight of scientific evidence—The degree to which a body of scientific information supports a finding or conclusion. Considerations in assessing the weight of evidence in a risk assessment may include quality of testing methods, size, and power of study design, consistency of results across studies, and biological plausibility of exposure-response relationships and statistical associations between stressors and effects.

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Executive Summary

Environmental stewardship is an important aspect of Lockheed Martin Corporation's (Lockheed Martin's) commitment to the communities in which Lockheed Martin operates. Consistent with this commitment, Lockheed Martin has assumed responsibility for the assessment and cleanup of environmental impacts associated with the Middle River Complex site. This report presents the feasibility study for the remediation of sediments adjacent to the Lockheed Martin Middle River Complex in Middle River, Maryland (Figure ES-1).

The site characterization investigations and risk assessments performed to date provide the information on the nature and extent of contamination, the nature of ongoing sources of contamination, the physical and chemical properties that influence the fate and transport of contaminants found at the site, and the risks to human health and the environment. The feasibility study describes and evaluates a range of remedial alternatives to address site risks through remediation of sediment contamination at the site. A recommended alternative for a final remedy is also provided in the feasibility study.

As part of Lockheed Martin's ongoing commitment to the Middle River Complex site and the surrounding community, Lockheed Martin established a community outreach program to inform and receive input from the community on potential remedial actions related to Middle River Complex sediments. Valuable feedback received through the community outreach process has been incorporated into this feasibility study.

This feasibility study was prepared as part of Lockheed Martin's Environmental Restoration Program. Although the Middle River Complex site is not addressed by the federal Superfund (a/k/a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) program, the feasibility study was prepared in accordance with the *Interim Final Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (United States Environmental Protection Agency [USEPA], 1988), as well as in accordance with the Maryland Department of the Environment (MDE) and USEPA regulatory requirements for the Lockheed Martin Middle River Complex site.

ES.1 SITE DESCRIPTION AND HISTORY

The Lockheed Martin Middle River Complex site is located at 2323 Eastern Boulevard in Middle River, Maryland. It is bounded by Eastern Boulevard (Route 150) to the north, Dark Head Cove to the south, Cow Pen Creek to the west, and Martin State Airport to the east.

In 1928, Glenn L. Martin, an early pioneer in aircraft manufacturing and the founder of the Glenn L. Martin Company (a Lockheed Martin heritage company), purchased land in Middle River, Maryland, to build and test aircraft. Today, Lockheed Martin assembles missile launch systems at one facility on site, and it leases another facility to Middle River Aircraft Systems, Inc., a subsidiary of General Electric Company, which manufactures and assembles aircraft parts. Other parcels of the land were sold over the years to industrial companies and to the state for operation of the Glenn L. Martin State Airport, known locally as Martin State Airport.

In the late 1990s, Lockheed Martin began environmental investigations at Middle River Complex. These investigations were performed to assess impacts from former industrial operations. Since then, Lockheed Martin has investigated groundwater, soil, air, and sediment at the Middle River Complex, and has performed some cleanup activities in upland storm drains. This feasibility study presents an evaluation of remedial alternatives and provides a recommended cleanup approach for sediment adjacent to the Middle River Complex.

Dark Head Cove and Cow Pen Creek are tidal surface water bodies that feed into Dark Head Creek, a tributary to Middle River, which is a tributary to Chesapeake Bay. The facility lies approximately 3.2 miles upstream of Chesapeake Bay. A portion of Middle River is a federal navigation channel within the United States Army Corps of Engineers (USACE) Baltimore District jurisdiction.

ES.2 NATURE AND EXTENT OF CONTAMINATION

The remedial investigation fieldwork for sediments was conducted from 2005 through 2011. Characterization investigations included chemical testing of surface and subsurface sediment samples, benthic macroinvertebrate and fish tissue samples, bioavailability testing of sediment and porewater, sediment age dating, sediment dewatering tests, benthic assessments, sediment stability analysis, and geotechnical testing.

Analytical data from surface and subsurface sediment samples show that polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and metals are the most frequently detected compounds in the sediments. The greatest detected concentrations of PCBs and PAHs were observed within Dark Head Cove along the shoreline and in shallow sediment near the outfalls of the Middle River Complex. Elevated metal concentrations, primarily cadmium, were observed within Cow Pen Creek, and in the deeper sediments of Dark Head Cove and Dark Head Creek. The spatial extent of potential contamination is illustrated in Figure ES-2.

ES.3 RISK SUMMARY

Chemicals of concern from the baseline human health risk assessment included polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs) expressed as benzo(a)pyrene equivalents (BaPEq), and arsenic, with PCBs presenting the highest potential risk.

The chemicals of concern in the sediment present a potential risk to human health through directly contacting the sediments (i.e., incidental ingestion and dermal contact) or by consuming fish taken from the study area. Cancer and non-cancer risk estimates developed for the consumption-of-fish exposure pathway exceed both United States Environmental Protection Agency and State of Maryland risk benchmarks. However, the PCB concentrations reported in fish tissue samples for the study area fall within the range of concentrations reported for the general Chesapeake Bay area.

The ecological risk assessment considered potential impacts to benthic (i.e., sediment dwelling) macroinvertebrates, (e.g., worms) fish, birds, and mammals. No risks were identified for birds, mammals, or fish. Potential risk was identified for benthic invertebrates through direct contact with contaminated sediment; due to several metals found at concentrations above which effects may be expected to occur to benthic organisms. Because of these results, site-specific studies were conducted to better evaluate potential risks to the benthic macroinvertebrates.

Sediment samples were also analyzed for acid-volatile sulfides and simultaneously extracted metals to determine whether the metals are bioavailable (i.e., potentially available for biological uptake). The results showed that metals are tightly bound to sulfides, as is common in estuarine environments where sulfides are abundant, and are therefore likely not bioavailable. A direct connection between these constituents and effects on the resident benthic community has not been made but cadmium, copper, lead, mercury, zinc, and total polychlorinated biphenyls have conservatively been identified as chemicals posing potential risks to benthic invertebrates and are therefore considered ecological chemicals of concern.

ES.4 REMEDIAL ACTION OBJECTIVES AND PRELIMINARY REMEDIATION GOALS

The remedial action objectives (RAOs) provide the foundation upon which preliminary remediation goals, cleanup levels, and remedial alternatives can be developed. The findings of the risk assessments described above were used to develop the RAOs for the feasibility study. The RAOs also guide the evaluation of remedial alternatives to ensure the recommended alternative(s) will protect human health and ecological receptors. The following RAOs have been defined for the cleanup of the Middle River Complex site:

- **Remedial Action Objective 1**: Reduce, to the extent practicable, human health risks associated with the consumption of resident fish by reducing bioavailable sediment concentrations of chemicals of concern.
- **Remedial Action Objective 2**: Reduce, to the extent practicable, human health risks associated with exposure to chemicals of concern through direct contact with sediments and incidental sediment ingestion by reducing sediment concentrations of chemicals of concern.
- **Remedial Action Objective 3**: Reduce, to the extent practicable, risks to benthic macroinvertebrates by reducing bioavailable sediment concentrations of chemicals of concern.

Preliminary remediation goals define target sediment concentrations that adequately protect human health and the environment and achieve the risk reductions identified for each remedial action objective. These preliminary remediation goals are applied either on a point basis or across the site on a site-wide area weighted-average basis, depending on the exposure pathway being addressed. The preliminary remediation goals will be evaluated by the Maryland Department of the Environment and the United States Environmental Protection Agency; final cleanup levels will be identified in the approval documents from the regulators.

ES.5 REMEDIAL ALTERNATIVES

The remedial alternatives evaluated in this feasibility study comprise a combination of remedial technologies intended to achieve the preliminary remediation goals associated with the remedial action objectives. The alternatives differ in the remedial action levels applied, the rate at which sediment-contaminant concentrations are reduced, and the type and scale of technologies used. A long list of remedial alternatives was assembled by combining one or more of the retained remedial technologies and process options which are removal (dredging), containment (capping/enhanced natural recovery), and *in situ* treatment as the primary active response actions for reducing risks, supplemented by passive measures (e.g., monitored natural recovery) as necessary to achieve remedial action objectives.

The long list of remedial alternatives was screened per United States Environmental Protection Agency guidance using three broad criteria (i.e., effectiveness, implementability, and cost) to reduce the number of alternatives that will undergo the detailed analysis. Input received from the community (through Lockheed Martin's community outreach process) and site-specific characteristics (e.g., chemical characteristics, sediment transport, sedimentation rates, navigation requirements, current use of waterway, land use, and future use considerations) were also considered during the screening process.

A short list of remedial alternatives was established for Middle River Complex sediments based on the initial screening process and community input (Table ES-1); the short list was retained from a longer list of 14 alternatives considered. The alternatives carried forward for detailed and comparative evaluation in this feasibility study are as follows:

- ***Alternative 1—No Action:*** This alternative is retained to provide a baseline against which to compare the other remedial alternatives.
- ***Alternative 3—Complete Removal:*** This alternative includes dredging the sediments with the highest concentrations of chemicals of concern wherever concentrations (at any depth) of these compounds are greater than cleanup levels. Complete removal includes two subalternatives (i.e., Alternatives 3A and 3B) that define the extent of removal; both are retained for further detailed evaluation.
- ***Alternative 4—Combined Action:*** The combined-action alternatives involve application of a combination of active and passive remedial technologies (i.e., removal, enhanced natural recovery, reactive enhanced natural recovery, *in situ* treatment, and monitored natural recovery) in the area of potential concern to address surface sediments. Five of the 10 subalternatives (i.e., 4F, 4G, 4H, 4I, 4J) were retained for further evaluation in this feasibility study. The performance of each subalternative in meeting project remedial action objectives is discussed below in the detailed and comparative evaluation of the alternatives.

ES.6 COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

The short list of remedial alternatives was evaluated in detail and compared against the two threshold and five primary balancing criteria that are prescribed by Comprehensive Environmental Response, Compensation, and Liability Act guidance. To be eligible for selection as the preferred alternative, each alternative must meet the two threshold criteria: (1) overall protectiveness of human health and the environment and (2) compliance with applicable or relevant and appropriate requirements of pertinent environmental laws. The primary balancing criteria against which the alternatives are evaluated include: long-term effectiveness and permanence; reduction of toxicity, mobility, and/or volume through treatment; short-term effectiveness; implementability; and cost.

Comparative evaluation of remedial alternatives was conducted using a qualitative comparative analysis and a more quantitative multi-criteria comparative analysis. The qualitative comparative analysis was done to evaluate the relative overall ranking of each remedial alternative. A five-star ranking system (corresponding to low, low-medium, medium, medium-high, and high levels) is used to assess the relative performance of each alternative (Table ES-2).

A more quantitative comparative-rankings analysis provided an evaluation of the relative overall ranking of each remedial alternative. Multi-criteria-decision methodology was used to distinguish more thoroughly the similarities and differences among the alternatives. A multi-parameter analysis tool, Criterium Decision Plus® (CDP), was used to weight and score the criteria of the remedial alternatives for the Middle River Complex site.

Results of detailed and comparative evaluation of the threshold and balancing criteria based on qualitative and multi-criteria quantitative analysis are summarized below.

***Overall protection of human health and the environment*—**Alternative 1, the No Action alternative, takes no measures to protect human health and the environment. Other alternatives meet the threshold criterion of overall protection of human health and the environment by: achieving the remedial action objectives via implementation of the engineered remedy; and providing monitoring to ensure that the preliminary remediation goals associated with the remedial action objectives are achieved.

All of the remedial alternatives evaluated (excluding No Action) would include institutional controls such as public outreach, education, as well as the on-going regional Middle River seafood consumption advisories issued by Maryland Department of Environment.

In summary, Alternatives 3 and 4 achieve the threshold criterion of overall protection of human health and the environment, and achieve project remedial action objectives through implementation of an engineered remedy. Alternative 1 does not achieve this threshold criterion.

***Compliance with applicable or relevant and appropriate requirements*—**All alternatives except Alternative 1 (No Action) comply with federal and state chemical- and location-specific applicable or relevant and appropriate requirements. Adequate engineering planning, design, and regulatory review would ensure that the remedies comply with these requirements.

***Long-term effectiveness and permanence*—**General analysis factors considered in the comparative evaluation of the long-term effectiveness and permanence of the alternatives include preventing human health risks, minimizing ecological risks, assessing residual potential risk, and technology reliability.

Human health remedial action objective (RAO) 1 (associated with fish consumption) would be achieved at the end of construction under the combined-action alternatives 4F, 4G, 4I, and 4J (with less removal volume than would be achieved under the complete-removal alternatives). Alternatives 3 and 4 achieve human health direct-contact remedial action objective 2 at the end of construction. Alternatives 3A, 3B, and 4F achieve benthic remedial action objective 3 at the end of the construction. Other alternatives achieve this objective within 82 to 93% of the area of potential concern by the end of construction.

***Reductions in toxicity, mobility, and volume through treatment*—**No reduction of toxicity, mobility, or volume through treatment would be achieved under the No Action, complete removal, and the combined-action alternatives 4H and 4I because no treatment would be implemented. Alternatives 4F, 4G and 4J incorporate *in situ* treatment, and therefore do somewhat reduce toxicity, mobility, and volume. Under Alternative 4J, as much as 10% of contaminants are expected to be treated by reducing bioavailability; for Alternatives 4F and 4G, up to 20 to 40% of contaminants are expected to be managed by *in situ* treatment. The treatment is considered non-reversible, an important consideration in the evaluation.

Short-term effectiveness— Short-term effectiveness is a criterion that addresses impacts that result from implementation and active remediation. More dredging involves more construction, handling, and transportation, and is considered the least protective of workers; it also poses the greatest short-term risk to the environment and to the community.

No short-term impacts occur under No Action alternative. Removal alternatives would cause the greatest short-term impacts due to large removal volume and associated dredge components, and resulting energy use, air emissions, and impacts on water resources. The air pollution emissions generated from all combustion activities are correlated to the remedial action construction activities.

Implementability—This evaluation criterion incorporates consideration of the technical and administrative feasibility of implementing the remedial alternatives, and the availability of services and materials.

Complete-removal alternatives have more complex technical and administrative (e.g., coordination with regulators) implementability issues due to the complexity of dredging and ancillary technologies (i.e., transporting, water management, disposal, monitoring, and residuals management). Similarly, Alternatives 4I and 4J, which are designed to remove more volume of material and require a longer construction period, have a comparatively higher potential for problems and delays than Alternatives 4H and 4G, which are designed to remove smaller volumes of material and have a shorter construction time. Alternative 4F involves reactive enhanced natural recovery (i.e., thin layer placement of sand mixed with activated carbon). The alternative has low administrative implementability, due to concerns that placement of the recovery layer reduces the federal navigation depth established for the Middle River.

Cost—This criterion provides a comparison of the capital costs (engineering, construction, and supplies) and annual or periodic costs (operation and maintenance costs, monitoring, institutional controls, and ongoing administration) of each alternative. Total cost for the alternatives range from $18.1 million (Alternative 4H) to $41.7 million (Alternative 3A). The total costs, which were developed to allow comparison of the remedial alternatives, are estimated with expected accuracies of -30 to +50%, in accordance with the USEPA (1988) guidance.

Modifying criteria—Evaluation of the modifying criteria will be completed after the proposed plan has been submitted to regulatory agencies and has been released for public review, and will follow analysis of public comment on the proposed plan. During development of this feasibility study, community input on remedial alternatives was received through Lockheed Martin's community outreach process and incorporated into the evaluation matrix.

ES.7 RECOMMENDED REMEDIAL ALTERNATIVE

The detailed and comparative evaluation of the candidate remedial alternatives identified Alternative 4G as the recommended alternative for implementation because of the following characteristics:

- Alternative 4G achieves site-specific preliminary remediation goals associated with remedial action objectives, and also achieves applicable or relevant and appropriate requirements, through implementation of an engineered remedy that includes contaminant removal, *in situ* treatment to reduce the mobility of contaminants, and monitored natural recovery.
- Alternative 4G scores the best among the alternatives under the Comprehensive Environmental Response, Compensation, and Liability Act balancing evaluation-criteria.
- The potential for re-exposure to remaining subsurface contamination is negligible. Localized impacts are unlikely to affect site-wide average concentrations. Achievement of remedial action objectives would be verified through monitoring. Contingency actions would be taken if necessary.
- Low risks would be posed to site workers, the community, and the environment during implementation.
- Technical and administrative implementability during construction is considered high.
- Well-established adequacy and reliability controls will ensure the integrity and performance of the remedy through a combination of monitoring, maintenance, and institutional controls that would be designed and implemented over the next 20 years following construction.
- Alternative 4G has the lowest environmental footprint (except for No Action and Alternative 4H) in terms of greenhouse gas emissions, fuel consumption, use of natural resources, and landfill volume requirements.
- Alternative 4G achieves equal overall benefits relative to other alternatives at a lower cost, providing the most cost-effective and protective remedy.

Alternative 4G includes the following:

- removal of about 48,800 cubic yards of contaminated sediments from more than 12.5 acres, targeting Cow Pen Creek and the area in front of the Dark Head Cove bulkhead

- *in situ* treatment of contaminated sediments over 8.5 acres (the remainder of the area of potential concern)

- monitored natural recovery of about 4 acres of the *in situ* treatment area

- shoreline stabilization, habitat enhancement, and riparian planting after the remedial construction, if necessary

- a long-term monitoring, operation, and maintenance program of *in situ* treatment areas to verify the remedy

- institutional controls entailing public outreach and education. Regional Middle River seafood consumption advisories issued by Maryland Department of Environment would continue

This alternative is estimated to cost $19.4 million. Figure ES-3 illustrates active remedial actions associated with the recommended alternative. The specific action areas will be refined during the design process.

ES.8 NEXT STEPS

This feasibility study for the remediation of Cow Pen Creek and Dark Head Cove sediments located adjacent to the Lockheed Martin Middle River Complex is scheduled to be submitted to Maryland Department of the Environment and the United States Environmental Protection Agency in winter 2012. Lockheed Martin will seek regulatory approval of this feasibility study and the supporting studies (i.e., the sediment risk assessment and the sediment characterization report). Upon approval of the cleanup plan, a public meeting and public comment period will be scheduled. Lockheed Martin is expecting to implement the remedial actions in 2015 – 2017.

Lockheed Martin is committed to its partnership with the Middle River community, and is committed to maintaining a high level of community involvement and outreach and communication as work progresses. Lockheed Martin will also hold information availability sessions with the community before the remedial construction begins. Lockheed Martin remains committed to two-way communication with the community to ensure that questions are answered and issues and concerns are addressed in a timely manner.

Table ES-1
Short List of Remedial Alternatives

Remedial Alternatives		Description/Highlights	Cost
No Action	1	• CERCLA baseline alternative used for comparison to other alternatives	None
Complete Removal	3A	• Removal of impacted sediments over the AOPC in CPC, DHC and Dark Head Creek • 143,200 cy removal • Remedial Action Objectives (RAOs) achieved at end of construction	$41.7M
	3B	• Removal of impacted sediments over the AOPC in CPC and DHC • 99,600 cy removal • RAOs achieved at end of construction	$30.2M
Combined Action	4F Partial Removal, Reactive ENR	• Removal in CPC, DHC bulkhead and outfalls. • 48,800 cy removal over 12.5 acres; 8.5 acre reactive ENR (13,800 cy); 8.5 acre long-term monitoring • RAOs achieved at end of construction	$21.5M
	4G Partial Removal, *In situ* Treatment, MNR	• Removal in CPC, DHC bulkhead and outfalls. • 48,800 cy removal over 12.5 acres; 8.5 acre in situ treatment; 3.7 acre MNR; 8.5 acre long-term monitoring • Progress towards human health RAOs is 99.5% • Benthic RAO is achieved at 93% of the AOPC; average 6 years of MNR to reach benthic RAO in remaining 7% of the AOPC	$19.4M
	4H Partial Removal at DHC, CPC, and MNR	• Removal in CPC, DHC bulkhead and outfalls. • 48,800 cy removal over 12.5 acres; 8.5 acre of MNR; 8.5 acre long-term monitoring • Progress towards human health RAOs is 82% • Benthic RAO is achieved at 82% of the AOPC; average 11 years of MNR to reach benthic RAO in remaining 18% of the AOPC	$18.1M
	4I Partial Removal at DHC, CPC, and MNR	• Removal in CPC, DHC bulkhead and outfalls, additional removal in DHC and in front of the Wilson Point Park over 3.5 acre • 62,900 cy removal over 16 acres; 5 acre MNR; 5 acre long-term monitoring • Human health RAOs achieved at the end of construction • Benthic RAO is achieved at 90% of the AOPC; average 5 years of MNR to reach benthic RAO in remaining 10% of the AOPC	$21.7M
	4J Partial Removal at DHC, CPC, *In situ* Treatment, MNR	• Removal in CPC, DHC bulkhead and outfalls, additional removal in DHC and in front of the Wilson Point Park over 3.5 acre • 62,900 cy removal over 16 acres; 2 acres in situ treatment; 3 acres MNR; 5 acre long-term monitoring • Human health RAOs achieved at end of construction • Benthic RAO is achieved at 93% of the AOPC; average 1 year of MNR to reach benthic RAO in remaining 7% of the AOPC	$22.1M

Acronyms:
CERCLA – Comprehensive Environmental Resource, Compensation, and Liability Act
CPC – Cow Pen Creek
cy – cubic yard
DHC – Dark Head Cove
ENR – enhanced natural recovery
MNR – monitored natural recovery
$M – million dollars
AOPC – area of potential concern
RAO – remedial action objective

Table ES-2

Qualitative Comparative Analysis of Remedial Alternatives

Evaluation Criteria		**Remedial Alternatives:** **1** No Action	**3A** Removal at CPC, DHC, Dark Head Creek	**3B** Removal at CPC, DHC	**4F** Partial Removal, Reactive ENR	**4G** Partial Removal, *In situ* Treatment, MNR	**4H** Partial Removal, MNR	**4I** Partial+ Removal, MNR	**4J** Partial+ Removal, *In situ* Treatment, MNR
Overall Protection of Human Health and Environment	Achieve RAOs	All remedial alternatives achieve RAOs at varying performance. No Action is considered not achieving RAOs due to unacceptable risks to human health and environment until it meets the RAOs in a timeframe of about 100 years.							
	Time to Achieve Human Health RAOs (RAO 1 and RAO 2)	No Action achieves RAO 1 in 30 years. Alternatives 3A, 3B, 4F, 4I, and 4J achieve RAO 1 at the end of construction. Alternatives 4G and 4H achieve RAO 1 in one year and 10 years respectively. All alternatives except No Action achieve RAO 2 at the end of construction.							
		*	*****	*****	*****	*****	***	*****	*****
	Time to Achieve Benthic RAOs (RAO 3)	No Action achieves RAO 3 in 100 years. Alternatives 3A, 3B, 4F achieve RAO 3 at the end of construction. Alternatives 4G achieves RAO 3 up to 13 years; Alternative 4H up to 26 years; Alternative 4I up to 12 years, Alternative 4J up to 3 years.							
		*	*****	*****	*****	***	**	***	****
Compliance with ARARs		Not expected to comply	All remedial alternatives comply with ARARs						
		*	*****	*****	*****	*****	*****	*****	*****
Long-term Effectiveness		Long-term effectiveness is considered higher for removal-focus and larger removal alternatives than the alternatives relying on effectiveness of *in situ* treatment and MNR.							
		*	*****	*****	****	***	***	****	****
Short-term Effectiveness		Short-term impacts are higher for removal-focus alternatives and increase with increased removal volume.							
		*****	*	**	****	****	****	***	***
Implementability		Implementability of removal-focus alternatives is less than the combined action alternatives. Potential for technical and administrative difficulties, schedule delays increase with the dredge volume. Alternative 4F has low administrative implementability due to navigation channel status of Middle River.							
		*****	*	**	**	****	****	***	***
Cost		*****	*	**	***	***	*****	***	***
Modifying Criteria (Regulatory and Public Acceptance)		Regulatory acceptance is not ranked at this time. Public acceptance is ranked based on the input received from the community.							
		*	**	***	*****	*****	***	****	*****
	Overall Summary =	**	**	***	*****	*****	****	****	*****

Ranking Index =	*	**	***	****	*****
	Low	Low-Medium	Medium	Medium-High	High

CPC=Cow Pen Creek; DHC=Dark Head Cove; RAO=Remedial action objective, MNR=Monitored natural recovery; ENR=Enhanced natural recovery; ARAR=Applicable or relevant and appropriate requirements

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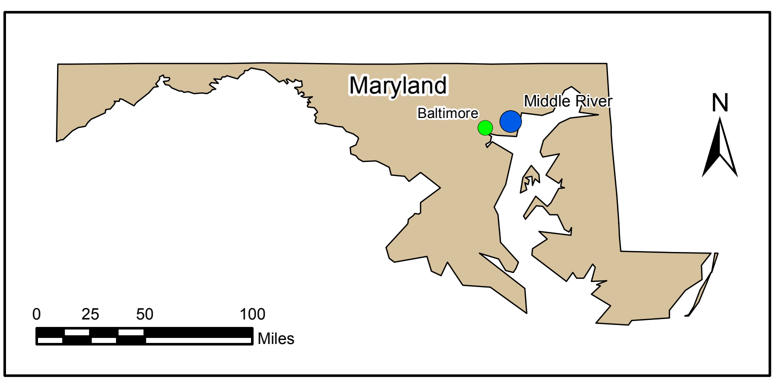

Figure ES-1

Middle River Complex
Site Location and Vicinity Map

Lockheed Martin Middle River Complex
Middle River, Maryland

DATE MODIFIED: 8/21/12	CREATED BY: MP

TETRA TECH

TETRA TECH

Figure ES-2
Area of Potential Concern
Lockheed Martin Middle River Complex (MRC)
Middle River, Maryland

Legend

- Stormwater Outfall Locations
- No Action (Polygon < PRG/RAL)
- Area of Potential Concern
- Buildings/Roads
- 101 Thiessen Polygons and Sample Location Number

PRG = Preliminary Remediation Goal
RAL = Remedial Action Level

500 250 0 500
Feet

Drawn By: T. WHEATON 05/27/11
Checked By: S. OZKAN 11/19/12
Approved By:

Contract Number: 112IC02903

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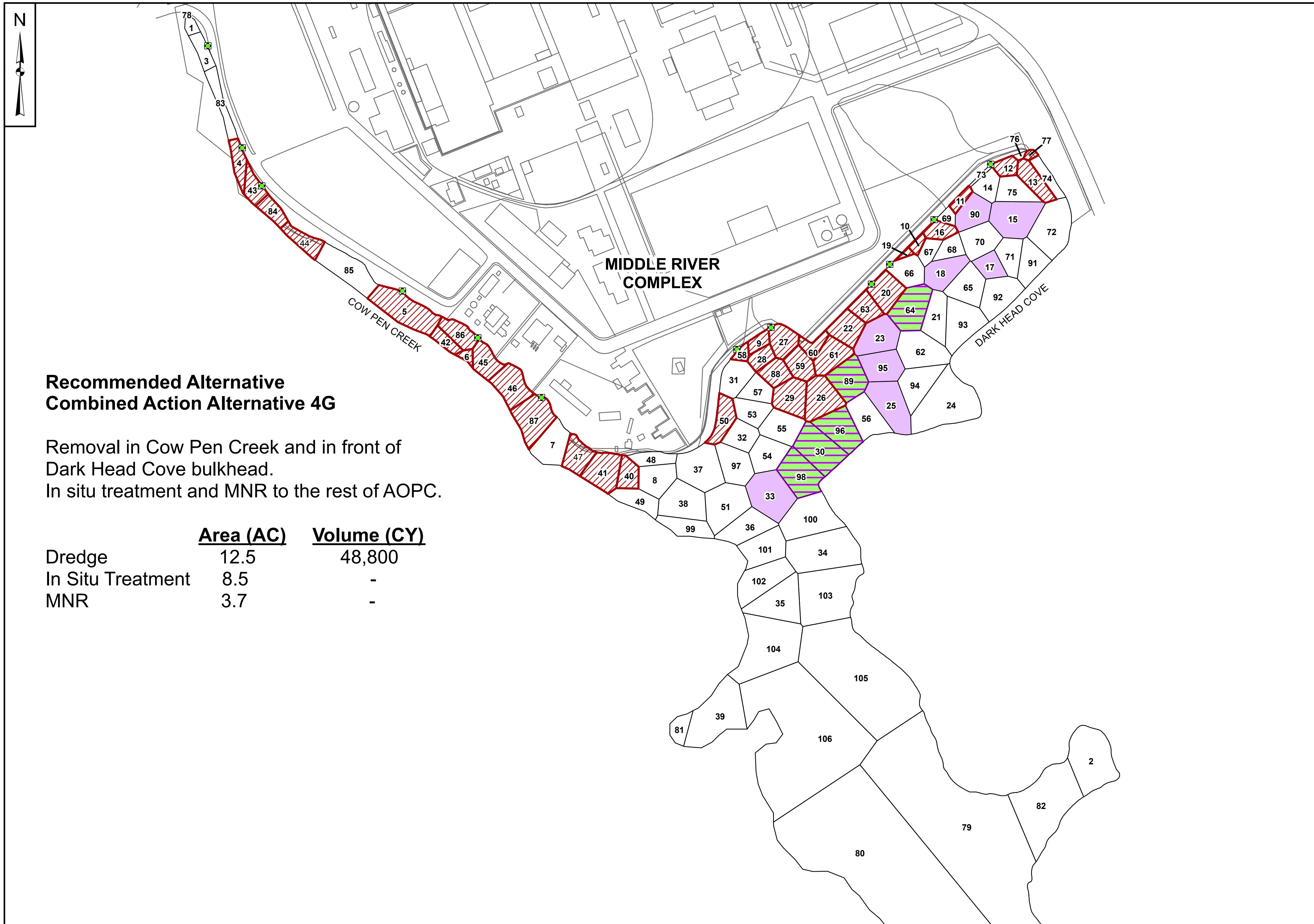

Recommended Alternative
Combined Action Alternative 4G

Removal in Cow Pen Creek and in front of Dark Head Cove bulkhead.
In situ treatment and MNR to the rest of AOPC.

	Area (AC)	Volume (CY)
Dredge	12.5	48,800
In Situ Treatment	8.5	-
MNR	3.7	-

TETRA TECH

Figure ES-3
Recommended Alternative
Alternative 4G
Combined Action
Lockheed Martin Middle River Complex (MRC)
Middle River, Maryland

Legend

- Stormwater Outfall Locations
- No Action (Polygon < PRG/RAL)
- In Situ Treatment
- In Situ Treatment + MNR
- Removal
- Buildings/Roads
- 101 Thiessen Polygons and Sample Location Number

PRG = Preliminary Remediation Goal
RAL = Remedial Action Level
MNR = Monitored Natural Recovery
AOPC = Area of Potential Concern

500 250 0 500 Feet

Drawn By: T. WHEATON 07/05/11
Checked By: S. OZKAN 11/19/12
Approved By:

Contract Number: 112IC02903

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Section 1
Introduction

This feasibility study (FS) summarizes the results of the remedial investigations and evaluations that have been completed by the Lockheed Martin Corporation (Lockheed Martin) for the remediation of sediments located adjacent to the Lockheed Martin Middle River Complex in Middle River, Maryland (Figure 1-1). This FS has been prepared as part of Lockheed Martin's Environmental Restoration Program. Although the Middle River Complex (MRC) site is not part of the federal Superfund (a/k/a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) program, the FS was prepared in accordance with CERCLA guidance (United States Environmental Protection Agency [USEPA], 1988), as well as in accordance with Maryland Department of the Environment (MDE) requirements for the environmentally impaired sediments associated with the Lockheed Martin Middle River Complex (referred to herein as the MRC or the site).

1.1 REGULATORY BACKGROUND

The waters adjacent to the Middle River Complex are considered waters of the United States and are regulated by the State of Maryland. The proposed sediment remediation at the Middle River Complex will be performed with the oversight of the MDE Controlled Hazardous Substance Enforcement Division of its Environmental Restoration and Redevelopment Program (also known as the state Superfund program). The Maryland Superfund division oversees the assessment and cleanup of historically contaminated hazardous waste sites in Maryland that have not been placed on the *National Priorities List* (NPL). Because polychlorinated biphenyls (PCBs) are in site sediments at concentrations greater than 50 parts per million (ppm), the USEPA also has jurisdiction under the Toxic Substances Control Act (TSCA) and its implementing regulations.

1.2 PURPOSE AND SCOPE

The purpose of a FS is to identify and evaluate remedial alternatives to prevent, mitigate, respond to, or remedy releases or threatened releases of hazardous substances, pollutants, or contaminants at or from the site. This Middle River Complex FS was conducted in accordance with CERCLA, the *National Contingency Plan* (NCP), the MDE requirements for the Lockheed Martin Middle River Complex, and other relevant USEPA guidance. This work was also performed in accordance with the *Interim Final Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (USEPA, 1988, or subsequently issued guidance) and the *Guidance for Data Usability in Risk Assessment* (USEPA, 1992 or subsequently issued guidance).

The FS is the mechanism for evaluating and screening remedial technologies to ensure that appropriate remedial alternatives are developed and evaluated. This document presents relevant information regarding potential remedies available for the site and the methods used to select an appropriate remedy. This FS focuses on identifying remedial alternatives to address the contaminated sediments located adjacent to the MRC and within Cow Pen Creek, Dark Head Cove, and Dark Head Creek. The data and information used to develop this FS were previously reported in the documents discussed below.

1.3 PRE-FEASIBILITY STUDY DELIVERABLES

Several reports have been prepared and submitted to MDE and USEPA, in accordance with federal and state regulations. Those deliverables have helped all parties reach consensus regarding important remedial investigation findings, conclusions, and recommendations completed in advance of this FS. Deliverables submitted to or prepared for submission to regulatory agencies for review before this FS include the following:

- ***Surface Water and Sediment Sampling Report*** **(Tetra Tech, 2006):** This document includes results of sediment sampling, site surveying, and reconnaissance activities; submitted to both agencies for review in 2006.

- ***Additional Characterization and Sediment Sampling Data Summary Report*** **(Tetra Tech, 2011a):** This document includes information regarding field and laboratory testing and treatability studies,and provides additional data regarding sediment stratigraphy and geotechnical properties; submitted to both agencies for review in 2011.

- ***Fish Tissue Report*** **(Tetra Tech, 2011b):** This document, also submitted to federal and state regulators in 2011, includes fish tissue sampling results from fish collected in the study area.

- ***Sediment Risk Assessment*** **(Tetra Tech, 2011c):** This document is the most recent risk assessment prepared for sediments at the site, and includes both a human health and ecological risk assessment. It was submitted to the USEPA and MDE in 2011.

- ***Additional Sediment Characterization Report*** **(Tetra Tech, 2012a):** This document, which further characterizes site sediments, is undergoing internal review and has not yet been submitted to the regulators. However, the data from that study were considered in preparation of this FS. This report contains further characterization of site sediments and includes geotechnical data and investigation results. The results of sediment dewatering-elutriate tests, field vane-shear tests, column settling tests, and dredge elutriate tests are also included in this report.

1.4 FEASIBILITY STUDY REPORT ORGANIZATION

This FS incorporates the findings of the extensive sampling program that has been conducted in and on sediments adjacent to the Middle River Complex, and the results of human health and ecological risk assessments of site sediments. The results of the site characterization investigation and risk assessment studies culminate in the identification of potential risks, and define the study area boundary used in the FS. This document is organized as follows:

Executive Summary: Provides a brief overview of site background, the remedial alternative evaluation process, and the recommended alternative.

Section 1.0—Introduction: Provides general project background and the purpose and scope of the FS report.

Section 2.0—Site Background and Current Conditions: Presents background and environmental setting information regarding the site and surrounding area. The section includes a conceptual model overview for the site, and discussions of previous investigations and remediation activities, the nature and extent of the contamination, potential source areas, and pathways to site sediments. This section also includes a discussion regarding source control measures undertaken and a summary of the baseline ecological and human health risk assessments.

Section 3.0—Remedial Action Objectives and Preliminary Remediation Goals: Summarizes the remedial action objectives (RAOs) developed for the site (based on the risk assessments) and identifies the preliminary remediation goals (PRGs) that will achieve the remedial action objectives.

Section 4.0—Screening of Remedial Technologies and Process Options: Summarizes the identification and screening of the remedial technologies and process options applicable to the site.

Section 5.0—Development of Remedial Alternatives: Identifies potential remedial action areas and remedial action levels and summarizes the assembly and initial screening of representative remedial alternatives.

Section 6—Detailed Evaluation of Remedial Alternatives: Presents a detailed analysis of each remedial alternative retained for further evaluation. The detailed evaluation was performed in accordance with the *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (USEPA, 1988).

Section 7.0—Comparative Analysis of Remedial Alternatives: The comparative analysis section provides an evaluation of the relative performance of each alternative with respect to the nine CERCLA evaluation criteria. This detailed comparative evaluation of the candidate remedial alternatives led to the selection of one alternative, which will be recommended to the regulators for implementation at the site.

Section 8.0—Reference: Provides a complete list of the references cited in this document.

Tables and figures are included at the end of their respective sections. This document is also supported by the following appendices:

- Appendix A—Development of Human Health Preliminary Remediation Goals
- Appendix B—Development of Ecological Preliminary Remediation Goals
- Appendix C—Sediment Bathymetry Profiles
- Appendix D—Community Input to Remedial Alternatives
- Appendix E—Detailed Cost Estimates
- Appendix F—Estimation of Short-Term Effects, Environmental Footprint, and Sustainability Measures
- Appendix G—Criterium Decision Plus® Analysis

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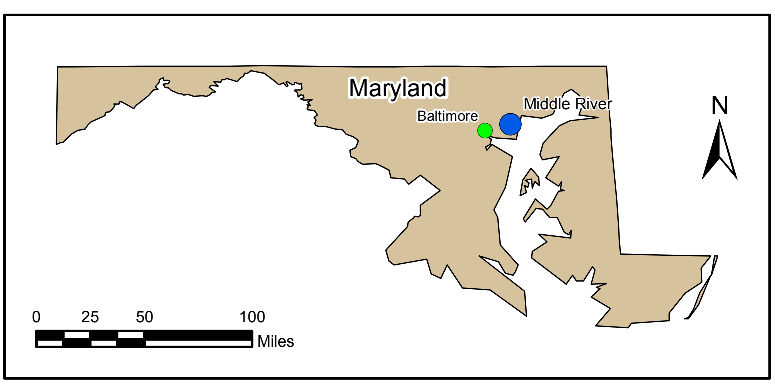

Figure 1-1

Middle River Complex
Site Location and Vicinity Map

Lockheed Martin Middle River Complex
Middle River, Maryland

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Section 2
Site Background and Current Conditions

This section describes the site and surrounding area, provides a narrative of the site operational and ownership history, and discusses the investigation/remedial history, areas of concern, and current site conditions. This section summarizes the Middle River Complex (MRC) site setting, including the following conditions:

- the nature and extent of contamination
- the location and extent of the identified contaminated area, including maps with sample collection sites cross-referenced to the sample identification numbers in the data summary
- potential contamination sources, pathways, and source control
- an overview of the conceptual site model
- a summary of the baseline human health and ecological risk assessments

2.1 MIDDLE RIVER COMPLEX SITE BACKGROUND

The Lockheed Martin Corporation (Lockheed Martin) MRC is located at 2323 Eastern Boulevard in Middle River, Maryland. Figure 2-1 is a facility layout map. The MRC consists of approximately 180 acres of land and 12 main buildings. It includes an active industrial area and yard, perimeter parking lots, an athletic field, a vacant lot with an extensive concrete slab, a trailer and parts storage lot, and numerous grassy areas along the facility perimeter. Locked chain-link fences surround all exterior lots and the main industrial area. The MRC is bounded by Eastern Boulevard (Route 150) to the north, Dark Head Cove to the south, Cow Pen Creek to the west, and Martin State Airport (MSA) to the east.

LMC Properties, Inc. (LMCPI), the current owner, conducts activities at the MRC that are limited to facility and building management and maintenance. The MRC has three main tenants: Middle River Aircraft Systems (MRAS), a wholly owned subsidiary of General Electric Company; Maritime Systems & Sensors (MS2)—Marine Systems; and Applied NanoStructured Solutions LLC (ANS), a Lockheed Martin subsidiary. MRAS designs, manufactures, fabricates, tests, overhauls, repairs, and maintains aeronautical structures, parts, and components for military and commercial applications. Maritime Systems & Sensors—Marine Systems fabricates, assembles, tests, and otherwise supports vertical-launch systems. The third tenant, ANS occupies a smaller portion of the site than the other tenants. ANS is involved in the development and commercialization of nanotechnology. Historically, the property has been used for aircraft and missile-launching systems design, development, manufacturing, and sales.

The facility is broken up into tax blocks, which segregate the MRC property into a series of land parcels for tax assessment purposes (Figure 2-1). This proved to be a convenient way to segregate the property for participation in the State of Maryland's Voluntary Cleanup Program.

2.2 ENVIRONMENTAL SETTING

This section presents general information regarding the environmental setting for the MRC site and relevant surrounding area. Current land use, residential establishments, site physiography, geology and hydrogeology, and navigation requirements are also discussed in this section.

2.2.1 Land Use

The MRC is an industrial facility within the broader Chesapeake Industrial Park. It is surrounded primarily by commercial, industrial, and residential establishments. Six other facilities, comprising the remainder of the Chesapeake Industrial Park, are adjacent to the MRC. These include Tilley Chemical Company, Inc. (a food- and pharmaceutical-chemical distributor for personal care and other industries), North American Electric (an industrial and commercial electrical contractor), Johnson and Towers (a heavy-duty diesel equipment, truck, and boat repair and maintenance company), Poly Seal Corp. (a producer of various flexible packaging types), Exxon (a gasoline filling station and convenience store), and the Middle River Post Office. Residential developments lie on the opposite shores of Cow Pen Creek, Dark Head Cove, and Dark Head Creek, as well as north of Route 150 and Eastern Boulevard (Figure 2-2).

2.2.2 Physiography

The site lies within the Western Shore of the Coastal Plain physiographic province. Coastal Plain topography is generally characterized by low relief. The MRC topography slopes gently from approximately 32 feet above mean sea level (MSL) to sea level (Cassell, 1977). The topography slopes from Eastern Boulevard to the southwest and south toward Cow Pen Creek and Dark Head Cove.

2.2.3 Geology, Hydrogeology, and Hydrology

Geologic maps of Baltimore County show that the MRC is underlain by the Potomac Group, a Cretaceous-age geologic group comprised of unconsolidated and interbedded layers of gravel, sand, silt, and clay ranging from zero to 800 feet thick. Soils logging beneath the MRC (conducted during extensive site characterization activities) identified a very heterogeneous substrate. The underlying soils are composed primarily of silty sands, fine- to medium-grained sands, silty clays, clayey silts, and plastic clay, with the primary lithology being clay to silty clay. Sand lenses were encountered, but do not appear to be continuous beneath the facility. Shallow groundwater tends to flow in the more sandy lenses toward the surface water bodies, and surface flow contours have a gradient similar to those of the overlying topography (Tetra Tech, 2012a).

The MRC lies at the junction of Cow Pen Creek and Dark Head Cove. Both are tidal surface water bodies that feed into Dark Head Creek, a tributary to Middle River, which is a tributary to Chesapeake Bay. The facility lies approximately 3.2 miles upstream of Chesapeake Bay. No surface water bodies lie within or cross the Lockheed Martin MRC. The average annual maximum water level range is approximately -2.0 feet MSL to +4.0 feet MSL. Storm water infiltrates into the surface soils at the MRC facility, or is collected as runoff by the facility's storm water management system and released through outfalls that discharge to Cow Pen Creek and/or Dark Head Cove (Figure 2-1). There are nine storm water outfalls at the MRC; however, only eight of the outfalls are currently permitted and actively used. There are some small areas immediately adjacent to Cow Pen Creek and Dark Head Creek from which runoff discharges as sheet flow directly into these water bodies. Other outfalls may have been used historically but are no longer in service. Storm water runoff from the Chesapeake Industrial Park and a portion of the MSA (across Wilson Point

Road), as well as from some of the area along Eastern Boulevard, is collected through a storm-water conveyance system and discharged to Cow Pen Creek and Dark Head Cove.

A Maryland National Pollutant Discharge Elimination System (NPDES) permit (surface industrial-discharge permit number 00DP0298, NPDES No. MD0002852) is maintained by LMCPI for the outfalls at MRC; it was issued by the Maryland Department of the Environment (MDE) Industrial Discharge Permits Division, Water Management Administration. The NPDES permit authorizes the discharge of facility storm water runoff from eight permitted discharge points (i.e., Outfalls 001, 002, 003, 004, 005, 006, 007, and 009; Outfall 008 is no longer in service). Sanitary wastewater and process wastewater is generated by MRAS. The facility pretreats and discharges wastewater under an industrial user discharge permit (permit number WWDP#1579), issued to MRAS by the Baltimore County Department of Public Works Bureau of Utilities (Baltimore County, 2011).

2.2.4 Navigation Requirements

A portion of Middle River and extending to Dark Head Cove is a federal navigation channel within the United States Army Corps of Engineers (USACE) Baltimore District jurisdiction. The USACE and the State of Maryland have concurrent jurisdiction over management of the channel. The navigation channel was constructed in 1940, and provides a channel totaling 3.7 miles (see Figure 2-3). The federally authorized navigation channel is 200 feet wide and 10 feet deep from the mouth of Middle River at Chesapeake Bay to the head of Dark Head Creek. In the branch of Dark Head Creek, an anchorage basin 10 feet deep, 2,000 feet long and generally 400 feet wide extends northeasterly from the head of the channel (i.e., Dark Head Cove).

The navigation project was completed in 1942, and the USACE has conducted reconnaissance surveys since then; to date, no additional dredging has been performed (Blama, 2012). The USACE completed the most recent reconnaissance survey on March 29, 2011. The current depths in Dark Head Cove as surveyed by the USACE range from -12 to -8 feet mean lower-low water (MLLW) (USACE, 2012).

2.3 SUMMARY OF PREVIOUS REMEDIAL INVESTIGATIONS AND ACTIVITIES

This section includes a summary of previous MRC upland remediation studies and activities, as well as sediment-related investigations and studies. The sediment studies include benthic and fish-tissue studies, site bathymetry, a sediment-age dating study, and studies of sediment hydrodynamic stability, sediment geotechnical characteristics, sediment settling characteristics, and dredging treatability.

2.3.1 Previous Upland Remediation Studies and Activities

The following environmental activities have been conducted at the Lockheed Martin MRC:

- underground storage tank closures and abandonments
- soil excavations
- Phase I environmental site assessment (ESA)
- Phase II ESA
- groundwater investigations
- sub-slab vapor intrusion investigations
- human health and ecological risk assessments

In a 2003 facility-wide Phase I ESA at Lockheed Martin MRC, thirteen recognized environmental concerns (RECs), associated primarily with current site conditions, were identified (Earth Tech, 2003). Subsequent review of historical site activities identified another 18 RECs at the facility (Tetra Tech, 2004). Many of the identified RECs are in the southern portion of the facility along the waterfront, and could have potentially contributed to sediment contamination. Soil and groundwater sampling at the RECs has identified sporadic impacts in soil and groundwater underlying the facility. As a result, the MRC upland has been entered into the MDE Voluntary Cleanup Program.

2.3.2 Previous Sediment-Related Investigations

Various MRC site investigations have identified surface water and sediment contamination resulting from historical landfilling and plant activities. Surface water and sediment impacts include elevated concentrations of polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and metals. Sediment samples were analyzed for PCB as Aroclors, (the most commonly known trade names for PCB mixtures manufactured from 1930 to 1979). With the exception of Aroclor-1016, the last two numbers in the trade name designation correspond to the percentage of chlorine by weight. Total PCBs (denoted herein as PCBs) equal the sum of detected Aroclor concentrations. In some parts of the feasibility study (FS) text, when specific Aroclors are not being referenced, the terms PCB(s) and Aroclor(s) may be used interchangeably.

Three in-water sampling investigations were performed at the MRC between 2005 and 2008. In March 2005, seven surface water and 12 sediment samples were collected; in October 2005, 10 surface water and 50 sediment samples were collected; and in November 2008, 146 sediment samples from four depth intervals were collected (Figure 2-4). Sampling depth intervals range from zero to six inches below ground surface (bgs), six to 18 inches bgs, 18 to 30 inches bgs, and 30 to 54 inches bgs. Samples were analyzed for volatile organic compounds (VOCs), semivolatile organic compound (SVOCs) including PAHs, PCBs, and priority pollutant metals.

A characterization of contaminated sediment was provided in the *Surface Water and Sediment Sampling Report* (Tetra Tech, 2006); this document also contained human health and ecological risk assessments for the surface water and sediments of Cow Pen Creek, Dark Head Cove, and Dark Head Creek. The 2006 human health risk assessment (HHRA) determined that non-cancer risks associated with both surface water and sediment were within a range acceptable to regulators, and that potential carcinogenic risks associated with surface water were less than the MDE risk threshold of 1×10^{-5} (or a one-in-100,000 incremental probability of developing cancer). The risk estimate was within the 1×10^{-4} to 1×10^{-6} United States Environmental Protection Agency (USEPA) cancer risk range and, more importantly, did not exceed 1×10^{-4}, the benchmark typically used to determine if further evaluation is necessary.

Potential carcinogenic risks due to exposure to sediment exceeded the MDE threshold, but fell within the USEPA acceptable risk range of 10^{-4} to 10^{-6} (an incremental increased lifetime cancer risk of one-in-10,000 to one-in-one-million). The primary contributors to risk included arsenic, PAHs, and PCBs.

The results of the 2006 ecological risk assessment (ERA) determined that both lower (benthic macroinvertebrates) and upper-trophic-level organisms (e.g., great blue heron) were potentially at risk. Cadmium in surface water, and barium, silver, and three PAHs (benzo(a)pyrene, benzo(g,h,i)perylene, and indeno(1,2,3-cd)pyrene) in sediment, were determined to be the major contributors to risk. In addition, mercury in the diet of great blue herons was also identified as an ecological concern through food chain modeling (based on sediment concentrations of mercury).

An additional sediment investigation was performed in 2010. Sediment samples were collected from 24 site locations, and from three sites that were located away from possible MRC influences to determine background conditions reflecting an urbanized coastal area. Sediment samples were collected from the surface (zero to six inches), six to 18 inches, 18 to 30 inches, and 30 to 52 inches below the surface water/sediment interface. These intervals are consistent with depths sampled during previous investigations and allowed for consistency in data evaluation and risk assessment. Sediment samples were analyzed for semivolatiles (including PAHs), PCBs, and metals. Several samples were also analyzed for acid-volatile sulfides (AVS)/simultaneously extracted metals (SEM). A summary of the risk assessment based on the 2010 data is presented in Section 2.6 of this report.

2.3.3 Benthic and Fish Tissue Studies

Benthic macroinvertebrate samples were collected in 2010 to evaluate the status of benthic communities residing in sediment at the site. Benthic macroinvertebrate samples were also collected from three background/reference locations (i.e., locations not affected by contaminants possibly leaving the site) and were used for comparison to site samples (Figure 2-5). Benthic macroinvertebrate samples were collected from seven site locations, including two in Cow Pen Creek and five in Dark Head Cove. Tetra Tech performed identical diversity and abundance assessments at the three reference areas to compare these locations with similar environments in the Middle River area.

The selected reference areas included one with little to no shoreline development (Marshy Point), one with typical regional waterfront development (i.e., Bowleys Quarters), and from the Middle River at a location upstream of the river’s confluence with Dark Head Creek presumably removed from possible MRC influences. Reference locations are shown in Figure 2-5. Reference locations were selected before mobilization to be representative of sediment conditions in an urbanized coastal area reflecting non-point runoff. None of the three reference locations appeared to be near any industrial point sources, and they had similar substrates to site locations. The final sampling locations in each reference area were selected in the field to avoid possible effects associated with any recognized industrial point-sources. Reference locations were confirmed with global positioning system (GPS) readings during field reconnaissance in the initial stages of fieldwork to ensure that the specific reference-sampling locations are similar in nature to the sampling locations in Cow Pen Creek and Dark Head Cove. The Middle River location was approximately 4,000 feet south of MRC, and approximately 2,000 feet upstream of the river's confluence with Dark Head Creek, at a location where it was presumed there would be limited to no influence from the MRC even with tidal movement. Sediment analytical data at this location indicated that concentrations of some metals in some of the depth intervals were elevated when compared to sediment concentrations in the Bowleys Quarters and Marshy Point samples. Whether the metals concentrations at this sampling location are due to MRC influence or to other sources is not clear. However, data from this sampling location suggests that it might not represent regional background conditions and would bias the background dataset high; therefore, chemical data from this location were excluded from the background data set.

Criteria to assess the similarity of reference sampling locations to site sampling locations included grain size, water depth, salinity, temperature, and pH (a measure of the acidity/alkalinity of a solution). Field instruments measured salinity, temperature, dissolved oxygen, and pH. Depth was measured with a tape, and grain size was evaluated qualitatively by comparison to a grain-size chart. To compare substrate from the reference locations, a composite sample was collected from each sampling location and analyzed for grain size, total organic carbon (TOC), PCBs, PAHs, and total priority pollutant metals. One reference site (Marshy Point), representing the most (comparatively) pristine local-area environmental conditions in an area with little to no shoreline development, had relatively good benthic conditions. The other two local reference sites, Bowleys Quarters and a remote downstream reference site in Middle River, are located in areas having typical regional waterfront development. Both sites showed some indications of conditions stressful for benthic macroinvertebrates.

Benthic macroinvertebrate fauna in tidally influenced brackish water vary spatially and are heterogeneous (patchy) in nature, so five individual grab samples were collected at each benthic sampling location in an effort to obtain representative analytical results. The individual grab samples from each location were collected from within an approximately 25-foot circle, taking care to avoid sampling the same sediment area twice. The five individual grab samples for each sampling location were composited at the laboratory and processed as a single sample. Some indications of stress to benthic organisms (i.e., a greater abundance of pollution-tolerant organisms than pollution-sensitive organisms) were found at all sites local to the MRC. However, some sites local to the MRC had a greater density of benthic organisms than the reference sites.

In 2010, fish samples were collected from five site locations and three reference locations to measure chemical concentrations in their tissue (Tetra Tech, 2011b). Site-associated fish collection locations included one in Cow Pen Creek, two in Dark Head Cove, and two at the confluence of the two water bodies. To compare these locations with similar environments in the Middle River area, samples of the same fish species were also collected from reference areas at Marshy Point, Bowleys Quarters, and Middle River.

Fish sampling protocols and the target species selected for fish tissue analyses were consistent with the MDE regional fish monitoring program. Targeted speciesfor collection and tissue residue analysis included the channel catfish and brown bullhead because both are demersal (i.e., bottom feeding) and expected to be resident (i.e., non-migratory). These fish are likely to accumulate chemicals from sediment and are edible (MDE Science Services Administration, 2009). Channel catfish were collected as proposed, but attempts to capture brown bullhead were unsuccessful. Sample collection goals identified in the work plan were met by collecting and submitting tissue samples from white catfish for tissue-residue analysis; white catfish is also a demersal species, and is a resident equivalent.

As discussed in the 2011 *Fish Tissue Report* (Tetra Tech, 2011b), concentrations of chemicals detected in fish tissue samples collected in the immediate vicinity of the MRC study area are similar to reference and regional concentrations. Average total PCB concentrations in channel catfish (the species most frequently collected in this study) were less than the average concentrations reported by MDE for regional samples collected from the Back River and Middle River (which most likely represent the region from which the site data were collected).

The PCBs with higher chlorine content bioaccumulate in fish through the food chain, resulting in a different level of residue in fish tissue compared to the levels detected in sediment samples. Metals concentrations in channel catfish from the site were generally similar to reference concentrations, based on a comparison of site versus reference-area average concentrations. Several metals detected in sediment were not detected in fish tissue, including cadmium, which had elevated concentrations in sediment samples collected from the site.

2.3.4 Bathymetry

Tetra Tech performed a bathymetric survey in Dark Head Cove, in accessible portions of Cow Pen Creek, and at the confluence of the two water bodies in August 2010 (see Figure 2-6). Tetra Tech used the research vessel *Storm*, a 21-foot jet boat configured with a dual-multibeam echosounder (MBE) system. The Middle River bathymetry survey mapped in high detail the morphology (form and structure) of Dark Head Cove and, to the extent possible (given the dense floating and semi-submerged vegetation), Cow Pen Creek. Water depths within the survey area ranged from 0.0 to 13.0 feet, and averaged 8.0 United States survey feet as referenced to MLLW, consistent with the USACE datum. These depths are shallower than the USACE survey depths for Dark Head Cove (as noted in Section 2.2.4), because bathymetric survey areas outside the navigation channel include Cow Pen Creek.

2.3.5 Sediment Stability

A hydrodynamic modeling analysis estimated the stability of bed sediment in Cow Pen Creek and the Dark Head Cove forks of Dark Head Creek relative to wind- and wave-generated bottom velocities and associated shear stresses (Tetra Tech, 2011a). The analysis considered simulation of two extreme events: a high rainfall event (100-year, 24-hour) in the Cow Pen Creek and Dark Head Creek watersheds, and a historical storm-surge and wind event associated with Hurricane Isabella during September 2003. Modeling results indicated that the MRC sediment bed is stable, except for the upstream area of Cow Pen Creek where a 100-year 24-hour storm event could transport material from upstream of Cow Pen Creek.

The USEPA Environmental Fluid Dynamic Code, which involved determining bed stresses during simulated events, was used for the modeling analysis. Model-forcing functions included runoff into Cow Pen Creek and Dark Head Cove, tidal water surface elevation at the mouth of Dark Head Creek, and wind forcing over the entire model domain. Modeled bed stresses are less than 0.1 Newton per square meter (N/m^2) over most of the study area, except for the upstream area of Cow Pen Creek, where the maximum stresses reach 4 N/m^2 (Tetra Tech, 2011a).

Field investigations of critical bed-stresses that could erode cohesive sediments in the Chesapeake Bay region (Maa, et al., 1998, 2002, 2008) indicate that 0.1 N/m^2 is a lower boundary for critical-erosion stress. Sand and non-cohesive silt beds are also stable at stresses below 0.1 N/m^2 (Garcia, 2008). Therefore, the general conclusion of the analysis is that the sediment bed is stable, except for the upstream area of Cow Pen Creek. The modeled 100-year 24-hour storm event could transport eroded material from within and upstream of Cow Pen Creek, outside of the study area.

During such an event, the corresponding suspended-sediment-concentration range modeled for the mouth of Dark Head Creek could be from 140 to 1,000 milligrams per liter (mg/L). An estimated erosion depth from the one-day event could be as much as 10 centimeters (cm), and would be anticipated to occur in the upstream area of Cow Pen Creek, where bed stresses would be the highest. However, conservatism is built into the hydrodynamic model, because the wind-induced stresses do not account for local sheltering effects. Due to the relatively sheltered nature of Dark Head Cove and Cow Pen Creek, normal tidal conditions, including monthly spring tides with a range of 1.58 feet (0.48 meter), are not anticipated to pose a potential for erosion.

Sediment stability can also be susceptible to disturbance during earthquakes. The site is in Seismic Zone 1, corresponding to an effective peak ground-acceleration of 0.075 of gravity (g) (*Uniform Building Code* [UBC], 2006). Probabilistic seismic-hazard analyses for the MRC site using United States Geological Survey (USGS) de-aggregation plots result in peak ground-accelerations of 0.006g, 0.02g, and 0.07g for nominal 100-year, 500-year, and 2,500-year events, respectively.

These peak ground-accelerations correspond to weak–to–light shaking, associated with no to very light potential damage (USGS, 2011). The significant central Virginia earthquake of August 23, 2011 was a magnitude 5.8 with peak ground-accelerations corresponding to an approximately 500-year event. This quake was felt in Baltimore, and caused light to moderate shaking. Resuspension of MRC sediments were not observed during this 500-year event. Due to very low seismic activity in the region, resuspension potential of MRC sediments due to a seismic event is considered negligible. MRC sediments are expected to remain stable under known regional seismic conditions.

2.3.6 Sediment Age Dating

Sediment-age dating enabled an evaluation of sediment stability, an estimate of the period during which chemicals of potential concern (COPC) may have been released to the sediments, and an assessment of rates of natural recovery. Sediment cores were collected from three locations in August 2010 and evaluated for sediment age, stability, and sedimentation rate. Sediment chronology work is based on analyzing for and interpreting the levels of the radioactive nuclides lead (Pb)-210 and cesium (Cs)-137 in samples taken at various depths in sediment cores. This analysis derives sedimentation rates and calendar dates for the sediments. Average inferred sedimentation rates at Dark Head Cove, Dark Head Creek, and at the mouth of Cow Pen Creek are estimated at 0.8 centimeters per year (cm/year), 1.3 cm/year, and 0.38 cm/year, respectively (Tetra Tech, 2011a). Average sedimentation rates and bed stresses estimated for a 100-year 24-hour storm event are illustrated in Figure 2-7.

2.3.7 Sediment Characterization

Most of the information presented in this section regarding characterization of site sediments was obtained from the *Additional Sediment Characterization Report* (Tetra Tech, 2012a). In December 2011, geotechnical cores and sediment samples were collected for the FS from selected locations distributed over the Middle River sediment study area to better characterize the sediment environment and substrate at the MRC. and to use these results in the remedial design. The locations of these sediment cores are shown in Figure 2-5; logs of the cores are in Appendix A of the *Additional Sediment Characterization Report* (Tetra Tech, 2012a).

Visual classification of the sediment cores and laboratory tests on selected sediment-core samples indicate that the top three to five feet of MRC sediments typically consist of elastic silt underlain by fat clay intermixed with lean clay, sandy lean clay, and sandy elastic silt. In Cow Pen Creek and the confluence of Dark Head Cove and Cow Pen Creek, the elastic silt stratum is typically underlain by fat clay. In Dark Head Cove, the elastic silt stratum is typically underlain by lean clay, sandy elastic silt, sandy lean clay, organic silt, and silty sand (Tetra Tech, 2012a).

2.3.8 Shear-Strength and Consolidation Characteristics

Shear-strength and consolidation characteristics of MRC sediments were investigated in December 2011. *In situ* field vane-shear and laboratory vane-shear tests were conducted to determine the strength properties of MRC sediments. The field and laboratory test results indicate that the upper 10 feet of MRC sediments are very soft (zero to 200 pounds per square foot [psf]) to soft (200 psf to 500 psf). *In situ* field vane-shear testing and laboratory vane-shear testing resulted in peak shear-strength values in the range of 10–292 (psf) and zero to 451 psf, respectively (Tetra Tech, 2012a). Peak shear-strength values were determined for the different soil strata of MRC sediments and are as follows:

- elastic silt: 10–99 psf
- lean clay: 59–233 psf
- fat clay: 20–179 psf
- sandy lean clay: 245–451 psf

Shear-strength properties provide information for analyses of the slope stability of dredge cuts, the bearing capacity of underlying sediments, backfill design, enhanced natural recovery or cap placement, and design of a cofferdam or temporary sheet-pile wall, if needed, to isolate the work area or divert Cow Pen Creek flow during sediment removal, if needed.

Consolidation tests determined the compressibility behavior of MRC sediments under potential loading of residuals-management backfill after dredging, enhanced natural recovery, or conventional sediment capping. Based on the test results, MRC sediments are expected to consolidate under the potential load of material placed over soft deposits. During remedial design, consolidation of MRC sediments under such potential loading will be considered in monitoring material placement operations and cap thickness (if applied) over time. Post–consolidation conditions (long–term settlement after placement of cap material) will also be considered for long–term design evaluations.

2.3.9 Column Settling Tests

A column settling test (CST) defines the anticipated settling behavior of sediments that may be dredged, and predicts the distance that suspended solids may travel. A CST also allows for the design of appropriate best management practices to avoid potential exceedances of water quality standards during dredging, help select appropriate potential dredging methods, and predict potential water quality effects.

Composite sediment samples were collected from locations across Dark Head Cove and Cow Pen Creek in December 2011 for the CSTs. The CST results from Cow Pen Creek samples demonstrate faster zone-settling during the first few hours of the test as compared to the Dark Head Cove test results, probably due to the sand content of the Cow Pen Creek sediments. However, as the CST progressed and the primary settling mechanism became flocculant settling in the column supernatant, the settling velocity of the creek sediment slowed until it resembled the settling rate of the Dark Head Cove sediments. The lowest total suspended solids (TSS) concentration that the CST for Cow Pen Creek sediments achieved was 200 mg/L, whereas the lowest TSS concentration achieved by the Dark Head Cove CST was 16 mg/L. Most of the sediments in the Dark Head Cove CSTs settled, and the supernatant clarified within approximately two days (Tetra Tech, 2012a).

2.3.10 Dewatering Elutriate Tests and Dredge Elutriate Tests

A dewatering elutriate test (known as a pillow test) and a dredge elutriate test (DRET) were conducted to identify potential treatment requirements for dewatering [ensuring that elutriates meet ambient water quality criteria (AWQC) before discharge], and to evaluate parameters that will affect potential dredging design. The DRET was performed on a composite of representative dredge material to assess potential contaminant mobility in the water column during dredging. During dredging, AWQC must be met before sediment dewatering elutriate can be discharged back to Dark Head Cove or Cow Pen Creek.

To identify possible treatment requirements to meet AWQC, elutriate samples were filtered to remove/reduce PCB concentrations associated with suspended sediment particles. Filtration sizes used in the test included a three- to five-micron filter paper to simulate a typical sand filter and a 0.45-micron filter paper to simulate the filtering effect of activated carbon (not including adsorption). Detection limits for Aroclors were not low enough to evaluate whether they meet applicable AWQC concentrations (0.014 micrograms per liter [µg/L]), but the laboratory performing the elutriate analyses did achieve a method detection limit of 0.2 µg/L. Therefore, the “treatment goal” for Aroclor is considered equivalent to the method detection limit, which was 0.2 µg/L at the time of the study.

The pillow test was performed on an 11% sediment slurry (original target slurry concentration was 10% solids) that was conditioned using a coagulant and flocculent (Solve 425 followed by

Solve 127) from WaterSolve, LLC. Once elutriate had been generated through the PT, an elutriate sample was collected from the composite container and analyzed for PCBs by USEPA Method 608 (Aroclors). Data suggest that Aroclor-1260 was the only PCB released into elutriate generated during the dewatering elutriate test, at a concentration of 0.3 µg/L. Filtration with the five-micrometer (µm) filter medium reduced the concentration of Aroclor-1260 to below detection limits (0.2 µg/L).

No Aroclors were released to the water column during the DRETs. Limited concentrations of PAHs (i.e., fluoranthene, pyrene) and metals were released to the water column during the DRETs. The metals and PAH compounds detected in the unfiltered samples appear to have been removed to below AWQC effluent limitations after filtration through a 0.45-µm filter medium. During the DRETs, cadmium and lead concentrations consistently exceeded AWQC in unfiltered samples. However, filtration through a 0.45-µm filter medium removed cadmium and lead concentrations to below AWQC (Tetra Tech, 2012a).

2.4 NATURE AND EXTENT OF CONTAMINATION

This summary of the nature and extent of site contamination includes a discussion of previous sediment data collected at the site in 2005 and 2008, as well as the 2010 sediment data.

2.4.1 Sediment Cores

The 2010 sediment investigation focused on areas where insufficient data were available from previous investigations. Sediment samples were collected in 2010 from 24 site and three reference locations. Sediment samples were collected from zero to six, six to 18, 18 to 30, and 30 to 52 inches below the surface-water/sediment interface. Sediment samples were analyzed for PAHs, PCBs, and metals. In addition, some sediment samples were analyzed for AVS/SEM.

Figures 2-8 to 2-18 show the distribution and the horizontal and vertical extent of chemical concentrations in MRC sediments, based on the analytical results obtained from the sediment samples collected between 2005 and 2010, in concert with the conclusions of the human health and ecological risk assessments., Each figure has four sections representing the four sampled depth-intervals. Distributions of COPC are presented in Thiessen polygons delineated around the sampling locations (i.e., with each line of the polygon representing half the distance to the adjacent sampling point). The chemical concentration assigned to each polygon is the concentration of the chemical in the sample taken within the polygon boundary.

2.4.1.1 PAHs

Concentrations of total PAH compounds detected in the site samples in 2010 ranged from 1.2 micrograms per kilogram (µg/kg) to 457,300 µg/kg (Figure 2-16). The range of benzo(a)pyrene equivalent (BaPEq) concentrations was 0.090 µg/kg to 38,387 µg/kg (Figure 2-17). Per USEPA guidelines, a BaPEq concentration is calculated from a group of seven carcinogenic PAHs and utilized for purposes of human health risk assessment. The highest concentrations of total PAHs (sum of all detected PAHs) were in samples collected along the shoreline of MRC and in Dark Head Cove. In surface sediment, the highest PAH concentrations were in samples collected from a location at the upper part of Cow Pen Creek, the eastern portion of Dark Head Cove (near MSA), and from the middle of the cove adjacent to the MRC property. The PAH concentrations tend to be higher in the middle two depth intervals (six to18 inches and 18 to 30 inches) than in surface sediment or the lowest interval, although the upper reaches of Cow Pen Creek also had elevated PAH concentrations in the top three intervals down to a 30-inch depth. The PAH concentrations were also elevated in sediment samples collected from the middle two intervals near Outfall 09. Overall, PAH results were consistent with previous findings.

2.4.1.2 PCBs

Detected concentrations of total Aroclors (PCBs) ranged from 11 µg/kg to 54,000 µg/kg (Figure 2-15). A site-wide surface area weighted-average concentrations (SWAC) was calculated for PCBs, using the areas and contaminant concentrations associated with each Thiessen polygon, with larger polygons given more weight in the calculation than smaller ploygons. The SWAC for total PCBs was 945 µg/kg. Surface sediment PCB concentrations were highest adjacent to the shoreline of the MRC complex and in the middle of Dark Head Cove. The areas with the most elevated concentrations were well bounded and defined by other samples with lower concentrations. These findings are similar to those found in previous investigations.

2.4.1.3 Metals

Several metals were detected in sediment at concentrations in excess of screening values. Metals of particular interest included cadmium, chromium, copper, lead, mercury, and zinc (Figures 2-8 through 2-13). In general, cadmium and chromium cocentrations exceededtheir respective sediment guideline concentrations more often than other metals (Figures 2-8 and 2-9 respectively). The greatest concentrations of metals in Dark Head Cove are generally found in samples from the six- to 18-inch and 18- to 30-inch depth intervals; this indicates that sediment with higher concentrations is being buried under cleaner sediments. In some areas in Cow Pen Creek, the highest concentrations were detected in the surface interval, which was expected because the deposition rate (as estimated from the age dating analysis) is probably lower in the creek, and the scour there appears to be greater than in Dark Head Cove.

2.4.2 Porewater

Sediment porewater was extracted (via centrifugation) at the laboratory from core depths corresponding to the top three intervals sampled (depths of zero to six, six to 18, and 18 to 30 inches) to determine the equilibrium concentrations of COPC in porewater (both horizontally and vertically) near the MRC. Porewater concentrations of arsenic, cadmium, selenium, and PAHs exceeded surface water ecological-screening values at all three intervals in one or more samples. Porewater concentrations of lead exceeded surface water ecological screening-values in one depth.

Aroclor-1260 concentrations exceeded surface water ecological screening-values in all porewater samples in which it was detected. Aroclor-1260 was reported as not detected in the 18–30 inch interval; however, the detection limit for Aroclor-1260 in that depth's sample(s) was greater than its screening level of 0.000074 µg/L. This means that Aroclor-1260 may be present in the sample at a concentration above its screening level, but below the analytical instrument's level of detection. As discussed further in Appendix B, the screening level is based on the Great Lakes water quality criteria for the protection of upper trophic level wildlife, and is not based on the protection of aquatic receptors such as benthic invertebrates. Other published Aroclor-1260 screening values that are protective of aquatic receptors range from 1.3 µg/L to 94 µg/L (Suter and Tsao, 1996). All PCB porewater detections were much lower than 1.3 µg/L, as were the analytical detection limits.

2.4.3 Contaminant Bioavailability

Various samples were collected and analyses performed to evaluate whether the chemicals in the sediment might be bioavailable to ecological receptors, including a comparison of sediment AVS to

SEM, sediment porewater chemistry analyses, and a benthic macroinvertebrate community study. Sediment samples from seven locations were collected from each depth interval and analyzed for AVS/SEM. Metals in the SEM analysis include cadmium, chromium, copper, lead, nickel, silver, and zinc. In general, concentrations of AVS were higher than SEM in most samples, indicating that simultaneously extracted metals were not be expected to be bioavailable or directly toxic to benthic macroinvertebrates.

One sample in the shallowest depth interval (six to 18 inch interval), and two in the 18–30 inch depth interval, had AVS/SEM ratios within a range the USEPA considers "uncertain" for potential toxicity to benthic macroinvertebrates (USEPA, 2005a). These are the only sampled locations where a potential for toxicity was indicated throughout the vertical sediment column. The AVS/SEM samples that had the potential for toxicity do not correspond to samples with the highest sediment concentrations of these metals.

2.5 PRELIMINARY CONCEPTUAL SITE MODEL OVERVIEW

A conceptual site model (CSM) for MRC sediments was produced as part of the exposure-assessment component of the *Sediment Risk Assessment* (Tetra Tech, 2011c); the exposure assessment provides an evaluation (either quantitatively or qualitatively) of the type and magnitude of exposure to chemicals at, or migrating from, a site. As the foundation of the exposure assessment, the CSM includes an illustration of both current and future scenarios for land use, and an identification of potential contaminant sources, contaminant release mechanisms, transport routes, receptors, and other appropriate information. Figure 2-18 illustrates the study area CSM, which is discussed in the following sections.

2.5.1 Sources of Environmental Contamination

Water bodies surrounding the MRC are subject to a variety of influences, given the highly developed nature of the area. Potential sources of contamination to Dark Head Cove and Cow Pen Creek include historical industrial discharges, surface spills, releases, and waste management activities, which may have been the primary sources of contamination. Other sources may include runoff from MSA, as well as from surrounding residential properties and roadways.

Results of previous sediment investigations, as well as investigations of the MRC tax blocks, indicate that the most likely source of PCB contamination in sediment is PCB-contaminated soil in Tax Block E. It is believed that the PCBs originated from transformers at former Building D (formerly located in Tax Block E), and were possibly released during operation but may also have been released during building demolition. This source is being addressed in remedial actions planned for Block E, and will precede any sediment remedial actions. Therefore, a continuing source of PCB contamination will be eliminated to prevent sediment re-contamination. Sediment remedial actions will likely include a long-term monitoring program to verify achievement of remedial goals. The effectiveness of source control actions taken in Tax Block E will also be confirmed through this long-term monitoring program. Accessible contaminated sediment was removed during an interim remedial measure (IRM) completed for Block E storm drains.. Final remediation of the storm drains will be coordinated with sediment remediation so as not to re-introduce potential contamination.

Forensic analysis indicates that the PAHs in Dark Head Cove and Cow Pen Creek sediments are consistent with urban runoff. The results of the alkylated-PAH analyses indicate that the types and concentrations of monoaromatic hydrocarbons and PAHs identified in the sediment are consistent with those found in urban soils and associated runoff. Although storm water samples did not contain detectable levels of PAHs, sediment associated with storm water displayed a signature deemed associated with urban runoff and similar to that found in Cow Pen Creek and Dark Head Cove sediments. This indicates that the water bodies adjacent to the Middle River Complex receive contributions of PAHs from other sources, such as Eastern Boulevard and other roadways.

Several metals were detected in sediment at elevated concentrations, but some of these concentrations were less than, or only slightly greater than, regional background concentrations (see Figures 2-8 through 2-13). Metals of particular interest include cadmium, chromium, copper, lead, mercury, and zinc. Metals found above regional background concentrations may be associated with historical site operations, including manufacturing, machining, and metal plating, and the discharge of process wastewater to Cow Pen Creek and Dark Head Cove. The greatest concentrations of metals in Dark Head Cove were generally found in samples collected from the six to 18 inch and the 18–30 inch depth intervals, indicating that sediment with higher concentrations is being buried under cleaner sediments, and thus is likely associated more with past rather than current sources.

Some elevated metals concentrations were observed in surface samples in Cow Pen Creek, which is to be expected, because the deposition rate (as estimated from age-dating analyses) is probably lower in that location, and the scour appears to be greater than in the cove.

2.5.2 Contaminant Fate and Transport

Contaminants released from the primary sources can potentially be transported to Dark Head Cove and Cow Pen Creek. As stated earlier, the MRC has nine (eight active) storm-water outfalls that discharge storm water into Cow Pen Creek and Dark Head Cove (see Figure 2-1). Most surface water runoff from rainfall discharges from the MRC to Cow Pen Creek and Dark Head Cove through the outfalls mentioned above. Some surface water runoff presumably discharges to these water bodies as overland sheet flow, and some precipitation infiltrates into the ground in unpaved areas. Infiltrating precipitation could result in the transport of contamination from surface soil to subsurface soil and groundwater at the facility. Groundwater beneath the MRC flows into Cow Pen Creek and Dark Head Cove at very low flux rates (Tetra Tech, 2012b).

A large portion of the MRC facility is covered with structures, pavement, or gravel. Grassy areas are present around the northern portions of the property with a mixture of grass, concrete cover, and exposed soil at the southern side, and grass to a limited extent at the southwestern portion of the property. The western side of the facility is primarily parking lots and street. The surface cover material largely prevents soil in unpaved areas from eroding into Cow Pen Creek and Dark Head Cove. Volatile contaminants in groundwater may enter site structures through sub-slab vapor intrusion. However, most of these contaminants would be expected to remain in groundwater until it eventually discharges into adjacent surface water bodies.

The surface cover may, to a certain degree, also prevent soil erosion due to wind and storm water runoff. However, erosion may have been a significant contaminant transport mechanism in the past. For example, PCBs in surface soil at Block E appear to have been transported to the adjacent water bodies via storm water runoff. This source-and-transport mechanism will be addressed through remediation of Block E soils before remediation of site sediment, and the effectiveness of source control would be verified through a long-term monitoring program of the selected remedy for MRC sediments. Under current conditions, storm water runoff from the MRC and the entire surrounding area is most likely the major contaminant-transport mechanism to the adjacent surface water bodies.

Contaminants released to surface water, sediment, or sediment porewater in the study area may be transferred among these media. Contaminants in surface water may transfer to sediment through deposition, or to porewater through partitioning. Contaminants in sediment may transfer to surface water through resuspension, or to porewater through partitioning. Contaminants in porewater may transfer to sediment or surface water through partitioning. As previously discussed, sedimentation rates at Dark Head Cove, Dark Head Creek, and at the mouth of Cow Pen Creek are estimated at 0.8 centimeters per year (cm/year), 1.3 cm/year, and 0.38 cm/year, respectively (Tetra Tech, 2011a). In the sheltered waters of Dark Head Cove and Dark Head Creek where sedimentation rates are higher than in Cow Pen Creek, this sedimentation is anticipated to sequester contamination beneath additional layers of sediment.

2.5.3 Current and Future Receptors of Concern and Exposure Pathways

The MRC is currently used for commercial/industrial purposes and it is anticipated that it will remain a commercial/industrial facility for the foreseeable future. However, recreational activities (wading, swimming, and fishing) do occur in the adjacent surface water bodies and presumably will occur in these areas in the future. Therefore, the HHRA provided an evaluation of possible risks to potential recreational receptors from direct contact with sediment COPC via incidental ingestion and dermal contact, as well as via ingestion of fish taken from the study area. Direct-contact exposures to surface water are not included in the CSM because the findings in the original HHRA for this pathway did not indicate unacceptable risks (Tetra Tech, 2006; 2011b), and because chemical concentrations in the available surface water samples from 2010 do not exceed human health screening levels. Surface water was therefore not considered a medium of concern in the HHRA.

As shown in the CSM, chemical contaminants originating from the site can enter surface water and sediment in Cow Pen Creek and Dark Head Cove through discharge from storm water outfalls and groundwater, and as a consequence of surface water/sediment runoff. Benthic macroinvertebrates (i.e., organisms that live on or in sediment) and aquatic organisms (e.g., fish in Cow Pen Creek, Dark Head Cove, and Dark Head Creek) could be exposed to chemicals through direct contact with surface water and sediment, ingestion of surface water and sediment, and consumption of contaminated food. Many benthic macroinvertebrates are a food source for higher trophic-level organisms such as fish, blue crabs, birds, and mammals. Benthic macroinvertebrates can accumulate contaminants that can be transferred to piscivorous animals when the macroinvertebrates are consumed.

Aquatic plants could also be exposed to contaminants through direct contact and absorption through their roots. This applies especially to shallow water areas along Cow Pen Creek. Water depth in most of Dark Head Cove, however, is too deep for many aquatic plant species. Toxicity data for rooted and submerged vegetation are sparse, so aquatic plant toxicity was not quantitatively evaluated in the ERA. Airborne transport of dust and inhalation of contaminants at the MRC are negligible pathways for ecological receptors because the sediment is covered with water.

2.6 SUMMARY OF THE BASELINE HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENTS

Tetra Tech prepared a *Sediment Risk Assessment* for the MRC in 2011 (Tetra Tech, 2011c) that included both an HHRA and an ecological risk assessment. Summaries of these risk assessments are included in the following sections.

2.6.1 Baseline Human Health Risk Assessment

Cancer and non-cancer risk estimates were developed for human receptors potentially exposed to COPC using MRC study area sediments samples and fish tissue samples collected from Cow Pen Creek, Dark Head Cove, and selected reference areas. The primary COPC evaluated were PCBs, PAHs (expressed as BaPEq), and arsenic. A COPC is a chemical detected at a maximum concentration exceeding conservative screening levels established for an environmental medium (e.g., sediment). COPC are evaluated quantitatively in the HHRA.

The 2011 HHRA provided an evaluation of COPC concentrations in both surficial and deeper sediments and in fish tissue samples. However, exposure to the deeper sediments would potentially occur only if such sediments were to be exposed (possibly by dredging or other disturbance) and deposited on surface soils or surficial sediments. The results of the 2011 HHRA are summarized in Table 2-1. The risk estimates are compared to both MDE and USEPA risk management benchmarks defined in the table. As a general guideline, the need for environmental remediation is evaluated in an FS when risk management benchmarks are exceeded.

Cancer risk estimates developed for the direct-contact exposure pathways (i.e., incidental ingestion of and dermal contact with [i.e., touching] sediments) do not exceed the USEPA target risk range of a one-in-10,000 (1×10^{-4}) to one-in-one million (1×10^{-6}) risk or probability of developing cancer. However, the risk estimates do exceed the MDE risk benchmark of 1×10^{-5} (a one-in-100,000 probability of developing cancer) when sediment COPC in the zero to six inch, six to 18 inch, and 18 to 30 inch depth intervals are assessed. The primary risk drivers (i.e., chemicals contributing most significantly to the estimated risks) are BaPEq and PCBs. Hazard indices for the direct-contact exposure pathways do not exceed 1, indicating that adverse non-carcinogenic health effects are not anticipated if a receptor contacts the sediments. (A hazard index of 1 is the non-cancer risk management benchmark established by both the MDE and the USEPA.) Based on the HHRA results, PAHs, PCBs, and arsenic are selected as chemicals of concern (COC) for direct contact with sediment exposure; these are the chemicals that will be further evaluated in this FS.

Cancer and non-cancer risk estimates developed for the consumption-of-fish exposure pathway, based on sediment concentrations (and assuming bioaccumulation between sediments and fish), exceed both the MDE and USEPA risk management benchmarks. Exceedances occur when COPC in the zero to six inch, six to 18 inch, and 18 to 30 inch depth intervals are evaluated. A few metals (e.g., antimony and cobalt), PAHs, and PCBs are the primary cancer and non-cancer risk drivers for the fish-consumption exposure pathway.

The analysis for the consumption-of-fish exposure pathway presented in the preceding paragraph based on sediment sample results, was conducted to compliment and support the risk assessment using chemical concentrations detected in actual fish tissue samples (which produced slightly different results, discussed in the following paragraph). In addition, the sediment-based analysis was performed because the sediment sample database is larger and more robust than the fish tissue sample database. Several sources of uncertainty impact risk assessment results based on food-chain modeling (e.g., the use of default bioaccumulation factors to predict fish tissue concentrations based on sediment concentrations). Consequently, risk assessment results based on actual fish tissue data are typically considered more representative of a study area, and are relied upon to identify COC for further evaluation in the FS.

Cancer and non-cancer risk estimates developed for the consumption-of-fish exposure pathway based on evaluation of actual fish tissue data for the study area exceed both USEPA and Maryland risk benchmarks. PCBs are the only identified risk drivers. However, according to data from the MDE surface water monitoring program ,PCB concentrations reported in fish tissue samples from the study area fall within the range of concentrations reported for the general Chesapeake Bay area. Based on the HHRA results, PCBs are selected as COC for the consumption-of-fish exposure pathway, and are further evaluated in this FS.

The risk estimates above must be interpreted with the understanding that COPC concentrations detected at background sediment locations, as well as the study area locations, exceed the conservative sediment screening levels used in the HHRA (i.e., screening levels for both direct contact and consumption-of-fish exposure pathways). Risk estimates for the consumption-of-fish exposure pathway based on maximum background sediment concentrations exceed both Maryland and USEPA cancer risk benchmarks. A review of both study area data and data reported in open scientific literature indicates that COPC concentrations detected in the MRC study area are a function both of study-area-specific and regional sources of contamination. The HHRA identified PCBs, PAHs (expressed as BaPEq) and arsenic as COC, with the caveat that site concentrations of arsenic may represent background conditions. Remedial goals established for this FS consider study area and regional background conditions as appropriate.

2.6.2 Baseline Ecological Risk Assessment

The ecological endpoints evaluated in the ERA were benthic macroinvertebrates, fish, and birds and mammals that consume fish and benthic macroinvertebrates. The ecological risk assessment identified total PCBs and the metals cadmium, copper, lead, mercury, and zinc as COC. The results of the ERA are summarized in Table 2-2. A more detailed summary of the ERA follows.

Multiple lines of evidence were used to evaluate risks to benthic macroinvertebrates. Sediment chemistry was the primary measure by which potential risks were evaluated, but AVS/SEM data, porewater data, and benthic macroinvertebrate community data were also used in the evaluation. Several chemicals were initially selected as COPC for risks to sediment macroinvertebrates because they had been detected at concentrations that exceeded screening levels, or because they lacked a screening level.

Risks to benthic macroinvertebrates from metals in sediment are possible, with the greatest likelihood of those effects occurring in the areas where probable-effects concentrations (PECs) are exceeded. Concentrations of metals at some locations are similar to background concentrations. At many locations, however, metals concentrations (especially cadmium, copper, lead, mercury, and zinc) are greater than PECs and background values. Generally, the highest concentrations of metals are in the 6 to 18 inch and 18 to 30 inch depth intervals, with much lower concentrations in the 30 to 52 inch depth interval.

Potential risks are posed to benthic macroinvertebrates by PCBs and PAHs at several onsite locations, especially in Dark Head Cove surface sediment near Outfall 05. Total PAHs also pose potential risks to benthic macroinvertebrates at the eastern end of the cove (BaPEq are not used to evaluate risk to macroinvertebrates). However, PAH concentrations in most samples near MRC were similar to PAH concentrations throughout the region based on background data. Of 101 surface sediment samples analyzed for PAHs, total PAH concentrations exceeded the maximum background value (for each depth interval) in only eight surface sediment samples. The PAH forensic data suggest that PAHs present in most MRC samples are probably due to typical urban runoff. Therefore, PAHs are not retained for further evaluation or identified as COC.

Evaluations of AVS/SEM data, *ex situ* porewater data, and benthic macroinvertebrate community data indicate some uncertainty regarding whether the chemicals in sediment are bioavailable and significantly affecting the benthic community. Chemical concentrations in the porewater samples are less than criteria with only a few exceptions. At most locations where AVS/SEM and *ex situ* pore-water samples were collected, data indicate bioavailability is low. This conclusion is based on an evaluation of the AVS and SEM data, along with the fraction of organic carbon present in the samples, as described in USEPA (USEPA, 2005c) and detailed in Appendix B. Basically, any sediment with a ratio of SEM-AVS to fraction of organic carbon (foc) [(SEM-AVS)/foc] less than 130 micromoles per gram (µmols/g) organic carbon poses a low risk of adverse biological effects due to cadmium, copper, lead, nickel, and zinc. Most of the (SEM-AVS)/foc concentrations in the site samples are less than 130 µmols/g of organic carbon.

As identified in the ERA, concentrations of cadmium, copper, lead, mercury, zinc, and total PCBs are greater than their respective PECs, and thus pose a potential risk to benthic invertebrates.

However, using PECs to evaluate risk to benthic invertebrates is asscoaited with some uncertainty because PECs are literature-based, nonsite-specific values. In addition, other lines of evidence at this site, such as AVS/SEM, indicate low potential for bioavailability. Benthic community analyses indicate an impaired, but not absent benthic community; although the benthic community was stressed in all MRC samples, it was also stressed in background samples. However, to be protective, these chemicals were retained as final ecological COPCs in sediments near MRC. Under current conditions, ecological receptors are expected to be exposed only to surface sediment (the zero to six inch depth interval, also considered the bioactive zone). In surface sediment, cadmium and total PCBs pose the greatest potential risk to benthic receptors.

Even though chromium was detected in several samples at concentrations exceeding sediment benchmarks, it was determined that chromium was not likely to impact benthic macroinvertebrates for several reasons. All porewater concentrations of chromium were less than the ecological screening-value for surface water, indicating that the bioavailability of chromium in sediment is low. Chromium in porewater is not toxic up to a co-located sediment chromium concentration of 1,530 mg/kg.

Chromium found in sediments is primarily in two oxidation states: trivalent chromium, which is relatively insoluble and nontoxic; and hexavalent chromium, which is much more soluble and toxic. Hexavalent chromium is thermodynamically unstable in anoxic sediments. Since AVS is formed only in anoxic sediments, sediments with measurable AVS concentrations are not likely to contain toxic hexavalent chromium (USEPA, 2005c). The data from the seven samples analyzed for AVS/SEM suggest that the chromium present in sediments is not toxic. Overall, the porewater and AVS/SEM data indicate that potential risks posed by chromium is limited to a few sampling locations, so chromium was not retained for further evaluation, nor was it identified as a COC.

Based on COPC concentrations in fish tissue collected from Cow Pen Creek and Dark Head Cove, the ERA concluded that fish did not appear to be at significant risk from sediment contamination, and/or that risks were similar to those estimated for other similar environments within the region.

In the ERA, food chain modeling was conducted to evaluate risks to piscivorous birds and mammals consuming fish and incidental sediment from Cow Pen Creek and Dark Head Cove. The results indicated that bioaccumulative chemicals present in sediment in all four depth intervals pose negligible risks to upper trophic level receptors. Food chain modeling for piscivorous birds and mammals addressed the transfer of contaminants from sediment to consumed food sources, such as benthic organisms and fish. (The term "piscivorous" is used in a broad sense to describe birds and mammals that prey not only upon fish, but also on a variety of aquatic and benthic organisms.)

The food chain was modeled under scenarios representing both current conditions (i.e., contamination in the upper six inches of sediment is available to receptors) and possible future conditions (i.e., contamination in deeper sediment that may be exposed through dredging). Results indicate that potential risks to these receptors are not a concern. The ecological risk assessment identified total PCBs, cadmium, copper, lead, mercury, and zinc as contaminants of concern.

Table 2-1
Human Health Risk Assessment Summary
Page 1 of 3

Environmental Medium/Data Evaluated	Do Risk Estimates for Recreational User Direct Contact With Sediments Exceed Risk Benchmarks: 1E-05 Cancer Risk Level (CRL) or Hazard Index (HI) of 1? (Chemicals of Concern)	Do Risk Estimates for Recreational Fisher Exceed Risk Benchmarks: 1E-05 Cancer Risk Level (CRL) or Hazard Index (HI) of 1? (Chemicals of Concern)	Comments/Risk Management Considerations
Sediments : 0-6" - 95%UCL 0-6" - Wt. Avg.	Yes (CRL = 4E-05)/ Yes (CRL = 2E-05) [***BaPEq/PCBs(95%UCL only)*/As**]	*Yes (CRL = 1E-03; HI >1)* *Yes (CRL =3E-04; HI >1)* *[BaPEq/PCBs/Sb/Co]*	Direct contact risks do not exceed USEPA target cancer risk range (1E-06 to 1E-04). Most of the study area sediments are continuously submerged therefore frequency of direct contact exposure is likely to very limited. Arsenic concentrations likely reflect background conditions. *Risk estimates presented in italics* are based on the modeled transfer of chemicals from sediments to fish and are presented for informational purposes only because actual fish tissue data (see below) were evaluated in the human health risk assessment (HHRA). ***Chemicals of concern recommended for further evaluation in the feasibility study are presented in bold italics.***
Sediments : 6-18" - 95%UCL/ 6-18" - Wt. Avg.	Yes (CRL = 3E-05)/ Yes (CRL = 2E-05) [***BaPEq /PCBs(95%UCL only)***/As]	*Yes (CRL =9E-04; HI >1)* *Yes (CRL =2E-04; HI >1)* *[BaPEq/Sb/PCBs/Co]*	Direct contact risks do not exceed USEPA target cancer risk range. Direct contact with deeper, subsurface sediments is very unlikely unless sediments are disturbed. Arsenic concentrations likely reflect background conditions. *Risk estimates presented in italics* are based on the modeled transfer of chemicals from sediments to fish and are presented for informational purposes only because actual fish tissue data (see below) were evaluated in the HHRA. ***Chemicals of concern recommended for further evaluation in the feasibility study are presented in bold italics.***

Table 2-1
Human Health Risk Assessment Summary
Page 2 of 3

Environmental Medium/Data Evaluated	Do Risk Estimates for Recreational User Direct Contact With Sediments Exceed Risk Benchmarks: 1E-05 Cancer Risk Level (CRL) or Hazard Index (HI) of 1? (Chemicals of Concern)	Do Risk Estimates for Recreational Fisher Exceed Risk Benchmarks: 1E-05 Cancer Risk Level (CRL) or Hazard Index (HI) of 1? (Chemicals of Concern)	Comments/Risk Management Considerations
Sediments : 18-30" - 95%UCL/ 18-30" - Wt. Avg.	Yes (CRL = 5E-05)/ Yes (CRL = 2E-05) [***BaPEq /As***]	*Yes (CRL =5E-04; HI >1)* *Yes (CRL =2E-04; HI >1)* *[BaPEq/PCBs/Sb(minor contributor-wt avg scenario)/Co]*	Direct contact risks do not exceed USEPA target cancer risk range. Direct contact with deeper, subsurface sediments is very unlikely unless sediments are disturbed. Arsenic concentrations likely reflect background conditions. *Risk estimates presented in italics* are based on the modeled transfer of chemicals from sediments to fish and are presented for informational purposes only because actual fish tissue data (see below) were evaluated in the HHRA. ***Chemicals of concern recommended for further evaluation in the feasibility study are presented in bold italics.***
Sediments : >30" - 95%UCL/ >30" - Wt. Avg.	No/ No	*Yes (CRL =5E-05; HI >1)* *Yes (CRL =5E-05; HI >1)* *[BaPEq/PCBs/Sb(minor contributor-95%UCL scenario)/Co]*	Direct contact risks do not exceed USEPA target cancer risk range or State of Maryland Department of the Environment cancer risk benchmark (1E-05). Direct contact with deeper, subsurface sediments is very unlikely unless sediments are disturbed. Arsenic concentrations likely reflect background conditions. *Risk estimates presented in italics* are based on the modeled transfer of chemicals from sediments to fish and are presented for informational purposes only because actual fish tissue data (see below) were evaluated in the HHRA. ***Chemicals of concern recommended for further evaluation in the feasibility study are presented in bold italics.***

Table 2-1
Human Health Risk Assessment Summary
Page 3 of 3

Environmental Medium/Data Evaluated	Do Risk Estimates for Recreational User Direct Contact With Sediments Exceed Risk Benchmarks: 1E-05 Cancer Risk Level (CRL) or Hazard Index (HI) of 1? (Chemicals of Concern)	Do Risk Estimates for Recreational Fisher Exceed Risk Benchmarks: 1E-05 Cancer Risk Level (CRL) or Hazard Index (HI) of 1? (Chemicals of Concern)	Comments/Risk Management Considerations
Fish Tissue Data from MRC Study Area	NA	Yes (CRL = 2E-04; HI>1) [***PCBs***, Cr (assumed hexavalent)]	Cancer risk estimates for study area fish tissue samples exceed USEPA target cancer risk range and are twice those calculated for the reference area fish tissue samples. Cancer risk estimates for PCBs approximately equal to 2E-04. Chromium unlikely to be present as predominantly hexavalent chromium. ***Chemicals of concern recommended for further evaluation in the feasibility study are presented in bold italics.***
Fish Tissue Data from Reference Area	NA	Yes (CRL = 1E-04; HI>1) [PCBs, Cr (assumed hexavalent)]	Cancer risk estimates do not exceed USEPA target cancer risk range. Cancer risk estimates for PCBs equal to approximately 3E-05. Chromium unlikely to be present as predominantly hexavalent chromium.

BaPEq – benzo(a)pyrene equivalents
Co – Cobalt
Cr – Chromium
CRL – cancer risk level
HHRA – human health risk assessment
HI – hazard index
MRC – Middle River Complex
NA – not applicable
PCB – polychlorinated biphenyl
Sb – Antimony
UCL – upper confidence level
USEPA – United States Environmental Protection Agency
Wt. Avg. – weighted average

Table 2-2
Ecological Risk Assessment Summary

Assessment Endpoint	Final Chemicals of Potential Concern
Protection of benthic invertebrates from adverse effects on their survival, reproduction, and growth	Total Aroclor Cadmium Copper Lead Mercury Zinc
Protection of fish from adverse effects on their survival, reproduction, and growth.	None (negligible ecological risk)
Protection of piscivorous birds from adverse effects on their survival, reproduction, and growth	None (negligible ecological risk)
Protection of piscivorous mammals from adverse effects on their survival, reproduction, and growth	None (negligible ecological risk)

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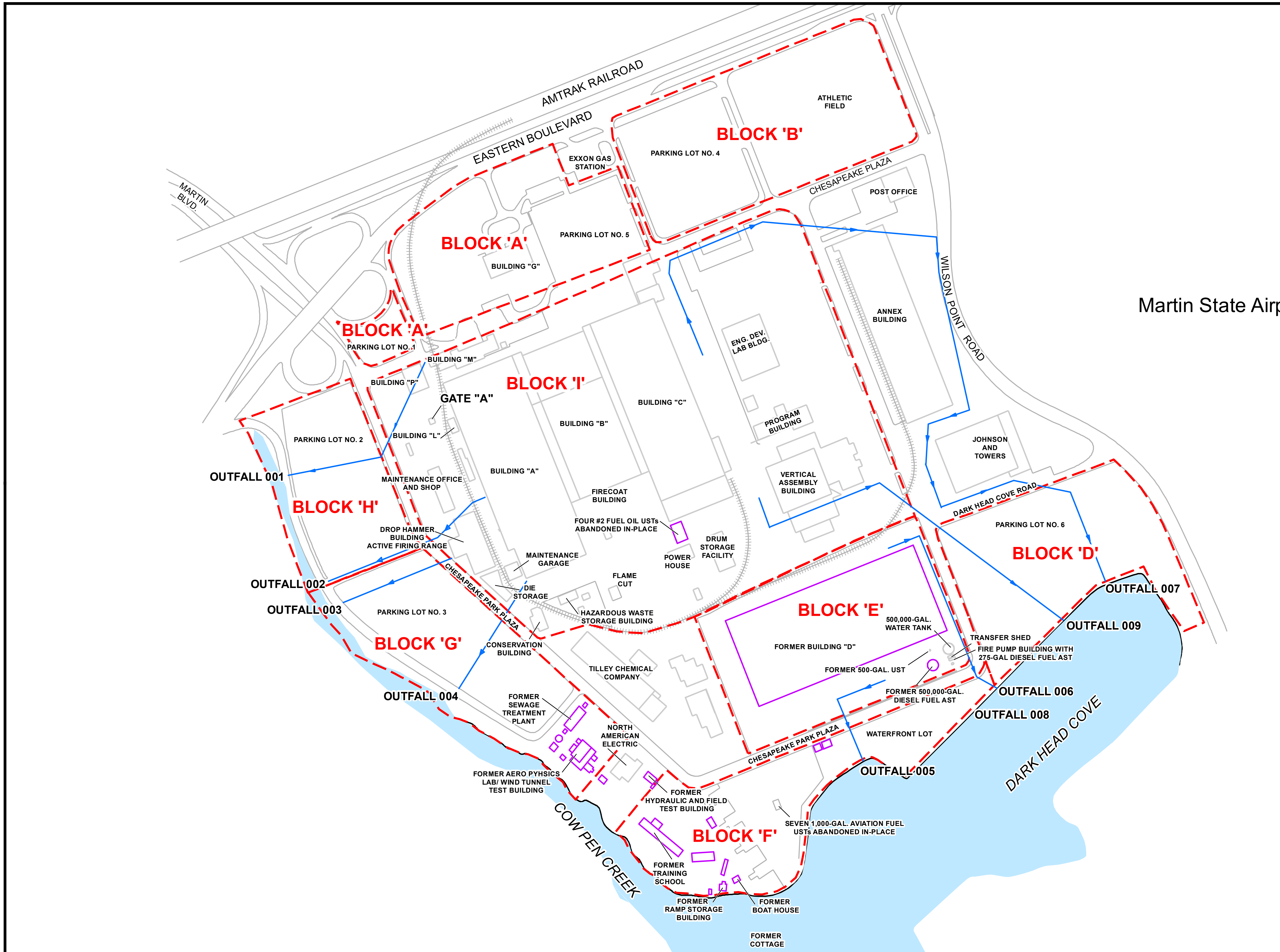


FIGURE 2-1

MIDDLE RIVER COMPLEX FACILITY MAP

LEGEND

OUTFALL 0004 NPDES PERMITTED OUTFALL

STORM WATER AND FLOW DIRECTION

EXISTING STRUCTURE

FORMER STRUCTURE

MIDDLE RIVER COMPLEX TAX BLOCK BOUNDARY

NOTE:
OUTFALL 008 IS INACTIVE

Lockheed Martin Middle River Complex
Middle River, Maryland

0 150 300 600 Feet

N

DATE MODIFIED: 11/13/12

CREATED BY: MP

TETRA TECH

Map Document: (K:\GProject\middle_river\Maps\Middle River Complex Facility Map_111312.mxd)
11/13/2012 -- 1:11:34 PM

TETRA TECH

Figure 2-2
Middle River Complex
Environmental Setting Map
Lockheed Martin Middle River Complex
Middle River, Maryland

Drawn By: MP 7/24/12
Checked By:
Approved By:

Contract Number: 112IC02903

Map Document: (K:\GProject\middle_river\Maps\MRC Environmental Setting Map.mxd)
7/24/2012 -- 1:31:12 PM

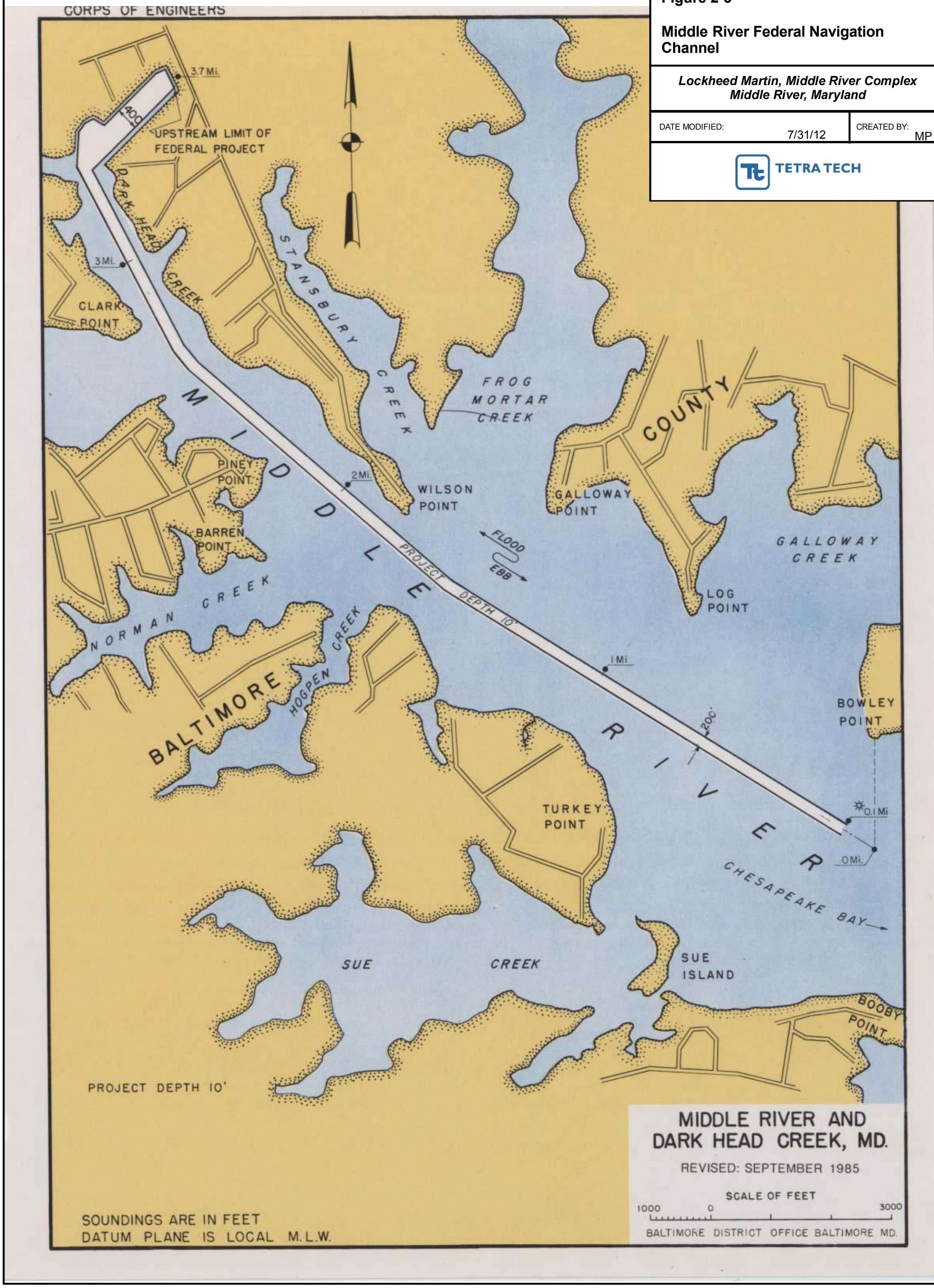
Figure 2-3

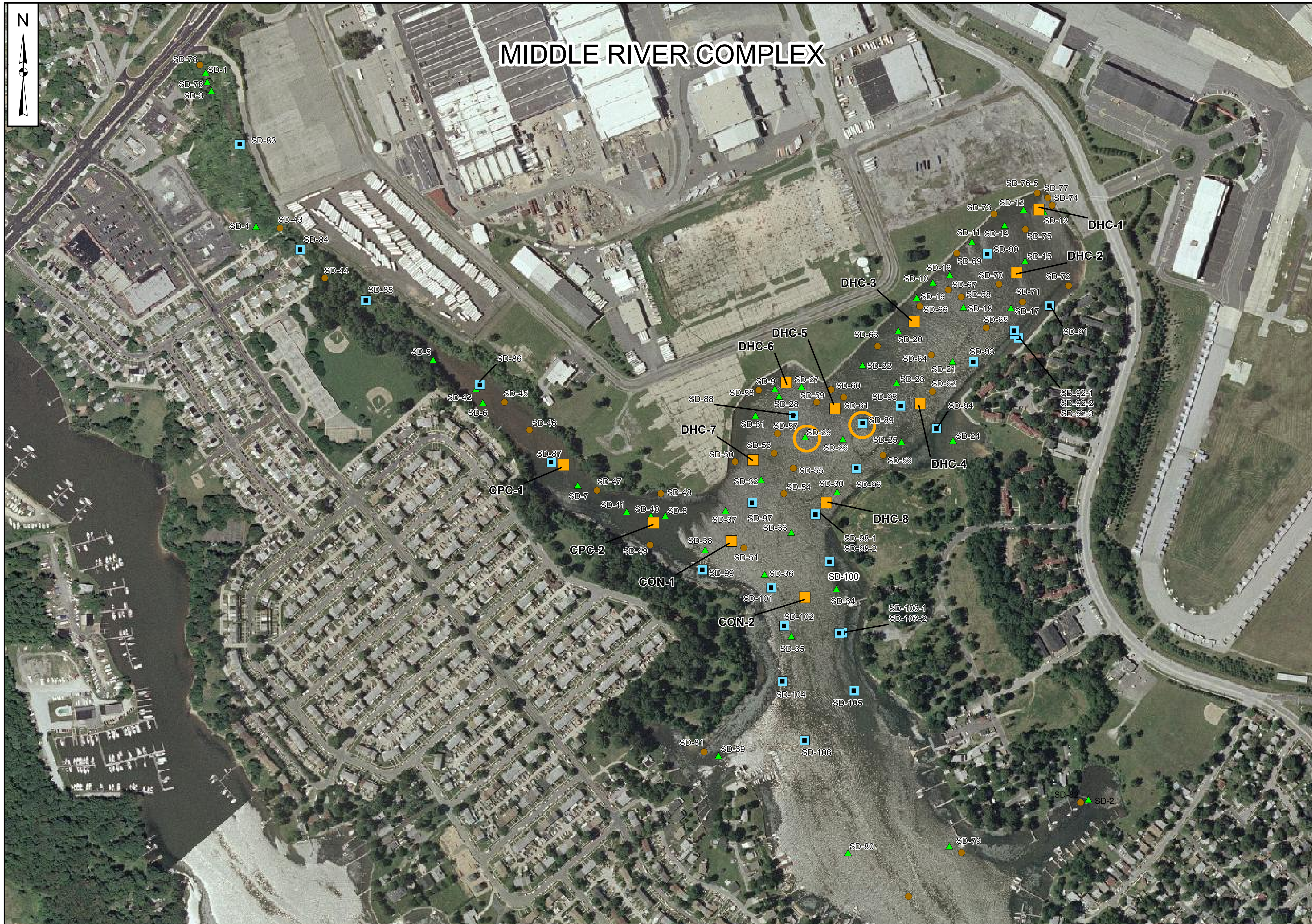
Middle River Federal Navigation Channel

Lockheed Martin, Middle River Complex
Middle River, Maryland

DATE MODIFIED: 7/31/12	CREATED BY: MP

TETRA TECH





TETRA TECH

Figure 2-4
Sediment Sample Locations
Lockheed Martin Middle River Complex
Middle River, Maryland

Legend

- Sediment Sample Locations- 2011
- Sediment Sample Locations- 2005
- Sediment Sample Locations- Nov 2008
- Delineation Sample - 2010
- Treatability Testing Sample Location- 2011

500 250 0 500
Feet

Drawn By: MP 2/27/12
Checked By:
Approved By:

Contract Number: 112IC02903

Map Document: (K:\GProject\middle_river\Maps\Figure 3-1_sediment_sample_locations 022712.mxd)
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Map Document: (K:\GProject\middle_river\Maps\Sediment Reference Locations_082812.mxd)
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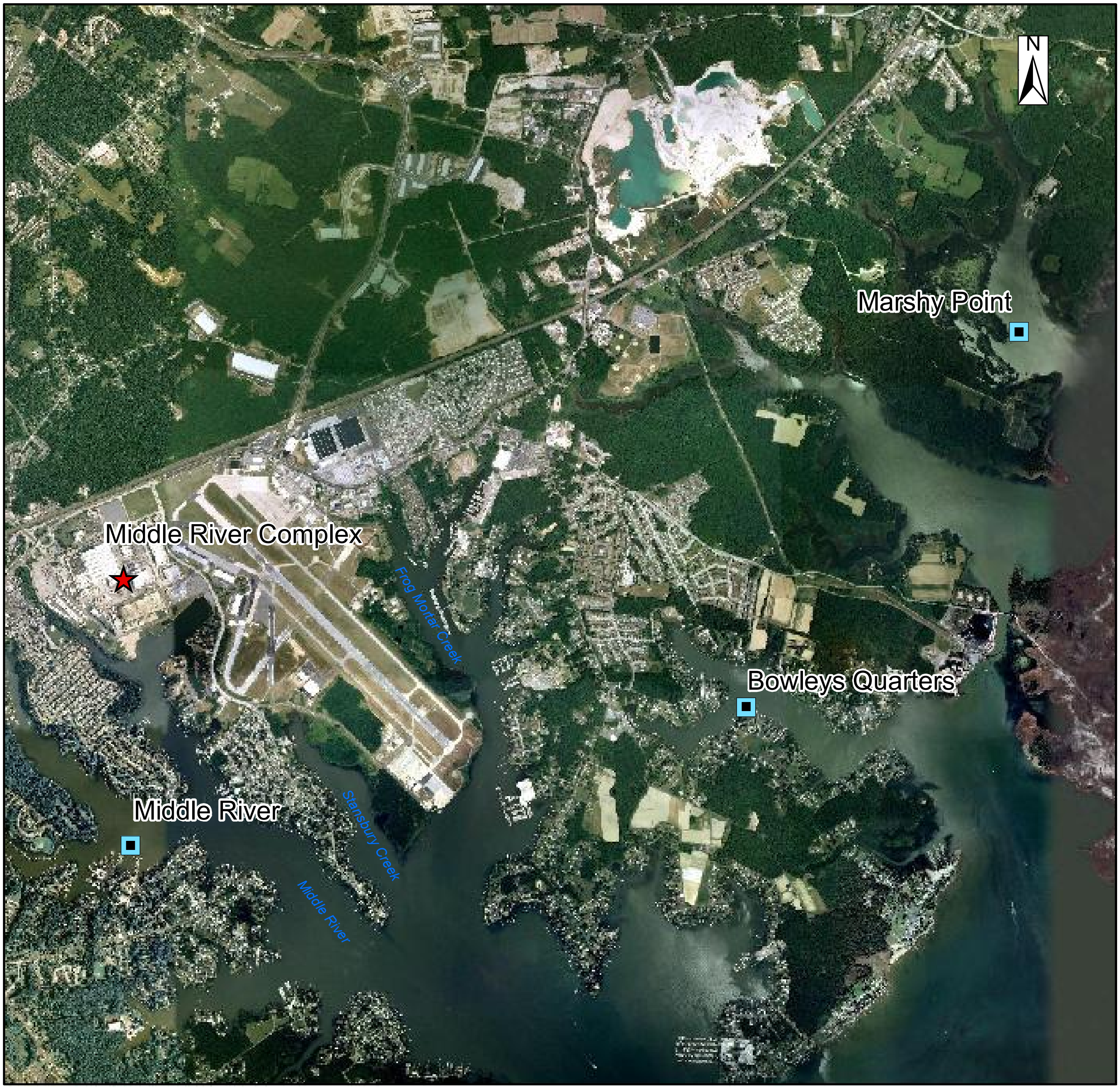


Source: Google Earth Pro, 2008

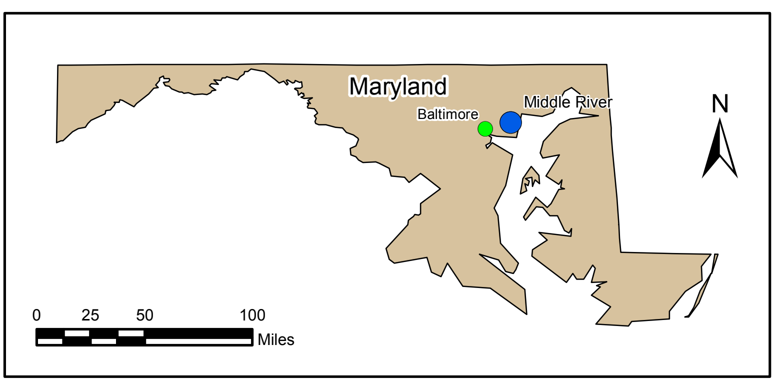


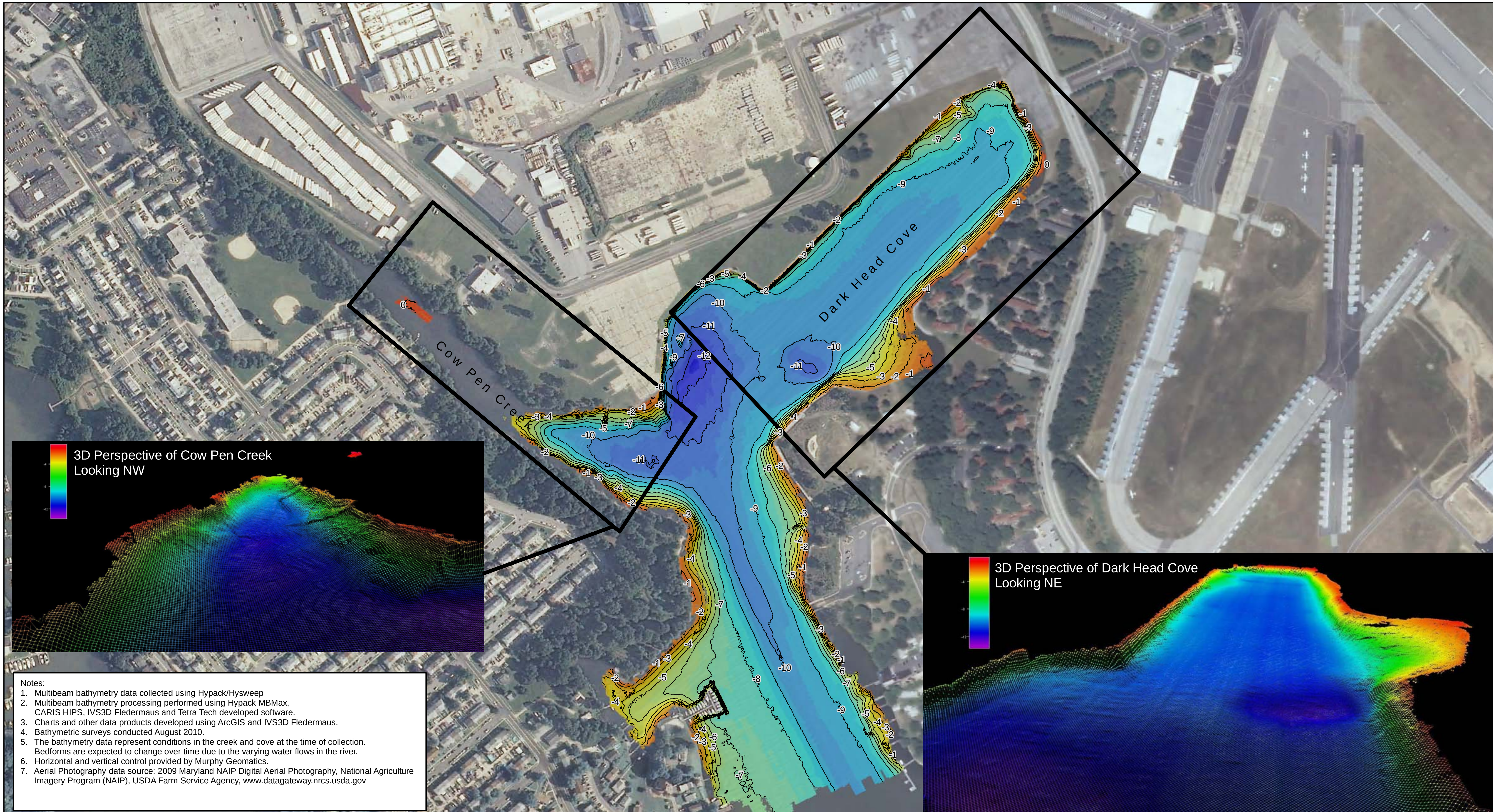
Figure 2-5

Middle River Complex
Reference Locations

Lockheed Martin Middle River Complex
Middle River, Maryland

DATE MODIFIED: 8/28/12	CREATED BY: MP

TETRA TECH



Notes:

1. Multibeam bathymetry data collected using Hypack/Hysweep
2. Multibeam bathymetry processing performed using Hypack MBMax, CARIS HIPS, IVS3D Fledermaus and Tetra Tech developed software.
3. Charts and other data products developed using ArcGIS and IVS3D Fledermaus.
4. Bathymetric surveys conducted August 2010.
5. The bathymetry data represent conditions in the creek and cove at the time of collection. Bedforms are expected to change over time due to the varying water flows in the river.
6. Horizontal and vertical control provided by Murphy Geomatics.
7. Aerial Photography data source: 2009 Maryland NAIP Digital Aerial Photography, National Agriculture Imagery Program (NAIP), USDA Farm Service Agency, www.datagateway.nrcs.usda.gov

Elevation (ft)

- -0.5 - 0
- -1 - -0.5
- -1.5 - -1
- -2 - -1.5
- -2.5 - -2
- -3 - -2.5
- -3.5 - -3
- -4 - -3.5
- -4.5 - -4
- -5 - -4.5
- -5.5 - -5
- -6 - -5.5
- -6.5 - -6
- -7 - -6.5
- -7.5 - -7
- -8 - -7.5
- -8.5 - -8
- -9 - -8.5
- -9.5 - -9
- -10 - -9.5
- -10.5 - -10
- -11 - -10.5
- -11.5 - -11
- -12 - -11.5
- -12.5 - -12
- -12.9 - -12.5
- 1 ft Contour

N / W / E / S

0 100 200 300 400

US Survey Feet

1:5,000

Geodetic Settings		Survey Equipment	
Horizontal Datum	State Plane NAD-83	**Multibeam Sonar**	RESON 7125/Ross 875-X
Projection	Maryland FIPS 1900	**Positioning System**	Leica 1230 RTK GPS/Applanix
Horizontal Units	US Survey Feet	**Heading Sensor**	Applanix POS MV
Vertical Units	US Survey Feet	**Motion Sensor**	Applanix POS MV
Vertical Datum	MLLW	**Sound Speed Profilers**	Falmouth NXIC/Seabird SBE 19
Vertical Control	Murphy Geomatics, MIDR14	**Dates Surveyed**	August 3 & 4, 2010
Horizontal Control	Murphy Geomatics, MIDR14	**Cell Size/Grid Method**	3ft/CARIS Uncertainty

Figure 2-6 Middle River Site Bathymetry

TetraTech Inc.
19803 North Creek Parkway
Bothell, WA 98011
1 (425) 482 7600

Survey Technicians:	B. Johnston, C. Burt	**Plate** 1
Drafted by:	MJ Watson	
Checked by:	R. Feldpausch, B. Bridge	**Sheet:** 1 of 1

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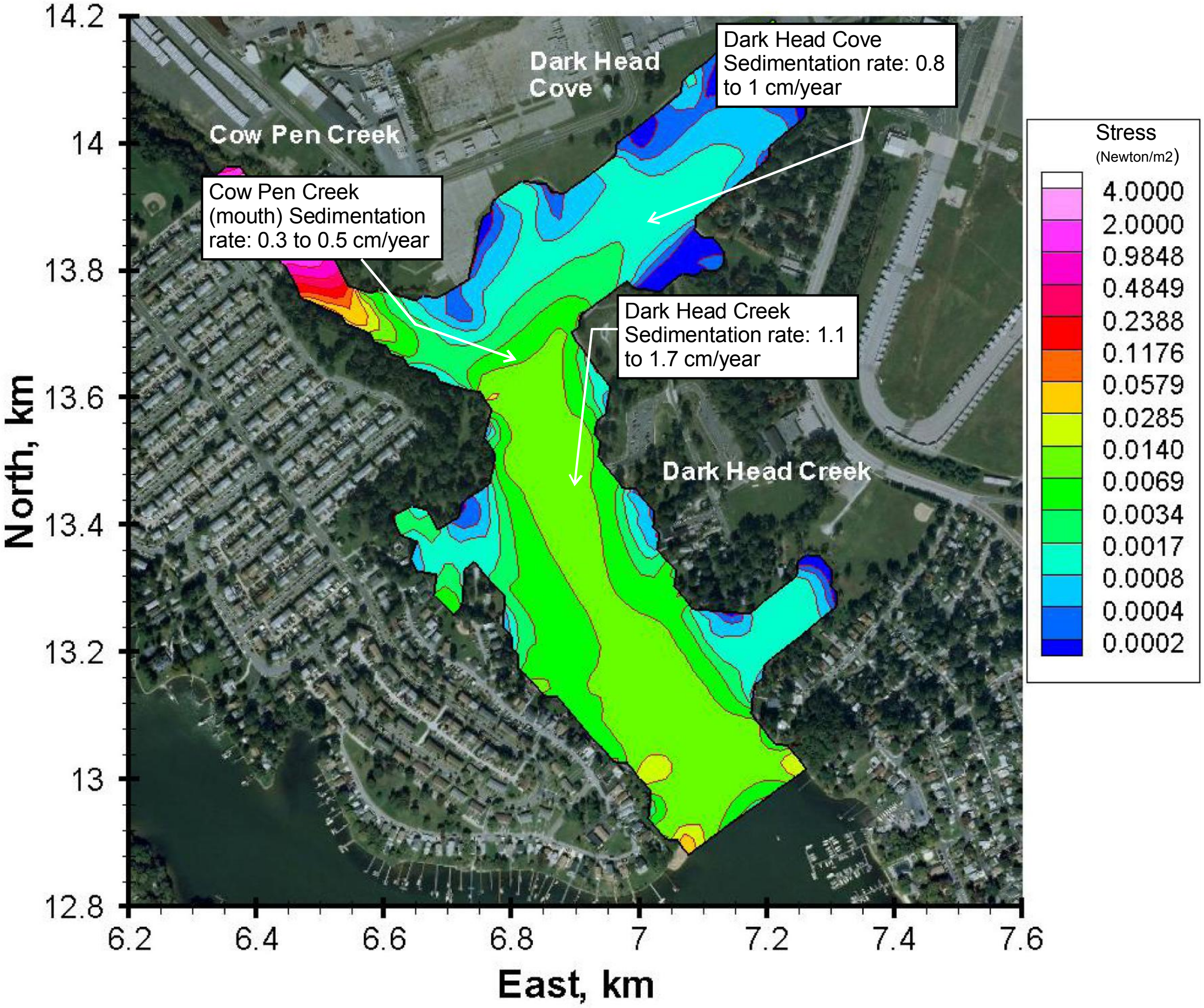

TETRA TECH

Figure 2-7

Average Sedimentation Rates and Maximum Bed Stress During 100-year 24-hour Storm
Lockheed Martin, Middle River Complex
Middle River, Maryland

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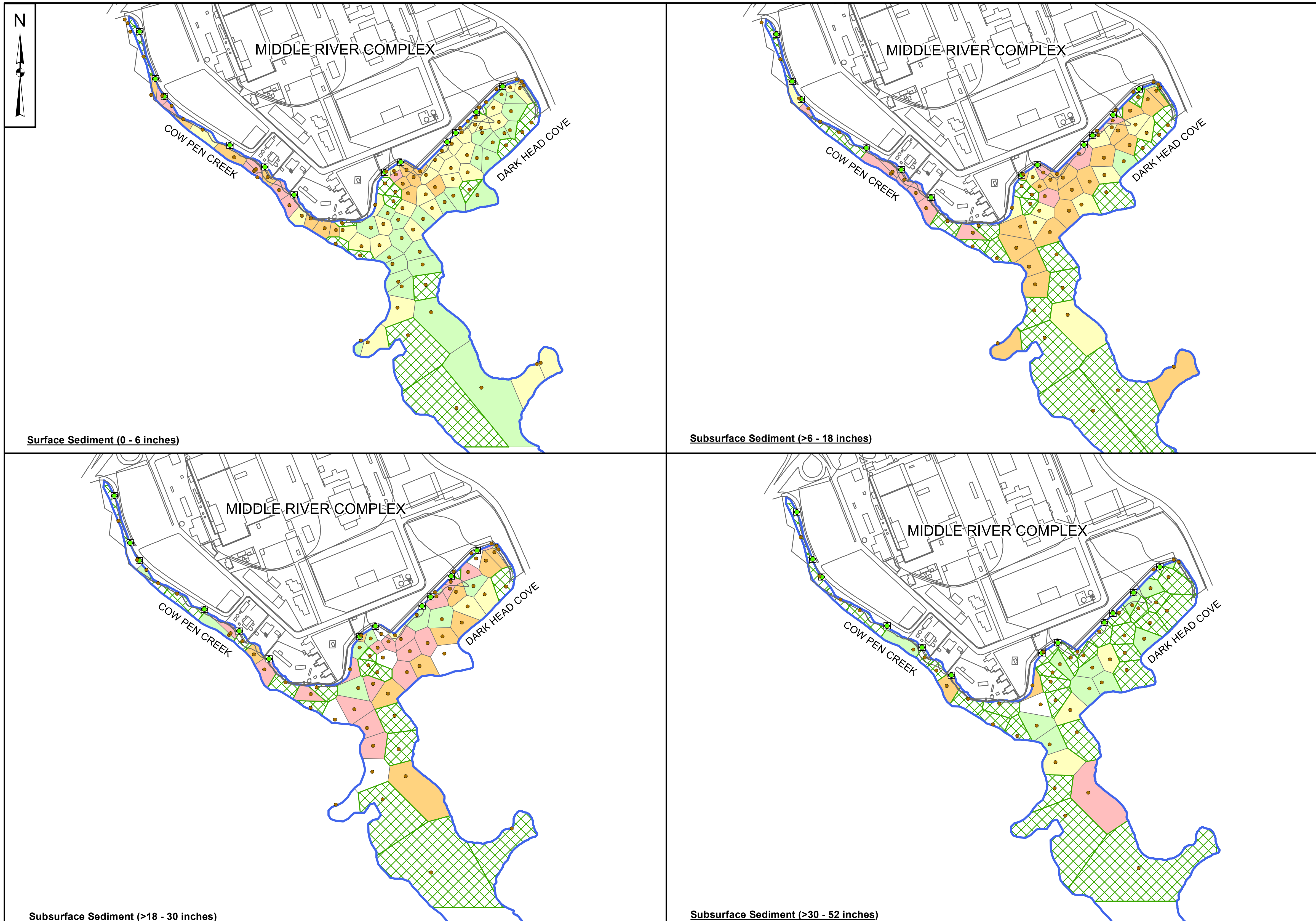
DATE MODIFIED: 8/1/12

CREATED BY: MP

FIGURE NUMBER 2-7



TETRA TECH

Figure 2 - 8
Thiessen Polygons for
Cadmium in Sediment
Lockheed Martin Middle River Complex
Middle River, Maryland

Legend

- Cadmium Sample Location
- Stormwater Outfall Locations

Cadmium Thiessen Polygons (mg/kg)

- Less than Background
- < or = 0.99
- > 0.99 - 4.98
- > 4.98 - 10
- > 10 - 25
- > 25
- Buildings/Roads
- Shoreline

Threshold Effect Concentration = 0.99
Probable Effect Concentration = 4.98
2X Probable Effect Concentration = 10
5X Probable Effect Concentration = 25

Background Concentration
SD 0-6" = 0.95 mg/kg
SD 6-18" = 0.91 mg/kg
SD 18-30" = 0.36 mg/kg
SD 30-52" = 0.34 mg/kg

All Location ID's Begin with "SD - "

1,080 540 0 1,080 Feet

Drawn By: S. PAXTON 12/17/10
Checked By: S. OZKAN 11/20/12
Approved By:

Contract Number: 112IC02903

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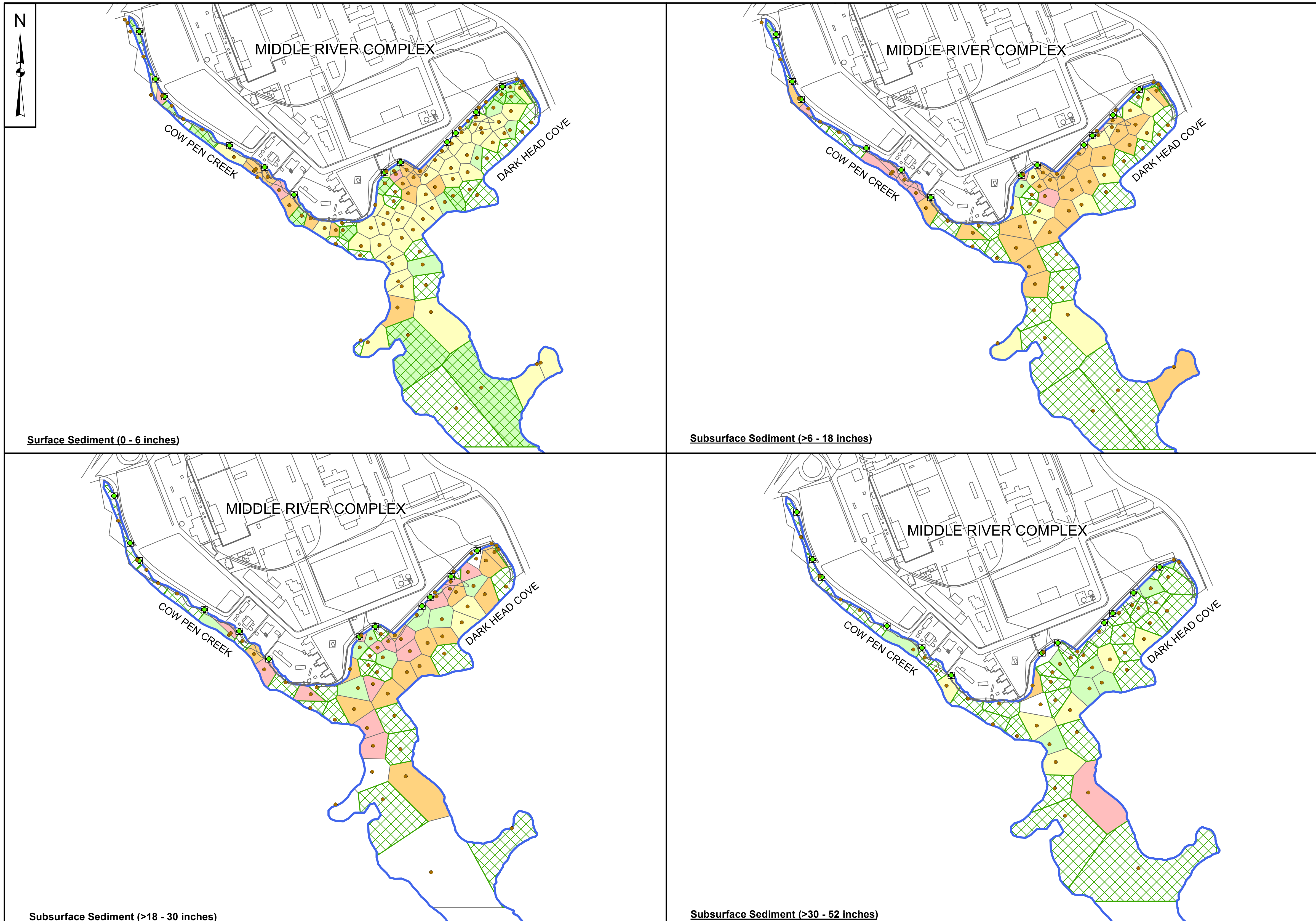

TETRA TECH

Figure 2 - 9
Thiessen Polygons for
Chromium in Sediment
Lockheed Martin Middle River Complex
Middle River, Maryland

Legend

- Chromium Sample Location
- Stormwater Outfall Locations

Chromium Thiessen Polygons (mg/kg)

- Less than Background
- < or = 43.4
- > 43.4 - 111
- > 111 - 222
- > 222 - 555
- > 555
- Buildings/Roads
- Shoreline

Threshold Effect Concentration = 43.4
Probable Effect Concentration = 111
2X Probable Effect Concentration = 222
5X Probable Effect Concentration = 555

Background Concentration
SD 0-6" = 90.9 mg/kg
SD 6-18" = 66.8 mg/kg
SD 18-30" = 33.2 mg/kg
SD 30-52" = 32.9 mg/kg

All Location ID's Begin with "SD - "

1,080 540 0 1,080 Feet

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Checked By: S. OZKAN 11/14/12
Approved By:

Contract Number: 112IC02903

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TETRA TECH

Figure 2 - 10
Thiessen Polygons for
Copper in Sediment
Lockheed Martin Middle River Complex
Middle River, Maryland

Legend

- Copper Sample Location
- Stormwater Outfall Locations

Copper Thiessen Polygons (mg/kg)

- Less than Background
- < or = 31.6
- > 31.6 - 149
- > 149 - 298
- > 298 - 745
- > 745
- Buildings/Roads
- Shoreline

Threshold Effect Concentration = 31.6
Probable Effect Concentration = 149
2X Probable Effect Concentration = 298
5X Probable Effect Concentration = 745

Background Concentration
SD 0-6" = 110 mg/kg
SD 6-18 = 54 mg/kg
SD 18-30" = 16.2 mg/kg
SD 30-52" = 14 mg/kg

All Location ID's Begin with "SD - "

1,080 540 0 1,080 Feet

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Checked By: S. OZKAN 11/14/12
Approved By:

Contract Number: 112IC02903

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TETRA TECH

Figure 2 - 11
Thiessen Polygons for
Lead in Sediment
Lockheed Martin Middle River Complex
Middle River, Maryland

Legend

- Lead Sample Location
- Stormwater Outfall Locations

Lead Thiessen Polygons (mg/kg)

- Less than Background
- < or = 35.8
- > 35.8 - 128
- > 128 - 256
- > 256 - 640
- > 640
- Buildings/Roads
- Shoreline

Threshold Effect Concentration = 35.8
Probable Effect Concentration = 128
2X Probable Effect Concentration = 256
5X Probable Effect Concentration = 640

Background Concentration
SD 0-6" = 151 mg/kg
SD 6-18" = 95.5 mg/kg
SD 18-30" = 18.7 mg/kg
SD 30-52" = 18.6 mg/kg

All Location ID's Begin with "SD - "

1,080 540 0 1,080
Feet

Drawn By: S. PAXTON 12/17/10
Checked By: S. OZKAN 11/14/12
Approved By:

Contract Number: 112IC02903

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TETRA TECH

Figure 2 - 12
Thiessen Polygons for
Mercury in Sediment
Lockheed Martin Middle River Complex
Middle River, Maryland

Legend

Mercury Sample Location

Stormwater Outfall Locations

Mercury Thiessen Polygons (mg/kg)

Less than Background

< or = 0.18

> 0.18 - 1.06

> 1.06 - 2.12

> 2.12 - 5.3

> 5.3

Buildings/Roads

Shoreline

Threshold Effect Concentration = 0.18
Probable Effect Concentration = 1.06
2X Probable Effect Concentration = 2.12
5X Probable Effect Concentration = 5.3

Background Concentration
SD 0-6" = 0.71 mg/kg
SD 6-18" = 0.29 mg/kg
SD 18-30" = 0.053 mg/kg
SD 30-52" = 0.051 mg/kg

All Location ID's Begin with "SD - "

1,080 540 0 1,080
Feet

Drawn By: S. PAXTON 12/17/10
Checked By: S. OZKAN 11/14/12
Approved By:

Contract Number: 112IC02903

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TETRA TECH

Figure 2 - 13
Thiessen Polygons for Zinc in Sediment
Lockheed Martin Middle River Complex
Middle River, Maryland

Legend

- Zinc Sample Location
- Stormwater Outfall Locations

Zinc Thiessen Polygons (mg/kg)

- Less than Background
- < or = 121
- > 121 - 459
- > 459 - 918
- > 918 - 2295
- > 2295
- Buildings/Roads
- Shoreline

Threshold Effect Concentration = 121
Probable Effect Concentration = 459
2X Probable Effect Concentration = 918
5X Probable Effect Concentration = 2295

Background Concentration
SD 0-6" = 327 mg/kg
SD 6-18" = 209 mg/kg
SD 18-30" = 95.5 mg/kg
SD 30-52" = 94.7 mg/kg

All Location ID's Begin with "SD - "

1,080 540 0 1,080 Feet

Drawn By: S. PAXTON 12/17/10
Checked By: S. OZKAN 11/14/12
Approved By:

Contract Number: 112IC02903

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TETRA TECH

Figure 2 - 14
Thiessen Polygons for Arsenic in Sediment
Lockheed Martin Middle River Complex (MRC)
Middle River, Maryland

Legend

- Arsenic Sample Location
- Stormwater Outfall Locations

Arsenic Thiessen Polygons (mg/kg)

- < or = 18.3
- > 18.3 - 95% UTL for MRC Background Data
- Buildings/Roads
- Shoreline

Background Concentration
(Maximum MRC Study Area)
SD 0-6" = 13.5 mg/kg
SD 6-18" = 10.5 mg/kg
SD 18-30" = 6.9 mg/kg
SD 30-52" = 6.8 mg/kg

All Location ID's Begin with "SD - "

UPL = Upper Prediction Limit
UTL = Upper Tolerance Limit
PRG = Preliminary Remediation Goal
EPA = U.S. Environmental Protection Agency
NOAA = National Oceanic and Atmospheric Administration

Background	UTL	UPL
MRC Study Area	18.3	14.4
EPA/NOAA	31	30.5

1,080 540 0 1,080 Feet

Drawn By: T. WHEATON 04/19/11
Checked By: S. OZKAN 11/14/12
Approved By:

Contract Number: 112IC02903

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TETRA TECH

Figure 2 - 15
Thiessen Polygons for
Total Aroclor in Sediment
Lockheed Martin Middle River Complex
Middle River, Maryland

Legend

Total Aroclor Sample Location

Stormwater Outfall Locations

Total PCBs Thiessen Polygons (µg/kg)

< or = 59.8

> 59.8 - 676

> 676 - 1352

> 1352 - 3380

> 3380

Buildings/Roads

Shoreline

Threshold Effect Concentration = 59.8
Probable Effect Concentration = 676
2X Probable Effect Concentration = 1352
5X Probable Effect Concentration = 3380

Categories show different intervals of chemical concentrations.

Site-specific background = ND
Regional level = 1500 µg/kg *

*Regional levels are Presented on Table 4-10 of Tetra Tech 2011c.

All Location ID's Begin with "SD - "

ND = Non-Detect

1,080 540 0 1,080 Feet

Drawn By: S. PAXTON 12/20/10
Checked By: S. OZKAN 11/14/12
Approved By:

Contract Number: 112IC02903

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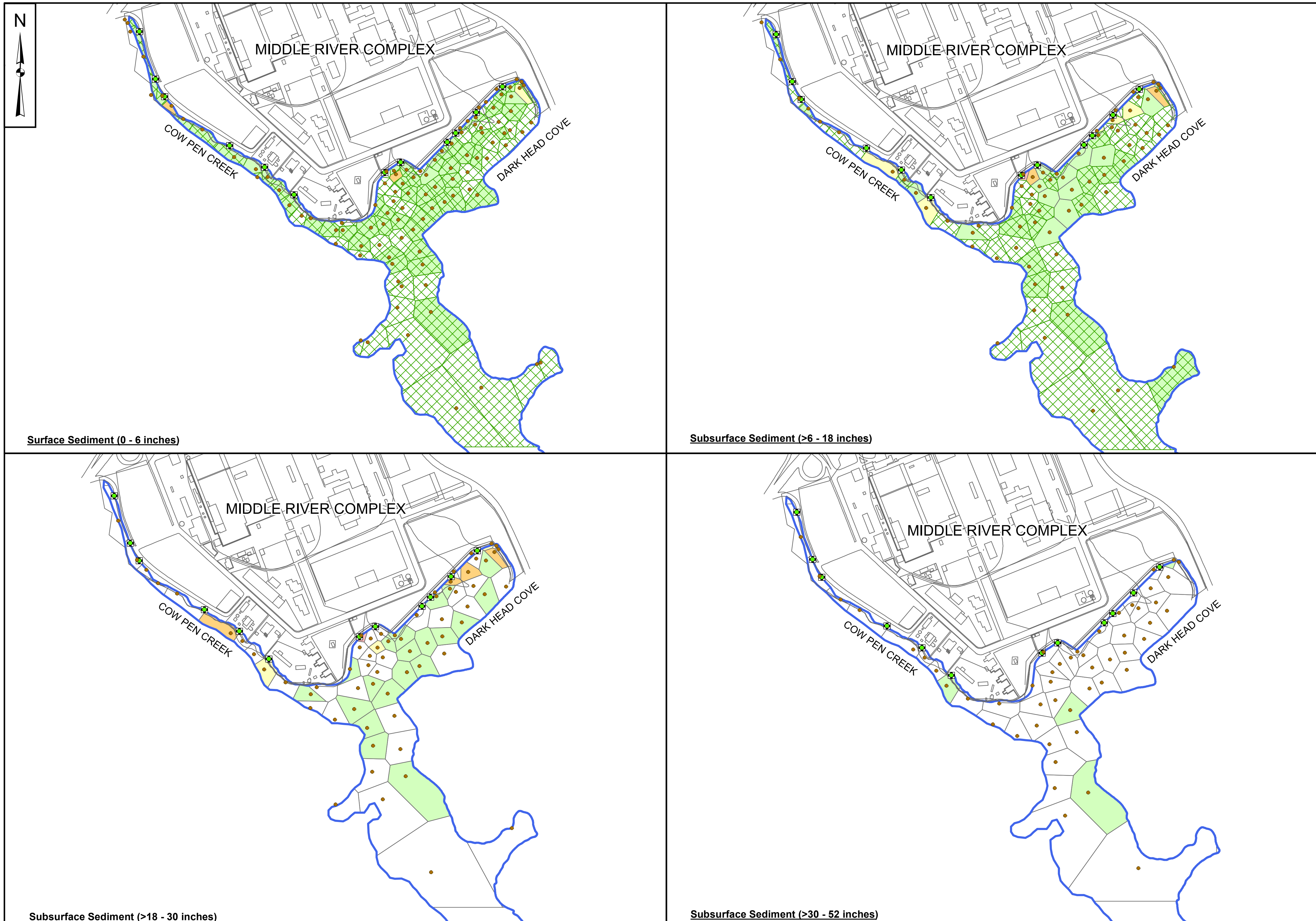

TETRA TECH

Figure 2 - 16
Thiessen Polygons for
Total PAHs in Sediment
Lockheed Martin Middle River Complex
Middle River, Maryland

Legend

- Total PAH Sample Location
- Stormwater Outfall Locations

Total PAH Thiessen Polygons (μg/kg)

- Less than Background
- < or = 1610
- > 1610 - 22800
- > 22800 - 45600
- > 45600 - 114000
- > 114000
- Buildings/Roads
- Shoreline

Threshold Effect Concentration = 1610
Probable Effect Concentration = 22800
2X Probable Effect Concentration = 45600
5X Probable Effect Concentration = 114000

Background Concentration
SD 0-6" = 15350 μg/kg
SD 6-18" = 5060 μg/kg
SD 18-30" = ND
SD 30-52" = ND

All Location ID's Begin with "SD - "

PAH = Polycyclic Aromatic Hydrocarbons
ND = Non-Detect

1,080 540 0 1,080 Feet

Drawn By: S. PAXTON 12/17/10
Checked By: S. OZKAN 11/14/12
Approved By:

Contract Number: 112IC02903

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TETRA TECH

Figure 2 - 17
Thiessen Polygons for
Benzo(a)pyrene Equivalents
(Positive Hits Only) in Sediment
Lockheed Martin Middle River Complex
Middle River, Maryland

Legend

- PAH Sample Location
- Stormwater Outfall Locations

BaP Eq Thiessen Polygons (µg/kg)

- Less than Background
- < or = 700
- > 700 - 1600
- > 1600
- Buildings/Roads
- Shoreline

Risk Based Concentration (RBC) for recreational user (direct contact risk) (IE-05 cancer risk level) = 700 µg/kg

Background Concentration
SD 0-6" = approximately 700 µg/kg
SD 6-18" = approximately 100 µg/kg
SD 18-30" = ND
SD 30-52" = ND

All Location ID's Begin with "SD - "

BaP Eq = Benzo(a)Pyrene Equivalents
PAH = Polycyclic Aromatic Hydrocarbons
ND = Non-Detect

1,080 540 0 1,080 Feet

Drawn By: S. PAXTON 12/17/10
Checked By: S. OZKAN 11/14/12
Approved By:

Contract Number: 112IC02903

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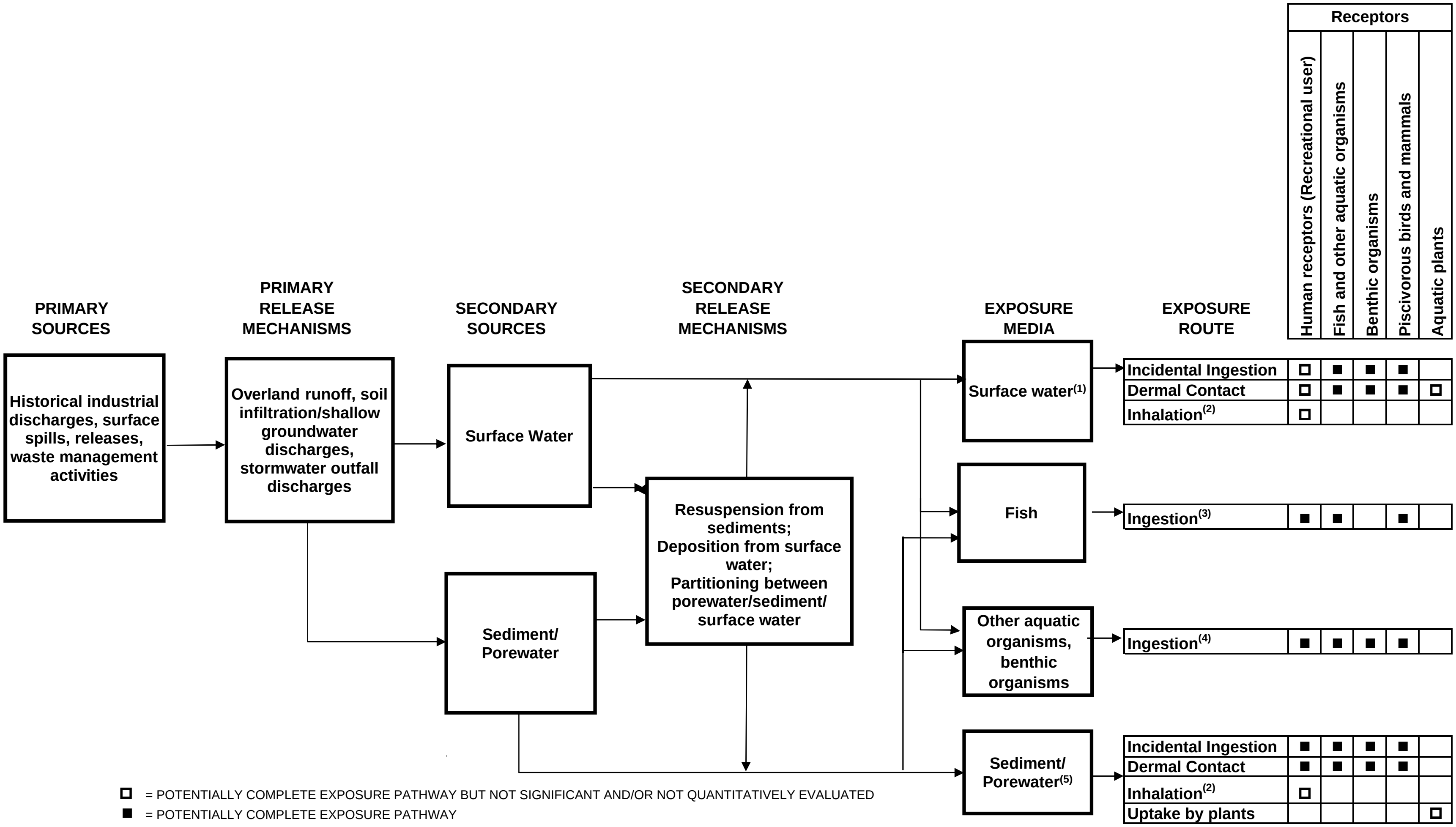
Figure 2-18

Conceptual Site Model
Lockheed Martin, Middle River Complex
Middle River, Maryland



1 - Direct contact with surface water is a complete exposure pathway but is not significant for the recreational user because contaminant concentrations in surface water did not result in unacceptable risks in the previous (2006) HHRA, and no contaminant concentrations in available 2010 surface water samples exceeded human health screening levels.
2 - Inhalation of volatile organic chemicals in surface water/sediment is not considered a significant pathway because of the low concentrations detected in surface water/sediment samples and because the sediments are submerged.
3 - Ingestion of fish that have accumulated chemicals from surface water, sediment, or porewater.
4 - Ingestion of other aquatic organisms and benthic organisms that have accumulated chemicals from surface water, sediment, or porewater.
5 - Only benthic invertebrates are expected to be exposed to chemicals in porewater.
MRC = Middle River Complex.

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Section 3
Remedial Action Objectives and Preliminary Remediation Goals

This section provides a description of the development of a set of narrative (i.e., non-numerical) remedial action objectives (RAOs) for the site. Remedial action objectives are developed to protect human health and the environment, and provide the foundation upon which preliminary numerical remediation goals, cleanup levels, and remediation alternatives can be developed. The RAOs pertain to the specific exposure pathways and receptors that were evaluated in the human health and ecological risk assessments, and for which potentially regulatorily unacceptable risks were identified (see Section 2.6).

Remedial action objectives are the basis for developing numerical preliminary remediation goals (PRGs), the target endpoint contaminant-concentrations that are believed sufficient to protect human health and the environment based on available site information (USEPA, 1997a). For the Middle River Complex (MRC) site, PRGs are numerical concentrations for sediment that will protect a particular receptor from regulatorily unacceptable exposure to a chemical via a specific pathway.

In addition to ensuring that human and ecological receptors are protected, remedial actions to clean up a site must also take into account applicable or relevant and appropriate requirements (ARARs). The ARARs are derived from federal, state, and local legal requirements and may potentially govern remedial activities. The estimates of human health and ecological risks, together with federal and state legal requirements (i.e., ARARs), are considered during definition of RAOs and development of PRGs.

3.1 APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

Identifying federal, state, and local legal requirements is a key component in developing RAOs and in the planning, evaluation, and selection of remedial action alternatives. The definitions of ARARs are as follows:

- ***applicable requirements*** are cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a Comprehensive Environmental Resource, Compensation, and Liability Act (CERCLA, or Superfund) site

- ***relevant and appropriate requirements*** are cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law, which, although not "applicable" to a hazardous substance, pollutant, contaminant, or remedial action, location, or other circumstance at a site, address problems or situations sufficiently similar to those encountered at the site that their use is well suited to the particular site

Some federal, state, and local environmental and public health governmental authorities may develop criteria, advisories, guidance documents, and proposed standards that are not legally enforceable, but that contain useful information for implementing a cleanup remedy or selecting cleanup levels. These fall into the category of criteria "to be considered" (referred to as TBCs). TBCs are not mandatory, but they may complement the identified ARARs.

The ARARs may be categorized as chemical-specific, action-specific, and location-specific:

- ***Chemical-specific*** ARARs are health-risk-based numerical values or methodologies that establish concentration or discharge limits for particular contaminants. Examples include drinking water maximum contaminant levels (MCLs) and Clean Water Act (CWA) Ambient Water Quality Criteria (AWQC).

- ***Action-specific*** ARARs are technology- or activity-based requirements, limitations on actions, or conditions involving special substances. Examples of action-specific ARARs include wastewater discharge standards.

- ***Location-specific*** ARARs are restrictions on actions or contaminant concentrations in certain environmentally sensitive areas. Examples of such areas that are regulated under various federal laws include floodplains, wetlands, and locations where endangered species or historically significant cultural resources are present.

Summaries of federal and Maryland chemical-specific ARARs and TBCs are included in Tables 3-1 and 3-2. These ARARs and TBCs provide some medium-specific guidance on regulatorily "acceptable" or "permissible" concentrations of contaminants. Table 3-3 summarizes federal location-specific ARARs and TBCs for this feasibility study (FS). These ARARs and TBCs place restrictions on activities or contaminant concentrations based on the particular characteristics or location of the MRC site.

3.2 REMEDIAL ACTION OBJECTIVES

Remedial action objectives provide a general description of what the cleanup will accomplish and serve as the design basis for the remedial alternatives developed in the FS (United States Environmental Protection Agency [USEPA], 1999). The RAOs should be as detailed as possible without limiting the range of possible remedial alternatives. The USEPA (1999) guidance states that RAOs should specify the following:

- exposure pathways, receptors, and the chemicals of concern (COC)
- regulatorily acceptable chemical concentrations or ranges of concentrations for each exposure pathway

The following RAOs were developed for the MRC site based on the outcome of the human health and ecological risk assessments, and considered the ARARs and TBCs presented in Section 3.1:

RAO 1: Reduce, to the extent practicable, human health risks associated with the consumption of resident fish by reducing bioavailable sediment concentrations of COC. The human health risk assessment provided an evaluation that identified the exposure scenarios likely to present the highest risks at the site. Per USEPA guidance (USEPA 1989), reasonable maximum exposure (RME) scenarios were used to formulate RAOs and evaluate cleanup alternatives. The RME scenario with the highest risk estimates for the MRC site is consumption of fish exposed to site sediments by recreational fishermen. The risk-driver COC identified for this scenario are polychlorinated biphenyls (PCBs), benzo(a)pyrene equivalents (BaPEq), and arsenic in resident seafood organisms. However, because only PCBs were detected in actual fish tissue data, PCBs were selected as COC for the consumption-of-fish exposure pathway.

Meeting this RAO will require that site-wide surface weighted-average COC concentrations in surface sediments be reduced to achieve a corresponding reduction in the concentration of COC in fish tissue. Exposure of these organisms to contaminants in sediment occurs within the biologically active zone, which includes the surficial sediment layer where organisms might have direct-contact exposure, and the upper layers of sediment where prey organisms may take up sediment contaminants. Reducing concentrations of COC in the upper surface layers of sediment will help reduce concentrations of COC in fish tissue that may occur through direct contact with sediment, and will reduce the transfer of COC to sediment porewater and surface water (which may also be a source of sediment contaminants in fish tissue). Reducing concentrations of COC in sediment that may transfer to porewater and surface water would be expected to also reduce concentrations in dietary items through which fish may be exposed.

RAO 2: Reduce, to the extent practicable, human health risks associated with exposure to COC through direct contact with sediments and incidental sediment ingestion by reducing sediment concentrations of COC. The human health risk assessment provides an estimate of regulatorily unacceptable cancer risks associated with direct contact or incidental ingestion of sediments during swimming, wading or fishing. The risk drivers for the direct-contact scenarios are BaPEq, arsenic, and PCBs. Reducing the excess cancer risk for the exposure pathways would entail reducing contaminant concentrations in surface sediment to risk-based levels or background. Human exposure to the COC for the exposure pathways may occur within the upper one to two feet of sediment, depending on the activity. Deeper sediments will not contribute appreciably to these risks unless they are exposed in the future.

RAO 3: Reduce, to the extent practicable, risks to benthic macroinvertebrates by reducing bioavailable sediment concentrations of COC. The conclusion in the ecological risk assessment is that ecological risks are possible for the benthic macroinvertebrate community. The ecological risk assessment identified cadmium, copper, mercury, lead, zinc, and total PCBs as potential risk drivers for the benthic macroinvertebrate community. Achievement of this RAO is determined on a point basis and can be demonstrated through comparison to the PRG. Exposure of benthic organisms to COC occurs within the biologically active zone, which is generally defined as the upper six inches (15 centimeters) of sediment (Furota and Emmett, 1993). Deeper sediments will not contribute appreciably to these risks unless they are exposed in the future. In some areas, achieving and maintaining this RAO may therefore require addressing deeper sediments that contain these risk drivers if they are potentially subject to exposure due to erosion or other forces that may disturb the overlying sediments.

The focus of RAO development is the impact of the contaminated sediments on human health and the benthic invertebrate communities that populate the site. Whereas the RAOs narratively define the intent of any remedial actions that may be undertaken to address these risks, numerical values (PRGs) are required to evaluate remedial alternatives for the site. The PRGs define the concentrations of COC in affected media that correspond to the RAOs (i.e., concentrations that will protect ecological and human receptors). Development of PRGs is discussed in Section 3.3.

3.3 PRELIMINARY REMEDIATION GOALS

Preliminary remediation goals (PRGs) are the chemical endpoint-concentrations associated with each RAO that are believed to be sufficient to protect human health and the environment, based on available site information (USEPA, 1997b). The PRGs in this FS are used to guide the evaluation of proposed remedial alternatives for sediment. Per USEPA guidelines, PRGs should be based on a combination of ARARs and the RAOs that are designed to minimize risks to human health and the environment. As presented in Tables 3-1 through 3-3, key ARARs for this project include the Maryland Department of the Environment (MDE) cleanup standards for soil and groundwater, the federal Clean Water Act, and the federal Rivers and Harbors Act. This section describes the development of human health and ecological PRGs for the sediment COC identified and evaluated in this FS. The COC and routes of exposure initially identified in the *Sediment Risk Assessment* (Tetra Tech, 2011c) are listed below.

Receptor of concern (exposure scenario)	Chemicals of concern
Recreational fisher: (Consumption of fish taken from Cow Pen Creek and Dark Head Cove) **Remedial Action Objective 1**	Polychlorinated biphenyl compounds (PCBs) Arsenic (As) Polycyclic aromatic hydrocarbons (PAHs), specifically those used to calculate the benzo(a)pyrene equivalent concentration (BaPEq[1]): Benzo(a)pyrene Benzo (a)anthracene Benzo (b)fluoranthene Benzo (k)fluoranthene Chrysene Dibenz (a,h) anthracene Indeno(1,2,3-cd)pyrene
Recreational user: (Direct human contact with the sediments of Cow Pen Creek and Dark Head Cove) **Remedial Action Objective 2**	Arsenic (As) PCBs BaPEq
Benthic organisms: (Direct contact with the sediments of Cow Pen Creek and Dark Head Cove). **Remedial Action Objective 3**	PCBs Cadmium (Cd) Copper (Cu) Mercury (Hg) Lead (Pb) Zinc (Zn)

[1]These PAHs will be referred to as the BaPEqs throughout the following narrative.

The PRGs developed for the MRC site are numerical values that complement the narrative RAOs. As such, they may be used as cleanup levels and post-cleanup monitoring criteria, or as criteria for measuring the performance of site remediation. The range of potential PRGs for risk-driver COC are presented in Table 3-4; these PRGs are protective for human health reasonable maximum exposure (RME) scenarios and for ecological receptors. Table 3-4 also includes the following:

- Descriptive statistics for site-specific background-sediment data for samples from the following locations near Middle River: Bowleys Quarters, Marshy Point, MRC-SW/SD-1, SD-1, and SD-78. (See Section 4 of the Sediment Risk Assessment [Tetra Tech, 2011c] for the detailed analytical results.)

- Descriptive statistics for sediment concentration data for numerous sampling locations across the upper Chesapeake Bay: The data were extracted and summarized from USEPA and National Oceanic and Atmospheric Administration (NOAA) websites, as described in Attachment A in Appendix A of this FS. This data set (and the associated descriptive statistics) provides a regional understanding of chemical concentrations in sediments across the upper Chesapeake Bay.

- Risk-based concentrations (RBCs) for a recreational fisherman routinely consuming fish taken from Cow Pen Creek/Dark Head Cove, and RBCs for the recreational user directly exposed to sediments in Cow Pen Creek/Dark Head Cove while recreating (e.g., boating, fishing, swimming, wading): These RBCs are potential PRGs for the site and represent the one-in-one million (1×10^{-6}), one-in-100,000 (1×10^{-5}), and one-in-10,000 (1×10^{-4}) cancer risk levels (i.e., probabilities of developing cancer) and/or a hazard index of 1 (i.e., the no adverse non-cancer effect level) for COC detected in sediment. These RBCs were calculated using the methodology described in Appendix A, Sections A.1 and A.2; detailed calculations are in Attachment B of Appendix A.

- Recommended risk-based PRGs for benthic organisms exposed to site sediments. Development of the PRG values in Table 3-4 is also discussed in Appendix B.

If a chemical was not identified as a COC for a particular human exposure scenario or ecological receptor, the chemical is identified as "Not COC" in Table 3-4, and no PRG is identified. The PRGs selected for further evaluation in the FS were based on the information presented in Table 3-4, and are summarized in Table 3-5. The rationale for the selection of PRGs is presented below.

3.3.1 Development of Human Health PRGs

This section presents rationale for selecting PRGs retained for further evaluation in the FS. The lowest PRGs are for protection of human health (RAOs 1 and 2), representing the 1×10^{-6} cancer risk level and a hazard index of 1. Additionally, if background concentrations are greater than the calculated RBCs, then the PRGs default to background concentrations. The PRGs selected for further evaluation in the FS are highlighted in Table 3-4, and summarized in Table 3-5.

3.3.1.1 Recommended Preliminary Remediation Goal for PCBs

The recommended PRG for RAO 1 for PCBs is a site-wide area weighted-average concentration of 195 micrograms per kilogram (µg/kg). As detailed in Attachment A of Appendix A, this concentration is the regional background level (the 95% upper prediction limit [UPL]), calculated based on data collected across the upper Chesapeake Bay by USEPA and NOAA. This regional background level is recommended as the PRG for RAO 1 because, as summarized in Table 3-4, calculated risk-based PRGs for the recreational fisher consuming fish are 2.3–23 µg/kg for the 1×10^{-6} and 1×10^{-5} cancer risk levels, respectively. These calculated, risk-based concentrations are less than the regional background level, and thus are not suitable for selection as the PRG in this FS. The following items relate to the PRG selected for PCBs:

- The referenced regional background data set was used to determine a background level for the study area because PCBs were not detected in background sediments in the data set specific to the study area. This may be a consequence of the fact that the data set for the study area includes only 11 background sediment samples; in contrast, analytical results for 95 samples were available in the regional background data set.

- The recommended PRG is less than the calculated risk-based PRGs representing the 1×10^{-4} cancer risk level (presented in Table 3-4). Thus, although the recommended PRG exceeds the calculated risk-based PRG for the 1×10^{-5} cancer risk level (the MDE risk management benchmark), the recommended PRG is nevertheless within the USEPA target cancer-risk range for making remedial decisions (i.e., 1×10^{-4} to 1×10^{-6}).

- The 95% UPL was chosen because it is a commonly used and relatively conservative statistical benchmark for background. In general, UPLs are recommended as estimates of background values. If background and site contaminant distributions are comparable, then a typical site concentration should lie below a 95% UPL. A site observation exceeding the background 95% UPL indicates some evidence of contamination due to site-related industrial activities

3.3.1.2 Recommended Preliminary Remediation Goal for BaPEq

The BaPEq PRG recommended for RAOs 1 and 2 is 700 µg/kg, measured as a site-wide surface weighted-average. This is the maximum detected background concentration and the 95% UPL reported for the background-sediment data set. The recommended PRG also represents the 1×10^{-5} cancer risk level for a lifelong recreational user hypothetically exposed to sediments through direct contact in the study area.

As shown in Table 3-4, calculated RBCs for the recreational fisher consuming fish are less than the study-area-specific background level; they are therefore not included for further evaluation in the FS. The recommended PRG is within the range of BaPEq concentrations reported in the regional background sediment data set discussed in Attachment A of Appendix A, and is less than the 95% UPL calculated for that data set. As reported in the scientific literature, a significant number of anthropogenic sources contribute to the BaPEq concentrations typically detected in background soils and sediments; this recommended PRG is likely on the lower end of the concentration range typically detected in sediments in a highly developed area such as the MRC.

3.3.1.3 Recommended Preliminary Remediation Goals for Arsenic

The arsenic PRG recommended for RAOs 1 and 2 is a site-wide surface weighted-average of 18.3 milligrams per kilogram (mg/kg). This concentration is the 95% Upper Tolerance Limit (UTL) calculated for background sediment in the study area data set. Like UPLs, UTLs are also used as estimates of background as they are upper threshold statistics. This value is the recommended PRG because, as summarized in Table 3-4, risk-based PRGs calculated for the recreational fisher consuming fish and the recreational user contacting sediment are less than the background level.

The background level (18.3 mg/kg) is based on the background sample data and is within the range of the regional background values presented in Attachment A of Appendix A.

3.4.2 Development of Ecological PRGs

The potential for adverse ecological effects due to exposure to chemicals released to the environment through historical activities at the MRC was evaluated through the ecological risk assessment (ERA) conducted for MRC sediments (Tetra Tech, 2011c). The conclusions presented in the ERA led to the retention of total PCBs and certain metals as final chemicals of potential concern (COPC) for potential risk to benthic invertebrates, based on an evaluation of surficial and subsurface sediment (i.e., at depth intervals of six to 18 inches, and 18–30 inches, respectively). The methodology used to develop sediment PRGs will protect benthic invertebrates, and is described in Appendix B. As discussed in the previous section, risks to benthic invertebrates are possible from certain metals and total PCBs in the sediment.

Under current conditions, ecological receptors are primarily exposed only to the surficial sediment (i.e., top six inches); cadmium and total PCBs are the risk-drivers in this interval. However, because deeper sediment could be exposed if the surficial sediment is removed (such as during dredging), subsurface sediment was also evaluated, as a conservative measure. Copper, lead, mercury, and zinc could also be of concern with respect to sediment-dwelling invertebrates if the subsurface sediment became surficial sediment. PRGs were therefore developed for cadmium, copper, lead, mercury, zinc, and total PCB concentrations; these COC were selected based on sediment chemistry, acid-volatile sulfides (AVS)/simultaneously extracted metals (SEM) results, porewater chemistry, and benthic invertebrate community data. As discussed in Section 2.5.2, porewater and AVS/SEM data indicate that potential risks posed by chromium is limited to a few sampling locations, so chromium was not retained for further evaluation or identified as a COC.

Sediment screening-levels (i.e., “lower-effects” values) are used to initially select chemicals as COPC in ERAs; they are not generally used as cleanup levels. Less conservative sediment benchmarks (referred to herein as “higher effects” values) are often used for deriving risk estimates, and are also used for developing PRGs. The lower-effects values are typically defined as concentrations below which effects on sediment macroinvertebrates are not expected, whereas higher effects values are typically defined as concentrations above which adverse effects to sediment macroinvertebrates are probable (MacDonald, et al., 1996, 2000a). Therefore, the first step in the PRG development process is to identify the higher effects values for each of the sediment COPC.

Table B-1 in Appendix B presents the higher-effects values (such as freshwater probable-effect concentrations [PECs] and marine probable-effect levels [PELs]) for each of the COPC. As discussed above, based on the salinity of the surface water (between one and 10 parts per thousand), and to be conservative, the lower of the freshwater or marine surface water and sediment screening levels were used in the ERA to meet (conservative) screening objectives. This approach was followed for selecting the surface water screening levels used to evaluate the porewater results in this PRG document for the same reason. The porewater results were not used to set PRGs; they were used to evaluate the relative bioavailability of the chemicals in the sediment. However, because the sediment benchmarks were used to set PRGs, the greater of the freshwater or marine benchmark was used as the basis for the PRG. In a brackish environment, such as exists at the site, both freshwater and marine values are appropriate for screening. This approach for setting PRGs is less conservative than the conservative approach used in a screening-level ERA to identify COPCs.

The AVS/SEM and porewater data were then used to determine whether the PECs could be adjusted to account for the site-specific bioavailability. Table B-2 in Appendix B presents the bulk-sediment chemical concentrations, the AVS/SEM results, and the porewater results for samples collected from seven locations adjacent to the site. PECs and surface water criteria used for comparison to porewater results are also included. All surface water criteria in Table B-2 are the lower of the freshwater and marine-water ecological screening levels from USEPA Region 3 Biological Technical Assistance Group [BTAG] (USEPA, 2006a, b).

Sediment concentrations shaded black in Table B-2 are concentrations greater than their respective PECs; porewater concentrations shaded black are concentrations exceeding their respective surface water criteria. The ratio of simultaneously extracted metals/acid-volatile sulfides to the fraction of organic content in sediments [(SEM-AVS)/f_{oc}] is shaded black if its value exceeds 130 micromoles per gram (μmol/g) of organic carbon, indicating the chemical is potentially bioavailable. As discussed in Appendix B, SEM-AVS)/f_{oc} concentrations greater than 130 μmol/g indicate that a sample may pose adverse biological effects due to cadmium, copper, lead, nickel, and zinc, while samples with SEM-AVS)/f_{oc} concentrations less than 130 μmol/g should pose lower risks. The table includes the results for all metals included in the SEM analysis, because the results for all metals are needed to calculate a total SEM value.

The (SEM-AVS)/f_{oc} values in the sediment samples collected from zero to six inches at all seven locations were less than 130 µmol/g. AVS concentrations in four samples were greater than the SEM concentrations, resulting in negative values (indicating the metals are not expected to be bioavailable). Only three sediment samples, collected in the deeper intervals (two at SD87 from depths of 6 to 18 inches and18 to 30 inches, and one at SD89 at a depth of 18 to 30 inches) had (SEM-AVS)/f_{oc} values that were slightly greater than 130 µmol/g. The total SEM values in those three samples are based primarily on the SEM concentration for zinc; the SEM concentrations for the other metals combined account for less than 25 percent of the total SEM value. Also, none of the porewater metals concentrations in those three samples exceeded their respective surface water criteria, indicating that the metals were not partitioning from the sediment to the porewater.

The benthic macroinvertebrate community study provides a third line of site-specific evidence used to develop the PRGs. As presented above, benthic macroinvertebrate samples were collected from seven site locations and three reference locations. A suite of benthic characteristics (i.e., metrics), including the Chesapeake Bay Benthic Index of Biotic Integrity (CB-B-IBI) for oligohaline estuaries, were then calculated, providing an indication of benthic community health. The CB-B-IBI is calculated by scoring six metrics of benthic community structure and function according to established thresholds. The scores for each metric (on a 1 to 5 scale) are then averaged to form the index for each site. Samples with index values of 3.0 or more are considered to have good benthic conditions, indicative of good habitat quality. One of the reference sites (Marshy Point) had good benthic conditions according to the CB-B-IBI (3.0), while the other two reference sites (Bowleys Quarters [2.3], and Middle River Downstream [2.0]) had values that were similar to the scores from the site locations (1.7 to 2.3), indicating stressful conditions for benthic macroinvertebrates based on CB-B-IBI scores. All seven sites near MRC in Cow Pen Creek and Dark Head Cove had CB-B-IBI scores indicating stress to benthic organisms.

Because contaminants such as metals and PCBs are elevated in some of the site samples where benthic macroinvertebrates were collected, it is possible that the contaminants contribute to the findings discussed above. However, the evaluation of benthic data also suggest that habitat, nutrient conditions (i.e., high levels of detritus [non-living organic material such as dead plants]), or some other type of background disturbances or inputs are negatively affecting benthic organisms in the general study area (in MRC samples as well as background samples). Some benthic macroinvertebrates such as pollution-tolerant *tubificid oligochaetes* and *spionid polychaetes* can survive in sediment with high amounts of detritus, but this type of environment may not be conducive to the survival of other more sensitive macroinvertebrates. (Both *tubificid oligochaetes* and *spionid polychaetes* were found at the site, and were also found to a lesser degree at the reference sites.) Therefore, although the total abundance of benthic macroinvertebrates increased at the locations with high amounts of detritus, other metrics such as the low abundance of pollution-sensitive taxa and other tolerance scores led to lower CB-B-IBI scores.

In summary, as presented in the evaluation above, the porewater and AVS/SEM results provide two lines of evidence that metals in the sediment are not highly bioavailable. In addition, the benthic community evaluation indicates that, although the benthic community at the site sampling locations is stressed, it is similarly stressed at two of the three background/reference stations. Although uncertainty remains as to whether this stress is caused by chemicals at the site or by natural conditions, the site benthic community is generally similar to those in the surrounding area; it does not appear to be significantly impacted by chemicals in the sediment. Also, as indicated above (and in Section 2.3.3), some sites local to the MRC had a greater density of benthic organisms than the reference sites, indicating the organisms were thriving at the site, even if many of them were classified as pollution-tolerant.

Based on the AVS/SEM and porewater analyses in the surficial and deeper sediment samples, cadmium at concentrations greater than six and 10 times the PEC (4.98 mg/kg), respectively, was not bioavailable. Although this evaluation supports a higher PRG, the recommended PRG for cadmium is set at twice the PEC (9.96 mg/kg). This value was selected because it is still conservative and is expected to be protective of sediment macroinvertebrates, and because remedial alternatives would not change significantly with slightly greater PRGs. It may be appropriate to set a clean-up goal that is higher than the PRG selected here at a later time, since it would be equally protective. This evaluation will be further evaluated during the design process.

All porewater concentrations of copper were less than its surface water screening level, with an exception at SD-85. This, combined with the AVS/SEM results (as discussed in more detail in

Appendix B) indicates that copper is even less bioavailable than cadmium in site sediment. Therefore, similar to cadmium, a PRG of twice its PEC (149 mg/kg), or 298 mg/kg, is recommened for copper.

Based on the AVS/SEM and porewater analysis, the bioavailability of lead and zinc is expected to be low. Although specific bioavailability data was not available for mercury (it was not analyzed for in the AVS/SEM or porewater samples), the bioavailability of mercury is expected to be similar to that of the other metals. Therefore, the PRGs for lead, mercury, and zinc were set at the greater of their respective PEC or background concentration. The background level of lead (190 mg/kg) is greater than the PEC (149 mg/kg). Conversely, the PECs for mercury (1.06 mg/kg) and zinc (459 mg/kg) are greater than their respective background concentrations. Therefore, the PRG for lead is based on its background concentration (198 mg/kg), and the PRGs for mercury (1.06 mg/kg) and zinc (459 mg/kg) are based on their PECs.

Similar to what was done for the metals, the greater of the freshwater or marine higher effects value was used to develop a PRG for total PCBs. Thus, the PCB PRG is 0.676 mg/kg, based on the freshwater PEC (MacDonald et al., 2000a). However, the primary site-specific parameter that affects the bioavailability of PCBs is organic carbon concentration in the sediment. In MacDonald et al. (2000b), sediment quality guidelines expressed on an organic carbon–normalized basis were converted to dry weight (dry wt)-normalized concentrations, assuming one percent organic carbon. The average percent of organic carbon in surficial sediment at the site is greater than three percent;If a site-specific value of 3 percent was used to convert the values, the guidelines would be three time higher. The relatively high organic carbon concentration in the site sediments compared to the assumptions used to develop the PEC provides a line of evidence to suggest that using the PEC for the PCBs PRG is likely to be conservative. Since all of porewater detections of PCBs were much lower than 1.3 µg/L (the lowest chronic value for aquatic organisms in Suter and Tsao, [1996]), risks to aquatic organisms, including sediment macroinvertebrates, from PCBs in the porewater are not likely. As a result, using the PEC (0.676 mg/kg, or 676 µg/kg) as the PRG for PCBs is expected to be protective of benthic macroinvertebrates at the site.

Table 3-1
Federal Chemical-Specific Applicable or Relevant and Appropriate Requirements (ARARs) and To Be Considered (TBC) Criteria
Middle River Complex, Middle River, Maryland
Page 1 of 2

Requirement	Citation	Synopsis	Evaluation/action to be taken
Cancer slope factors (CSFs)	—	CSFs are guidance values used to evaluate the potential carcinogenic hazards caused by exposure to contaminants.	CSFs are considered in developing human health protection values for soils and sediments at the site.
Reference doses (RfDs)	—	RfDs are guidance values used to evaluate the potential non-carcinogenic hazards caused by exposure to contaminants.	RfDs are considered in developing human health protection values for soils and sediments at the site.
Clean Water Act	33 U.S.C. 401; 33 U.S.C. 141; 33 U.S.C. 1251-1316; 40 CFR 230, 231, 404; 33 CFR 320-330	Clean Water Act regulates dredge/fill and other in-water construction work.	Dredging and other in-water construction must meet specific standards that apply to any construction activity in or near state waters.
Resource Conservation and Recovery Act (RCRA) Land Disposal Restrictions	42 U.S.C. 7401-7642; 40 CFR 268	Land disposal of hazardous waste	RCRA land disposal restrictions are considered for disposal of dredged sediments.
Toxic Substance Control Act	15 U.S.C. 2605; 40 CFR761	Management and disposal of materials containing polychlorinated biphenyls (PCBs)	Toxic Substance Control Act is considered for disposal of sediments with PCB concentrations greater than 50 parts per million (ppm).
Solid Waste Disposal Act	42 U.S.C. 215103259-6901-6991; 40 CFR 257, 258	Requirements for solid waste handling management and disposal	Covers non-hazardous waste generated during remedial activities unless wastes meet recycling exemptions.

U.S.C. – United States Code
CFR – Code of Federal Regulations

Table 3-1
Federal Chemical-Specific Applicable or Relevant and Appropriate Requirements (ARARs) and To Be Considered (TBC) Criteria
Middle River Complex, Middle River, Maryland

Requirement	Citation*	Synopsis	Evaluation/action to be taken
National Pollutant Discharge Elimination System (NPDES)	40 CFR 122, 125	Point-source standards for new discharges to surface water	Remediation discharges must comply with substantive requirements of NPDES rules. If upland handling of sediment is planned, construction storm water requirements will be addressed including development of a storm water pollution prevention plan and implementation of best management practices. NPDES program requirements will be reviewed as part of project final design.

U.S.C. – United States Code
CFR – Code of Federal Regulations

Table 3-2
State Chemical-Specific Applicable or Relevant and Appropriate Requirements (ARARs) and To Be Considered (TBC) Criteria
Middle River Complex, Middle River, Maryland

Requirement	Citation	Synopsis	Evaluation/action to be taken
Maryland Surface Water Quality Criteria	*Code of Maryland Regulations* (COMAR) 26.08.02.03	Establish minimum standards for surface water quality for each designated use. Standards are available to protect both human health and aquatic life.	Considered in determining the extent of surface water contamination and discharge criteria for alternatives that involve discharges to surface water and process water.
Maryland Department of the Environment *Cleanup Standards for Soil and Groundwater*	Not codified	Guidance for remedial actions based on land use and projected use of groundwater for potable purposes.	These guidelines are used in determining cleanup goals. The values in the tables are considered when determining cleanup concentrations for soil and groundwater. By the definition of ARARs in the *National Contingency Plan*, state requirements must be state laws or regulations; an environmental or facility siting law; promulgated; more stringent than the federal requirement; identified in a timely manner; and consistently applied. The Maryland *Cleanup Standards for Soil and Groundwater* are not promulgated as a law or regulation and should not be considered an ARAR.

Table 3-3
Federal Location-Specific Applicable or Relevant and Appropriate Requirements (ARARs) and To Be Considered (TBC) Criteria
Middle River Complex, Middle River, Maryland
Page 1 of 2

Requirement	Citation	Synopsis	Evaluation/action to be taken
Endangered Species Act of 1973	16 U.S.C. 1531; 50 CFR 81, 225, 402	Provides for consideration of the impacts on endangered and threatened species and their critical habitats. Requires federal agencies to ensure that any action carried out by the agency is not likely to jeopardize the continued existence of any endangered or threatened species or adversely affect its critical habitat.	A review of the available information indicates that no state or federally listed endangered or threatened species are known to permanently or seasonally reside near the Middle River Complex. For this reason, the Endangered Species Act would not be applicable or relevant and appropriate to actions taken at the site.
Archaeological and Historic Preservation Act	16 U.S.C. 469; 36 CFR Parts 62 and 65	Establishes requirements relating to potential loss or destruction of significant scientific, historical, or archaeological data. Also requires federal agencies to consider the existence and locations of landmarks on the *National Registry of Natural Landmarks* to avoid undesirable impacts on such landmarks.	The landmarks within and surrounding the Middle River Complex are not classified as potentially significant scientific, historical, archaeological, or national landmarks. For this reason, the Archaeological and Historical Preservation Act is not applicable or relevant and appropriate to actions taken at the site.
Fish and Wildlife Coordination Act, Improvement Act, and Conservation Act	16 U.S.C. 661 and 33 CFR 320.3; 16 U.S.C. 742a; 16 U.S.C. 2901	These acts require that the U.S. Fish and Wildlife Service, National Marine Fisheries Service, and related state agencies be consulted before structural modification of any body of water, including wetlands. If modifications must be conducted, the regulation requires that adequate protection be provided for fish and wildlife resources.	These agencies would be consulted regarding remedial alternatives that alter a stream or wetland.
National Environmental Policy Act (NEPA) Regulations, Wetlands, Floodplains, etc., Executive Order 11990	Executive Order 11990 and 40 CFR Subsection 6.302 [a] Appendix A	These regulations contain procedures for complying with Executive Order 11990 on wetlands protection. Appendix A of this order states that no remedial alternative may adversely affect a wetland if another practicable alternative is available. If no alternative is available, impacts from implementing the chosen alternative must be mitigated.	These regulations would apply for remedial actions that affect a wetland.

Table 3-3
Federal Location-Specific Applicable or Relevant and Appropriate Requirements (ARARs) and To Be Considered (TBC) Criteria
Middle River Complex, Middle River, Maryland
Page 2 of 2

Requirement	Citation	Synopsis	Evaluation/action to be taken
NEPA Regulations, Floodplain Management, Executive Order 11988	Executive Order 11988 and 40 CFR Part 6, Appendix A	Appendix A of this order describes the policy for carrying out the Executive Order regarding floodplains. If no practicable alternative exists to performing cleanup in a floodplain, potential harm must be mitigated and actions taken to preserve the beneficial value of the floodplain.	For removal actions in a floodplain, different alternatives that reduce the risk of flood loss and restore and preserve the floodplain will be considered.
CWA	33 U.S.C. 401; 33 U.S.C. 141; 33 U.S.C. 1251-1316; 40 CFR 230, 231, 404; 33 CFR 320-330	CWA regulates dredge/fill and other in-water construction work.	Dredging and other in-water construction must meet specific standards that apply to any construction activity in or near state waters.
NPDES	40 CFR 122, 125	Point-source standards for new discharges to surface water	Remediation discharges must comply with substantive requirements of NPDES rules. If upland handling of sediment is planned, construction storm water requirements will be addressed, including development of a storm-water pollution prevention plan and implementation of best management practices. NPDES program requirements will be reviewed as part of final project design.

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Table 3-4
Support Information for Preliminary Remediation Goals for Risk-Driver Chemicals in Lockheed Middle River Complex Sediment

Chemicals of Concern	Background Concentrations in Sediment: Combined NOAA/USEPA Data - Upper Chesapeake Bay - Maximum	Background Concentrations in Sediment: Combined NOAA/USEPA Data - Upper Chesapeake Bay - 95% UPL	Background Concentrations in Sediment: Site-Specific Maximum Across 0-6" 6-18" 18-30" 30-52" Intervals	Background Concentrations in Sediment: Site-Specific 95% UTL Across 0-6" 6-18" 18-30" 30-52" Intervals	Site Sediment Data: Sediment Depth Intervals: 0-6" 6-18" 18-30" 30-52" (95 % UCL Unless Specified Otherwise)	Risk-Based Threshold Concentrations: Spatial Scale of Exposure	RAO 1. Recreational Fisher (Consumption of Fish): Adult 10^{-4} Cancer Risk	RAO 1: Adult 10^{-5} Cancer Risk	RAO 1: Adult 10^{-6} Cancer Risk	RAO 1: Non-Cancer HQ = 1	RAO 2. Direct Human Contact with Sediments: Adult 10^{-4} Cancer Risk	RAO 2: Adult 10^{-5} Cancer Risk	RAO 2: Adult 10^{-6} Cancer Risk	RAO 2: Child Non-Cancer HQ = 1	RAO 3. Benthic Organisms[1]
Total PCBs (µg/kg dw) (BSAF-based)	498 (positive only and 1/2 U)	**195** (positive only and 1/2 U)	Not Detected	NA	Aroclor 1260 (most prevalent): 5000/1500/220/20	Site-wide	**230-640 (Varies based on TOC)**	**23-64 (<bkgd) (Varies based on TOC)**	**2.3-6.4 (<bkgd) (Varies based on TOC)**	**39-110 (<bkgd) (Varies based on TOC)**	**100,000**	**10000**	**1000**	**5600**	NA
					Maximum Aroclor 1260 concentration: 54,000/14000/1300/ 120	Point	NA	NA	NA	NA	NA	NA	NA	NA	**676[1]**
Arsenic (mg/kg dw)	32.6	30.5	13.5 (UPL = 15 Based on all available samples.)	**18.3**	10/7.6/6.8/6.6	Site-wide	**650**	**65**	**6.5 (<bkgd)**	**1200**	**180**	**18**	**1.8 (<bkgd)**	**108**	Not COC
					Maximum Concentration: 37.2/12.6/12.3/35.9	Point	NA	NA	NA	NA	NA	NA	NA	NA	Not COC
BAP equivalents (µg TEQ/kg dw)	1282 (positive only and 1/2 U)	858 (positive only)/847 (1/2 U)	**Maximum Surface Data**: **700/2,000** (Positive only/use 1/2 U). **UPL for all surface** (using 1/2 U) = 4000. **UPL for all available samples** (using 1/2 U) = 3000.	1410 (positive only)/6230 (1/2 U)	1700/1800/3000/180 (Calculated using 1/2 U)	Site-wide	Not COC in fish tissue. Calculated value based on transfer factor approximates bkgd: 400-1100.	Not COC in fish tissue. Calculated value based on transfer factor is less than bkgd.	Not COC in fish tissue. Calculated value based on transfer factor is less than bkgd.	NA	**7000-16000**	**700-1600 (approximates bkgd)**	**70-160 (<bkgd)**	NA	NA
					Maximum Concentration 6500/12100/38700/810 (Calculated using 1/2 U)	Point	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lead (mg/kg dw)	217	153	151	**190**	Arithmetic Mean Concentration: 407/131/89.4/18.9	Site-wide	Not COC	Not COC	Not COC	Not COC	Not COC	Not COC	Not COC	Not COC	NA
					Maximum Concentration: 31500/1370/316/163	Point	NA	NA	NA	NA	NA	NA	NA	NA	128[1]
Cadmium (mg/kg dw)	5.1	1.9	0.95	1.4	23.8/52.4/53/10	Site-wide	Not COC	Not COC	Not COC	Not COC	Not COC	Not COC	Not COC	Not COC	NA
					Maximum Concentration: 296/306/296/33.6	Point	NA	NA	NA	NA	NA	NA	NA	NA	**9.96[1]**
Copper (mg/kg dw)	246	118	110	110	112/93.6/67.3/22.1	Site-wide	Not COC	Not COC	Not COC	Not COC	Not COC	Not COC	Not COC	Not COC	NA
					Maximum Concentration: 183/178/147/84.1	Point	NA	NA	NA	NA	NA	NA	NA	NA	**298[1]**
Mercury (mg/kg dw)	0.73	0.39	0.71	1.7	0.43/0.82/1.5/0.23	Site-wide	Not COC	Not COC	Not COC	Not COC	Not COC	Not COC	Not COC	Not COC	NA
					Maximum Concentration: 3.5/3.5/6.1/1.5	Point	NA	NA	NA	NA	NA	NA	NA	NA	**1.06[1]**
Zinc (mg/kg dw)	844	552	327	401	352/411/508/144	Site-wide	Not COC	Not COC	Not COC	Not COC	Not COC	Not COC	Not COC	Not COC	NA
					Maximum Concentration: 636/1300/2980/4370	Point	NA	NA	NA	NA	NA	NA	NA	NA	**459[1]**

Notes:
1 - Consensus based probable effects concentration for freshwater systems (MacDonald*et al*., 2000); "2x" the benchmark is provided in some cases. Please see text for explanation.
2 - Selected preliminary remediation goals are shown in bold underline

BAP = benzo(a)pyrene
bkgd = background
BSAF = biota-sediment accumulation factor
COC = chemical of concern
dw = dry weight
USEPA = United States Environmental Protection Agency
HQ = hazard quotient
mg/kg = milligram per kilogram
NA = not applicable
NOAA = National Oceanic and Atmospheric Administration
PCB = polychlorinated biphenyl
RAO = remedial action objective
TOC = total organic carbon
TEQ = toxicity equivalency
U = non-detected
UCL = upper confidence limit
µg/kg = microgram per kilogram
UPL = upper prediction limit
UTL = upper tolerance limit

Table 3-5
Summary of Preliminary Remediation Goals for Risk-Driver Chemicals of Concern in Lockheed Middle River Complex Sediment
Middle River Complex, Middle River, Maryland

Risk Driver Chemical of Concern	Spatial Scale of Exposure	RAO 1: Recreational User: Consumption of Fish	RAO 2: Direct Human Contact with Sediments	RAO 3: Benthic Organisms
Total PCBs (µg/kg dw)	Site-wide	background (195) [1/]	1000	n/a
	Point	n/a	n/a	676
BaPEq (µg TEQ/kg dw)	Site-wide	background (700/2,000) [2/]	background (700/2,000)	n/a
	Point	n/a	n/a	n/a
Arsenic (mg/kg dw)	Site-wide	background (18.3) [3/]	background (18.3)	n/a
	Point	n/a	n/a	n/a
Lead (mg/kg dw)	Site-wide	n/a	n/a	n/a
	Point	n/a	n/a	background (190) [3/]
Cadmium (mg/kg dw)	Site-wide	n/a	n/a	n/a
	Point	n/a	n/a	9.96
Copper (mg/kg dw)	Site-wide	n/a	n/a	n/a
	Point	n/a	n/a	298
Mercury (mg/kg dw)	Site-wide	n/a	n/a	n/a
	Point	n/a	n/a	1.06
Zinc (mg/kg dw)	Site-wide	n/a	n/a	n/a
	Point	n/a	n/a	459

Notes:

[1/] Recommended background concentration is UPL calculated based on combined NOAA/USEPA dataset. Significant variation observed in dataset. PCBs were not detected in MRC background dataset.

[2/] Recommended background concentration is maximum detected concentration reported for MRC study-area-specific background sediment dataset. Significant variation observed in dataset. The 700 µg/kg value is for BaPEq calculated using positive results only. The 2,000 µg/kg value is for BaPEq calculated using one-half of the detection limit for non-detected results.

[3/] Recommended background concentration is UTL calculated for MRC study-area-specific background sediment dataset. Reasonable agreement with combined USEPA/NOAA datasets.

Acronyms:

BaPEq – benzo(a)pyrene equivalents
dw – dry weight
mg/kg – milligrams per kilogram
MRC – Middle River Complex
µg/kg – micrograms per kilogram
n/a – not available/not applicable
PCBs – polychlorinated biphenyls
NOAA – National Oceanic and Atmospheric Administration
RAO – remedial action objective
TEQ – toxicity equivalents
USEPA – U.S. Environmental Protection Agency
UPL – upper prediction limit
UTL – upper tolerance limit

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Section 4
Screening of Remedial Technologies and Process Options

The identification, description, and screening of remedial technologies and process options that may be applicable to the Lockheed Martin Corporation (Lockheed Martin) Middle River Complex (MRC) in Middle River, Maryland is provided in this section. Representative, effective, and implementable process options are identified and selected to carry forward for developing remedial alternatives for MRC sediments.

4.1 REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS SCREENING OVERVIEW

The identification and screening of remedial technologies and process options used in this section follow United States Environmental Protection Agency (USEPA) guidance (USEPA, 1988) and consist of the following three general steps:

1. Identify and describe general response actions (GRAs), the broad categories of remedial actions that may be appropriate for the MRC sediment (the medium of concern), as a single action or a combination of actions which may be taken to satisfy the remedial action objectives (RAOs) developed for the site.

2. Identify and screen the technologies and process options (e.g., specific processes within each technology type) applicable to each GRA to ensure that only those technologies and process options applicable to the contaminants present, their physical matrix (e.g., sediments), and other site characteristics will be considered and carried forward into the assembly of alternatives. This screening will be based primarily on the effectiveness of the technology in addressing the contaminants at the site but will also take into account the implementability and cost of each technology.

3. Identify preliminary volumes or areas of sediment to which GRAs might be applied, taking into account the requirements for protectiveness as identified in the RAOs and the specific chemical and physical characteristics of the site.

4.1.1 Definitions

The terms *general response action* (GRA), *technology types,* and *process options* are used throughout this section, and the definitions of these terms are provided below. In combination, they provide a structure for identifying and screening the technologies, processes, and administrative tools available for implementing remedial actions.

> *General response actions* broadly describe the kinds of media-specific remedial measures that could be applied to manage the human health and ecological risk-drivers. At MRC, they range from no action to complete removal with treatment or disposal, encompassing the possible remedial actions that could be used to achieve the RAOs. Identifying GRAs appropriate to contaminated sediments reduces and focuses the list of technologies to be screened.

> *Technology types* are the general technologies that describe a means for achieving a GRA. Examples of technology types include dredging, dry excavation, and physical and chemical treatment. Removal is a GRA that can be achieved using excavation or dredging technologies, whereas treatment is a GRA achieved using physical, biological, or chemical technologies.

> *Process options* are specific processes within each technology type. For example, chemical treatment, which is a technology type, includes such process options as solvent extraction and slurry oxidation. Process options are selected based on the characteristics of the medium and the technologies available to address the medium.

4.1.2 Screening Criteria for Candidate Technologies

According to USEPA guidance (USEPA, 1988), the initial screening of potential remedial technologies (and associated process options) identified for each GRA is based on effectiveness, implementability, and cost. Technologies may be applicable to all or only portions of the MRC site due to site-specific factors. Technologies considered should be commercially available, and should have been proven on a project or projects similar in size and site conditions to the site. The three screening criteria for candidate technologies are defined as follows:

- *Effectiveness* is the degree to which RAOs can be attained for the MRC site using a given technology. This criterion is also used to evaluate the short-term and long-term adverse effects the potential remedial alternative may have on the environment. Evaluation of effectiveness for MRC sediments includes the following: (1) the potential effectiveness of technology/process options in processing the estimated volumes of sediment and in meeting the remediation goals identified in the RAOs; (2) potential impacts to human health and the environment during the construction and implementation phase; and (3) the degree to which the technology/process is proven and reliable, given the risk drivers and conditions of MRC sediments.

- *Implementability* includes constructability of the technology, availability of treatments, associated administrative activities, and availability of materials. It addresses whether the intended remedial alternative can be implemented in a specific area requiring remediation. Factors to be considered in evaluating implementability at the MRC site include the following: site access; site bathymetric conditions; physical obstructions (such as piers); water depths; depths of sediment contamination; and sediment transport and disposal considerations.

  Other factors to be considered when evaluating the implementability of a remediation technology include: meeting federal, state, and local regulations; the degree and speed of remediation; size and availability of equipment; local and regional agency project-support; public acceptance; anticipated future land use; and other planned and/or ongoing projects and activities at or near the MRC.

- *Order-of-magnitude costs* are estimated based on experience with the technology on similar projects and include relative costs for equipment, labor, waste management, and permitting, among other considerations that are required to design and construct the process options being evaluated. Order-of-magnitude costs alone are not used to screen out a potential remediation option but are used in consideration of and in combination with the other screening criteria.

4.1.3 Sustainability Considerations

In addition to the three screening criteria described above, USEPA recognizes that incorporating sustainability principles can help increase the environmental, economic, and social benefits of a cleanup. USEPA has a “green remediation” strategy that applies to all Superfund cleanups to enhance the environmental benefits of federal cleanup programs by promoting sustainable technologies and practices (USEPA, 2012b). Green remediation strategy objectives include the following: (1) protecting human health and the environment by achieving remedial action goals; (2) supporting sustainable human and ecological use and reuse of remediated land; (3) minimizing impacts to water quality and water resources; (4) reducing air toxics emissions and greenhouse gas production; (5) minimizing material use and waste production; and (6) conserving natural resources and energy.

Green remediation comprises a range of best management practices that may be applied throughout the cleanup process. These practices provide potential waste management improvements; conserve or preserve energy, fuel, water, and other natural resources; reduce greenhouse gas emissions; promote sustainable long-term stewardship; and reduce adverse impacts on local communities during and after remediation activities.

Lockheed Martin has long been driven by the concept of sustainability and continues to seek and implement green and sustainable remediation solutions in remediation projects. The Corporation's sustainability measures include reduction in landfill waste, reduction in water and carbon emissions, infrastructure improvements, green power purchases, building Leadership in Energy and Environmental Design certified facilities, and safety performance awards. Lockheed Martin's long-term sustainability efforts in core business areas incorporate the use of hybrid life-cycle assessment to estimate environmental impacts across supply chain and operations, to fully assess the types and quantities of materials and resources used, to determine how these materials are sourced and the path they follow into the facilities,and to estimate product use and end-of-life considerations. At remediation sites, Lockheed Martin's goal is to protect human health and the environment and to perform environmental remediation in the most effective, efficient and affordable manner possible. Consistent with the Corporation's green and sustainable strategy for remediation projects, Lockheed Martin will explore and implement sustainability measures to reduce the environmental footprint of cleanup activities developed in this FS during remedial design and implementation.

In this section, sustainability criteria were not formally used to screen potentially applicable technologies, but they are considered in the detailed evaluation of each alternative in Section 6 and the comparative evaluations of alternatives in Section 7. Environmental footprint estimates of the remedial alternatives, sustainability measures, and best management practices that could be applied during cleanup activities are briefly discussed in Appendix F.

4.2 GENERAL RESPONSE ACTIONS AND TECHNOLOGIES

The GRAs are medium-specific actions that can be used to satisfy RAOs. Remediation of contaminated sediments can be accomplished using a number of different technologies or a combination of technologies. The GRAs and technology types appropriate for consideration in the remediation of contaminated sediments at the MRC are as follows, and are briefly described in the sections below:

- no action
- monitored natural recovery
- containment
- *in situ* treatment
- *ex situ* treatment
- disposal/reuse
- institutional controls
- enhanced natural recovery
- removal

4.2.1 No Action

No Action is a remedial approach retained by default, as required by the Comprehensive Environmental Resource, Compensation, and Liability Act (CERCLA, or Superfund). No Action can only be the selected remedy if the site poses no regulatorily unacceptable risks to human health or the environment. The MRC risk assessments show regulatorily unacceptable risks to human health and the environment (Tetra Tech, 2011c); therefore, the No Action alternative is retained for comparison but not discussed in detail in this FS.

4.2.2 Institutional Controls

Institutional controls are non-engineered controls such as legal or administrative measures that restrict human use or access of the site, thereby preventing or reducing exposure to contaminants by limiting or controlling activities that could lead to human exposure (USEPA, 2005a). Fish consumption advisories, restrictions on use of the waterway, deed restrictions, and restrictive covenants are examples of institutional controls. Institutional controls are typically used in conjunction with remedial measures such as dredging, containment, natural recovery, *in situ* treatment, etc. The nature and future use of the site and surrounding areas must be considered when developing institutional controls that leave contamination in place.

4.2.3 Monitored Natural Recovery

Monitored natural recovery (MNR) of contaminated sediments relies on naturally occurring physical, chemical, and/or biological processes to isolate, destroy, or otherwise reduce the mobility or toxicity of contaminants over time. The acceptability of natural recovery as a response action depends upon the time to recover to regulatorily acceptable contaminant levels in comparison to active remedies, and whether those recovery processes are permanent or reversible. Under MNR, risk reduction is achieved in one or more of the following ways:

- the contaminants are converted to a less toxic form through transformation processes, such as biochemical degradation or abiotic transformation which convert the contaminants to less toxic forms.
- loss of contaminants through diffusion into overlying water.
- exposure levels are reduced by a decrease in contaminant concentration levels in the near-surface sediment zone through burial or mixing-in-place with cleaner sediment.
- exposure levels are reduced by a decrease in contaminant concentration levels in the near-surface sediment zone through dispersion of particle-bound contaminants or diffusive or advective transport of contaminants to the water column.

Monitored natural recovery would entail a long-term monitoring program designed to observe and assess sediment chemistry and health of the biological community. Results of such a monitoring program determine the progress of natural recovery toward achieving RAOs.

4.2.4 Enhanced Natural Recovery

Enhanced natural recovery (ENR) for sediment involves the application of thin layers of clean material over areas where natural recovery processes are already occurring at a rate that is insufficient to reduce risks within an acceptable period. By applying thin layers of clean sediments over an area and allowing natural re-sorting or bioturbation to mix the contaminated and clean sediment layers, the natural recovery process is accelerated, resulting in a surface layer with chemical concentrations that are within regulatorily acceptable levels. The performance of ENR can be increased through *in situ* treatment by using *in situ* sorbent amendments. The reactive material (such as activated carbon, or organoclay) is mixed with the thin layer of clean material and reduces migration of dissolved contaminants in sediment porewater by binding them through adsorptive processes. The technology is called reactive ENR when sediment amendments are mixed into the ENR layer. A long-term monitoring program would likely be conducted in conjunction with ENR (USEPA, 2005a) to verify the effectiveness of the technology.

4.2.5 Containment (Capping)

Containment is in-place physical isolation or immobilization of contaminants in sediment through *in situ* capping. This technique involves placing clean capping material over areas of contaminated sediment to reduce the risk of human or biotic contact with contaminated sediment through stabilization and physical and chemical isolation mechanisms (USEPA, 2005a).With effective *in situ* cap placement, the bioavailability and mobility of contaminants in the underlying sediments would be immediately limited because the biota are physically isolated from the contaminated sediments.

Four general types of *in situ* caps are available: (1) conventional sediment caps, (2) composite caps, (3) armored caps, and (4) reactive caps. Conventional caps are constructed of granular material (such as clean sediment, clay, sand, or gravel) and may include a habitat-mix layer for habitat improvement. A more complex cap design (generally referred to as a composite cap) can include geotextiles, liners, and other permeable or impermeable elements in multiple layers. Armored caps include larger material such as gravel, cobbles, or quarry spalls to prevent erosion or loss of an underlying chemical isolation layer. Reactive caps incorporate reactive media such as activated carbon to attenuate the flux of contaminants. Example designs of conventional, composite, armored, and reactive caps are shown in Figure 4-1 (EPRI, 2007). A long-term monitoring program and institutional controls would be required to verify and maintain the integrity and performance of the cap.

4.2.6 Removal

Removal refers to the dredging or excavation of contaminated sediments from a site. Following removal, the dredged material is transferred to a treatment or a disposal facility. Excavation involves removing sediments in the absence of overlying water, whereas dredging is removal of sediment below the water column by mechanical or hydraulic methods. In general, following removal of contaminated sediments, clean fill material is placed in areas to manage residual contamination or to re-establish pre-existing bottom grades. If remaining contamination exceeds approved levels for residuals, the remaining contamination is typically capped in place.

Removal action is usually followed by the ancillary technologies and process options including dewatering of removed sediments, treatment of wastewater associated with dredging, and transportation and disposal of dredged or excavated sediments.

4.2.6.1 Dewatering

Removed sediment usually requires dewatering (either by gravity or mechanical equipment) to produce a material that is more easily handled, able to pass the paint filter test, and of sufficient strength for landfill disposal. Dewatering also minimizes the weight and cost of material to be transported and disposed, and makes transportation of the material easier and more cost-effective. During the dewatering process, sand may be separated from fine material fractions and, if relatively clean, may be considered for beneficial re-use. Dewatering requires management and potential treatment of wastewater before discharge either to a sanitary sewer or to surface water. As with all construction activities, dewatering processes will likely incorporate best management practices to protect air and surface water quality, as deemed appropriate during design. The two types of dewatering processes available, mechanical and passive, are summarized below.

***Mechanical dewatering*—**Typical mechanical dewatering processes include centrifugation, hydrocyclones, filter presses, and belt presses. These technologies physically force water from sediment. Centrifugation uses centrifugal force to separate liquids from solids. Water and solids are separated based upon density differences. A cloth filter or the addition of chemicals helps separate fine particles. Mechanical dewatering processes are suitable for areas where larger passive dewatering systems are impractical.

Hydrocyclones are continuously operated devices that use centrifugal force to accelerate the settling rate and separation of sediment particles in water. Slurries enter near the top of cone-shaped hydrocyclones and spin downward toward the point of the cone. The particles settle out through a drain in the bottom of the cone, while the effluent water is withdrawn through a pipe exiting the top of the cone. The production rate and minimum particle size separated depend on the diameter of the hydrocyclone.

Diaphragm filter presses use an inflatable diaphragm to add additional force to the filter cake before dewatered sediments are removed from the filter. Filter presses operate in a series of vertical filters that filter sediments from the dredge slurry as the slurry is pumped past the filters. Once the surface of the filter is covered by sediment and the pressure has been applied, the flow of the slurry is stopped and the caked sediments are removed. Filter presses are available in portable units similar to the centrifuge units.

Belt presses and plate filter presses use porous belts or plates with filters to compress sediments. Slurries are sandwiched between the belts or plates and high-pressure compression is applied, which promotes drainage through the filter medium and separation. Flocculants are often used to help remove water from the sediments. The overall dewatering process usually involves gravity-draining free water, initial low-pressure compression, and finally high-pressure compression. Belt presses can be fixed-base or transportable. They are commonly used in sludge management operations at municipal and industrial wastewater treatment plants.

***Passive dewatering*—**Passive dewatering involves settling suspended sediment particles via gravity and passively draining clarified water from the sediment. Many passive dewatering approaches are available. For mechanically dredged sediments, dewatering may involve gravity settling and separation and may be done on a transfer barge in the dredge operations area. The process may include haul barges outfitted with side drains or baffles to allow overflow of the clarified water. More commonly, mechanically dredged sediments are transferred to dewatering pads designed for gravity dewatering and collection of decant water in sumps for further treatment prior to discharge. Hydraulically dredged sediments can be dewatered in bermed ponds or lagoons, or sediment/water slurry may be pumped into geotextile bags (e.g., Geotubes®, a type of passive filter) and allowed to gravity drain.

4.2.6.2 Wastewater Treatment

Requirements for and methods used to treat wastewater are driven by the water quality criteria applicable to the discharge-receiving system (e.g., sanitary sewer systems or site surface water). Sanitary sewer systems have additional limitations on quantity, or flow rate, of discharge based on the capacity of the system. Water separated from dredged sediments may be decanted directly back to the receiving water without further treatment. If required, wastewater treatment may consist of gravity sedimentation potentially followed by filtration steps such as sand filtering. Further processing to substantively comply with Clean Water Act and National Pollutant Discharge Elimination System (NPDES) requirements (such as treatment with granular activated carbon [GAC]) will be evaluated based on the anticipated quality of the process water relative to discharge requirements.

4.2.6.3 Transportation

All remedial alternatives incorporating removal actions will also require transportation or conveyance methods for the sediment removed. Removed sediment can generally be transported via barge to a shoreline transfer facility. Sediment is then generally loaded to either trucks or rail cars by derrick cranes or mechanical conveyors for transfer to the final destination, such as a landfill. In cases of on-site disposal, sediment may be directly conveyed from barges or the dredge via pipeline. A new USEPA requirement to notify the affected region whenever contaminated material is being shipped through an "Environmental Justice" community (e.g., racial minorities, residents of economically disadvantaged areas) en route to the final disposal location must also be complied with.

4.2.7 *In situ* Treatment

In situ treatment is the in-place use of chemical or biological methods to reduce contaminant bioavailability, concentrations, mobility, or toxicity. With this technology, sediment is not removed from the site during or after treatment. Examples of *in situ* treatment include enhanced biodegradation, oxidation, sediment flushing, and adding sorbent amendments such as activated carbon, organoclay (to bind persistent organic pollutants) and natural minerals such as apatite, zeolites, or bauxite to bind toxic metals to sediments.

Guidance from USEPA encourages tracking and evaluation of treatment technologies, although significant technical limitations currently exist for many technologies applicable to sediments (USEPA, 2005a). In general, the *National Contingency Plan* and USEPA, under CERCLA, prefer treatment of contaminated media over containment or disposal (USEPA, 1988).

4.2.8 *Ex situ* Treatment

Ex situ treatment involves post-removal application of treatment technologies to transform, destroy, or immobilize COC in the contaminated dredge material. *Ex situ* treatment is performed to meet chemical and physical requirements for treatment or disposal, and/or to reduce the volume/weight of sediment that requires transport, treatment, or restricted disposal. Examples of *ex situ* treatment include stabilization, separation, solidification, thermal destruction, and vitrification.

Ex situ treatment technologies require sediment removal, generally followed by sediment dewatering and treatment of both the dewatered sediment and water. This approach requires treatment application in a nearby confined facility or lined dewatering pad, where physical, chemical, biological, and/or thermal processes remove contaminants from the sediment.

4.2.9 Disposal/Reuse

Disposal is the permanent placement of material that has been removed from the site into a permitted and/or appropriate structure or facility. Examples of disposal alternatives include in- or near-water facilities such as confined aquatic-disposal facilities or confined disposal facilities, and upland and off-site landfills. Any off-site disposal facility must be permitted and in compliance with the CERCLA off-site policy (i.e., the facility must also comply with all substantive permit requirements). Beneficial reuse is an alternative to disposal for some dredge material if, after treatment, some or all of the separated material(s) can be used for other purposes, such as industrial fill or daily landfill cover.

4.3 TECHNOLOGY SCREENING

The GRAs, technology types, and process options considered for MRC site sediments are listed in Table 4-1. These technologies were qualitatively evaluated and screened based on their effectiveness, implementability, and order-of-magnitude costs (the criteria previously described in Section 4.1.2). This screening evaluation process is intended to streamline the development of remedial alternatives for more detailed evaluation in the FS. Consistent with CERCLA guidance (USEPA, 1988), representative process options are selected to represent each technology type, to evaluate the remedial alternatives further and develop cost estimates. Selecting a representative process option does not preclude reexamining other similar process options later in the design phase of the project. Evaluation and screening of remedial technologies and process options is provided in this section, and summarized in Table 4-2.

4.3.1 Evaluation and Screening of Institutional Controls

Institutional controls are typically administrative actions that limit site or resource use. They are most often used in conjunction with remedial technologies that isolate or leave contaminated sediments in place, or in circumstances where concentrations of contaminants in fish or shellfish are expected to pose risks to human health for some time. Institutional controls include educational tools, seafood consumption advisories, easements, covenants, deed restrictions, enforcement and permit tools, and shoreline access, property use, and water use restrictions.

***Effectiveness*—**The effectiveness of institutional controls (ICs) depends on the cooperation of site owners, site users, and the public. The effectiveness of ICs also depends upon how they are enforced by the relevant agency or governmental entity. When implemented in conjunction with more active technologies, institutional controls can help effectively manage exposure risks to protect human health.

USEPA (2005b) guidance recommends using institutional controls in "layers" or in "series" to enhance protectiveness by simultaneously using more than one control with the same goal (e.g., a consent decree and a deed notice). Choosing the best combination of institutional controls that will protect human health and the environment is therefore quite important. Institutional controls have proven effective and reliable in meeting human health RAOs when designed, implemented, monitored, and enforced effectively with the cooperation of site users, owners, and the public.

***Implementability*—**Community information/education, fish and/or shellfish consumption advisories and related signs, and boating operations/anchorage restrictions are all technically implementable at the MRC. Administration of these controls would require the cooperation of the implementing agencies, as well as public acceptance and commitment from the public, site users, and site owners. Implementation of ICs at the MRC consists of developing an institutional controls plan that will prevent disturbance of contaminated sediments that remain in place and prevent unauthorized use of Cow Pen Creek and Dark Head Cove. If waterway use restrictions such as a no-anchor zone designation are to be applied, such an institutional control will be implemented through federal rule-making by the United States Coast Guard and the United States Army Corp of Engineers (USACE) in consultation with Maryland Department of Natural Resources (DNR). ICs would also include a requirement for regular site inspections to verify and enforce the continued application of these controls.

***Cost*—**The cost of implementing ICs compared to other GRAs is low. The cost is related to legal and administrative implementation costs. Costs associated with monitoring the institutional controls and enforcement activities may be incurred.

***Screening result*—**Institutional controls are considered appropriate as a component of a combined remedial alternative applicable to the MRC, but are not considered as the sole component of a remedy. Institutional controls are retained for consideration in the FS.

4.3.2 Evaluation and Screening of Monitored Natural Recovery

Monitored natural recovery of contaminated sediments relies on naturally occurring physical, chemical, and/or biological processes such as burial, biodegradation, and dilution to reduce the mobility or toxicity of contaminants over time.

Effectiveness—The COC in site sediments generally resist biodegradation and dissolution. The primary mechanism of natural recovery at the MRC are burial and dilution via sediment deposition. Sedimentation-rate analyses for sediments in Dark Head Cove, Cow Pen Creek, and the confluence of the two water bodies indicate that the highest sedimentation rates are expected at the confluence of Dark Head Cove and Cow Pen Creek downstream of the site (1.1 to 1.7 centimeters per year [cm/year]). The sedimentation rate in Dark Head Cove is 0.8 to 0.99 cm/year, and at the mouth of Cow Pen Creek it is 0.3 to 0.51 cm/year (Tetra Tech, 2011a). Low sedimentation rates and the magnitude of COC concentrations in Cow Pen Creek suggest that MNR alone has a relatively low effectiveness in achieving RAOs in a reasonable timeframe (i.e, estimated time to reach RAOs is 96 years). Sedimentation rates in Dark Head Cove and at the confluence suggest that MNR will have moderate to high effectiveness in achieving RAOs. Monitored natural recovery is considered effective as a component of a combined remedial alternative.

Implementability—MNR is technically implementable for site conditions. Long-term monitoring of site conditions presents no significant implementation challenges.

Cost—Monitored natural recovery is generally a lower cost option as compared to active remediation, which involves containment, removal, or treatment of sediment. Long-term monitoring costs vary widely depending upon the regulatory expectations, media of concern, and residual risks.

Screening result— Monitored natural recovery technology is considered appropriate as a component of a combined remedial alternative applicable to the MRC, but it is not considered as the sole component of a remedy. It is retained for consideration in the FS.

4.3.3 Evaluation and Screening of Enhanced Natural Recovery

Enhanced natural recovery accelerates MNR by adding a thin layer of clean material (typically 15 to 23 centimeters (cm) [six to nine inches]) over areas with relatively low contaminant concentrations to enhance or encourage natural recovery processes already demonstrated to be occurring at a site.

Enhanced natural recovery differs from capping in that it is not designed to provide long-term isolation. Rather it accelerates natural depositional processes, immediately reduces concentrations of contaminants available for exposure, facilitates re-establishment of benthic organisms, and minimizes short-term disruption of the benthic community (as compared to other active remediation technologies) while ongoing recovery processes that reduce the bioavailability or toxicity of contaminants in sediments (Merritt et al., 2009).

Effectiveness— Enhanced natural recovery alone may have low to moderate effectiveness in achieving RAOs in all areas of the MRC. However, in areas where hazards posed by contaminated sediment are relatively low (e.g., COC concentrations equal to or less than two times the PRGs), ENR is expected to be moderately to highly effective in immediately achieving RAOs by reducing COC concentrations in the surface layer in the long term primarily due to the dilution effect. Enhanced natural recovery effectiveness can be increased by adding reactive media such as activated carbon in a thin layer of clean material to promote chemical immobilization of contaminants and reduce their bioavailability.

Implementability— Enhanced natural recovery is technically implementable for site conditions. It will require substantive compliance with Sections 404 and 401 of the Clean Water Act and Endangered Species Act. In-water work will need to be conducted during a seasonal window (i.e., time of year restriction) to minimize potential impacts to important fish, wildlife, and habitat resources in the area. The timing of the in-water work restrictions will be determined by the State of Maryland during the process of reviewing the project application for a water quality certification. Dark Head Cove is a federally authorized navigation channel where the project depth is -10 feet mean lower low-water (MLLW). Placement of ENR materials will reduce existing water depths. Administrative implementability of ENR is considered low because of the federal navigation channel status of the site, and associated difficulties in obtaining USACE concurrence. Resources needed for ENR are readily available from multiple vendors, and procurable through competitive bidding. Numerous marine contractors, suitable construction equipment, and sufficient skilled labor are available in the region to implement a monitoring program or execute placement of a thin layer of material over contaminated sediment at the MRC.

Cost—The major cost activity of enhanced natural recovery is placement of a thin layer of clean granular material. Enhanced natural recovery costs generally range from low to moderate, and therefore fall between the low cost generally associated with MNR and the higher costs associated with containment and/or removal. Use of reactive media increases raw materials costs. Enhanced natural recovery monitoring costs may be significant depending on the term and magnitude of the monitoring program. Long-term monitoring costs vary widely depending upon regulatory expectations, media of concern, and residual risks.

Screening result**—**Enhanced natural recovery technology is considered applicable to the MRC as a component of a combined remedial alternative, but not as the sole component of a remedy, and is therefore retained for consideration in the FS.

4.3.4 Evaluation and Screening of Containment Technologies

Containment in the context of impacted MRC sediments, involves *in situ* capping.

Effectiveness**—**Conventional and composite capping technologies are effective in achieving the RAOs for all site COC. Capping isolates contaminants from the overlying water column, prevents direct contact with aquatic biota, and provides new clean substrate for re-colonization by benthic organisms. Capping is considered very effective in areas where groundwater flux is low, and for low-solubility and highly sorbed contaminants such as polychlorinated biphenyls (PCBs), for which the principal transport mechanism is sediment resuspension and deposition. Caps must be designed to withstand the bottom shear stresses that develop during normal and extreme (storm) conditions to prevent the release and resuspension of contaminated sediment.

The use of geotextiles (composite cap) may be an effective substitute for sand or clean sediment, but would likely require some form of armoring to remain in place. The sorbent/sequestering capacity of a cap can be improved by increasing the organic carbon content of the capping material. A reactive cap containing a single reactive media-type may be effective at achieving RAOs for a particular COC, but may not be effective for a suite of multiple COC with varying characteristics.

Implementability**—**Physical site conditions influence the selection and implementability of sediment caps. For instance, sediment caps may result in bed elevation changes that result in unacceptable impacts to navigation, floodplain, or ecological habitat. Conventional sediment caps require underlying sediments with sufficient bearing strength to support the cap. Additionally, sediment caps may not be stable in areas with steep bed slope or highly erosive hydrodynamic conditions.

All capping technologies and process options are technically implementable at the MRC. With respect to administrative implementability, the primary institutional or administrative issue of capping relates to federal navigation channel status, riparian land ownership and requirements for long-term site use, and cap monitoring. Institutional controls will be required with any capping alternative, including restrictive covenants, deed or use restrictions, and potential waterway use restrictions for activities able to disturb a cap, as well as commitment to a long-term operation, maintenance and monitoring plan.

Capping will require compliance with Sections 404 and 401 of the Clean Water Act and the Endangered Species Act. In-water capping will need to be conducted during a seasonal window to minimize potential impacts to important fish, wildlife, and habitat resources in the area. The timing of the in-water work restrictions will be determined by the State of Maryland during the process of reviewing the project application for a water quality certification. Numerous marine contractors, suitable construction equipment, and sufficient skilled labor are available in the region to execute a contaminated-sediment capping project. Resources for capping are available from multiple vendors and procurable through competitive bidding. Conventional sediment caps have an established history of successful implementation nationwide.

***Cost*—**Capping costs are moderate compared to other remedial technologies and process options such as dredging, dewatering, treatment, and disposal. Costs are influenced by the required thickness of the cap and complexity of design (e.g., multiple layers or materials), any reactive media to be used (e.g., activated carbon), and long-term monitoring and implementation of institutional controls. The costs of composite and reactive caps are moderate to high compared to the conventional cap.

***Screening summary*—**All capping technologies are retained for consideration as a component of a combined remedial alternative in the FS.

4.3.5 Evaluation and Screening of Removal Technologies

Dredging is the most common way to remove contaminated sediment from a body of water. Excavation removes sediments in the absence of overlying water, whereas dredging removes sediment through the water column. For dredging projects, several site-specific characteristics must be considered, including the depth of the water column, volume of material to be removed, width and depth of the dredge cut, sediment characteristics, the possibility of disturbing a protected or beneficial habitat, and the presence of debris. Three types of dredging were considered: mechanical dredging, hydraulic dredging, and specialty dredging.

Effectiveness**—**Environmental dredging attempts toremove sediment that is contaminated above certain action levels, while minimizing the spread of contaminants to the surrounding environment through dredging. Removal technologies using mechanical and hydraulic dredging and excavation technologies are all effective in achieving the RAOs. Removal effectiveness depends on the site-specific characteristics and resolution of major issues relevant to environmental dredging projects, known as the "4Rs" (Bridges et al., 2008). These include: (1) sediment *resuspension* from dredging operations; (2) *release* of contaminants from bedded and suspended sediment in connection with dredging; (3) *residual* contaminated sediment produced by and/or remaining after dredging; and (4) environmental *risks* that are the target of and associated with dredging. Experience gained nationwide over the past 15 years allows current environmental dredging practices to address these issues. Release of contaminants from suspended sediments during dredging is monitored in pilot dredging studies and full-scale dredging projects. Monitoring data from pilot dredging projects performed in Fox River and Grasse River and other early studies showed that two to three percent of dredged PCBs were transported downstream from the project area (Bridges et al., 2008).

Recently, the effectiveness of dredging at Superfund megasites in United States, where remedial cost is expected to exceed 50 million dollars, has been assessed by National Research Council (NRC, 2007). The committee found that dredging alone achieved the desired contaminant-specific cleanup levels at only a few of the 26 reviewed megasite dredging projects. Placement of a layer of clean material over sediments with elevated contaminant concentrations (i.e., undisturbed residuals) after dredging was often necessary to achieve cleanup levels.

Hydraulic and specialty dredging equipment entrains a larger volume of water into dredged sediments (which must be subsequently managed) than does a mechanical dredge. A wide range of percent-solids for hydraulic dredges is reported, but 5 to 10 percent solids can be expected for most environmental dredging projects, whereas mechanical dredging removes the sediment at nearly the same solids content as the *in situ* sediments (USEPA, 2005a). Hydraulically dredged sediments are typically pumped in slurry form to a dewatering area and dewatered in settling basins, sediment processing facilities, or in geotextile dewatering tubes. Hydraulic and specialty dredging is generally more effective than mechanical dredging in less dense sediments (i.e., those with a greater water content). The nature and extent of debris in the sediment may also greatly limit the effectiveness of hydraulic dredging; therefore, typically debris is removed prior to hydraulic dredging.

Mechanical dredge equipment is particularly effective in removing stiff or dense sediments. It is most suitable for removing gravel, dense sand, and very cohesive sediments such as clay, glacial till, peat, and highly consolidated silts. Mechanical dredging minimizes the volume of sediments and additional water to be managed. Excavation technologies are effective for shoreline areas and shallower intertidal areas that are partially exposed during low tides; however, overall applicability is restricted due to the limited area for which this technology may be appropriate or effective. Excavation equipment may be additionally effective at removing debris in certain areas. Cutterhead, plain suction, horizontal auger, and pneumatic specialty dredge heads are subject to clogging by debris and are incapable of removing larger pieces of loose rock and debris.

Implementability—All of the dredging technologies described above are technically implementable at the MRC. The factors affecting effectiveness also influence implementability. Removal technologies and the availability of equipment and skilled operators are important factors. Hydraulic dredging requires an initial debris sweep and upland facilities to process the sediment and water slurry generated.

With respect to administrative feasibility, dredging will require compliance with Sections 404 and 401 of the Clean Water Act and the Endangered Species Act. In-water dredging will need to be conducted during a seasonal window of time to minimize potential impacts to important fish, wildlife, and habitat resources in the area. The timing of the in-water work restrictions will be determined by the State of Maryland during the process of reviewing the project application for a water quality certification. Any off-site disposal of dredged material must be at a landfill that meets USEPA criteria. All generator requirements related to off-site transport and disposal of the dredged material must be met. Resources for these removal technologies are available from multiple vendors and procurable through competitive bidding. Numerous marine contractors, suitable construction equipment, and sufficient skilled labor are available in the region to execute a contaminated-sediment removal project.

***Cost*—**The cost of a removal action is higher than other GRAs, due to costs for confirmation sampling and the ancillary technologies associated with removal, such as sediment transport, dewatering, and disposal, water treatment, and residuals management. Critical cost factors for mechanical dredging include operator skill, water depths, requirements to minimize sediment loss or re-suspension (among other factors), all of which influence dredge cycle-time (i.e., the time required to capture and release one bucket load of sediment). Excavation approaches incorporate moderate costs when conducted at shoreline areas or during low tide. Excavation approaches used in conjunction with dewatering of the area to be excavated in the dry (by using measures such as sheet piling or cofferdams) may impose higher costs. Hydraulic dredging costs are influenced by the space and resources required to handle and process dredged sediments, as well as costs to treat the water used to slurry the sediment during dredging. A cost-comparison analysis of cofferdam installation, followed by excavation versus treatment of water released from hydraulically-dredged sediment during dewatering, can be performed in the design phase to evaluate the feasibility of these technologies for the specific application at MRC.

***Screening summary*—**All removal technologies are retained in the FS for further consideration.

4.3.6 Evaluation and Screening of Ancillary Technologies

The ancillary technologies and process options (i.e., dewatering, wastewater treatment, transportation) are associated with removal technology. Screening of ancillary technology types and process options is summarized in Table 4-2.

***Evaluation*—**The anticipated effectiveness of ancillary technologies associated with removal of MRC sediments is considered moderate to high. All ancillary technologies are applicable to MRC sediments and technically implementable for conditions within the MRC. Selection of specific ancillary technology will be refined during design.

***Screening summary*—**All ancillary technology types and process options are retained for further consideration in the FS.

4.3.7 Evaluation and Screening of *In Situ* Treatment Technologies

Treatment technologies for sediments reduce or eliminate toxicity, mobility, or volume of a chemical of concern by implementing a process that alters, bonds with, isolates, or completely destroys the chemical.

Evaluation—The anticipated effectiveness of *in situ* treatment technologies for MRC sediments is considered moderate to high. Although no *in situ* treatment technologies (e.g., biological, physical, and chemical) have been implemented full-scale at a contaminated site. Laboratory research and pilot-scale applications of *in situ* remediation with sorbent amendments (e.g., activated carbon) show a reduction in the bioavailability of various pollutants such as PCBs, polycyclic aromatic hydrocarbons (PAHs), and metals (Ghosh et al., 2011). Ongoing monitoring of pilot-scale *in situ* amendment projects shows the effectiveness of sorbents in reducing contaminant bioavailability, with no significant adverse effects to the benthic community (Menzie and Ghosh, 2011).

Critical barriers to adopting *in situ* remediation approaches are the availability of efficient methods for delivering amendments to contaminated sediments and understanding the physical, chemical, and biological processes in the field that control the effectiveness of this technology. Other challenges requiring resolution are potential negative impacts on the water column by sediment disturbance during application of the reactive materials or amendments; controlling the treatment process to provide uniform results throughout the sediment; effectiveness of the process under saturated, anaerobic conditions at ambient temperatures; and the development of methods to treat deeper sediment deposits.

Screening summary—Adding reactive material as an *in situ* treatment technology is retained for further consideration in the FS.

4.3.8 Evaluation and Screening of *Ex Situ* Treatment Technologies

For most sediment removed from Superfund sites (MRC is not a Superfund site) in the United States, *ex situ* treatment is not conducted before disposal, generally because sediment sites often have widespread low-level contamination (USEPA, 2005a). However, pretreatment, such as particle-size separation for hazardous/nonhazardous waste disposal, is common. The COC concentrations at the MRC, as with most sediment sites, are classified as low-level-threat waste.

Evaluation—*Ex situ* treatment options with potential applicability to the MRC include conventional soil washing/particle separation, sediment washing, solidification, and thermal treatment (incineration, low or high temperature thermal desorption). The primary objective of sediment treatment is to decontaminate the sediment such that it could meet standards for beneficial re-use, which would avoid landfill disposal costs.

To date, *ex situ* treatment of sediments, although a subject of considerable interest nationwide, has mostly been limited to soil washing in full-scale sediment remediation projects. The process of soil washing includes sorting dredged sediments for oversized objects, applying high-pressure water in a preprocessor, and placing in a tank where air is used to turn organic materials into foam, with the subsequent removal of foam. An oxidant is introduced to the remaining sediments to clean contaminants, and the water is separated by centrifuging. The water is put back into the system or disposed of offsite while the sediment is turned into a reusable product. A recent pilot test of soil washing was conducted for the Passaic River sediments. The study was deemed ineffective by the USEPA, and the results of the study did not justify application of the technology at full scale for the Passaic River sediments.

A key limitation of soil washing and other *ex situ* treatment technologies is the fines content, because contamination is predominately adsorbed to fine sediment particles (silts and clays). Geotechnical data from sediment samples obtained from Cow Pen Creek and Dark Head Cove, indicate that the MRC surface and subsurface sediments are predominantly fine-grained (passing a #200 sieve) and are approximately 83% silts and clay (Tetra Tech, 2012a). Given that these sediments would likely still contain residual contamination in fines following treatment, the potential for reuse acceptance is considered low. Consequently, sediments would likely require disposal at an off-site facility even after treatment.

Solidification is another proven *ex situ* treatment technology that reduces the moisture content of dredged sediments and reduces the leachability of some metals. This process consists of adding cement, kiln dust, or other absorbent, and a solidification agent. As with soil washing, this process does not treat all COC in site sediment, and the sediment would still require landfill disposal. Furthermore, solidification would have to be limited to ensure that the pH of the treated waste isn't elevated to the point of creating a hazardous waste. Materials such as straw and sawdust have sometimes been used to absorb water in sediment to avoid a pH adjustment that could increase the leaching of metals.

Technologies that destroy or detoxify contaminants have been accepted at very few cleanup projects involving contaminated sediment sites for two main reasons: (1) balancing treatment costs with a beneficial reuse market for the material is difficult, and (2) in general, upland and in-water disposal alternatives are much less expensive. The MRC remediation project is not expected to produce a large volume of sediment over a sufficiently long period to meet the economic and implementability criteria requirements; therefore, incorporating an *ex situ* treatment technique into a remedial alternative is not justified for the site.

The anticipated effectiveness of *ex situ* treatment technologies, such as thermal or biological treatment for sediments at the MRC, is low because none of these technologies alone would treat both organic and inorganic sediment contaminants. A combination of technologies would be needed for them to be effective. For example, thermal and biological treatment could be considered for organic contaminants, but metals cannot be treated with these technologies. Metals can be treated with soil washing, extraction technologies, or by solidification. In general, these treatment technologies are expected to provide limited incremental benefit regarding toxicity reduction, destruction, and immobilization, relative to the benefit obtained by removing the contaminated sediment from the ecosystem and disposing of this sediment at an off-site landfill.

Screening summary—*Ex situ* treatment technologies such as sediment washing, thermal treatment, separation, and solidification are not carried forward for detailed analysis in the FS based on the evaluation presented above. However, e*x situ* treatment technologies may still need to be further evaluated during design because regulatory requirements may mandate treatment before disposal of removed MRC sediments. Therefore, these technologies are retained for design.

4.3.9 Evaluation and Screening of Disposal/Reuse Technologies

Disposal actions are typically combined with removal actions. Dredged material may be disposed of on-site or at an off-site waste disposal facility. In both cases, final placement of the material must be in a manner that will prevent the contaminated dredge material from returning to the environment. On-site disposal can be done on land, in a near-shore confined disposal facility (CDF), or in a confined aquatic disposal (CAD) facility. Off-site disposal can be either at an aquatic disposal site or at an approved upland waste disposal facility.

Effectiveness—Off-site disposal at permitted landfills is considered effective. On-site disposal is potentially effective but has other limitations. The effectiveness of a disposal technology depends upon the residual concentrations of COC in the dredged or treated sediments. Subtitle D landfills are suitable for all contaminants not designated by the state as dangerous waste, as Resource Conservation and Recovery Act (RCRA) hazardous waste, or as Toxic Substances Control Act (TSCA) remediation waste. Sediments or sediment intervals identified as containing PCBs at concentrations greater than 50 parts per million are considered hazardous wastes under TSCA, and are required to be either disposed of in an approved TSCA landfill or destroyed. However, if USEPA approves a risk-based option (40 Code of Federal Regulations [CFR] 761.61[c]) for PCB remediation waste, solid waste landfills or RCRA Subtitle C hazardous waste landfills may also be used, if consistent with the disposal facility permit and state regulations.

Beneficial reuse is defined as the reuse of dredged material or some portion of it as a resource instead of disposing of it as a solid waste. It provides for the use of the dredged material in a productive manner, such as to create or restore habitat, or for landscaping, soil/material enhancement, construction fill, land reclamation, etc. Dredged material may thus have some economic, social, or environmental value if applied for beneficial reuse. Segregating sand from contaminated sediment could potentially reduce the volume of dredged material requiring disposal.

Geotechnical data obtained from sediment samples collected from Cow Pen Creek and Dark Head Cove indicates the range of sand content in sediment is estimated at zero to 20%, and greater sand fractions are mostly found at depths of five feet and below. Removal at these depths is not likely to be required based on the vertical extent of site COC. Therefore, the volume of sand, if separated from the MRC sediments, is unlikely to provide any savings relative to the total disposal cost. Sand can be segregated from sediment using soil-washing and hydrocyclone separators.

In general, beneficial reuse has limited effectiveness due to limitations of the associated treatment technologies. Treatment and permitting issues aside, beneficial reuse presents an opportunity to reduce the quantity of imported backfill for use as cap material if the reused material is acceptable for use on-site. Treated materials must meet dredged material management plan (DMMP) guidelines for beneficial use at in-water locations other than at the MRC (e.g., as capping material or habitat enhancements).

The DMMP guidelines determine the suitability of treated material for beneficial reuse. Several factors, including the physical and chemical characteristics of the material, regulatory criteria and approvals, and environmental concerns, must be considered in the DMMP. In all cases, federal, state, and local laws incorporate provisions such that any beneficial use of treated dredged sediments must not result in a regulatorily unacceptable risk to human health or the environment, and must not be used in a manner that degrades application-site conditions in soil, surface water, groundwater, and air. Beneficial reuse of dredged material will be further evaluated during the remedial design phase.

Implementability—Off-site disposal of dredged sediments at permitted landfills is routinely implemented. On-site disposal is more difficult to implement given the time required to fully investigate, design, site, and permit a containment facility. Beneficial reuse of dredged material is more difficult to implement given treatment limitations and permitting requirements.

Costs—The cost assessment of the disposal options is based on the relative cost of a disposal process-option as compared to others. Off-site disposal at permitted landfills may have moderate to high associated costs, depending on waste characterization. Developing an on-site disposal option will require significant expenditures to evaluate, design, acquire land, and construct, after which additional costs are incurred to operate and monitor the facility. Costs associated with beneficial reuse of dredged material may be moderate to high depending on the treatment technique, reuse requirements, and the effectiveness/usability of dredged materials for the intended purpose.

Screening summary—Off-site upland disposal technologies (i.e., permitted landfills) are retained for evaluation as part of remedial alternatives in the FS. Other off-site disposal options and beneficial reuse options are retained for consideration during design, but are not carried forward for detailed analysis in the FS (Table 4-2).

4.4 SUMMARY OF RETAINED TECHNOLOGIES

This section discusses how potentially applicable remedial technologies and process options were identified and screened for use in developing and evaluating site-wide remedial alternatives for the

MRC FS. This screening was based on site-specific conditions and the major risk drivers for MRC sediments. Each technology was evaluated for its effectiveness, implementability, and relative cost.

Figure 4-2 and Table 4-2 list the remedial technologies retained for further consideration, based on the results presented above. Of the retained technologies, *ex situ* treatment techniques, open water disposal, and beneficial reuse will be further evaluated during design, but not carried forward for detailed analysis in this FS. These technologies are retained for potential incorporation into alternatives during design, should further development of the current alternatives demonstrate a need to expand or replace the currently assembled suite of technologies.

Table 4-1
Identification of Candidate General Response Actions, Remedial Technologies, and Process Options
Middle River Complex, Middle River, Maryland
Page 1 of 6

GRA	Technology Type	Process Option	Brief Description
No Action	None	Not Applicable	No active remedy.
Institutional Controls	Physical, Engineering, or Legislative Restrictions	Consumption Advisories	Advisories to indicate that consumption of fish and shellfish in the area may present a health risk.
		Access Restrictions	Constraints, such as fencing and signs, placed on property access.
		Proprietary Controls	Easements, covenants, deed restrictions.
		Waterway Use Restrictions	Regulatory constraints on uses such as vessel wakes, anchoring, and dredging.
Natural Recovery	Monitored Natural Recovery	Biodegradation	Degradation of site organic contaminants by chemical or biological processes. Low molecular weight hydrocarbons may be partially or completely degraded. High molecular weight hydrocarbons, including polychlorinated biphenyls (PCB)s can be degraded, but it usually requires long time periods. Metals may become chemically bound, but are not degraded.
		Sedimentation	Contaminated sediments are buried (by naturally occurring sediment deposition) to deeper intervals that are less biologically available.
		Recovery Modeling	Recovery modeling through desorption, dispersion, diffusion, dilution, volatilization, resuspension, and transport.
		Long-term Monitoring	Long-term site monitoring designed to ensure that contaminants are being sequestered, degraded, or controlled at expected rates and permanence to adequately protect human health and the environment.
	Enhanced Natural Recovery	Thin-layer placement to augment natural sedimentation	Application of a thin layer of clean sediments and natural resorting, sedimentation, or bioturbation to mix the contaminated and clean sediments, resulting in acceptable chemical concentrations.

Table 4-1
Identification of Candidate General Response Actions, Remedial Technologies, and Process Options
Middle River Complex, Middle River, Maryland

GRA	Technology Type	Process Option	Brief Description
Containment	Capping	Conventional Sediment	Use of commercially obtained clean sandy materials or dredged fine-grained sediments to achieve contaminant isolation.
		Armored Cap	Cobbles, pebbles, or larger material are incorporated into the cap to prevent erosion in high-energy environments or to prevent cap breaching by bioturbation.
		Composite Cap	Soil, media, and geotextile cap placed over contaminated material to inhibit migration of contaminated porewater and/or inhibit bioturbation.
		Reactive Cap	Incorporation of materials such as granular activated carbon or iron filings to provide chemical binding of contaminants migrating in porewater.
Removal	Dredging	Hydraulic Dredging	Hydraulic dredges cut and slurry sediments with water so that the material can be transported through a pipeline to a selected land-based dewatering facility.
		Mechanical Dredging	A barge-mounted floating crane maneuvers a dredging bucket. The bucket is lowered into the sediment; when the bucket is withdrawn, the jaws of the bucket are closed, retaining the dredged material.
		Specialty Dredging	These specialty dredges may combine aspects of both hydraulic and mechanical dredges such as the Bonacavor hydraulic excavator, Amphibex, Dry Dredge (DRE Technologies), and IHC Holland Crawl Cat Cutter Suction Dredge.
	Excavation	Excavator	This removal option includes erecting sheet pile walls or a cofferdam around the contaminated sediments to dewater. Removal then involves conventional excavation (backhoe) equipment. Removal during low tides may not require sheet pile walls or cofferdams.
	Ancillary Technologies	Dewatering	Passive dewatering on-barge: mechanically dredged sediments are placed within a barge, which either allows excess water to flow into the water, or to accumulate in an on-board sump where it is removed and treated. Passive dewatering at lagoons/ponds: dredged sediments are placed within constructed lagoons where sediments are allowed to gravity settle. Passive dewatering in geotubes: hydraulically dredged sediments are pumped into geotubes, polymer is added to enhance gravity consolidation and dewatering. Mechanical dewatering includes dewatering by centrifugation, belt press, hydrocyclone, diaphragm or plate-and-frame filter press.
		Wastewater Treatment	Dredged water treatment by sedimentation, filtration, coagulation aid, flocculation and settling, adsorption carbon filter, and oxidation.
		Transportation	Transportation of dredged sediments by truck, rail, barge, or pipeline.

Table 4-1
Identification of Candidate General Response Actions, Remedial Technologies, and Process Options
Middle River Complex, Middle River, Maryland

GRA	Technology Type	Process Option	Brief Description
***In Situ* Treatment**	Biological	*In Situ* Slurry Biodegradation	Anaerobic, aerobic, or sequential anaerobic/aerobic degradation of organic compounds with indigenous or exogenous microorganisms. Oxygen, nutrients, and pH are controlled to enhance degradation. Requires sheet piling around entire area and slurry treatment performed using aerators and possibly mixers.
		In Situ Aerobic Biodegradation	Aerobic degradation of sediment *in situ* with the injection of aerobic biphenyl enrichments or other co-metabolites. Oxygen, nutrients, and pH are controlled to enhance degradation.
		In-situ Anaerobic Biodegradation	Anaerobic degradation *in situ* with the injection of a methanogenic culture, anaerobic mineral medium, and routine supplements of glucose to maintain methanogenic activity. Nutrients and pH are controlled to enhance degradation.
	Chemical	*In Situ* Slurry Oxidation	Oxidation of organics using oxidizing agents such as ozone, peroxide, or Fenton's reagent.
		Dechlorination	The process mixes contaminated sediment with an alkali metal-hydroxide based polyethylene glycol reagent.
	Physical-Extractive Processes	*In Situ* Oxidation	An array of injection wells is used to introduce oxidizing agents such as ozone to degrade organics.
		Sediment Flushing	Water or other aqueous solution is circulated through contaminated sediment. An injection or infiltration process introduces the solution to the contaminated area and the solution is later extracted along with dissolved contaminants. Extraction fluid must be treated and is often recycled.
	Physical-Immobilization	Reactive Material Addition	Reactive material such as granulated activated carbon (GAC) or organoclay is worked into surface sediments. Organics and some metals become preferentially bound to the GAC and are thus are no longer biologically available.
		Electro-chemical Oxidation	Proprietary technology in which an array of single steel piles is installed and low current is applied to stimulate oxidation of organics.
		Vitrification	Uses an electric current *in situ* to melt sediment or other earthen materials at extremely high temperatures (2,900-3,650°F). Inorganic compounds are incorporated into the vitrified glass and crystalline mass and organic pollutants are destroyed by pyrolysis.
		Aqua MecTool™ Stabilization	A caisson (18 by 18 feet) is driven into the sediment and a rotary blade is used to mix sediment and add stabilizing agents. A bladder is placed in the caisson to reduce total suspended solids (TSS) and the vapors may be collected at the surface and treated.

GRA	Technology Type	Process Option	Brief Description
***Ex Situ* Treatment**	Biological	Landfarming/ Composting	Sediment is mixed with amendments and placed on a treatment area that typically includes leachate collection. The sediment and amendments are mixed using conventional tilling equipment or other means to provide aeration. Moisture, heat, nutrients, oxygen, and pH can be controlled to enhance biodegradation. Other organic amendments such as wood chips, potato waste, or alfalfa are added to composting systems.
		Biopiles	Excavated sediments are mixed with amendments and placed in aboveground enclosures. This is an aerated static pile composting process in which compost is formed into piles and aerated with blowers or vacuum pumps. Moisture, heat, nutrients, oxygen, and pH can be controlled to enhance biodegradation.
		Fungal Biodegradation	Fungal biodegradation refers to the degradation of a wide variety of organo-pollutants by using fungal lignin-degrading or wood-rotting enzyme systems (example: white rot fungus).
		Slurry-phase Biological Treatment	Aqueous slurry is created by combining sediment with water and other additives. The slurry is mixed to keep solids suspended and microorganisms in contact with the contaminants. Upon completion of the process, the slurry is dewatered and the treated sediment is removed for disposal (example: sequential anaerobic/aerobic slurry-phase bioreactors).
		Enhanced Biodegradation	Addition of nutrients (oxygen, minerals, etc.) to the sediment to improve the rate of natural biodegradation.
	Chemical/Physical	Oxidation/Reduction	Oxidation/ Reduction chemically converts hazardous contaminants to nonhazardous or less toxic compounds that are more stable, less mobile, and/or inert. The oxidizing agents most commonly used are hypochlorites, chlorine, and chlorine dioxide.
		Dehalogenation	Dehalogenation process in which sediment is screened, processed with a crusher and pug mill, and mixed with sodium bicarbonate (base catalyzed decomposition) or potassium polyethylene glycol. The mixture is heated to above 630 °F in a rotary reactor to decompose and volatilize contaminants. Process produces biphenyls, olefins, and sodium chloride.
		Sediment Washing	Contaminants sorbed onto fine soil particles are separated from bulk soil in an aqueous-based system on the basis of particle size. The wash water may be augmented with a basic leaching agent, surfactant, pH adjustment, or chelating agent to help remove organics and heavy metals.

Table 4-1
Identification of Candidate General Response Actions, Remedial Technologies, and Process Options
Middle River Complex, Middle River, Maryland

GRA	Technology Type	Process Option	Brief Description
***Ex Situ* Treatment (continued)**	Chemical/Physical (continued)	Slurry Oxidation	The same as slurry-phase biological treatment with the exception that oxidizing agents are added to decompose organics. Oxidizing agents may include ozone, hydrogen peroxide, and Fenton's reagent.
		Acid Extraction	Contaminated sediment and acid extractant are mixed in an extractor, dissolving the contaminants. The extracted solution is then placed in a separator, where the contaminants and extractant are separated for treatment and further use.
		Solvent Extraction	Contaminated sediment and solvent extractant are mixed in an extractor, dissolving the contaminants. The extracted solution is then placed in a separator, where the contaminants and extractant are separated for treatment and further use (example: B.E.S.T.™ and propane extraction process).
	Thermal	Incineration	Temperatures greater than 1,400 °F are used to volatilize and combust organic chemicals. Commercial incinerator designs are rotary kilns equipped with an afterburner, a quench, and an air pollution control system.
		High-temperature Thermal Desorption (HTTD)	Temperatures in the range of 600-1,200 °F are used to volatilize organic chemicals. These thermal units are typically equipped with an afterburner and baghouse for destruction of air emissions.
		Low-temperature Thermal Desorption (LTTD)	Temperatures in the range of 200-600 °F are used to volatilize and combust organic chemicals. These thermal units are typically equipped with an afterburner and baghouse for treatment of air emissions.
		Vitrification	Current technology uses oxy-fuels to melt soil or sediment materials at extremely high temperatures (2,900-3,650 °F).
	Physical	Separation	Contaminated fractions of solids are concentrated through gravity, magnetic, or sieving separation processes.
		Solidification	The mobility of constituents in a "solid" medium is reduced through addition of immobilization additives. Dredged sediments can also be mixed with amendments (e.g., Portland cement, lime, or fly ash mixture) or materials such as straw or sawdust to produce a product that passes regulatory requirements (e.g., paint filter test).

Table 4-1
Identification of Candidate General Response Actions, Remedial Technologies, and Process Options
Middle River Complex, Middle River, Maryland

GRA	Technology Type	Process Option	Brief Description
Disposal	On-site Disposal	Confined Disposal Facility (CDF)	Untreated sediment is placed in a near shore confined disposal facility that is separated from the river by an earthen berm or other physical barrier and capped to prevent contact. A CDF may be designed for habitat purposes.
		Contained Aquatic Disposal (CAD)	Untreated sediment is placed within a lateral containment structure (i.e., bottom depression or subaqueous berm) and capped with clean sediment.
	Off-site Disposal	Dredged Material Management Program (DMMP) Open-water Disposal	Treated or separated sediment is placed at an open water disposal site. Requires that the placed sediment be at, or below, DMMP disposal criteria for priority pollutants and potentially bioaccumulative chemicals.
		Subtitle D Landfill	Off-site disposal at a licensed commercial facility that can accept nonhazardous sediment.
		Subtitle C Landfill	Off-site disposal at a licensed commercial facility that can accept hazardous dewatered sediment removed from dredging or excavation. Depends on analytical data from dredged sediment. Dewatering required reducing water content for transportation.
		Toxic Substances Control Act (TSCA)-licensed Landfill	Off-site disposal at a licensed commercial facility that can accept TSCA sediment. Dewatering required reducing water content for transportation.
	Beneficial Reuse	On-site	Cleaned sediments treated to below state or federal guidelines may be beneficially reused for habitat creation, capping, or residual management.
		Off-site	Treated or untreated sediment is placed at an off-site location. Requires that sediment be at, or treated to, a concentration at or below cleanup levels for unrestricted land use and meet non-degradation standards.

GRA	Technology Type	Process Option	Effectiveness	Implementability	Cost	Screening Decision
No Action	None	Not Applicable	Not Effective.	Technically implementable for conditions within the MRC.	Low	Retained per NCP requirement
Institutional Controls	Physical, Engineering, or Legislative Restrictions	Consumption Advisories	Effective at limiting human exposure, not effective at protection for ecological receptors where impacts are ongoing.	Technically implementable for conditions on the MRC. Requires commitment and cooperation of public, implementing agencies. Available and demonstrated.	Low	Retained for further evaluation in the FS
		Access Restrictions and Proprietary Controls Waterway Use Restrictions	Effective at limiting human exposure. Limited effectiveness if used as sole remedy, but effective when used in conjunction with active remedies.	Technically implementable for the entire MRC.	Low	Retained for further evaluation in the FS
Natural Recovery	Monitored Natural Recovery	Biodegradation	Effective for PAHs but does not result in complete destruction of PCBs in acceptable time frame. Not applicable to metals.	Technically implementable for conditions within the MRC.	Low to Moderate	Retained for further evaluation in the FS
		Sedimentation	Potentially effective for MRC COCs via deposition and reburial. Requires demonstration of long-term deposition and burial.	Technically implementable for conditions within the MRC.	Low to Moderate	Retained for further evaluation in the FS
		Recovery Modeling	Can be effective for demonstration of long-term deposition and burial.	Technically implementable for conditions within the MRC. Available and demonstrated.	Low	Retained for further evaluation in the FS
		Long-term Monitoring	Can be effective for evaluation and maintenance of MRC following remedial actions.	Technically implementable for conditions within the MRC. Available and demonstrated.	Low to Moderate	Retained for further evaluation in the FS
	Enhanced Natural Recovery	Thin-layer placement to augment natural sedimentation	Effective for all MRC COCs. Applicable: 1) at areas where MNR processes are demonstrated, but faster recovery is required; or 2) as a residual management tool after completion of a removal action.	Technically implementable for conditions within the MRC. Thin-layer placements for ENR and residuals management have been applied nationally.	Low to Moderate	Retained for further evaluation in the FS
Containment	Capping	Conventional Sediment	Effective for contaminants with low solubility and high sorption where the main concern is resuspension and direct contact. Sediment with silt and clay is effective in limiting diffusion of contaminants. Sediment caps are generally more effective than sand caps for containment of contaminants with high solubility and low sorption.	Generally applicable to MRC conditions. Conventional sediment caps using river-dredged sediments have been applied in multiple locations nationally. Placement of clay caps may be considered in shallow water depth areas where minimal cap thickness is required. Special engineering controls will be needed to place clay cap in the MRC.	Low	Retained for consideration in the FS for all areas of the MRC.
		Armored Cap	Applicable to MRC COCs. Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants.	Applicable to areas of MRC where increased velocities from river flow, or potential scouring associated with propeller wash might be expected. Decreased water depth may limit future uses of waterway and may impact flooding, stream bank erosion, navigation, and recreation. Armored caps have been implemented nationally.	Low to Moderate	Retained for limited use in the FS for high-energy sections of the MRC.
		Composite Cap	Effective for MRC COCs. Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants. Can be used: 1) to limit cap thickness, 2) for low solids underlying sediments where additional floor-support is required, 3) as a bioturbation barrier, or 4) as a barrier for areas where methane generation may be an issue.	Applicable to MRC site conditions. Application must consider that decreased water depth may limit future uses of waterway and impact flooding, stream bank erosion, navigation, and recreation. Limited use in intertidal areas that support clamming and recreational activities. Application of composite capping is commercially demonstrated for projects with similar size and scope.	Low to Moderate	Retained for consideration in the FS for all areas of the MRC.

Table 4-2
Screening of Candidate General Response Actions, Remedial Technologies, and Process Options
Middle River Complex, Middle River, Maryland

GRA	Technology Type	Process Option	Effectiveness	Implementability	Cost	Screening Decision
Containment (cont)	Capping (cont)	Reactive Cap	Effective for MRC COCs. Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants.	Reactive capping is an innovative technology and may be applicable to site conditions on the MRC. Addition of materials to increase sorptive capacity of cap has been implemented nationwide.	Moderate	Retained for consideration in the FS as an innovative technology.
Removal	Dredging	Hydraulic Dredging	Applicable to all MRC COCs.	Generally applicable to MRC in-water site conditions. Best suited to low density, high water solids with little debris. Requires nearshore dewatering facilities and slurry pipeline. Water treatment and disposal required. Hydraulic environmental dredging is available and demonstrated in similar size projects.	Moderate to High	Retained for consideration in the FS for all areas of the MRC.
		Mechanical Dredging	Applicable to all MRC COCs.	Generally applicable to MRC in-water site conditions. Better suited for higher density, low water solids, and more effective at handling debris. Environmental buckets suitable for softer materials with low debris; clamshell buckets suitable for harder, dense sediments. Mechanical environmental dredging is available and demonstrated in similar size projects.	Moderate to High	Retained for consideration in the FS for all areas of the MRC.
		Specialty Dredging	Applicable to all MRC COCs. Effective for nearshore and/or intertidal areas where depths limit conventional dredging equipment.	Limited in application to nearshore shallow and/or intertidal areas that can be reached from shore or by specialty equipment designed to work on soft unconsolidated sediments. Equipment is commercially available and has been applied on projects of similar scope nationwide.	Moderate to High	Retained for consideration in the FS for shallow and/or intertidal areas of the MRC.
	Excavation	Excavator	Applicable to all MRC COCs.	Generally applicable to MRC in-water site conditions. Environmental excavators are suited for all materials (soft and dense), better able to handle debris, but may be depth limited. Dry excavation has limited in application to nearshore shallow areas that can be reached from shore. Excavators are available and demonstrated in similar size projects.	Moderate	Retained for consideration in the FS for shallow and/or intertidal areas of the MRC.
	Ancillary Technologies	Dewatering Wastewater Treatment Transportation	Applicable to all MRC COCs.	Technically implementable for conditions within the MRC	Moderate	Retained for further evaluation in the FS

GRA	Technology Type	Process Option	Effectiveness	Implementability	Cost	Screening Decision
***In Situ* Treatment**	Biological	*In situ* Slurry Biodegradation	Effective for PAHs but does not result in complete destruction of PCBs in acceptable time frame. Not applicable to metals.	Technically implementable for conditions within the MRC.	Moderate	Eliminated.
		In situ Aerobic Biodegradation	Biodegradation has not been demonstrated to effectively remediate metals or PCBs within a reasonable time frame.	Technically implementable for conditions within the MRC	Moderate	Eliminated.
		In situ Anaerobic Biodegradation				
	Chemical	*In-situ* Slurry Oxidation	Potentially effective for immobilizing COCs through TOC or sulfide sorption. Not demonstrated in full-scale applications effective for MRC COCs. Requires in-water steel piling around treatment area and extensive water quality monitoring outside piles.	Technically implementable for conditions within the MRC.	Moderate	Eliminated.
		Dechlorination	Has not been demonstrated to be effective for MRC COCs in sediments.	—	—	Eliminated
	Physical-Extractive Processes	*In situ* Oxidation	Has not been demonstrated to be effective for MRC COCs in sediments.	—	—	Eliminated
		Sediment Flushing	Bench scale tests are required to demonstrate effectiveness for MRC COCs.	Potentially applicable to MRC. Requires in-water steel piling around treatment area and extensive water quality monitoring outside piles. No known pilot or full-scale applications. Not considered innovative or available during MRC FS.	—	Eliminated
	Physical-Immobilization	Reactive Material Organoclay/ Activated Carbon Addition	Effective for MRC COCs. Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants.	Reactive capping is an innovative technology and may be applicable to site conditions on the MRC. Addition of materials to increase sorptive capacity of cap has been implemented nationwide.	Moderate	Retained for consideration in the FS as an innovative *in situ* treatment technology
		Electro-chemical Oxidation	Applicability for use in water is not known. No demonstrated sediment application.	—	—	Eliminated
		Vitrification	Effective at stabilizing COCs in soil applications, but requires less than 60% water content. Remaining sediment surface may not provide suitable habitat. No known sediment applications.	—	—	Eliminated
		Aqua MecTool™ Stabilization	Proprietary technology that has been effective in stabilizing metals and PCBs in soil.	Could be applicable to conditions in MRC. Requires treating sediments in place using caisson and proprietary injectors. Previous trials with this technology created water treatment problems inside the caisson. Not considered innovative or available during MRC FS.	—	Eliminated

GRA	Technology Type	Process Option	Effectiveness	Implementability	Cost	Screening Decision
***Ex Situ* Treatment**	Biological	Landfarming/ Composting	Not effective for metals and PCBs. PAHs are amenable to aerobic degradation.	—	—	Eliminated
		Biopiles	Not effective for metals and PCBs. Used for reducing concentrations of petroleum constituents in soils. Applied to treatment of non-halogenated VOCs and fuel hydrocarbons. Requires large upland area.	—	—	Eliminated
		Fungal Biodegradation	Not effective for metals and PCBs. No known full-scale applications. High concentrations of contaminants may inhibit growth. The technology has been tested only at bench scale.	—	—	Eliminated
		Slurry-phase Biological Treatment	Not effective for metals and PCBs. PAHs and some SVOCs are amenable to aerobic degradation. Large volume of tankage required. No known full-scale applications.	—	—	Eliminated
		Enhanced Biodegradation	Not effective for metals and PCBs. PAHs and some SVOCs are amenable to aerobic degradation.	—	—	Eliminated
	Chemical/Physical	Oxidation/Reduction	Suitable for sediments contaminated with metals, but not applicable to PCBs.	—	—	Eliminated
		Dehalogenation	PCB and dioxin-specific technology. Generates secondary waste streams of air, water, and sludge. Similar to thermal desorption, but more expensive. Solids content above 80% is preferred. Technology is not applicable to metals.	—	—	Eliminated
		Sediment Washing	Biogenesis™ Advanced washing process demonstrated effectiveness for metals and PCBs in sediments. High recalcitrant (e.g., PCB) contaminant concentration, increased percentage of fines, and high organic content increases overall treatment costs.	Potentially applicable to dewatered sediments on the MRC. Would require upland processing space, storage capacity for dredged sediments, wastewater treatment and discharge. Treated residuals would still require disposal. Equipment is commercially available, but has not been demonstrated on a project of similar scope and scale.	—	Retained for design, not carried forward for detailed analysis in the FS
		Slurry Oxidation	Applicable to SVOCs, but not PCBs or metals. Large volume of tankage required. No known full-scale applications. High organic carbon content in sediment will increase volume of reagent and cost.	—	—	Eliminated
		Acid Extraction	Has not been demonstrated to be effective for MRC COCs in sediments.	—	—	Eliminated
		Solvent Extraction	Potentially effective for treating sediments containing PCBs. Not applicable to metals. Extraction of organically-bound metals and organic contaminants creating residuals with special handling requirements. At least one commercial unit available.	Potentially applicable to dewatered (dry) sediments on the MRC containing primarily organic contaminants such as PCBs. Extracted organic contaminants from the process will need to be treated or disposed. Requires pre-treatment that involves screening of sediments. Equipment is commercially available, but has not been demonstrated on a project of similar scope and scale. This technology has been used to demonstrate under the USEPA SITE program, but there are no data for similar implementation of this technology for large-scale PCB-impacted sediment. No current or planned projects.	—	Eliminated

Table 4-2
Screening of Candidate General Response Actions, Remedial Technologies, and Process Options
Middle River Complex, Middle River, Maryland

GRA	Technology Type	Process Option	Effectiveness	Implementability	Cost	Screening Decision
***Ex Situ* Treatment (con't)**	Thermal	Incineration	High temperatures result in generally complete decomposition of PCBs and other organic chemicals. Effective across wide range of sediment characteristics but fine grained sediment difficult to treat. Not effective for metals.	Technically applicable to MRC site conditions. Especially effective and potentially required where COCs exceed TSCA limits (e.g., PCB >50 ppm). Only a small portion of MRC sediments are above TSCA. Metals not amenable to incineration. Mobile incinerators are available for movement to a fixed location in close proximity to the contaminated sediments.	—	Retained for design, not carried forward for detailed analysis in the FS
		High-temperature Thermal Desorption (HTTD)	Target contaminants for HTTD are PAHs and PCBs, which are destroyed by the heating process. Metals not destroyed.	Technically applicable to MRC site conditions. Especially effective and potentially required where COCs exceed TSCA limits (e.g., PCB >50 ppm). Technology readily available as mobile units that would need to be set up at a fixed location in close proximity to the contaminated sediments. Cement-Lock® Technology demonstration projects partially destroyed organics and encapsulated metals in the product matrix. The Cement-Lock® product passes the TCLP test for priority pollutants. Cement-Lock® Technology -Two demonstration projects started. Both experienced equipment related problems and were shut down.	—	Retained for design, not carried forward for detailed analysis in the FS
		Low-temperature Thermal Desorption (LTTD)	Target contaminants for LTTD are SVOCs and PAHs. May have limited effectiveness for PCBs. Metals not destroyed. Fine-grained sediment and high moisture content will increase retention times. Widely-available commercial technology for both on-site and off-site applications. Acid scrubber will be added to treat off-gas.	Potentially applicable to MRC. Demonstrated effectiveness at several other sediment remediation sites. Vaporized organic contaminants that are captured and condensed need to be destroyed by another technology. The resulting water stream from the condensation process may require further treatment.	—	Retained for design, not carried forward for detailed analysis in the FS
		Vitrification	Thermally treats PCBs, SVOCs and stabilizes metals. Successful bench-scale application to treating contaminated sediments in Lower Fox River, and in Passaic River.	Potentially applicable to MRC. Not commercially available or applied on similar site and scale. No known pilot or full-scale applications in sediments planned.	—	Eliminated
	Physical	Separation	Reduces volumes of COCs by separating sand from fine-grained sediments. Bench scale testing is required. At high PCB concentrations, the sand fraction retains levels may still require landfilling. Only applicable to adsorptive COCs that would adhere to the fine-grained soil. Offers greatest utility and cost saving benefits where concentrations of COCs would otherwise require incineration or Subtitle C disposal. 1) Demonstrated effectiveness for reduction in volume of highly contaminated sediments with a high percentage of sand-content; 2) Used to increase effectiveness of dewatering dredged material.	Potentially applicable dredged sediments in the MRC. Separation technologies available and have been used in several programs of similar size and scope. Applicable to potential dredge areas containing higher sand content. 1) Readily implementable, resulting in reduced contaminated sediment volume; 2) Can be combined with soil washing to improve contaminant separation and/or destruction; 3) Mobile units are available; 4) Separated sand may be available for potential beneficial reuse, capping, or disposal.	Moderate	Retained for design, not carried forward for detailed analysis in the FS

Table 4-2
Screening of Candidate General Response Actions, Remedial Technologies, and Process Options
Middle River Complex, Middle River, Maryland

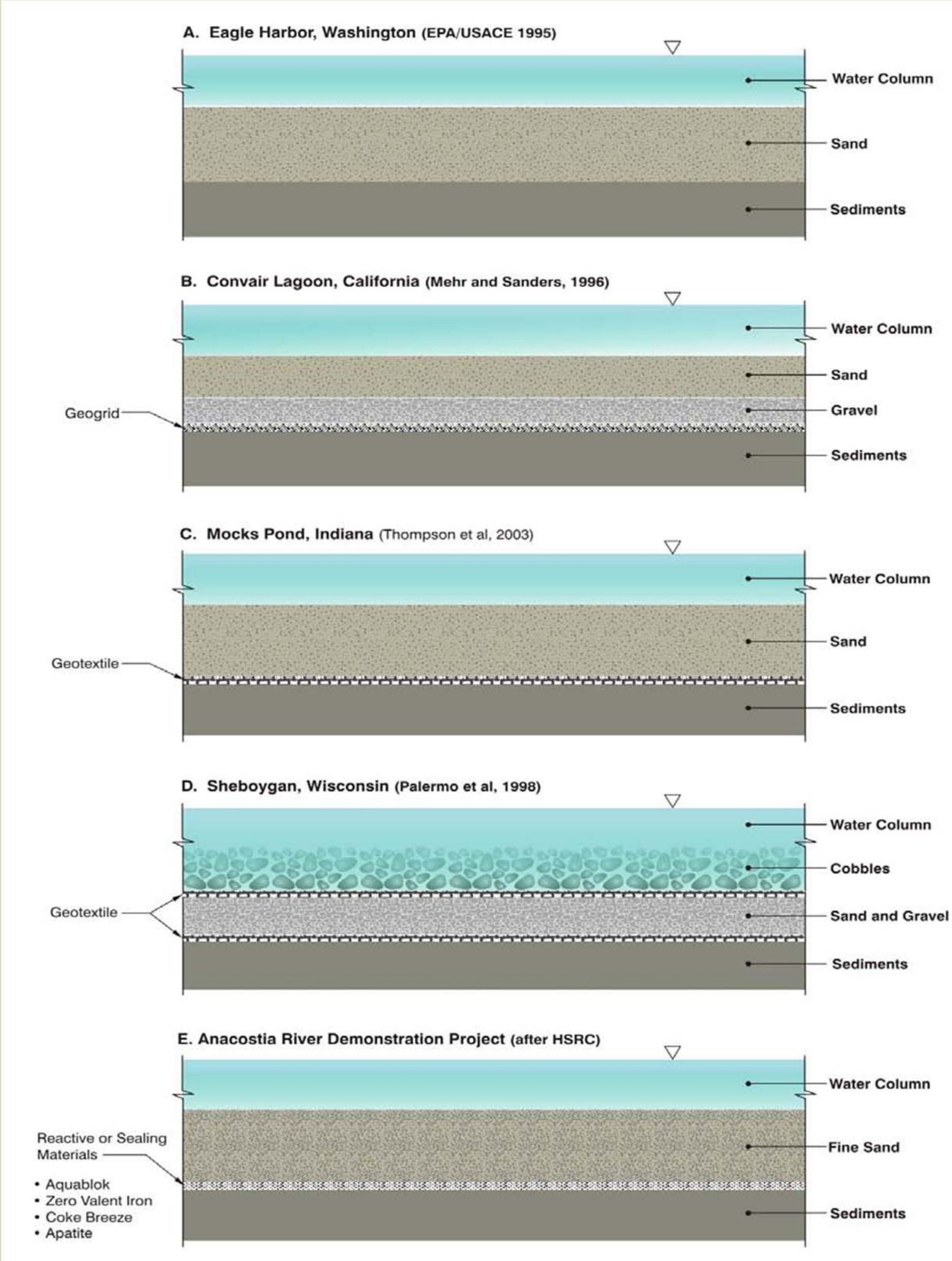
GRA	Technology Type	Process Option	Effectiveness	Implementability	Cost	Screening Decision
***Ex Situ* Treatment (con't)**	Physical (con't)	Solidification	Dependent on sediment characteristics and water content. Lime is particularly effective at volatilizing PCBs in wet sediment (by a phase transfer mechanism). Applicable to all MRC COCs. Principal application would be for high volumes of PCB-contaminated sediments that exceed hazardous waste criteria and would otherwise require incineration or Subtitle C disposal. (1) Lime has been successfully added to dredged material at other projects; (2) Effective during the dewatering operation to remove excess water and prepare material for disposal.	Potentially applicable to MRC. Lime has been successfully added to dredged material at other projects. Considered for use during the dewatering operation to remove excess water and prepare material for disposal. Applicable to all dredge areas of MRC. (1) Readily implementable; (2) Reagent materials readily available.	Moderate	Retained for design, not carried forward for detailed analysis in the FS
Disposal	On-site Disposal	Confined Disposal Facility (CDF)	Applicable to all MRC COCs below hazardous waste designations.	Requires large suitable near-shore or upland containment site that is not available at MRC. The technology restricts future use and presents long-term liability.	Moderate to High	Eliminated
		Contained Aquatic Disposal (CAD)	Applicable to all MRC COCs below hazardous waste designations.	Applicable to subtidal areas where sediments have sufficient bearing strength to support cap, and have low erosive potential. The technology restricts future use and presents long-term liability.	Moderate to High	Eliminated
	Off-site Disposal	Dredged Material Management Program (DMMP) Open-water Disposal	Applicable to all MRC COCs in sediments that are separated or treated to below the DMMP disposal standards. DMMP is a well-established and effective program with a long-term track record of monitoring to verify environmental protectiveness.	Applicable throughout MRC. Sediments that require remediation are not likely to meet the open-water disposal criteria.	Moderate	Retained for design, not carried forward for detailed analysis in the FS
		Subtitle D Landfill	Applicable to all MRC COCs below hazardous waste designations. Subtitle D landfills highly effective for long term, permanent containment of contaminated materials.	Applicable throughout MRC for both dewatered and wet sediments. 1) Several licensed landfills exist that can receive dredged materials; 2) Transfer facilities for moving sediments from MRC to the landfills needed on-site; 3) Transport infrastructure in-place on the MRC; 4) Options exist for moving wet sediments - eliminating need for on-site dewatering facilities.	Moderate to High	Retained
		Subtitle C Landfill	Applicable to all MRC COCs exceeding hazardous waste designations. Subtitle C landfills are federally regulated facilities and are highly effective for long-term, permanent containment of highly contaminated materials.	Applicable throughout MRC for dewatered sediments Option for disposal of listed, hazardous wastes	High	Retained
		TSCA-licensed Landfill	Applicable to all MRC COCs above hazardous waste designations. TSCA-licensed landfills highly effective for long term, permanent containment of contaminated materials.	Applicable throughout MRC for both dewatered and wet sediments.	High	Retained

GRA	Technology Type	Process Option	Effectiveness	Implementability	Cost	Screening Decision
Disposal (con't)	Beneficial Reuse	On-site	Applicable to all MRC COCs in sediments that are either below, or treated-to below the reuse standards for uplands and in-water. Beneficial reuse of sediments.	Applicable throughout MRC. Potential use of sediments that meet soil requirements as upland fill, or other beneficial upland uses including daily landfill cover. Potential beneficial reuse as in-water ENR, capping material, and habitat enhancement. May be implementable for high volumes of materials with low concentrations of COCs, or for treated sediments	Low	Retained for design, not carried forward for detailed analysis in the FS
		Off-site	Applicable to all MRC COCs in sediments that are separated or treated to below the DMMP disposal standards. DMMP is a well-established and effective program with a long-term track record of monitoring to verify environmental protectiveness.	Applicable throughout MRC. Sediments that require remediation are not likely to meet the open-water disposal criteria.	Low	Retained for design, not carried forward for detailed analysis in the FS

Acronyms:

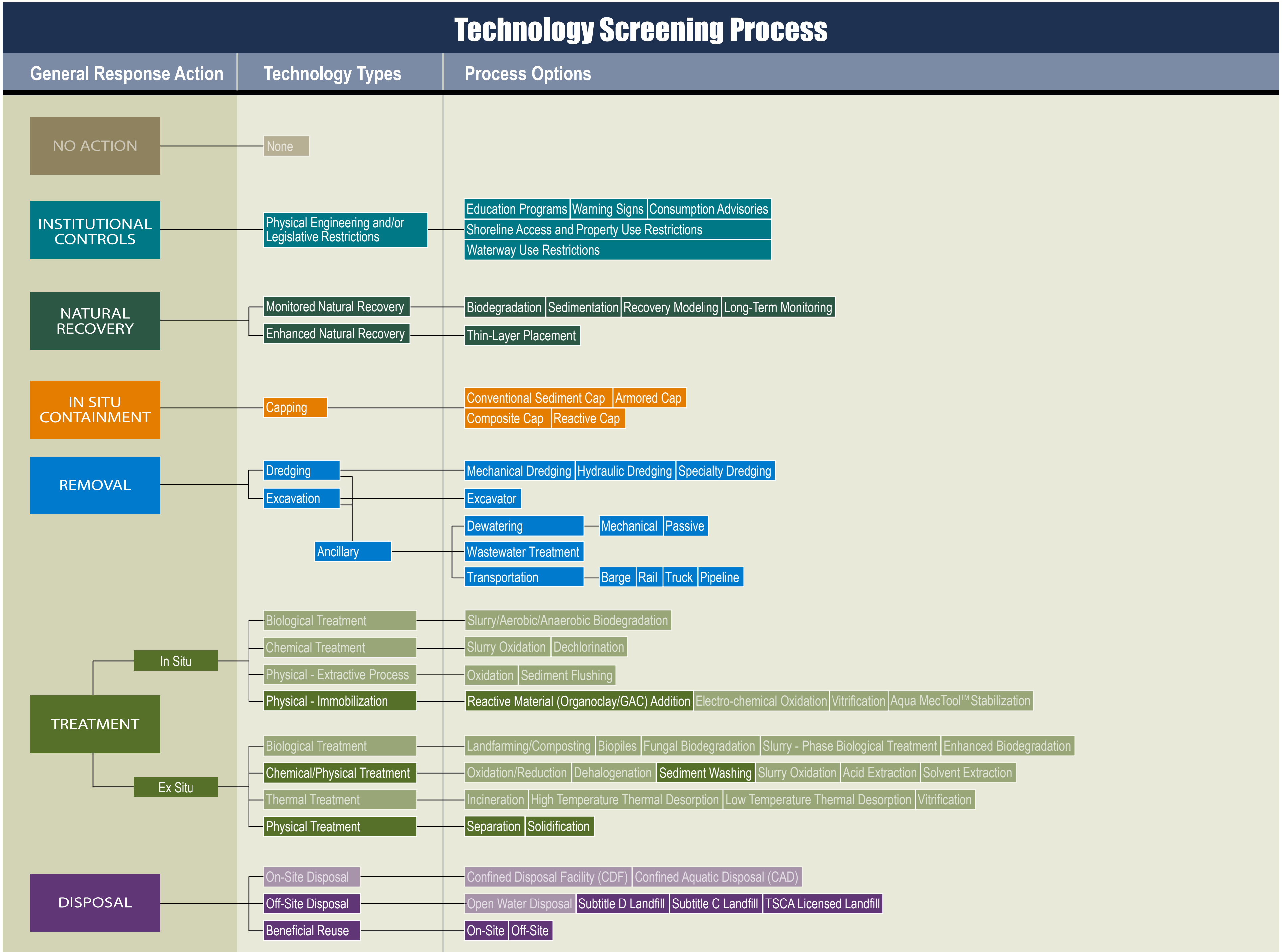
CAD – contained aquatic disposal
CDF – confined disposal facility
COC – chemicals of concern
CPC – Cow Pen Creek
DMMP – dredged material management program
ENR – enhanced natural recovery
FS – feasibility study
HTTD – high-temperature thermal desorption
LTID – low -temperature thermal desorption
MNR – monitored natural recovery
MRC – Middle River Complex
PAHs – polycyclic aromatic hydrocarbons
PCBs – polychlorinated biphenyls
ppm – parts per million
SVOC – semivolatile organic compounds
TCLP – toxicity characteristic leaching procedure
TSCA – Toxic Substances Control Act

Figure 4-1. Example Cap Designs



Source: Electric Power Research Institute (EPRI), 2007.

Figure 4-2. Summary of Retained Technologies



TSCA=Toxic Substances Control Act; AC=activated carbon

Section 5
Development of Remedial Alternatives

This section presents the rationale, assembly, and description of the remedial alternatives evaluated to clean up Middle River Complex (MRC) contaminated sediments. The alternatives are assembled in a manner consistent with the federal Comprehensive Environmental Resource Compensation, and Liability Act (CERCLA, or Superfund) guidance (United States Environmental Protection Agency [USEPA], 1988). The set of alternatives developed herein represents combinations of remedial technologies and process options that are implementable and feasible. Except for Alternative 1 (No Action), these alternatives address the remedial action areas and remedial action objectives (RAOs), while allowing variation in the degree to which active remedial measures are applied to the whole site.

These remedial alternatives present a range in the extent of active remediation (i.e., areas of potential action), remedial technologies, and costs. For this feasibility study (FS), active remediation refers to dredging, capping, *in situ* treatment, enhanced natural recovery (ENR), and reactive ENR, whereas passive remediation refers to monitored natural recovery (MNR). This range of characteristics across the candidate remedial alternatives permits a detailed evaluation and comparative analysis (see Sections 6 and 7). The process used to develop these remedial alternatives is outlined in the following sections:

- Section 5.1, "Potential Remediation Action Areas and Remedial Action Levels," discusses the areas of potential concern (AOPC) – areas with elevated contaminant concentrations and higher levels of potential risk. Remedial action levels are used in the remedial alternatives to address potential risks and determine the appropriate remedial technology and application, such as capping, dredging, and ENR.
- Section 5.2, "Site-Specific Technology Evaluation," discusses and evaluates the effectiveness of each remedial technology based on site-specific properties, engineering assumptions, and other considerations.

- Section 5.3, “Assembly of Remedial Alternatives,” includes the long list of alternatives and a general description of each remedial alternative.
- Section 5.4, “Common Remedy Elements,” describes the elements applicable to all remedial alternatives.
- Section 5.5, “Description of Alternatives,” provides a description of the remedial alternatives evaluated in this FS.
- Section 5.6, “Screening Analysis of Alternatives,” presents the initial screening evaluation of the long-list of alternatives in terms of effectiveness, implementability, and cost.
- Section 5.7, “Community Outreach Process,” summarizes Lockheed Martin Corporation (Lockheed Martin) efforts to inform and receive input from the community regarding remedial actions related to MRC sediments.
- Section 5.8, “Short List of Remedial Alternatives,” presents the short list of remedial alternatives based on initial qualitative screening analysis and input from the community. The short list of alternatives is assembled and carried forward for detailed and comparative analyses in Sections 6 and 7 of this FS.

5.1 POTENTIAL REMEDIATION ACTION AREAS AND REMEDIAL ACTION LEVELS

This section defines the areas of potential concern, which are areas where elevated contaminant concentrations and higher levels of potential risk have been identified. The section also presents the remedial action levels (RALs) used in the remedial alternatives to address potential risks and determine the application of the appropriate remedial technology (e.g., dredging, *in situ* treatment, reactive ENR, ENR, MNR). The AOPC and the RALs are then used in assembling the suite of remedial alternatives for the site.

5.1.1 Areas of Potential Concern

The AOPC are areas of the site where sediment contaminant concentrations potentially pose a risk to human health or the environment and therefore may require remedial action. The AOPC are based upon the extent of potential risk-driver contamination and established preliminary remediation goals (PRGs) for MRC sediments. The AOPC footprints are established using the distribution of chemicals of concern (COC), as presented in the sediment characterization reports. Thiessen polygons were generated to estimate the extent of influence around each sampling location. The AOPC footprints are based on interpretation of sediment sample networks that are delineated with these Thiesssen polygons, rather than spatially interpolated concentration values. The Thiessen polygon approach is practical for the purposes of development and comparison of remedial alternatives; however, the actual extent of area requiring management based on selected RALs is likely to be over-estimated. During design, a refined spatial map of data in comparison to RALs will likely be used, and final areas and volumes subject to remediation may be refined as a result. Based on the Thiessen polygon approach, the following AOPC footprints were established in this FS:

- AOPC addressing the COC to 52 inches below the sediment surface (Figure 5-1a)
- AOPC addressing RAOs in surface sediments (Figure 5-1b)

The larger AOPC footprint (Figure 5-1a) represents any exceedance of PRGs to the depth of 52 inches (i.e., deepest depth of the sample analysis for characterization). Ongoing natural recovery through sediment deposition at the site has reduced surface contaminant concentrations in parts of Dark Head Cove and Dark Head Creek to the degree that cleanup goals in the biologically active zone have been achieved. Therefore, the surface AOPC footprint (Figure 5-1b) represents the area necessary to meet RAOs, and is based on exposure in the biologically active zone (i.e., zero to six inches). The AOPC are generally the focus of this FS, since these are the areas that pose a current risk to human health or the environment. The application of one or more remedial technologies within these areas is considered in developing the alternatives. The boundaries of AOPC may need to be refined during remedial design and remedial implementation.

5.1.2 Remedial Action Levels

The RALs are chemical-specific sediment concentrations that trigger remediation. The RALs are used in this FS to define the areas for application of different remedial technologies within the AOPC, and to meet the PRGs for RAOs 1, 2, and 3. The AOPC and the RALs are used in assembling the suite of remedial alternatives for the site.

Table 5-1 summarizes RALs for the risk-driver COC. The RALs to achieve RAOs 1 and 2 are different (i.e., higher) than the PRGs. These RALs determine where a combination of active and passive measures would be applied to achieve site-wide PRGs. For example, a site-wide polychlorinated biphenyl (PCB) RAL of 1,100 ppb (i.e., remediating areas where concentrations of PCBs are greater than or equal to 1,100 ppb) would result in a site-wide area weighted-average concentration of 195 ppb, which is the RAO 1 PRG for PCBs. The RALs to achieve point-based RAO 3 PRGs are same as the PRGs. Ultimately, the most conservative RALs are used in this FS to determine application of the appropriate remedial technology. Therefore, RALs that can achieve point-based RAO 3 PRGs for the applicable COC (i.e., PCBs, lead, cadmium, copper, mercury, and zinc) will be used.

Remedial alternatives are developed using these RALs and a combination of active and passive remedial technologies. Once active remediation has been completed, the achievement of the RAO-specific PRGs at the end of construction and over the longer term is determined based on a site-wide surface area weighted-average concentration for RAOs 1 and 2 and on a point-based evaluation for RAO 3. To determine remedy effectiveness in this FS, longer term reduction of surface sediment concentrations through natural recovery processes is considered. As discussed in Section 2, remedial actions in upland areas of MRC are ongoing and expected to control any ongoing sources to the adjacent sediments. Therefore, the assumption that newly deposited sediments will be clean, and no long-term increase in COC will occur due to possible contaminant contributions from off-site sources, is used in this FS.

5.2 SITE-SPECIFIC TECHNOLOGY EVALUATION

The technology screening in Section 4.3 resulted in retained remedial technologies to be incorporated into the remedial alternatives. These include: removal, capping, ENR, reactive ENR, MNR, and *in situ* treatment. This section presents general site- and project-specific considerations, and provides an evaluation of these remedial technologies, based on site-specific information gathered through remedial investigations completed to date (see Section 2).

5.2.1 Site- and Project-Specific Considerations

Section 2 summarizes the physical characteristics and history of the site, and the nature and extent of contamination. Other site- and project-specific considerations used in developing remedial alternatives include the following:

- Project stakeholders include Wilson Point and Hawthorne residents and other nearby neighbors, the Maryland Department of the Environment (MDE) and USEPA as primary regulators, the United States Army Corps of Engineers (USACE), Baltimore County, Chesapeake Bay environmental groups, and fishing/boating/recreational users.

- Dark Head Cove and Dark Head Creek are part of the Middle River federal navigation channel. The project depth established by the USACE is -10 feet mean lower-low water (MLLW). Activities in navigable waters require USACE concurrence that they will not conflict with the navigational purpose.

- In-water work will need to be restricted to certain times of the year to minimize potential impacts to important fish, wildlife, and habitat resources. Based on the timing of typical maintenance dredging projects in Baltimore County, the in-water work window is October 15 to February 15. However, the actual schedule of the time restrictions will be determined by the State of Maryland, during the review of the project application for a Water Quality Certification, and with consultation of National Marine Fisheries Services and Maryland Department of Natural Resources (DNR). In addition, the timing of recreational use of the waterway will also be considered.

- Estimated sedimentation-rate ranges are as follows: 1.1 to 1.7 centimeters per year (cm/year) in the confluence of Dark Head Cove and Cow Pen Creek, downstream of the site; 0.8 to 0.99 cm/year in Dark Head Cove; and 0.3 to 0.51 cm/year at the mouth of Cow Pen Creek (Tetra Tech, 2011a).

- In Cow Pen Creek, special consideration is required to ensure that if a remedy includes material placement, it will not reduce water depths or alter the flow-carrying capacity of the creek. Any remedial action in the creek will at a minimum maintain and preferably improve existing habitat conditions.

- Sediments consist of elastic silt, fat clay, lean clay, sandy elastic silt, sandy lean clay, organic silt, and silty sand (Tetra Tech, 2012a).

- Hydrodynamic analysis shows that the sediment bed in the study area is stable, except for the upstream area of Cow Pen Creek. A 100-year, 24-hour storm event could transport eroded material from Cow Pen Creek to outside of the study area. During such an event, the corresponding suspended-sediment-concentration range at the mouth of Dark Head Creek could range between 140 to 1,000 milligrams per liter (mg/L), and the depth of erosion from the one-day event could be as much as 10 centimeters (cm) in upstream areas of Cow Pen Creek.

- Current use of the waterway includes boating, fishing, swimming, watersports (windsurfing, water skiing, and jet skiing), and wading by individuals from the neighboring communities. The land-based portion of the MRC waterfront is not currently in active use.

- Future use of the site by the neighboring communities is likely to resemble present uses. Future development of the MRC shoreline may include continued industrial use, commercial use, a marina or hotel, third-party residential areas (e.g., condominiums), or mixed commercial/residential use. Single-family homes are unlikely. A public dock (on Hawthorne) and a Wilson Point Park extension (Tax Block D Panhandle) have been proposed.

5.2.2 Removal

Removal may involve mechanical dredging using a conventional barge-mounted clamshell dredge and/or environmental bucket, or hydraulic dredging with transport through a pipeline in slurry form and dewatering in geotextile tubes. Conventional excavation technologies, such as backhoes, loaders, or barge-mounted precision excavators, are applicable for use, as necessary, in shallow water operations such as parts of Cow Pen Creek, shoreline areas, in front of bulkheads, and debris removal.

5.2.2.1 Volume Estimates

The distribution of chemical concentrations in MRC sediments and their horizontal and vertical extent were determined at four depth intervals - zero to six inches, six to 18 inches, 18 to 30 inches, and 30 to 52 inches. Concentrations of COC in sediment samples are presented in Thiessen polygons assembled around the sampling locations (i.e., half the distance to the next sampling point) at each of these depth intervals. The areas of these polygons and the depth intervals were used to calculate the volume of contaminated sediments for the removal alternatives. The depth of removal varies based on the extent of the COC and the RALs to meet the RAOs.

The estimated volumes were estimated using the concentrations of COC in the discrete core interval data to estimate the dredge prisms, which are the required removal limits for FS-level analysis purposes. The dredge prisms will be refined during design for dredge operational considerations. Typically, as part of the FS, contingency volumes are included to account for volume creep. Volume creep contingencies that will be applied to the initial estimated dredge volumes include: (a) a typical 1.0-foot overdredging allowance; (b) allowance for additional sediment characterization (i.e., presence of contaminants beyond the currently estimated depth); (c) typical cleanup passes for residuals management; and (d) dredge cut-slope stability issues identified during design.

For FS-analysis purposes, and to account for these various causes of volume creep, estimated dredge neat-line volumes are increased by 50%. This adjustment is supported by the findings of a recent study on *in situ* volume creep for environmental dredging projects (Palermo and Gustavson, 2009), which recommends an adjustment factor of 50% (that is, an estimated dredge-prism volume equal to 1.5 times the neat-line prism volume) for FS-level considerations under typical site conditions. Sediment bathymetry profiles are provided in Appendix C. *AutoCAD/Civil3D*® engineering-design software will be used to refine removal volumes during design.

5.2.2.2 Environmental Controls during Dredging

Column settling test results (refer to Section 2.3.9) will be used to assess potential water quality impacts during dredging by estimating: (a) the mass rate at which bottom sediments become suspended in the water column as a result of dredging operations; (b) the resulting suspended sediment concentrations; and (c) the size and extent of the suspended sediment plume. Slow settling behavior of MRC sediments may require slower dredging operations and effective-engineering best-management practices to meet turbidity standards in the construction area.

The dredge elutriate test (DRET) data suggest limited COC releases from sediment to the water column occur during potential dredging. The partition coefficients calculated from the total and dissolved DRET results are associated with COC of limited mobility. Most of the detected concentrations of trace metals are associated with particles, except for antimony, arsenic, selenium, and thallium. Therefore, filtration will remove a significant amount of the COC waste load from the discharge of any future treatment system. In general, DRET results from all tests are relatively similar, with no significant COC releases noted in tests using different initial total suspended solids (TSS) concentrations or aeration times.

The release of COC through sediment resuspended during dredging is a major concern impacting the effectiveness of environmental dredging projects (refer to Section 4.3.5). Releases of PCB have been monitored in pilot dredging studies and full-scale dredging projects. Monitoring data from pilot dredging projects performed in Fox River and Grasse River, and other early studies, showed that two to three percent of the dredged PCBs were transported downstream from the project area (Bridges et al., 2008). For example, if total dredged sediments contain 60 kilograms of PCBs, approximately 1.5 kilograms is expected to be released into the water column. Dissolved contaminants are more bioavailable, are more likely to migrate farther in the water column, and may cause short-term increases of PCB concentrations in fish tissue. Engineering controls (e.g., silt curtains, semi-permeable silt curtains, structural barriers, etc.) will likely be applied in the dredging zone to limit or contain suspended particulates to the immediate area of operation.

5.2.2.3 Residuals Management

Some contaminated sediment will be resuspended into the water column during dredging operations and will settle back onto the dredged surface. Operational in-water controls are typically developed during remedial design to manage such residuals. Residuals management, ENR, or a sediment cap may be required following removal, depending on the removal depth and the contamination levels remaining at the dredged surface. For the purposes of the FS, we have assumed that removal will be followed by placement of a 6-inch layer of sand covering the dredge footprint.

5.2.2.4 Dewatering

Removed sediment will have to be dewatered to produce a material that is easier to handle, to meet transportation and landfill disposal requirements, and to minimize the weight and cost of material to be transported and disposed.

Considerations in evaluating and selecting dewatering methods include the following:

- the estimated volume of water generated by removal technology (e.g., the lower the volume of water generated, the easier and more cost-effective the dewatering process)
- the optimal water content of dewatered sediment (e.g., the lower the water content, the more cost-effective the material transport and disposal)
- the dredge production and rate
- upland or barge staging-area space limitations

During the design phase, considerations for dewatering methods will be evaluated with respect to project needs, project duration, and transport needs. Timely completion of the project, the need to meet performance standards for resuspension, release, and residuals, and compatibility among dredging, transport, treatment, and disposal requirements are not always mutually achievable. These considerations will therefore be appropriately balanced in the project design. A range of production rates may be calculated for a range of dredge sizes, and the numbers and sizes of dredges can be selected to meet performance standards or the desired project duration (Palermo et al., 2008).

Both mechanical and passive dewatering techniques will be considered during design. In this FS, both mechanical and hydraulic dredging are considered. Mechanically dredged sediments are assumed to be dewatered at a dewatering and transloading area. The dewatering pad will be designed to allow drainage and collection of decanted water. An existing asphalt laydown area can be used, if available, or a new one will be constructed as part of mobilization.

A protective barrier will be designed and constructed over the new pad or existing area. It will consist of geotextile fabric and an impermeable liner to prevent any dredged water infiltration into the subsurface. The subgrade protective barrier will be sloped to direct decant water and precipitation to a sump area, where site contact water will be collected and pumped to a water treatment plant. The pad will be able to support low ground pressure equipment to spread sediment during offloading, roll sediment to promote drying, and remove sediment by trucks during processing.

If sediments are removed hydraulically, a sediment/water slurry will be pumped via pipelines into geotextile tubes placed over the dewatering pad and allowed to gravity drain. A temporary water holding tank may be utilized to manage water associated with hydraulic dredging. During transport to the geotubes, environmentally safe polymers will be added to the sludge, which make the solids bind together and water separate and enhance dewatering of the dredged sediments. Effluent water with any exceess polymers will be collected and treated before discharge. If needed, the dewatered sediments may also be mixed with a stabilizing reagent to improve the strength of the sediments. If the sediments are mechanically dredged, the sediments will be transported to the dewatering pad and may be mixed with stabilizing agents to help dry and improve the strength of the sediments. The dewatering pad capacity will vary depending on the recommended alternative and will be designed to accommodate the volume of removed sediment and its associated dewatering and processing. Dewatering processes will incorporate best management practices during design. Surface water control structures and erosion control measures will be installed to protect air and surface water quality.

5.2.2.5 Dredge Water Management

Standard practice in remedial dredging involves dewatering dredged sediment on the dredge scows and allowing it to discharge back into the active dredge area. Appropriate best management practices (e.g., straw bales and filter fabric) are installed to filter these discharges and to comply with water quality criteria established for the dredging operations. We have assumed that water from dewatering will be released within the limits of the dredge operating area protected by silt curtains, and subject to compliance with water quality criteria.

The dredged water may need to be treated before it can be discharged, depending on agreed water quality compliance criteria. Water management is a necessary part of dredged-material transloading operations. Storm water and drainage from sediments generated in the transloading facility are assumed to be captured, stored, treated, and either discharged to the local sanitary sewer under a

Baltimore County discharge authorization, or returned to surface water subject to water quality compliance criteria. To account for water management, the FS-level cost estimates include daily water management to treat and discharge water back to the water body, or to discharge dredged water to the sewer and publicly owned treatment works under a permit with the Baltimore County industrial waste program.

5.2.2.6 Transloading and Upland Disposal

Dredged material placed in the barge will be transported to a dewatering and transloading area where it will be dewatered and transferred to lined shipping containers and/or trucks for disposal at the landfill. Other methods of transloading sediment, such as direct container loading on barges, may be considered during remedial design. The logistics and actual capacity of the transloading operations will also be determined during remedial design. The FS-level cost estimates include establishing a dewatering and transloading area, sediment handling and transport to the landfill, and disposal of sediment at the landfill.

In this FS, Grows North Landfill in Morrisville, Pennsylvania, a Lockheed Martin–approved disposal site, is assumed to be the upland disposal facility for removal alternatives. Additional disposal locations may be considered during the design phase. Grows North Landfill is a permitted Subtitle D landfill, approved to receive sediments that pass the paint filter test. The hazardous waste landfill identified for any Toxic Substances Control Act (TSCA) waste (i.e., sediments or sediment intervals with PCB concentrations greater than 50 parts per million [ppm]) is Chemical Waste Management in Model City, New York.

5.2.2.7 Slope Stability and Bulkhead Stability

Dredging in sloped areas will be carefully evaluated during remedial design to prevent sloughing and slope failure during remedial activities. Existing shoreline slopes are at a ratio of approximately 1 vertical to 2 horizontal (approximately 26 degrees). or flatter. For this FS, dredging and capping slopes are assumed to be at a 1 vertical to 3 horizontal ratio (approximately 17 degrees), or flatter.

Recently, a reconnaissance study was completed to document approximately 1,800 linear feet of site shoreline features and conditions, and the bulkhead along Dark Head Cove (Tetra Tech, 2012c). The shoreline within the limits of this reconnaissance study comprised of stone riprap/broken concrete and overgrown vegetation, reinforced concrete bulkhead constructed on embedded steel sheet-piling and wooden fender piles, and stone riprap with concrete overlayment.

During the reconnaissance study, the condition of the concrete bulkhead was observed to be poor; deteriorating and extensive erosion was evident on the shore side and under certain sections of the bulkhead. Cracks, spalling, and missing deck/slab were noted at various locations. The record drawings suggest that the bulkhead is mainly supported by sheet piling. Numerous areas of erosion were noted between the bulkhead deck and the adjacent grade. The shoreline condition in the area of stone riprap with concrete overlay varies. Major cracking of the concrete overlayment was observed at some locations. In general, the degree of erosion and undermining of adjacent areas varies along the shoreline (Tetra Tech, 2012c).

Removal in front of the existing bulkhead in Dark Head Cove could destabilize this aged bulkhead; dredging activities have the potential to undermine the structure. The structural and geotechnical stability of the bulkhead will be further evaluated, and a protective set back distance will be established during remedial design.

5.2.3 Capping and Enhanced Natural Recovery (ENR)

Conventional sand cap would be used for the alternatives involving containment of contaminated sediment. During design, USACE capping guidance will be used to determine the thickness and gradation of the cap (Palermo et al., 1998; Clarke et al., 2001), based on evaluation of various factors including bioturbation, consolidation, erosion, and operational considerations such as propeller scour, chemical isolation, and required navigation and water depths. For this FS, and consistent with USACE capping guidance, a sand cap thickness of three feet was assumed for all cap areas.

Thinner or thicker caps may be developed during remedial design, depending on surface COC concentrations, elevation considerations such as navigation depths, or to accommodate unrestricted use of benthic resources. The gradation of cap material depends on factors such as habitat, erosion, and scour potential. No assumptions regarding a specific material gradation have been made in this FS because the range of material unit costs for sand capping material of different gradations is very narrow, and is not be expected to significantly affect estimated costs.

Enhanced natural recovery is included in areas where COC concentrations are greater than RALs as an alternative to conventional isolation capping which will not be required to achieve RAOs. During design, the ENR material will be evaluated to ensure that the placed ENR layer is appropriate for benthos in the area. The ENR thickness will be determined based on the surface COC concentrations, so that ENR will result in a surface layer with contaminant concentrations within regulatorily acceptable levels.

A fully mixed layer of surface sediment would result following application of a layer of clean material (approximately equal to the thickness of the 10 centimeter [four inch] biologically active zone) through bioturbation and other mixing mechanisms. At long-term, steady-state condition, this mixed layer would be comprised of one-half clean, applied material and one-half existing surface sediment. Assuming the bioturbation activity depth is five to 10 centimeters (National Research Council [NRC], 2001), and that a clean layer of sediments approximately 10 centimeters thick has been placed during ENR implementation, the long-term steady-state equilibrium condition (assuming complete mixing of the ENR material with the underlying sediment) could reduce contaminant concentrations in the biologically active zone by as much as 50%. This is a conservative assumption because natural sedimentation is ongoing at the site; during construction, a more typical clean-layer thickness will be 15 to 23 centimeters (six to nine inches), which will provide a greater contaminant concentration reduction than noted above. For cost estimating purposes, it is assumed that ENR application will be a minimum of six inches wherever it is applied.

Reactive ENR enhances the performance of the natural recovery layer by using *in situ* sorbent amendments. The reactive material (such as activated carbon) in the active layer reduces migration of dissolved contaminants in sediment porewater by binding them through adsorptive processes. In this FS, we have assumed that a reactive ENR layer would reduce total surface COC through both dilution (the application of a thin layer of sand) and adsorption (to the reactive material).

All in-water construction associated with capping and removal will be conducted during the designated in-water work window. The MDE has established a time of year restriction, also known as a seasonal window, from October 15 to February 15 for typical in-water construction projects in Baltimore County. The final work window will be defined and coordinated in consultation with other resource agencies before implementation.

5.2.3.1 Maintaining Water Depths

In federal navigation areas, where minimum elevations are required to be maintained, capping is restricted to areas where the existing surface sediment elevation provides adequate clearance for navigation and future maintenance activities. For capping projects in navigation channels, USACE typically requires a four-foot differential depth between the top of the cap and the deepest permitted maintenance depth. This depth would allow for a two-foot safety clearance and a two-foot maintenance over-dredge.

Middle River is a federal navigation channel with a project depth of -10 feet MLLW. Current depths in Dark Head Cove have been surveyed at -10 ±2 feet MLLW (USACE, 2012). Maintenance dredging has never been conducted, and Middle River is not in use as a navigation channel. The USACE may not allow placement of a conventional three-foot cap, or a thin six- to 12-inch ENR layer, in Dark Head Cove. Nonetheless, in this FS, alternatives that use containment and ENR components were carried forward for initial screening and detailed evaluation.

In Cow Pen Creek, special consideration will be given to ensuring that the material placement does not reduce water depths or alter the flow-carrying capacity of the creek. Any remedial action in the creek should at a minimum maintain and preferably improve existing habitat conditions.

5.2.3.2 Geotechnical Issues

Cap stability, bearing capacity, and sliding failures are typical geotechnical issues encountered in placing material (e.g., residuals management backfill after dredging, enhanced natural recovery, conventional sediment capping) over soft deposits. As discussed in Section 2.4, MRC sediments are considered very soft to soft based on *in situ* and laboratory shear-strength test results. The low shear-strength capacity of MRC sediments will not restrict material placement, but the placement technique will require slow installation of layers in thin lifts to minimize disturbance (i.e., pushing sediment sideways and upwards by the weight of sand) and mixing of underlying sediments.

The FS-level analysis of consolidation test results indicates that MRC sediments are over-consolidated, which means the MRC sediments have experienced higher load and stress (i.e., pre-consolidation stresses) than the current existing conditions. Pre-consolidation stresses are higher than the anticipated additional load of a conventional cap and ENR, suggesting that these sediments would not be expected to undergo significant primary consolidation during cap placement. Therefore, over-consolidation of sediments under a conventional cap, ENR, or residuals management loading is not a major concern for MRC sediments.

5.2.4 Monitored Natural Recovery

Monitored natural recovery relies on natural processes to return sediment concentrations to background levels. Monitored natural recovery requires an adequate sedimentation rate and deposition of less contaminated material over existing sediments to reduce surface concentrations to meet cleanup goals within a specified period, usually within 10 to 30 years. Sedimentation-rate analyses for sediments in Dark Head Cove, Cow Pen Creek, and the confluence of the two water bodies downstream of the site indicate that the highest sedimentation rates are expected in the confluence of Dark Head Cove and Cow Pen Creek downstream of the site (1.1 to 1.7 cm/year).

Sedimentation rates in Dark Head Cove and at the mouth of Cow Pen Creek are between 0.8 to 0.99 cm/year and 0.3 to 0.51 cm/year, respectively (Tetra Tech, 2011a). These sedimentation rates suggest that MNR alone has moderate to high effectiveness in achieving the RAOs in depositional areas of the site. The effectiveness of MNR at the confluence and in Dark Head Creek is supported by surface COC concentrations; no exceedances of PRGs have been observed in this area (Figure 5-1b).

Monitored natural recovery assumes a quasi steady-state equilibrium condition of continual mixing of newly deposited layer with the underlying sediment through bioturbation and other physical mixing processes. Such an approach can reduce contaminant concentrations in the biologically active zone by up to 50%. In this FS, we have conservatively assumed that 15 centimeters of sedimentation would be required to achieve a 50% reduction in surface contaminant concentrations. The average time needed to achieve this 50% reduction in COC concentrations (i.e., intrinsic half time) through natural sedimentation is typically approximated by exponential decay curves. The reason for this approximation is because a steady supply of sediment from upstream areas, and its deposition and mixing with the bioavailable zone (near-surface) sediment, predicts mathematically that the rate of change in bioavailable zone COC concentration changes exponentially over time toward the concentration of COC in incoming sediment. The intrinsic half times for a mixed layer depth of 15 cm associated with an average deposition rate of 0.8 cm/yr, is estimated as 13 years for Dark Head Cove and Dark Head Creek. Most of the Cow Pen Creek is subject to erosional forces (see Section 2.3.5), and natural sedimentation is expected to occur only at the mouth of the creek. Therefore, no natural recovery is assumed in Cow Pen Creek.

5.2.5 *In situ* Treatment

In this FS, surface broadcasting of bulk activated carbon (AC) pellets, without additional capping material, is assumed as the *in situ* treatment technology used to reduce the bioavailability of MRC COC. Currently, two such products are available in the market: AquaGate and SediMite™. Both of these products are agglomerates comprised of a treatment agent (usually AC), a weighting agent to make it sink and resist resuspension, and an inert binder. They are designed to cause minimal environmental impact, and can thus be used whenever a primary goal is to limit destruction of existing habitat. The most viable remedial applications for AC include depositional environments that are hydrodynamically stable and have low erosion potential, and sensitive environments where minimizing habitat disruption is a goal (e.g., contaminated sediments in aquatic or marine grass beds and wetlands).

Dark Head Cove and Dark Head Creek are depositional environments with estimated sediment deposition rates of about 1 cm/year; therefore, i*n situ* treatment through surface broadcasting of AC pellets is considered a viable remedial technology for these areas. Hydraulic modeling based on a 100-year storm event has determined that shear forces sufficient to erode sediment (>0.1 Newtons per square meter [N/m^2]) have been found only in Cow Pen Creek. These data indicate that: (1) material in Cow Pen Creek could migrate into Dark Head Cove and Dark Head Creek, (2) *in situ* remedies may not be appropriate for Cow Pen Creek due to its susceptibility to erosion, and (3) *in situ* remedies may be applicable in Dark Head Cove and Dark Head Creek. Figure 2-7 illustrates sedimentation rates in these areas, based on the results of hydraulic modeling and average sedimentation rates determined by sediment age dating.

Activated carbon delivered through bulk AC pellets can treat sediments contaminated with PCBs, polycyclic aromatic hydrocarbons (PAHs), and other hydrophobic chemicals and, to a lesser extent, metals. Both the AC products mentioned above are designed to withstand dispersal through the water column with minimal release of active ingredients, followed by their slow disintegration and mixing into the sediment bioactive zone through natural sediment mixing processes such as bioturbation. Research in the last two decades has demonstrated that black carbonaceous particles (such as activated carbon, soot, coal, and charcoal) bind very strongly to hydrophobic organic compounds such as PCBs. The presence of such particles in sediments reduces exposure to these compounds (Lohmann et al., 2005; Ghosh et al., 2011), often by an order of magnitude or more when compared to natural organic matter lacking such particles. Natural-contaminant sequestration of contaminants in native sediments can be greatly enhanced by adding clean, manufactured, carbonaceous materials such as AC into sediments (Ghosh et al., 2011).

Recent field pilot-tests and laboratory studies show that adding AC to sediments can reduce PCB bioavailability by 50 to 95%. During a 2006 field pilot-study at Hunters Point, California, bulk AC was mixed with tidal mud-flat sediment using a Rototiller and slurry injection. Hunters Point is a net depositional site, with an average sedimentation rate of 1 cm/year. Ongoing monitoring at this site shows a 50 to 70% reduction in aqueous PCB (Cho et al., 2012).

A field pilot-study at Grasse River, New York, also conducted in 2006, mixed bulk AC with sediments at a water depth of 15 feet, using a Rototiller and tine sled to achieve a reported reduction of up to 95% in PCB uptake in benthic invertebrates (e.g., clams and worms) (Greenberg, 2012). Another pilot study in James River, Virginia, implemented surface broadcasting of pelletized AC (SediMite™), which reduced PCB biouptake in freshwater oligochaete by 90% (Ghosh, 2012). Recent research also indicates that AC is effective for *in situ* treatment of sediments contaminated by mercury, PAHs, and other metals.

Application of SediMite™ at the Aberdeen (Maryland) Proving Ground pilot-test area has shown that amending freshwater sediment with SediMite™ reduced mercury bioaccumulation in a freshwater oligochaete by 84%, and reduced methyl-mercury bioaccumulation by 90% (Ghosh, 2012). Laboratory research on applying AC to cadmium-contaminated sediments reduced cadmium bioavailability by 20 to 50% (Ghosh et al., 2008). Manufacturers of another sorbent, Thiol-SAMMs, claim that it can reduce cadmium bioavailability by up to 90%; however, to date no pilot-scale studies have been conducted using this sorbent.

In Norway, another pilot test for *in situ* treatment of persistent organic pollutants via placement of a thin reactive layer showed a reduction in PAH flux from contaminated sediments of up to 99% when a thin, two- to five-centimeter thick layer of sand mixed with AC was placed over contaminated sediments (Eek et al., 2011).

In this FS, the effectiveness of *in situ* treatment was evaluated using the assumption that a reduction in bioavailability of COC is correlated to effective reductions in bulk sediment concentrations and results in a reduction in the total concentration of COC, thereby resulting in a reduction in COC bioavailability. Based on the most recent research and pilot studies regarding AC application and its effectiveness in reducing the bioavailability of PCBs, PAHs and metals in sediments, we have conservatively assumed the effectiveness of *in situ* treatment is a 50% reduction in total PCBs, benzo(a)pyrene equivalents (BaPEq), and mercury concentrations, and 20% reduction in total metal concentrations.

5.3 ASSEMBLY OF REMEDIAL ALTERNATIVES

Remedial alternatives are developed by combining representative technologies and associated process options into assemblages applicable to site-specific features. These assemblages focus on removal (dredging), containment (capping/ENR), and *in situ* treatments as the primary active response actions to reduce risks, and these approaches are supplemented by passive measures such as MNR as necessary to achieve RAOs. The assemblages of remedial alternatives were developed based on the analyses and findings summarized in previous sections of this FS. These include the following:

- regulatory requirements (e.g., applicable or relevant and appropriate requirements [ARARs]), RAOs, and PRGs
- areas of potential concern discussed above and identified by the nature and extent of contamination evaluated in Section 2
- remedial action levels
- representative remedial technologies that were screened in Section 4
- site-specific technology evaluation

The long list of remedial alternatives, and the goals each alternative is designed to achieve, are as follows:

- ***Alternative 1—No action****:* This alternative provides a baseline against which to compare the other remedial alternatives; inclusion is required by CERCLA.
- ***Alternative 2—Complete containment****:* This alternative would contain risk-driver COC in the AOPC footprint, addressing COC to a depth of 52 inches by conventional capping.

- ***Alternative 3—Complete removal:*** This alternative would dredge sediments having the highest concentration of risk-driver COC in the AOPC footprint, addressing them to a depth of 52 inches, where risk-driver COC concentrations are greater than RALs for any depth. Complete removal has two subalternatives (i.e., 3A and 3B) that define the extent of removal within the AOPC footprint.

- ***Alternative 4—Combined action:*** This alternative would combine active and passive remedial technologies in the AOPC footprint to address MRC RAOs in surface sediments. This general alternative includes 10 subalternatives (i.e., 4A, 4B, 4C, 4D, 4E, 4F, 4G, 4H, 4I, 4J) to address the AOPC using a range of remedial technologies. The removal areas are focused on Cow Pen Creek and in front of the bulkhead in Dark Head Cove, where the removal depth is up to 52 inches. In remaining areas, a combination of other active or passive technologies (e.g., capping, ENR, thick ENR [i.e., 12 to 18 inches], reactive ENR, *in situ* treatment, and MNR) will be implemented over surface sediments where risk-driver COC concentrations are greater than RALs.

The components of these alternatives are illustrated in Figures 5-2 to 5-14. Common remedy elements for each alternative are discussed in the following section.

5.4 COMMON REMEDY ELEMENTS

5.4.1 Shoreline and Habitat Improvements

Removal actions in Cow Pen Creek and Dark Head Cove may require shoreline stabilization and habitat improvements after remedial construction. Following the removal action in near-shore areas, shoreline slopes are assumed to be stabilized with riprap or other shoreline stabilization measures as needed to ensure long-term slope stability. Habitat mix may be placed in the interstices of riprap to provide a more favorable environment for aquatic species. Treatment of shoreline areas and restoration of Cow Pen Creek after the remedial construction will be coordinated with MDE and stakeholders during remedial design. The FS-level cost estimates include the costs of shoreline stabilization, habitat enhancement, and riparian planting after remedial construction.

5.4.2 Institutional Controls

Current institutional controls (ICs) (including regional fish and shellfish consumption advisories pertaining to the greater Middle River study area issued by MDE, community information, and education) will remain as part of any remedial alternative. Lockheed Martin has an ongoing community outreach program to inform the community about remedial actions related to MRC sediments. This process is expected to continue to inform and educate the community about the long-term ICs that would remain as part of the constructed remedy. Section 5.7 contains more details about Lockheed Martin's community outreach.

Depending on the remedy, an IC plan may need to be developed during design to protect human health and the environment from any remaining contaminated sediments and to prevent use inconsistent with maintenance of the remediated area. If capping of contaminated sediments is part of a remedy, additional ICs to prevent the disturbance of any contaminated sediments that remain in place would be required. These ICs will include waterway use restrictions such as constraints on boating operations and anchorage and limitations on pile driving and dredging.

5.4.3 Monitoring

Monitoring is a sediment-remediation assessment technology to verify achievement of project RAOs. For this FS, the following two monitoring categories are assumed: (1) construction monitoring, which is short-term during construction to ensure operational performance; and (2) long-term operation and maintenance (O&M) monitoring, to confirm that the technologies are operating as intended and that remediation objectives are being achieved. Construction monitoring ensures construction quality assurance/quality control through bathymetric surveys and verification sediment sampling. These steps, along with water quality monitoring, will confirm that human health and the environment are protected during construction. We have assumed that long-term monitoring will be needed at areas that are not remedied by removal. The scope of the monitoring program will vary depending on the remedy selected.

The details of long-term monitoring, performance standards and benchmarks, and associated contingency actions will be outlined in an operations, maintenance, and monitoring plan (OMMP) that will be developed during design, before construction. The OMMP will cover the post-construction monitoring and maintenance required to ensure long-term remedy performance. The OMMP will also outline performance expectations and potential courses of action that should be taken based on sampling results, the passage of time, or the occurrence of natural phenomena such as earthquakes or significant weather events that could disturb remedy effectiveness.

5.5 DESCRIPTION OF ALTERNATIVES

This section describes each alternative in detail. A summary of actively remediated areas, volumes, and the (rough order of magnitude) costs associated with each remedial alternative is presented in Table 5-2. The components of each alternative are illustrated in Figures 5-2 to 5-14.

5.5.1 Alternative 1—No Action

The USEPA CERCLA guidance requires that the No Action alternative be considered for every site (USEPA, 1988). The No Action alternative reflects the site conditions described in the baseline risk assessment and remedial investigation. Under this alternative, no active remedial actions would be taken. This alternative does not meet the RAOs, but has been retained in theis FS, consistent with *National Contingency Plan* (NCP) requirements, for its use as a standard for comparing remedies.

5.5.2 Alternative 2—Complete Containment

Under Alternative 2, conventional sediment capping is used to contain contaminated sediments within the remedial action area, creating a clean surface suitable for reestablishing aquatic biota. The cap will be of sufficient thickness and particle size gradation to ensure isolation of impacted sediments, and will be able to withstand erosional forces. The complete containment area covers approximately 28 acres of the AOPC, as illustrated in Figure 5-2. This alternative meets RAOs upon completion of the remedy. Common remedy elements apply0. Additional ICs are required to protect the cap.

The ICs plan for this alternative include using restrictive covenants as the primary proprietary control. Owners of property subject to the covenant will be prevented from conducting any activity that could result in the release of residual contamination or its exposure to the environment. Regulators will work closely with property owners as new developments occur to ensure that development can proceed alongside implementation of short-term controls to minimize potential residual risks. The ICs will also require regular site inspections to verify and enforce continued application of these controls.

5.5.3 Alternative 3—Complete Removal

Complete-removal remedial alternatives include removal of contaminated sediments containing concentrations of risk-driver COC that are elevated above PRGs. These alternatives address contaminant-mass removal concerns and achieve RAOs at the end of construction. Removal areas and volumes are presented in Table 5-2. Two subalternatives were developed under the complete removal scenario.

5.5.3.1 Alternative 3A—Removal within AOPC Addressing Depth to 52 inches at Cow Pen Creek, Dark Head Cove, and Dark Head Creek

Alternative 3A includes removal of contaminated sediments containing elevated concentrations of risk-driver COC (i.e., concentrations above PRGs) to a depth of 52 inches. About 143,000 cubic yards of sediment over approximately 28 acres of the AOPC would be removed under this alternative. The overall removal footprint and removal areas at four depth intervals (i.e., zero to six inches, six to 18 inches, 18 to 30 inches, and 30 to 52 inches) are illustrated in Figures 5-3a and 5-3b. Common remedy elements described above will also apply.

5.5.3.2 Alternative 3B—Removal within AOPC Addressing Depth to 52 inches at Cow Pen Creek and Dark Head Cove

About 99,500 cubic yards of sediment from approximately 23 acres within the AOPC will be removed under this subalternative. Alternative 3B does not include an area of approximately five acres in Dark Head Creek where RAOs for surface sediments have already been achieved through MNR. The overall removal footprint and removal areas at four depth intervals are illustrated in Figures 5-4a and 5-4b. Common remedy elements will also apply.

5.5.4 Alternative 4—Combined Action

Under Alternatvie 4, a combination of active and passive remedial technologies is used to develop combined-action alternatives for the AOPC footprint to address MRC RAOs for surface sediments. This general alternative includes 10 subalternatives (i.e., 4A, 4B, 4C, 4D, 4E, 4F, 4G, 4H, 4I, 4J) to address contamination within the AOPC. Each subalternative uses a different combination of various remedial technologies (e.g., removal, capping, ENR, thick ENR, reactive ENR, *in situ* treatment, and MNR). The following methodology was applied in developing combined-action alternatives:

- ***Remediation of Cow Pen Creek contaminated sediments—***Removal is considered the most appropriate cleanup action for this area, due to the shallow and (potential) erosional environment of the creek. Elevated cadmium concentrations extending to a depth of 30 inches could be re-exposed in this area, and could cause further disruption to the benthic community by exceeding the cadmium PRGs. Removal would also allow natural restoration of creek habitat.

- ***Remediation of Dark Head Cove contaminated sediments—***A combination of technologies was considered for this area, and a range of alternatives was developed. The general strategy used for selecting specific technologies was as follows:

  Step 1: Determine the size of the removal footprint:

  a. Limited removal—areas in front of Outfall 5, where the highest PCB concentrations are located, including areas exceeding 50 ppm. These high PCB concentration areas are targeted for removal to meet project RAOs and TSCA 40 Code of Federal Regulations [CFR] 761.61 requirements. Removal is the preferred remedy at these locations, and will allow potential future development planned in front of outfalls and along the bulkhead.

  b. Expanded removal—includes the limited removal area above, plus an additional area in front of the bulkhead where elevated concentrations of PCBs, PAHs, and metals have been found. Removal in this area allows potential future development planned along the bulkhead.

  Step 2: Assign other active remedial technologies in remaining areas of the AOPC, based on their effectiveness:

  a. Capping is an effective technology to remediate all contaminated sediments in Dark Head Cove. Application of capping was limited to a few alternatives (Alternatives 4A, 4D, 4E) due to concerns about the federal navigation status of Dark Head Cove.

  b. Enhanced natural recovery reduces sediment contaminant concentrations in the active zone by up to 50%. Concentrations of each COC in each polygon were evaluated to determine if ENR alone is effective inachieving PRGs at the end of the construction.

     - For areas in which ENR alone is sufficient to meet the PRGs at the end of the construction, the technology was applied (Alternatives 4A, 4D, 4E).

     - For areas in which ENR alone is not sufficient to meet the PRGs at the end of construction, thick ENR, which reduces sediment concentrations further, or MNR, was considered (Alternatives 4A, 4D, 4E).

  c. *In situ* treatment by application of activated carbon may reduce total PCBs, BaPEq, and mercury concentrations by 50%, and metal concentrations by 20% (Section 5.2.4). Concentrations of each COC in each polygon were evaluated to determine if *in situ* treatment alone would be effective in achieving PRGs at the end of the construction.

     - For areas where *in situ* treatment alone is sufficient to meet the PRGs at the end of the construction, the technology was applied (Alternatives 4B, 4G, 4J).

- For areas where *in situ* treatment alone is not sufficient to meet the PRGs at the end of construction, additional ENR (which would further reduce sediment concentrations) and/or MNR were considered (Alternatives 4B, 4G).

d. Reactive ENR provides the effectiveness of both ENR and *in situ* treatment technologies by mixing activated carbon with sand, then placing it as a thin layer over the sediments. Concentrations of each COC in every polygon in Dark Head Cove would achieve PRGs at the end of the construction through reactive ENR. Application of reactive ENR was limited to a few alternatives, due to concerns about the federal navigation status of Dark Head Cove (Alternatives 4C, 4F).

e. Monitored natural recovery was considered at locations where ENR or in situ treatment technologies will not achieve PRGs at the end of the construction (Alternatives 4B, 4D, 4G). Monitored natural recovery was also evaluated as the sole remedial technology for individual areas (Alternative 4E, 4H, 4J).

f. Additional removal was considered for locations where an active remediation technology will be applied (e.g., *in situ* treatment), but further MNR is needed to achieve PRGs, and where the MNR duration was estimated to be longer than 20 years (Alternatives 4I, 4J).

Actively remediated areas and volumes are summarized in Table 5-2. Combined-action alternatives will all eventually meet RAOs, but the time to completion for each remedy varies. The performance of each subalternative in meeting RAOs is discussed in the screening evaluation of the alternatives (see Section 5.6).

5.5.4.1 Alternative 4A—Removal in Cow Pen Creek, Limited Removal in Front of the Dark Head Cove Bulkhead, Capping, ENR, Thick ENR, and MNR

Components of this alternative are illustrated in Figure 5-5. Removal areas are focused on Cow Pen Creek and a small area in front of the Dark Head Cove bulkhead where the highest PCB concentrations (20 to 54 ppm) in MRC sediments are located. About 26,600 cubic yards of contaminated sediment will be removed within seven acres of the AOPC (Table 5-2). Capping will be the next remedial technology, to be applied over an additional seven acres of sediment in front of the bulkhead. The rest of the AOPC will be managed through a combination of thick ENR (two acres), ENR (two acres), and MNR (three acres). Common remedy elements will also be applied, and additional ICs for property and water use restrictions will be required to protect the cap areas.

5.5.4.2 Alternative 4B—Removal in Cow Pen Creek, Limited Removal in Front of the Dark Head Cove Bulkhead, in situ Treatment, ENR, and MNR

This alternative is similar to Alternative 4A, but targets removal of about one more acre of elevated PCB concentration (greater than 4 ppm) sediment in front of the bulkhead. Thus, approximately 29,700 cubic yards of contaminated sediment will be removed (over about eight acres) within AOPC. *In situ* treatment will be applied to the rest of the AOPC (approximately 13 acres). To meet RAOs, 1.6 acres of the 13 acres will receive ENR and 5.3 acres will require MNR, in addition to the *in situ* treatment.

The components of the remedy are illustrated in Figure 5-6, and remedy metrics are summarized in Table 5-2. Common remedy elements will also be applied. Additional ICs related to property and water use restrictions will not be needed because there is no cap area under this alternative. *In situ* treatment and ENR areas are designed to meet RAOs through complete mixing of surface sediments. Disturbance of these areas through property and water use activities is therefore not an issue and no additional IC beyond common remedy elements will be required.

5.5.4.3 Alternative 4C—Removal in Cow Pen Creek, Limited Removal in Front of the Dark Head Cove Bulkhead, and Reactive ENR

Alternative 4C (Figure 5-7) includes the same removal footprint and volume as in Alternative 4B. The rest of the AOPC (about 13 acres) will be remediated by reactive ENR (an assumed 6-inch layer of sand mixed with activated carbon). Common remedy elements will also be applied. No additional ICs beyond common remedy elements will be required. The components of the remedy are illustrated in Figure 5-7, and its metrics are summarized in Table 5-2.

5.5.4.4 Alternative 4D—Removal in Cow Pen Creek and in Front of the Dark Head Cove Bulkhead, Capping, ENR, and MNR

The components of this alternative are illustrated in Figure 5-8a. Removal areas are focused on Cow Pen Creek and in front of the bulkhead. About 48,800 cubic yards of sediments will be removed over 12.5 acres within the AOPC. The removal area targets high PCB locations to meet RAO 1, and is designed to remove the most contaminant mass relative to total dredge volume. Figure 5-8b shows the removal areas divided into four depth intervals. About 1.5 acres will be capped in front of the Wilson Point Park, a location of elevated PCB and mercury concentrations.

This alternative also includes about four acres of ENR and five acres of MNR (Table 5-2). Common remedy elements will be applied. Additional ICs for property and water use restrictions will be required to protect the cap areas.

5.5.4.5 Alternative 4E—Removal in Cow Pen Creek and in Front of the Dark Head Cove Bulkhead, Capping, ENR, Thick ENR, and MNR

Alternative 4E is similar to 4D in that the removal and capping areas are the same. Alternative 4E includes applying a thicker ENR layer (12 to 18 inches) over two acres to achieve RAOs at the end of the construction. and to reduce MNR areas by two acres within the AOPC. Common remedy elements will also be applied. Additional ICs for property and water use restrictions will be required to protect the cap areas. Components of this remedy are illustrated in Figure 5-9, and its metrics are summarized in Table 5-2.

5.5.4.6 Alternative 4F—Removal in Cow Pen Creek and in Front of the Dark Head Cove Bulkhead plus Reactive ENR

Alternative 4F includes a removal volume similar to those of Alternatives 4D and 4E, and will target removal areas in Cow Pen Creek and in front of the Dark Head Cove bulkhead (Figure 5-10). About 48,800 cubic yards of contaminated sediments will be removed over 12.5 acres within the AOPC (Table 5-2). Reactive ENR will be applied to the rest of the 8.5-acre area. This combined-action alternative is designed to meet RAOs at the end of construction due to the effectiveness of reactive ENR (i.e., placing a thin layer of activated-carbon-amended sand over the contaminated sediments). Common remedy elements will be applied.

5.5.4.7 Alternative 4G—Removal in Cow Pen Creek and in Front of the Dark Head Cove Bulkhead, in situ Treatment, and MNR

Alternative 4G would involve removal of the same volume of material as in Alternative 4F (Figure 5-11). *In situ* treatment will be applied to the rest of the 8.5-acre area. Conservative assumptions regarding the effectiveness of activated carbon treatment indicate that about four acres of the *in situ* treatment area will require natural recovery (MNR) to meet RAOs. Common remedy elements would be applied.

5.5.4.8 Alternative 4H—Removal in Cow Pen Creek and in Front of the Dark Head Cove, and Bulkhead MNR

Alternative 4H includes removal of the same volume of material as in Alternatives 4D, 4E, 4F and 4G (Figure 5-11). The rest of the AOPC (about 8.5 acres) will be monitored to verify that natural recovery (MNR) is meeting RAOs. This alternative is designed as the most efficient way of removing contaminated mass from the site, and does not disturb the rest of the AOPC. Common remedy elements will be applied.

5.5.4.9 Alternative 4I—Removal in Cow Pen Creek and Dark Head Cove, and MNR

Alternative 4I is similar to Alternative 4H, but it expands the removal area by approximately 3.5 acres. The additional area includes more Dark Head Cove polygons that contain high COC concentrations (Figures 5-13a and 5-13b), and will require a longer period of MNR to meet RAOs. About 62,900 cubic yards of contaminated sediment will be removed over 16 acres within the AOPC (Table 5-2) under this alternative. The rest of the AOPC, about five acres, will be monitored to verify that MNR is meeting RAOs. Figure 5-13b shows the removal areas divided into four depth intervals. Common remedy elements will also apply.

5.5.4.10 Alternative 4J—Removal in Cow Pen Creek and Dark Head Cove, in situ Treatment, and MNR

Alternative 4J involves the same removal footprint and volume as in Alternative 4I, entails *in situ* treatment of about two acres, and MNR of about three acres within the AOPC (Figure 5-14 and Table 5-2). This alternative is designed to minimize reliance on MNR (compared to Alternative 4I) and *in situ* treatment (compared to Alternative 4G) to achieve RAOs. The size of the *in situ* treatment area is designed to match typical *in situ* treatment pilot-tests. Common remedy elements will be applied.

5.6 SCREENING ANALYSIS OF ALTERNATIVES

Screening analysis of the long list of remedial alternatives was performed per USEPA CERCLA guidance (USEPA, 1988). The guidance recommends that the long list of defined alternatives be evaluated according to three broad criteria: *effectiveness*, *implementability*, and *cost*. The screening evaluation is intended to reduce the number of alternatives that will undergo the detailed analysis.

The evaluation screening criteria used and evaluation results are discussed below. The screening evaluation of the long list of MRC remedial alternatives is summarized in Table 5-3.

5.6.1 Effectiveness Evaluation

Each alternative was evaluated qualitatively as to its effectiveness in providing human health and environmental protection and the reducing toxicity, mobility, or volume of COC (Table 5–3). Both short- and long-term effectiveness components were considered. Alternatives with *in situ* treatment components provide effectiveness through reduced COC bioavailability via application of activated carbon.

Complete-capping and removal alternatives (Alternative 2, 3A, 3B) are highly effective for overall protection of human health and environment when compared to the combined-action alternatives. Most combined-action alternatives provide moderate to high effectiveness; RAOs would be achieved for the combined alternatives in varying durations after the end of the construction, depending on performance of *in situ* treatment and MNR components. Areas addressed by thick ENR and reactive ENR would be highly effective in meeting RAOs immediately following construction. No alternative was screened out due to its effectiveness.

5.6.2 Implementability Evaluation

Implementability is a measure of the technical and administrative feasibility of constructing, operating, and maintaining a remedial action alternative. Specific site characteristics considered during the technology screening in Section 4 were also considered during the implementability evaluation of the remedial alternatives. Technical feasibility refers to the ability to construct, operate, and meet technology-specific regulations. It also includes the long-term operation, maintenance, replacement, and monitoring of technical components of the alternative, if needed. Administrative feasibility refers to the ability to obtain approvals from government agencies, the availability of treatment, storage, and disposal services, and the capacity and availability of equipment and technical expertise. Thus, the more difficult the administrative procedures and approvals are, and the more federal requirements exist for an alternative, the lower is its administrative feasibility.

The most important implementability restriction associated with evaluating the alternatives is the use of Dark Head Cove as part of the Middle River authorized federal navigation channel, which is subject to maintenance by the USACE. Any construction that would decrease the depth of surface water shallower than the authorized project depth of -10 feet MLLW would not likely be allowed by the USACE. Alternatives 2, 4A, 4C, 4D, 4E were screened out due to their low administrative feasibility (Table 5-3). Alternative 4F is retained even though it has a reactive ENR component. It was retained for consideration by USEPA and MDE, and for further coordination by USACE, in case reactive ENR is a remedy component preferred by these agencies.

Future land uses were another evaluation factor regarding alternative implementability. Alternatives that leave contamination in front of the bulkhead (i.e., 4A, 4B, and 4C) were not retained because residuals contamination would limit options for potential future development along the bulkhead in Dark Head Cove.

5.6.3 Cost Evaluation

For screening analysis purposes, rough order of magnitude cost estimates were computed for the alternatives evaluated (Table 5-2). Screening-level cost estimates were developing using generic unit costs, conventional cost-estimating guides, and earlier similar estimates as modified by site-specific information. The relative cost of each alternative was considered, but no MRC remedial alternatives was screened out due to its cost.

5.7 COMMUNITY OUTREACH PROCESS

In addition to evaluating remedial alternatives using criteria of effectiveness, implementability, and cost, community input through Lockheed Martin's community outreach efforts was considered in identifying the short list of alternatives. Lockheed Martin organized a public information session and three follow-up working group meetings to keep the community informed about environmental cleanup activities associated with sediments at MRC. The public information session was held on January 18, 2012, during which Lockheed Martin's plan for evaluating cleanup options for sediments near the MRC was presented (Lockheed Martin, 2011). Following the information session, three monthly education and involvement working group meetings were held on February 23, March 21, and April 26, 2012. Sediment characterization, risk assessment, remedial technologies and approaches, and a subset of remedial alternatives and evaluations were reviewed during these meetings.

The outreach process also enabled community input for evaluation of the alternatives. A summary of this input and a matrix of comments received from the community are included in Appendix D.

The working group members noted that the cost may be excessive compared to the benefits for complete removal alternatives, even though a total cleanup is considered ideal. Long construction periods and short-term disruption to the community were among other concerns related to the complete-removal alternatives.

Alternatives with partial removal and with components of *in situ* treatment and MNR received supportive comments from the public because they would meet all RAOs and are associated with lower cost, shorter construction time, and less disruption to the environment and community. The community also noted their concerns regarding the length of recovery through MNR in certain areas, the introduction of activated carbon to the water, and the effectiveness of activated carbon treatment. All the remedial alternatives reviewed by the public, as well as two additional alternatives (Alternatives 4I and 4J) developed based on the feedback received during the outreach process, are retained in the short list of alternatives and carried forward for detailed evaluation (see Section 5.8).

5.8 SHORT LIST OF REMEDIAL ALTERNATIVES

A short list of remedial alternatives (see Table 5-3) was established for MRC sediments based on the initial screening process (Section 5.6) and community input (Section 5.7). The alternatives carried forward for detailed and comparative evaluation in this FS are as follows:

- ***Alternative 1—No action:*** This alternative is retained to provide a baseline against which to compare the other remedial alternatives.
- ***Alternative 3—Complete removal:*** This alternative involves dredging sediments with the highest concentration of risk-driver COC in the AOPC footprint, where risk-driver COC concentrations are greater than RALs at any depth. This alternative has two subalternatives (i.e., 3A and 3B) that define the extent of removal within the AOPC footprint; both are retained for further detailed evaluation. Section 5.5.3 contains a detailed description of removal alternatives.
- ***Alternative 4—Combined action:*** The combined-action alternatives use a combination of active and passive remedial technologies in the AOPC footprint to address MRC RAOs in surface sediments. Five of the 10 subalternatives (i.e., 4F, 4G, 4H, 4I, 4J) are retained for further evaluation. The remedial technologies of removal, ENR, reactive ENR, *in situ* treatment, and MNR address the AOPC. Combined-action alternatives meet the RAOs upon completion of each remedy, but the time to achieve RAOs varies. The performance of each subalternative that meets RAOs is discussed in the detailed evaluation of the alternatives. Section 5.5.4 contains a detailed description of the retained combined-action alternatives.

Table 5-1
Summary of Preliminary Remediation Goals and Remedial Action Levels for Risk-Driver Chemicals of Concern at Lockheed Martin Middle River Complex

Risk-driver chemical of concern	Spatial scale of exposure	PRG	AOPC RAL
Total PCBs (µg/kg dw)	Site-wide	195 (background)	1,100[1]
	Point	676	676
BaPEq (µg TEQ/kg dw)	Site-wide	700 (background)	6,500[2]
	Point	N/A	N/A
Arsenic (mg/kg dw)	Site-wide	18.3 (background)	N/A[3]
	Point	N/A	N/A
Lead (mg/kg dw)	Site-wide	N/A	N/A
	Point	190	190[4]
Cadmium (mg/kg dw)	Site-wide	N/A	N/A
	Point	9.96	9.96[4]
Copper (mg/kg dw)	Site-wide	N/A	N/A
	Point	298	298[4]
Mercury (mg/kg dw)	Site-wide	N/A	N/A
	Point	1.06	1.06[4]
Zinc (mg/kg dw)	Site-wide	N/A	N/A
	Point	459	459[4]

Notes:

[1]RAL to achieve the site-wide PCB PRG. However, the RAL to achieve the point-based PRG for PCB is 676 ppb. Therefore, the AOPC RAL for PCBs is 676 ppb.

[2]RAL to achieve the site-wide BaPEq PRG. Baseline site-wide area weighted-average concentration (SWAC) for BaPEq is 763 ppb and BAP coexists with PCBs where a remedial action is applied to meet the point-based PRGs for PCBs. Therefore, the applied RAL for BaPEq varies and is less than 6,500 ppb.

[3]RAL to achieve the site-wide PRG for arsenic is not applicable. Baseline SWAC for arsenic is 7.8 ppm and meets site-wide PRG for arsenic.

[4]RALs to achieve the point-based PRGs

AOPC = Area of Potential Concern; PRG = Preliminary Remediation Goal; RAL = Remedial Action Level; N/A=Not Applicable.

Table 5-2
Remedial Alternatives - Actively Remediated Area, Volume and Cost Summary

Remedial Alternatives		Description	Removal Area (Acres)	Dredge Volume (cy) (Neat Volume)[1/]	Dredge Volume (cy) (FS Volume)[1/]	Cap Area (Acres)	MNR Area (Acres)	ENR Area (Acres)	Thick ENR Area (Acres)	In situ Treatment Area (Acres)	Activated Carbon (lb)	Reactive ENR Area (Acres)	Cap and Dredge Residual Backfill Volume (cy)[2/]	ENR Volume (cy)[2/]	Reactive ENR Volume (cy)[2/]	ROM FS Level Capital Cost Estimate (MM$)[3/]	ROM FS Level OM&M Cost Estimate (MM$)[4/]	ROM FS Level Total Cost Estimate
No Action	1	Baseline alternative used for comparison to other alternatives.	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Complete Containment	2	Capping over the AOPC (combined COCs footprint)	0.00	0.00	0.00	27.99	0.00	0.00	0.00	0.00	0.00	0.00	158,100	0.00	0.00	$20.6	$14.00	$34.5
Complete Removal	3A	Removal over the AOPC (combined COCs footprint)	27.99	95,419	143,128	0.00	0.00	0.00	0.00	0.00	0.00	0.00	33,300	0.00	0.00	$43.0	$0.00	$43.0
	3B	Removal at CPC, DHC	23.21	66,365	99,547	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25,500	0.00	0.00	$30.2	$0.00	$30.2
Combined Action	4A	Cow Pen Creek partial removal, Dark Head Cove limited removal, capping, thick ENR, MNR over the AOPC.	6.95	17,731	26,597	6.78	3.15	2.17	1.97	0.00	0.00	0.00	46,800	8,400	0.00	$14.4	$7.03	$21.4
	4B	Cow Pen Creek partial removal, Dark Head Cove limited removal, in situ treatment, ENR, MNR over the AOPC.	7.87	19,784	29,676	0.00	5.33	1.58	0.00	13.14	410,480	0.00	9,600	3,900	0.00	$12.4	$6.57	$19.0
	4C	Cow Pen Creek partial removal, Dark Head Cove limited removal, reactive ENR over the AOPC.	7.87	19,784	29,676	0.00	0.00	0.00	0.00	0.00	0	13.14	9,600	0	21,300	$12.5	$6.57	$19.0
	4D	Cow Pen Creek and Dark Head Cove partial removal, capping, ENR, MNR over the AOPC.	12.49	32,522	48,783	1.50	5.12	3.87	0.00	0.00	0	0.00	23,700	6,300	0.00	$17.1	$4.26	$21.3
	4E	Cow Pen Creek and Dark Head Cove partial removal, capping, thick ENR, MNR over the AOPC.	12.49	32,522	48,783	1.50	3.15	1.91	1.97	0.00	0	0.00	23,700	7,900	0.00	$17.3	$4.26	$21.5
	4F	Cow Pen Creek and Dark Head Cove partial removal, reactive ENR over the AOPC.	12.49	32,522	48,783	0.00	0.00	0.00	0.00	0.00	0	8.52	15,200	0	13,800	$17.2	$4.26	$21.5
	4G	Cow Pen Creek and Dark Head Cove partial removal, in situ treatment, MNR over the AOPC.	12.49	32,522	48,783	0.00	3.72	0.00	0.00	8.52	266,094	0.00	15,200	0	0	$16.9	$4.26	$21.1
	4H	Cow Pen Creek and Dark Head Cove partial removal, MNR over the AOPC.	12.49	32,522	48,783	0.00	8.52	0.00	0.00	0.00	0	0.00	15,200	0.00	0.00	$15.1	$4.26	$19.4
	4I	Cow Pen Creek and Dark Head Cove partial removal, MNR over the AOPC.	15.95	41,927	62,890	0.00	5.06	0.00	0.00	0.00	0	0.00	19,300	0.00	0.00	$19.5	$2.53	$22.0
	4J	Cow Pen Creek and Dark Head Cove partial removal, in situ treatment, MNR over the AOPC.	15.95	41,927	62,890	0.00	3.15	0.00	0.00	1.91	59,640	0.00	19,300	0.00	0.00	$19.9	$2.53	$22.4

Notes:

[1/] Neat dredge volumes were estimated by utilizing Thiessen polygons. For FS costing purpose, neat dredge volume was increased by 50% to account for the various causes of volume creep following the guidance by Palermo and Gustavson (2009).

[2/] Cap volume was estimated using 3.5 ft layer of sand over cap footprint to reach minimum 3 feet coverage. ENR material volume was estimated assuming 12 inch layer of sand over the footprint to reach minimum 6 inch coverage. Thick ENR material volume was estimated assuming 18 inch layer of sand over the footprint to reach 12 inch coverage. Reactive ENR volumewas estimated assuming 12 inch layer of sand mixed with activated carbon over the footprint to reach minimum 6 inch coverage. Dredge residual backfill material volume was estimated assuming 9 inch layer of sand over the footprint to reach minimum 6 inch coverage. Activated carbon amount was estimated as 35,000 kg/ha (31,232 lb/acre).

[3/] Total direct, indirect costs (e.g. labor, equipment, material costs), and contingencies. ROM level cost estimate expected accuracy range is -50 to +100 percent. ROM capital unit cost is $270/cy for dredge; $130/cy for cap, ENR, dredge residual backfill placement; $200K/acre for in situ treatment; $150/cy for reactive ENR placement.

[4/] Total periodic costs (e.g. O&M, monitoring, ICs). ROM level cost estimate expected accuracy range is -50 to +100 percent. ROM OM&M unit cost is $0 for dredge; $50K/acre for other areas in 30 years assuming 10 monitoring events.

AOPC=Area of potential concern; COC=Contaminant of concern; ENR=Enhanced natural recovery; MNR=Monitored natural recovery; FS=Feasibility study; ROM=Rough order of magnitude

Table 5-3
Screening Analysis of Draft Remedial Alternatives
Middle River Complex, Middle River, Maryland

Remedial Alternatives [1/]		Description/Highlights	Effectiveness	Implementability	Cost	Screening Decision
No Action	1	• CERCLA baseline alternative used for comparison to other alternatives.	None	High	None	Retained Baseline alternative
Complete Containment	2	• Containment of impacted surface sediments by conventional capping over the AOPC • 28 acre cap; 158,100 cy cap; 28 acre long-term OM&M • $34.5M	High	Low administrative feasibility due federal navigation channel status of DHC	High	Not retained Cost prohibitive Capping is not likely to be permittable by the USACE
Complete Removal	3A	• Removal of impacted sediments over the AOPC • 143,200 cy removal; 33,300 cy backfill • $43M	High	Low implementability due to complexity of large scale removal	High	Retained
	3B	• Removal of impacted sediments over the AOPC • 99,600 cy removal; 25,500 cy backfill • $30.2M	High	Low implementability due to complexity of large scale removal	High	Retained
Combined Action	4A Limited Removal, Cap, Thick layer ENR, MNR	• Removal in CPC, limited removal in DHC with high concentration COCs (polygons 9, 27, 58). • 26,600 cy removal over 7 acre; 55,200 cy cap, ENR, backfill; 3.2 acre MNR; 14 acre long-term OM&M • $21.4M	Moderate to high	Low administrative feasibility of cap and ENR due federal navigation channel status of DHC	Moderate	Not retained Capping is not likely to be not permittable by the USACE
	4B Limited Removal, *In situ* Treatment, ENR, MNR	• Removal in CPC, limited removal in DHC with high concentration COCs (polygons 9, 27, 28, 58, 59, 88). • 29,700 cy removal over 8 acre; 13,500 cy backfill, ENR; 13 acre in situ treatment; 5.3 acre MNR; 13 acre long-term OM&M • $19M	Moderate to high	Moderate to high	Low to moderate	Not retained Leaving contamination along the bulkhead in DHC may limit options for future development
	4C Limited Removal, Reactive ENR, MNR	• Removal in CPC, limited removal in DHC bulkhead and outfalls with high concentration COCs (polygons 9, 27, 28, 58, 59, 88). • 29,700 cy removal over 8 acre; 9,600 cy backfill; 13 acre reactive ENR (21,300 cy); 13 acre long-term OM&M • $19M	Moderate to high	Low to moderate Low administrative feasibility of reactive ENR due federal navigation channel status of DHC	Low to moderate	Not retained Leaving contamination along the bulkhead in DHC may limit options for future development
	4D Partial Removal, Cap, ENR, MNR	• Removal in CPC, DHC bulkhead and outfalls • 48,800 cy removal over 12.5 acres; 30,000 cy cap, ENR, backfill; 5.1 acre MNR; 8.5 acre long-term OM&M • $21.3M	Moderate to high	Low administrative feasibility of cap and ENR due federal navigation channel status of DHC	Moderate	Not retained Capping is not likely to be permittable by the USACE

Table 5-3 (continued)
Screening Analysis of Draft Remedial Alternatives
Middle River Complex, Middle River, Maryland

Remedial Alternatives [1/]		Description/Highlights	Effectiveness	Implementability	Cost	Screening Decision
Combined Action (con't)	4E Partial Removal, Cap, Thick layer ENR, MNR	• Removal in CPC, DHC bulkhead and outfalls • 48,800 cy removal over 12.5 acres; 31,600 cy cap, ENR, backfill; 3 acre MNR; 8.5 acre long-term OM&M • $21.5M	Moderate to high	Low administrative feasibility of cap and ENR due federal navigation channel status of DHC	Moderate	Not retained Capping and thick ENR is not likely to be permittable by the USACE
	4F Partial Removal, Reactive ENR	• Removal in CPC, DHC bulkhead and outfalls. • 48,800 cy removal over 12.5 acres; 15,200 cy backfill; 8.5 acre reactive ENR (13,800 cy); 8.5 acre long-term OM&M • $21.5M	High	Low to moderate Low administrative feasibility of reactive ENR areas due federal navigation channel status of DHC	Moderate	Retained Even though the reactive ENR is not likely to permittable, retained for agency considerations
	4G Partial Removal, *In situ* Treatment, MNR	• Removal in CPC, DHC bulkhead and outfalls. • 48,800 cy removal over 12.5 acres; 15,200 cy backfill; 8.5 acre in situ treatment; 3.7 acre MNR; 8.5 acre long-term OM&M • $21.1M	Moderate to high	Moderate to high	Moderate	Retained
	4H Partial Removal at DHC, CPC, and MNR	• Removal in CPC, DHC bulkhead and outfalls. • 48,800 cy removal over 12.5 acres; 15,200 cy backfill; 8.5 acre of MNR and long-term OM&M • $19.4M	Moderate	Moderate to high	Low to moderate	Retained
	4I Partial Removal at DHC, CPC, and MNR	• Removal in CPC, DHC bulkhead and outfalls, additional removal in DHC and in front of the Wilson Point Park over 3.5 acre (polygons 30, 96, 98, 64, 89) • 62,900 cy removal over 16 acres; 19,300 cy backfill; 5 acre MNR; 5 acre long-term OM&M • $22.0M	Moderate to high	Moderate to high	Moderate	Retained
	4J Partial Removal at DHC, CPC, *In situ* Treatment, MNR	• Removal in CPC, DHC bulkhead and outfalls, additional removal in DHC and in front of the Wilson Point Park over 3.5 acre (polygons 30, 96, 98, 64, 89) • 62,900 cy removal over 16 acres; 19,300 cy backfill; 2 acres in situ treatment; 3 acres MNR ; 5 acre long-term OM&M • $22.4M	Moderate to high	Moderate to high	Moderate	Retained

[1/] Notes:

1. Refer to Table 5-2 for remedial action areas, volumes and the rough order of magnitude cost estimates.
2. Retained alternatives are highlighted.

Acronyms:
CERCLA – Comprehensive Environmental Resource, Compensation, and Liability Act
CPC – Cow Pen Creek
cy – cubic yards
DHC – Dark Head Cove
ENR – enhanced natural recovery
MNR – monitored natural recover
$M – million dollars
OM&M – operation, maintenance, and monitoring
USACE – United States Army Corps of Engineers

TETRA TECH

Figure 5 - 1a
Area of Potential Concern
Addressing Depth to 52 inches
Lockheed Martin Middle River Complex (MRC)
Middle River, Maryland

Legend

- Stormwater Outfall Locations
- No Action (Polygon < PRG/RAL)
- Area of Potential Concern
- Buildings/Roads
- 101 Thiessen Polygons and Sample Location Number

PRG = Preliminary Remediation Goal
RAL = Remedial Action Level

500 250 0 500 Feet

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Checked By: S. OZKAN 11/14/12
Approved By:

Contract Number: 112IC02903

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Figure 5-1b
Area of Potential Concern
Addressing RAOs at Surface
Sediments to 6 Inches
Lockheed Martin Middle River Complex (MRC)
Middle River, Maryland

Legend

- Stormwater Outfall Locations
- No Action (Polygon < PRG/RAL)
- Area of Potential Concern
- Buildings/Roads
- 101 Thiessen Polygons and Sample Location Number

PRG = Preliminary Remediation Goal
RAL = Remedial Action Level
RAO = Remedial Action Objective

500 250 0 500
Feet

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Figure 5-2
Alternative 2
Complete Containment
Lockheed Martin Middle River Complex (MRC)
Middle River, Maryland

Legend

- Stormwater Outfall Locations
- No Action (Polygon < PRG/RAL)
- Conventional Capping
- Buildings/Roads
- 101 Thiessen Polygons and Sample Location Number

PRG = Preliminary Remediation Goal
RAL = Remedial Action Level

500 250 0 500
Feet

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Figure 5 - 3a
Alternative 3A
Complete Removal
Lockheed Martin Middle River Complex (MRC)
Middle River, Maryland

Legend

- Stormwater Outfall Locations
- No Action (Polygon < PRG/RAL)
- Removal
- Buildings/Roads
- 101 Thiessen Polygons and Sample Location Number

PRG = Preliminary Remediation Goal
RAL = Remedial Action Level

500 250 0 500
Feet

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Figure 5 - 3b
Alternative 3A
Removal Thiessen Polygons by Depth
Lockheed Martin Middle River Complex (MRC)
Middle River, Maryland

Legend

- Stormwater Outfall Locations
- No Action (Polygon < PRG/RAL)
- Removal
- Buildings/Roads
- 101 Thiessen Polygons and Sample Location Number

PRG = Preliminary Remediation Goal
RAL = Remedial Action Level

Note:
Removal volume calculations include shallower depth intervals above the deepest polygons for removal.

1,080 540 0 1,080 Feet

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TETRA TECH

Figure 5 - 4a
Alternative 3B
Removal at DHC and CPC
Lockheed Martin Middle River Complex (MRC)
Middle River, Maryland

Legend

- Stormwater Outfall Locations
- No Action (Polygon < PRG/RAL)
- Removal
- Buildings/Roads
- 101 Thiessen Polygons and Sample Location Number

PRG = Preliminary Remediation Goal
RAL = Remedial Action Level
DHC = Dark Head Cove
CPC = Cow Pen Creek

500 250 0 500
Feet

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Figure 5 - 4b
Alternative 3B
Removal Thiessen Polygons by Depth
Lockheed Martin Middle River Complex (MRC)
Middle River, Maryland

Legend

- Stormwater Outfall Locations
- No Action (Polygons < PRG/RAL)
- Removal
- Buildings/Roads
- 101 — Thiessen Polygons and Sample Location Number

PRG = Preliminary Remediation Goal
RAL = Remedial Action Level

Note:
Removal volume calculations include shallower depth intervals above the deepest polygons for removal.

1,080 540 0 1,080 Feet

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Figure 5-5
Alternative 4A
Combined Action
Lockheed Martin Middle River Complex (MRC)
Middle River, Maryland

Legend

- Stormwater Outfall Locations
- No Action (Polygon < PRG/RAL)
- ENR
- MNR
- Thick ENR (12-18 inch)
- Conventional Capping
- Removal
- Buildings/Roads
- 101 Thiessen Polygons and Sample Location Number

PRG = Preliminary Remediation Goal
RAL = Remedial Action Level
ENR = Enhanced Natural Recovery
MNR = Monitored Natural Recovery

500 250 0 500
Feet

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Figure 5-6
Alternative 4B
Combined Action
Lockheed Martin Middle River Complex (MRC)
Middle River, Maryland

Legend

- Stormwater Outfall Locations
- Removal
- No Action (Polygon < PRG/RAL)
- MNR
- In Situ Treatment
- In Situ Treatment + ENR
- In Situ Treatment + MNR
- In Situ Treatment + ENR + MNR
- Buildings/Roads
- 101 Thiessen Polygons and Sample Location Number

PRG = Preliminary Remediation Goal
RAL = Remedial Action Level
ENR = Enhanced Natural Recovery
MNR = Monitored Natural Recovery

500 250 0 500
Feet

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Figure 5-7
Alternative 4C
Combined Action
Lockheed Martin Middle River Complex (MRC)
Middle River, Maryland

Legend

- Stormwater Outfall Locations
- No Action (Polygon < PRG/RAL)
- Reactive ENR
- Removal
- Buildings/Roads
- 101 Thiessen Polygons and Sample Location Number

PRG = Preliminary Remediation Goal
RAL = Remedial Action Level
ENR = Enhanced Natural Recovery

500 250 0 500
Feet

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TETRA TECH

Figure 5-8a
Alternative 4D
Combined Action
Lockheed Martin Middle River Complex (MRC)
Middle River, Maryland

Legend

- Stormwater Outfall Locations
- No Action (Polygon < PRG/RAL)
- ENR
- MNR
- MNR after ENR
- Conventional Capping
- Removal
- Buildings/Roads
- 101 Thiessen Polygons and Sample Location Number

PRG = Preliminary Remediation Goal
RAL = Remedial Action Level
ENR = Enhanced Natural Recovery
MNR = Monitored Natural Recovery

500 250 0 500 Feet

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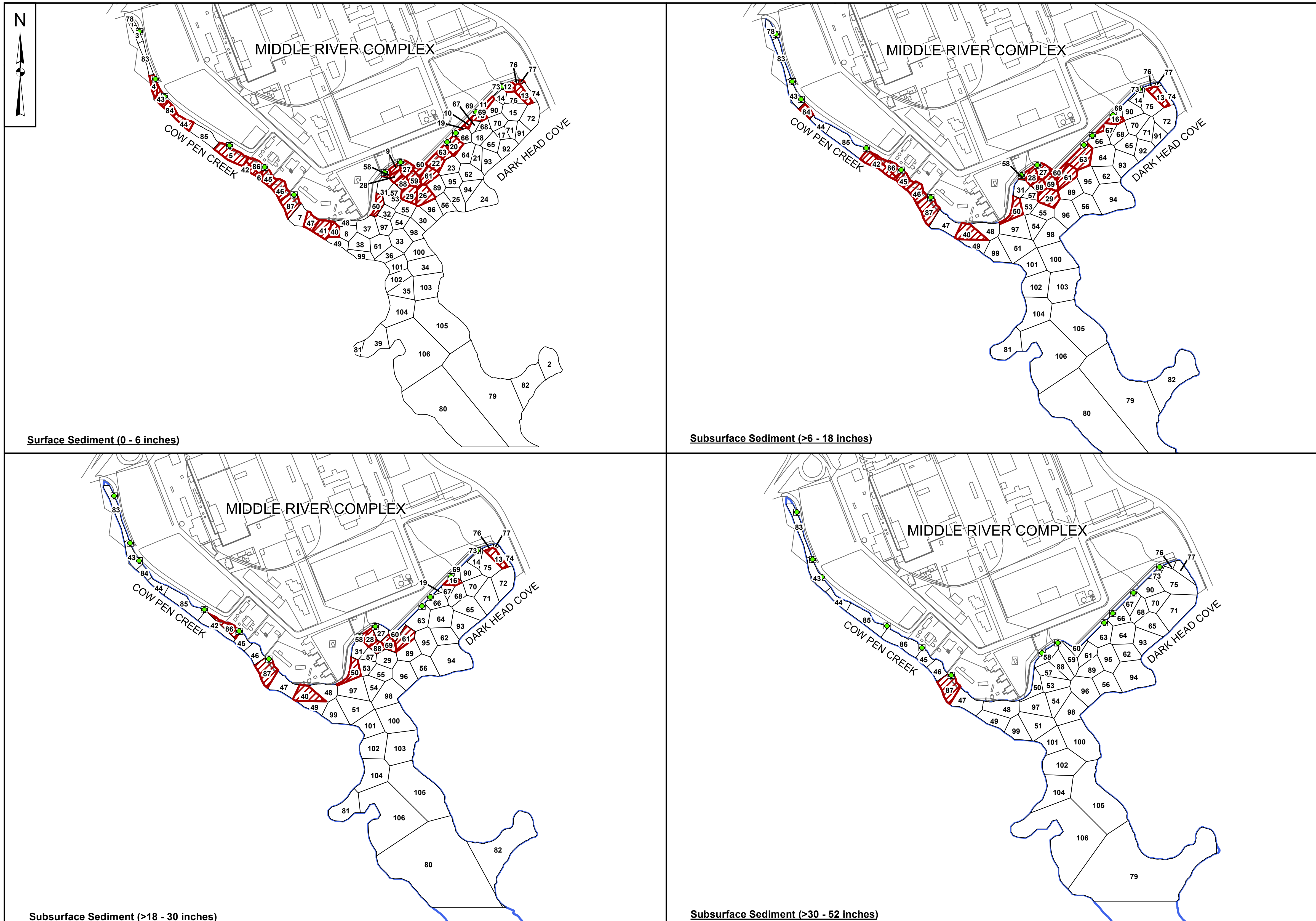

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Figure 5 - 8b
Alternative 4D
Removal Thiessen Polygons by Depth
Lockheed Martin Middle River Complex (MRC)
Middle River, Maryland

Legend

- Stormwater Outfall Locations
- No Action (Polygon < PRG/RAL)
- Removal
- Buildings/Roads
- 101 Thiessen Polygons and Sample Location Number

PRG = Preliminary Remediation Goal
RAL = Remedial Action Level

Note:
Removal volume calculations include shallower depth intervals above the deepest polygons for removal

1,080 540 0 1,080 Feet

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Approved By:

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TETRA TECH

Figure 5-9
Alternative 4E
Combined Action
Lockheed Martin Middle River Complex (MRC)
Middle River, Maryland

Legend

- Stormwater Outfall Locations
- No Action (Polygon < PRG/RAL)
- ENR
- MNR
- Thick ENR (12-18 inch)
- Conventional Capping
- Removal
- Buildings/Roads
- 101 Thiessen Polygons and Sample Location Number

PRG = Preliminary Remediation Goal
RAL = Remedial Action Level
ENR = Enhanced Natural Recovery
MNR = Monitored Natural Recovery

500 250 0 500
Feet

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Checked By: S. OZKAN 11/14/12
Approved By:

Contract Number: 112IC02903

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Figure 5-10
Alternative 4F
Combined Action
Lockheed Martin Middle River Complex (MRC)
Middle River, Maryland

Legend

- Stormwater Outfall Locations
- No Action (Polygon < PRG/RAL)
- Reactive ENR
- Removal
- Buildings/Roads
- 101 Thiessen Polygons and Sample Location Number

PRG = Preliminary Remediation Goal
RAL = Remedial Action Level
ENR = Enhanced Natural Recovery

500 250 0 500 Feet

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Checked By: S. OZKAN 11/14/12
Approved By:

Contract Number: 112IC02903

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Figure 5-11
Alternative 4G
Combined Action
Lockheed Martin Middle River Complex (MRC)
Middle River, Maryland

Legend

- Stormwater Outfall Locations
- No Action (Polygon < PRG/RAL)
- In Situ Treatment
- In Situ Treatment + MNR
- Removal
- Buildings/Roads
- 101 Thiessen Polygons and Sample Location Number

PRG = Preliminary Remediation Goal
RAL = Remedial Action Level
MNR = Monitored Natural Recovery

500 250 0 500
Feet

Drawn By: T. WHEATON 07/05/11
Checked By: S. OZKAN 11/14/12
Approved By:

Contract Number: 112IC02903

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TETRA TECH

Figure 5 - 12
Alternative 4H
Combined Action
Lockheed Martin Middle River Complex (MRC)
Middle River, Maryland

Legend

- Stormwater Outfall Locations
- No Action (Polygon < PRG/RAL)
- MNR
- Removal
- Buildings/Roads
- 101 Thiessen Polygons and Sample Location Number

PRG = Preliminary Remediation Goal
RAL = Remedial Action Level
MNR = Monitored Natural Recovery

500 250 0 500
Feet

Drawn By: T. WHEATON 05/10/11
Checked By: S. OZKAN 11/14/12
Approved By:

Contract Number: 112IC02903

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TETRA TECH

Figure 5 - 13a
Alternative 4I
Combined Action
Lockheed Martin Middle River Complex (MRC)
Middle River, Maryland

Legend

- Stormwater Outfall Locations
- No Action (Polygon < PRG/RAL)
- MNR
- Removal
- Buildings/Roads
- 101 — Thiessen Polygons and Sample Location Number

PRG = Preliminary Remediation Goal
RAL = Remedial Action Level
MNR = Monitored Natural Recovery

500 250 0 500
Feet

Drawn By: T. WHEATON 05/10/11
Checked By: S. OZKAN 11/14/12
Approved By:

Contract Number: 112IC02903

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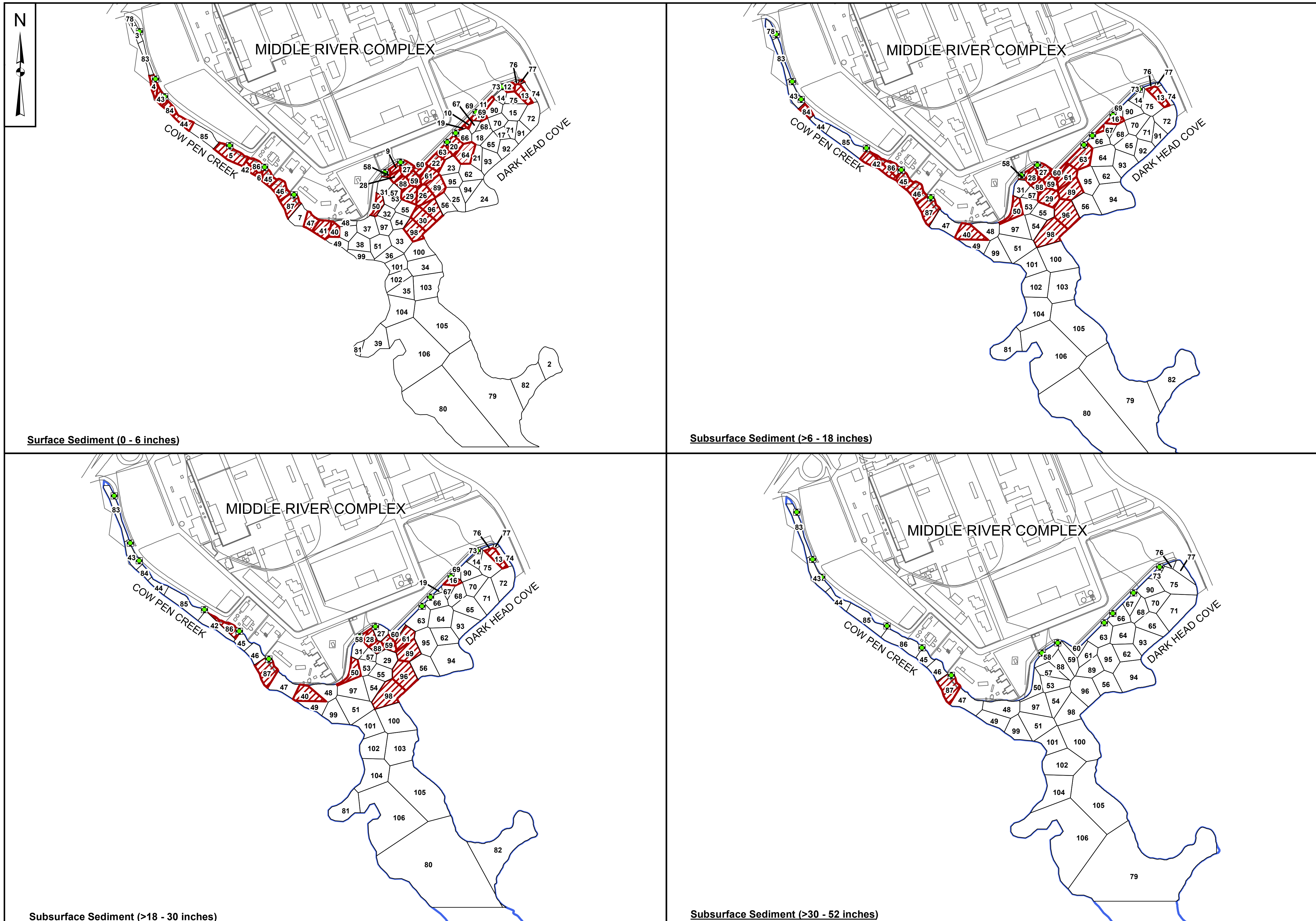

TETRA TECH

Figure 5 - 13b
Alternative 4I
Removal Thiessen Polygons by Depth
Lockheed Martin Middle River Complex (MRC)
Middle River, Maryland

Legend

- Stormwater Outfall Locations
- No Action (Polygon < PRG/RAL)
- Removal
- Buildings/Roads
- 101 — Thiessen Polygons and Sample Location Number

PRG = Preliminary Remediation Goal
RAL = Remedial Action Level

Note:
Removal volume calculations include shallower depth intervals above the deepest polygons for removal

1,080 540 0 1,080 Feet

Drawn By: T. WHEATON 05/11/11
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Contract Number: 112IC02903

TETRA TECH

Figure 5 - 14
Alternative 4J
Combined Action
Lockheed Martin Middle River Complex (MRC)
Middle River, Maryland

Legend

- Stormwater Outfall Locations
- No Action (Polygon < PRG/RAL)
- MNR
- In Situ Treatment
- Removal
- Buildings/Roads
- 101 Thiessen Polygons and Sample Location Number

PRG = Preliminary Remediation Goal
RAL = Remedial Action Level
MNR = Monitored Natural Recovery

500 250 0 500
Feet

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Contract Number: 112IC02903

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Section 6
Detailed Evaluation of Remedial Alternatives

In this section, each of the short list remedial alternatives developed in Section 5 is evaluated individually according to the standard criteria specified by the United States Environmental Protection Agency (USEPA, 1988) and the *National Contingency Plan* (NCP). A comparative evaluation of the remedial alternatives is presented in Section 7 to assess the relative performance of each alternative with respect to each evaluation criterion and action level, and to identify the key tradeoffs among them.

6.1 NATIONAL CONTINGENCY PLAN EVALUATION CRITERIA

The USEPA (1988) and the NCP (40 *Code of Federal Regulations* [CFR] Section 300.430[e][9][iii]) require consideration of nine evaluation criteria when evaluating remedial alternatives at Superfund sites. The NCP evaluation criteria are intended to provide a framework for assessing the risks, costs, and benefits of each remedial alternative. These nine evaluation criteria, categorized into three sets, form the basis for conducting detailed analyses and subsequently selecting an appropriate remedial action:

- ***Threshold criteria:*** Under the Comprehensive Environmental Resource, Compensation, and Liability Act (CERCLA), each alternative must meet the following threshold criteria to be eligible for selection as the preferred alternative:
    - overall protection of human health and the environment
    - compliance with applicable or relevant and appropriate requirement (ARARs)
- ***Primary balancing criteria:*** The five criteria listed below represent the primary criteria upon which the analysis is based:
    - long-term effectiveness and permanence
    - reduction of toxicity, mobility, and volume through treatment

- short-term effectiveness
- implementability (technical and administrative feasibility)
- cost

- ***Modifying criteria:*** The following modifying criteria are typically evaluated following the comment period for the proposed remedial action plan:
  - regulatory agency acceptance
  - community acceptance

In this feasibility study (FS), the relative performance of each alternative is assessed individually and comparatively with respect to the first seven of the nine CERCLA evaluation criteria. The two modifying criteria are typically assessed after the proposed plan has been reviewed by the Maryland Department of the Environment (MDE) and USEPA and discussed in a public meeting. During development of this FS, Lockheed Martin Corporation (Lockheed Martin) has worked directly with MDE and USEPA on the site characterization and risk assessment process, and has briefed them on draft remedial alternatives. In addition, Lockheed Martin has received input and comments from the public on the draft remedial alternatives through the community outreach process (see Section 5.7). These comments were incorporated into the detailed evaluation of the alternatives described in the sections below. They describe key ideas and concepts of the specific evaluations in this FS to determine how well an alternative addresses a particular criterion.

6.1.1 Overall Protection of Human Health and the Environment

This evaluation criterion assesses whether each alternative, as a whole, achieves and maintains adequate protection of human health and the environment. In this FS, the evaluation of each alternative is focused on whether that specific alternative achieves adequate protection, and describes how site risks posed via each identified pathway are being eliminated, reduced, or controlled through treatment or engineering and institutional controls. The evaluation also considers whether an alternative poses any regulatorily unacceptable short-term impacts (USEPA, 1988).

6.1.2 Compliance with Applicable or Relevant and Appropriate Requirements

This evaluation criterion considers whether the remedial alternative complies with the chemical-, location-, and action-specific ARARs. The federal and state ARARs applicable to the site are provided in Section 3 (Tables 3-1, 3-2 and 3-3). The screening described in this section is for those ARARs that relate to actions taken to implement the remedial alternatives. Approval and performance of the remedial alternatives will require that such actions comply with ARARs, to the extent practicable.

Maryland surface water quality criteria must be considered for for any alternative that involves discharges to surface water. Similarly, dredging and other in-water construction must meet specific standards under the Clean Water Act that apply to any construction activity in or near state waters. Resource Conservation and Recovery Act (RCRA) land disposal restrictions, the Toxic Substances Control Act (TSCA), and the Solid Waste Disposal Act are considered regarding disposal of dredged sediments. These ARARs are not discussed explicitly as part of the remedial alternative evaluation. All retained remedial alternatives are designed to comply with these ARARs, and required regulatory reviews and the remedial action work plan will ensure that the selected remedy also complies.

6.1.3 Long-Term Effectiveness and Permanence

Long-term effectiveness and permanence provide a means of evaluating, for each alternative, final site risks once the active remedial work has been completed. General analysis factors to be considered, as appropriate, follow:

- *Magnitude of residual risk remaining at the conclusion of remedial activities:* The characteristics of residuals will be considered, to the degree that they remain hazardous, taking into account their volume, toxicity, mobility, and propensity to bioaccumulate.
- *Adequacy and reliability of controls:* Containment systems and institutional controls are necessary to manage residuals. These may include an assessment of controls to determine if they are sufficient to ensure that any exposure to human and environmental receptors is within protective levels.

Evaluating the magnitude of residual risks will involve identifying the residuals remaining after completion of a given remedy (i.e., remaining sediments with chemicals of concern [COC] concentrations above cleanup goals) and the time required to meet remedial action objectives (RAOs).

Magnitude of sediment residual risks—The magnitude of residual risks was evaluated by assessing the surface and subsurface sediment contamination remaining after implementation of a specific remedy. The magnitude of surface contamination remaining under each remedial alternative was evaluated by estimating a site-wide area weighted-average concentration (SWAC) in residual contamination, determined for each sampling point from the historical sampling data. The weighted-average concentrations were calculated using the areas and contaminant concentrations associated with each polygon. Larger polygons were therefore given more weight in the calculation than smaller ploygons. For alternatives with a dredging component, the concentration of sediments underlying the removal interval at each location was used for the resulting initial residual surface sediment concentration.

For alternatives with an *in situ* treatment component, the site-wide residual COC concentrations in the *in situ* treatment areas were calculated by following the assumptions discussed in Section 5.2.5. The surface concentration of total polychlorinated biphenyls (PCBs), benzo(a)pyrene equivalents (BaPEq), and mercury were assumed to be reduced by 50%, and total metal concentrations were assumed to be reduced by 20% with the addition of activated carbon to surface sediments. If a location was in a reactive enhanced nautral recovery (ENR) area, the surface concentration at that location was reduced another 50%, to reflect the complete mixing of the thin layer (e.g., six inches) of clean material with the underlying surface sediments.

This site-wide area weighted-average residual surface concentration was used to determine if remedial activities applied in a given alternative will reach the preliminary remediation goals (PRGs) needed to acheive the (RAOs. The performance of each alternative in achieving PRGs for RAO 1 was assessed by estimating an incremental risk reduction (i.e., progress toward reaching RAO 1 PRGs from mean baseline conditions [the concentrations under the No Action alternative]). First, SWACs for each risk-driver COC were estimated for each remedial alternative. Then, the calculated SWACs were compared to the baseline (No Action alternative) SWACs. The results of this analysis are summarized in Table 6-2 and discussed in the detailed evaluation of each alternative.

Residual risk in subsurface sediment was evaluated by reviewing the contaminant mass remaining under surface sediments (i.e., below six inches) after the completion of the remedy, and estimating the potential risk of re-exposure. Potential mechanisms for re-exposing subsurface sediment include high-flow scour, propeller wash, construction activities, and seismic events. Sediment stability conditions of Cow Pen Creek and Dark Head Cove are discussed in Section 2.3.5. The subsurface contaminant mass (calculated based on sum of all risk-driver COC concentrations in the dredge volume) removed under each alternative is summarized in Table 6-1, and the potential risk of re-exposure is discussed in the detailed evaluation of each alternative.

Time to meet RAOs through monitored natural recovery—Assumptions associated with estimating the period of natural recovery necessary to meet RAOs are discussed in Section 5.2.3. The alternatives with a monitored natural recovery (MNR) component were evaluated by assuming it would take 13 years for areas in Dark Head Cove and Dark Head Creek to reach a total sediment deposition of 15 centimeters (assuming an average sedimentation rate of 0.8 centimeters per year [cm/year]); this is the amount needed to reduce concentrations of surface COC by 50%. No natural recovery is assumed for Cow Pen Creek. The results of this analysis are summarized in Tables 6-1 and 6-2, and discussed in the detailed evaluation of each alternative.

Adequacy and reliability of controls—Assessing the adequacy and reliability of controls focuses on monitoring, maintenance, and institutional controls (ICs). The No Action alternative is assumed to have none of these. The analysis focuses on the following considerations:

- likelihood that the remedial technologies will meet required process efficiencies or performance specifications
- type and degree of long-term management required
- long-term monitoring requirements
- operation, maintenance, and monitoring (OM&M) functions required
- difficulties and uncertainties associated with long-term OM&M functions
- potential need to replace technical components
- magnitude of threats or risks, should technical components need replacement
- confidence that controls can adequately handle potential problems
- uncertainties associated with land disposal of residuals and untreated wastes

For each combined-action alternative, site-wide monitoring and bathymetric surveys will be used to determine the condition of the remedy. Monitoring will be conducted at identified time intervals to assess the effectiveness of the remedy. Repairs, if needed, would be consistent with the original remedial design intent.

Other controls include ICs and source control. Current ICs on community information and education will remain part of any remedial alternative. The regional fish and shellfish consumption advisory program is administrated by MDE, and is independent of remedial activities to be performed at the site. These regional seafood consumption advisories will also remain in effect. Remediation of contaminated sediments in Dark Head Cove and Cow Pen Creek will reduce the baseline PCB SWAC from approximately 1,000 µg/kg to the regional background concentration of 195 µg/kg (i.e., RAO 1 PRG). However, the calculated risk (i.e., 3.1×10^{-5}) associated with the regional background PCB concentration also exceeds the acceptable MDE excess lifetime cancer risk of 1×10^{-5}. Site-specific bioaccumulation studies (sediment to fish) have not been conducted for the study area. However, remediation of sediments within the study area may not significantly reduce fish tissue concentrations (and thus risk), because the range of the fish (and therefore exposure) is beyond the study area. Fish at the site may not uniquely reflect site exposure in their tissue concentrations, but rather exposure from migration over much larger home ranges. The regional consumption advisories promulgated by MDE are due to the other sources of contamination. These sources will likely prevent reduction of fish tissue contamination levels to protective levels associated with unlimited fish consumption, regardless of the remedial action implemented at the Middle River Complex (MRC) site.

Potential recontamination is another important consideration related to long-term effectiveness and permanence under all remedial alternatives evaluated for the MRC site. As discussed in Section 2, remedial actions in upland areas of MRC are ongoing and expected to control any ongoing sources to the adjacent sediments. In this FS, potential sediment recontamination via in-water sources is a common uncertainty for each remedial alternative.

In addition to long-term institutional controls and the current fish consumption advisories, the alternatives with a removal component may also require short-term fish consumption advisories. Short-term impacts may occur during remedial construction when the highest sediment contaminant concentrations are being actively dredged. Releases of PCB have been monitored in pilot dredging studies and full-scale dredging projects. Monitoring data from pilot dredging projects performed in Fox River and Grasse River (and other early studies) showed that two to three percent of dredged PCBs were transported downstream of the project area (Bridges et al., 2008). Dissolved contaminants are more likely to migrate farther in the water column and, because they are more bioavailable, may cause short-term increases of PCB concentrations in fish tissue. Fish captured during other large-scale removal projects (e.g., at Lower Fox River Operable Unit 1, Hudson River, Bryant Mill Pond, and as part of the Allied Paper/Kalamazoo River/Portage Creek Superfund Site) indicate that tissue concentrations of PCB may increase during dredging, but then quickly decline thereafter (Wisconsin Department of Natural Resources [WDNR], 2011).

6.1.4 Reductions in Toxicity, Mobility, and Volume through Treatment

The degree to which site media are treated to permanently and significantly reduce the toxicity, mobility, or volume of site contaminants is assessed under this criterion. This assessment analyzes the destruction of toxic contaminants, the reduction of the total mass of toxic contaminants, the irreversible reduction in contaminant mobility, or the reduction in total volume of contaminated material that is accomplished by one or more treatment components of the remedial alternative. Site-specific technology evaluation of *in situ* treatment and reactive ENR are considered viable and effective remedial technologies for MRC sediments in Dark Head Cove and Dark Head Creek (refer to Section 5.2). Reductions in risk-driver COC bioavailability for each alternative with an *in situ* treatment component were evaluated under this criterion.

In situ treatment of MRC sediments through surface broadcasting of activated carbon pellets (or by mixing the pellets in with a thin sand layer) applied as reactive ENR was incorporated into some alternatives. As discussed in Section 4.3.8, *ex situ* treatment technologies were retained for design, but were not retained for further consideration in the MRC FS; therefore, no retained remedial alternative has an *ex situ* treatment component.

6.1.5 Short-Term Effectiveness

Short-term effectiveness is evaluated based on impacts to human health and the environment during implementation of the active remediation components of each alternative. The following factors are addressed as appropriate for each alternative:

- Protection of the community during remedial actions – This aspect of short-term effectiveness addresses any risk that results from implementation of the proposed remedial action, such as dust from excavation, transportation of dredged materials, air-quality impacts from construction equipment and truck traffic, or construction noise, that may affect human health.

- Protection of workers during remedial actions – This factor assesses potential physical hazard risks, and risks to workers from exposure to contaminants and operational hazards such as light, noise, and air emissions. It also assesses the effectiveness and reliability of protective measures that will be taken.
- Environmental impacts – This factor addresses the potential adverse environmental impacts that may result from the construction and implementation of an alternative, including habitat disturbance, consumption of natural resource materials (e.g., for capping), landfill capacity utilization, transportation mileage, particulate matter emissions, and gas emissions, and evaluates the reliability of the available mitigation measures in preventing or reducing the potential impacts.
- Time until remedial response objectives are achieved – This factor includes an estimate of the time required to achieve protection for either the entire site, or individual elements associated with specific site threats or areas.

Short-term environmental impacts of the active remedial actions were evaluated using the Naval Facilities Engineering Command (NAVFAC) *SiteWise* tool for green and sustainable remediation to calculate the environmental footprint of the remedial alternatives (NAVFAC, 2011). This method is consistent with Lockheed Martin's policy to implement green and sustainable remediation, and is consistent with the USEPA green remediation policy to enhance the environmental benefits of federal cleanup programs by promoting sustainable technologies and practices (USEPA, 2008, 2010, 2012b).

Green remediation evaluation is not a criterion for remedy selection. However, a green evaluation is presented in this FS to enhance the short-term effectiveness evaluation of each alternative.. Currently, USEPA plans to issue an Office of Solid Waste and Emergency Response (OSWER) policy on how green remediation strategies can factor into the NCP's nine evaluation criteria for remedy selection and the Superfund evaluation criteria (USEPA, 2010).

The *SiteWise* tool quantified the short-term environmental impacts (i.e., environmental footprint) of each retained remedial alternative. The potential environmental footprint of a cleanup action is associated with: (a) greenhouse gas emissions (GHG) such as carbon dioxide (CO_2) and others contributing to climate change; (b) energy use; (c) air emissions of criteria pollutants, including nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulate matter (PM_{10}); (d) water consumption; (e) resource consumption; (f) landfill space; and (g) worker safety. The *SiteWise* methodology and analysis results are in Appendix F.

The Lockheed Martin and USEPA green remediation strategy recognizes that opportunities exist to decrease the environmental footprint of cleanup activities and maximize the environmental outcome of a cleanup exist throughout the life of a project, extending from site investigation through development of cleanup alternatives and remedy design, construction, operation, and monitoring (USEPA, 2008). Consistent with the Lockheed Martin green and sustainable strategy in remediation projects and the USEPA green remediation strategy, Lockheed Martin will, to the maximum extent possible during remedial design and implementation, explore and implement sustainability measures that reduce the environmental footprint of cleanup activities developed in this FS. These sustainability measures are not discussed under the detailed evaluation of short-term environmental impacts for each alternative; however, potential measures and best management practices that can be applied during cleanup activities are briefly discussed in Appendix F.

Short-term environmental impacts also include potential elevated contamination increases in fish tissues due to resuspension of contaminated sediments and release of contamination into dissolved phase during removal. Monitoring data from dredging of PCB-contaminated sediments at other sites showed that two to three percent of the dredged PCBs were transported downstream, and into the water column, resulting in short-term increases in PCB concentrations in fish tissue (refer to Section 6.1.3). Short-term institutional controls will be needed to protect human health during, and shortly after, the construction for any alternative with a removal component, to prevent human health risks when the highest sediment contaminant concentrations are being actively dredged during remedial construction.

6.1.6 Implementability

This evaluation criterion considers the technical and administrative feasibility of implementing the remedial alternatives. The following implementability factors are considered:

- ***Technical feasibility:*** the relative ease of implementing or completing the remedial alternative, based on site-specific constraints (e.g., the constructability and operational reliability of the remedial alternative, as well as the ability to monitor the effectiveness of the remedial alternative)
- ***Administrative feasibility:*** coordination with other agencies (e.g., the steps required to coordinate with regulators, to establish long-term or future coordination among regulators, and the ease of obtaining permits for off-site activities, if required)

- ***Availability of services and materials:*** the availability of adequate treatment or storage facility capacity, handling/disposal facilities/services, and the availability of adequate equipment and specialists

6.1.7 Cost

This criterion refers to the total cost necessary to implement each remedial alternative. Total cost represents the sum of direct capital costs (e.g., materials, equipment, labor), indirect capital costs (e.g., engineering, management, contingency allowances), and annual and periodic costs (e.g., operation and maintenance [O&M] costs, monitoring, ongoing administration). These total costs, developed to allow comparison of the remedial alternatives, are estimated with expected accuracies of -30 to +50%, in accordance with USEPA (1988) guidance.

The cost estimates developed in this FS are expressed in current (2012) dollars, and the costs of remedial alternatives are compared using the estimated present value of the alternative based on the discount factor of seven percent. The net present value method allows costs for remedial alternatives to be compared by discounting all costs according to the year that the alternative is implemented. The USEPA suggests that the period of analysis for the present value analysis be set equivalent to the expected duration of a project to provide a complete life-cycle cost estimate of the remedial alternative (USEPA, 2000).

Most of the combined remedial alternatives developed for the MRC site require long-term activities, and are calculated using discount factors consistent with USEPA estimation guidance. The discount factor is assumed to be seven percent for institutional controls and long-term operation and maintenance costs. The FS cost estimates of all alternatives were calculated for a 10 to 50 year duration, based on the expected effectiveness of each alternative (i.e., the time required to meet project RAOs at areas where MNR is implemented). Indirect costs, including bid and scope contingency, project management, remedial design, and construction management/field activity oversight, were added to capital costs as percentages of the total cost. These percentages are based on the uncertainty, total cost, and/or complexity of the project. Detailed FS cost estimates and the cost estimate assumptions used for each alternative are provided in Appendix E.

6.1.8 Modifying Criteria

Modifying criteria are regulator and community acceptance, which may modify aspects of the preferred alternative. Modifying criteria are typically evaluated after the proposed plan has been submitted to the regulators and released for public review, and following analysis of public comment on the proposed plan. During development of this FS, Lockheed Martin has worked directly with MDE and USEPA on the site characterization and risk assessment process, and has briefed both agencies on draft remedial alternatives. In addition, during development of this FS, community comments were elicited and received through Lockheed Martin's community outreach process. These comments are summarized in Section 5.7, and the complete community input matrix is provided in Appendix D. Detailed evaluation of the retained alternatives includes an assessment of community acceptance regarding the remedial actions. Agency acceptance of remedial alternatives is unknown at this time, and is therefore not discussed in the detailed evaluation of alternatives that follow.

6.2 DETAILED ANALYSIS OF ALTERNATIVE 1: NO ACTION

The No Action alternative reflects baseline site conditions. Alternative 1 does not include any active remediation, monitoring, or institutional controls, and contaminated sediments would be left in place.

6.2.1 Threshold Criteria

The No Action alternative would not protect human health and the environment. RAOs would not be achieved in a reasonable period, the threshold criterion of achieving RAOs, one of which is to reduce ecological and human health risks associated with sediment contamination within the site to regulatorily acceptable levels, will not be met. Recent risk assessments show regulatorily unacceptable risks to human health and the environment (Tetra Tech, 2011c) under current site conditions.

All current risks would remain unabated under the No Action alternative. Natural recovery through degradation and other fate-and-transport processes will likely continue to reduce the COC concentrations. Under the No Action alternative, it will take approximately 30 years to achieve human health seafood consumption RAO 1, and up to 100 years to achieve benthic RAO 3, through natural recovery. However, changes in overall risk from the site are difficult to assess because under this alternative no monitoring would be performed.

6.2.2 Primary Balancing Criteria

The magnitude of residual risks remains the same because this alternative includes no remedial actions. Any future changes will occur only through natural processes. Untreated contamination in sediment will continue to pose risks to human health and the environment. The No Action alternative is the lowest-cost alternative, but it provides limited adequacy and reliability in terms of long-term risk controls, source control, and reduction of exposure pathways. The alternative is easy to implement because no action is being taken, and would have no associated costs.

6.3 DETAILED ANALYSIS OF ALTERNATIVE 3: COMPLETE REMOVAL

Alternative 3 involves removing sediments within the MRC site in areas of potential concern (AOPC) where risk-driver COC exceed PRGs, disposing the removed sediments off-site. This removal alternative includes two subalternatives (3A and 3B), that actively remediate approximately 28 or 23 acres of the AOPC, respectively (Figures 5-3 and 5-4).

6.3.1 Overall Protection of Human Health and the Environment

Removal alternatives meet RAOs immediately following construction. Alternative 3A, addressing COC to a depth of 52 inches, will remove about 99 metric tons of contaminant mass, while Alternative 3B will remove about 72.2 metric tons of contaminant mass from the MRC study area. The estimated construction period for the removal alternatives is two to four years. The remedial action area, removal volume, construction time, costs, and total contaminated mass removal for each alternative is provided in Table 6–1.

Increased risks to workers and the community from the general physical hazards of construction, noise, particulate emissions, and elevated contaminant concentrations in fish and shellfish tissue can potentially occur with increased removal quantities and increased time for removal activities. Protection of workers and the community from physical injury is manageable with appropriate planning and standard construction practices. In addition to the current regional fish consumption advisories issued by MDE, institutional controls will likely be required to protect consumers of resident seafood during construction.

Removal alternatives will not leave any subsurface sediment with contaminant concentrations above PRGs; therefore, re-exposure potential following active remediation is expected to be negligible.

Long-term monitoring will not be required because all subsurface contamination is removed, and the post-remedy residual surface concentrations meet all RAO PRGs. Regional institutional controls via informational devices such as education, public outreach, and seafood consumption advisories issued by MDE will remain. Removal alternatives may also require short-term fish consumption advisories, because short-term impacts may occur when the highest sediment contaminant concentrations are being actively dredged. Removal alternatives are further evaluated for their overall protectiveness of human health and the environment via the long-term effectiveness and permanence criteria and short-term effectiveness criteria provided below.

6.3.2 Compliance with ARARs

Alternative 3 would comply with the ARARs and to be considered (TBC) criteria provided in Tables 3-1 to 3-3 through adequate engineering design and the agency review process that ensures the remedy complies with these ARARs. Compliance decisions would be made and prepared during design, based on details in the remedial design and remedial action work plan and associated sections (e.g., environmental protection plan, construction quality control plan, waste management plan, transportation and disposal plan, storm water pollution and spill prevention plan, best management practices).

6.3.3 Long-Term Effectiveness and Permanence

General analysis factors considered in the detailed evaluation of alternatives for their respective long-term effectiveness and permanence are the magnitude of residual risks, time to meet RAOs, and the adequacy and reliability of controls. Removal alternatives satisfy ecological and human health RAOs because receptor exposure to contaminated sediments is prevented. Alternatives 3A and 3B meet RAOs at the end of construction, and leave no surface or subsurface contamination greater than PRGs. About 72.2 to 99 metric tons of COC mass (calculated by summing all risk-driver COC concentrations in the dredge volume) will be removed by dredging 99,500 to 143,100 cubic yards of sediment, under Alternatives 3A and 3B. No long-term monitoring and maintenance requirements are needed for complete-removal alternatives.

Alternative 3A has the largest dredge area (28 acres), and thus requires a proportionately larger effort to manage dredging residuals. Alternative 3A also has the largest dredge volume (143,100 cubic yards), and requires more material handling, dredge water management, transporting, and upland disposal, compared to Alternative 3B, which involves dredging approximately 23 acres and removing 99,500 cubic yards of sediment. The construction duration of Alternative 3A is estimated at two to four construction years; time to construct Alternative 3B is estimated at two to three years.

Post-removal-action confirmation sampling and analysis will be conducted after construction to directly measure residual conditions. Corrective actions will be taken if dredged areas fail to meet performance requirements. Current ICs associated with regional seafood consumption advisories, public outreach, and education will remain.

6.3.4 Reduction in Toxicity, Mobility, or Volume through Treatment

No reduction of toxicity, mobility, or volume will be achieved through treatment under the removal alternatives, because no treatment is implemented.

6.3.5 Short-Term Effectiveness

Alternative 3 risks to workers and the community from the general physical hazards of construction, noise, particulate emissions, and elevated contaminant concentrations in fish and shellfish tissue are the highest compared to other alternatives, and risks increase with increased removal quantities. Elevated COC concentrations in fish tissue often occur in large dredging projects during dredging, followed by a decline shortly after remediation is completed, typically within a year or less (WDNR, 2011). Local transportation impacts (e.g., traffic and noise) from implementing these alternatives is proportional to the estimated number of truck miles needed to support material hauling operations, and increases with proposed dredged volume increases: Alternative 3A – 9,550 truck trips, at 2,400,000 miles; Alternative 3B – 6,640 truck trips, at 1,660,000 miles; see Table 6-3).

Short-term environmental impacts for active remedial actions were estimated using the Naval Facilities Engineering Command *SiteWise* tool that assesses the environmental footprint of cleanup activities (NAVFAC, 2011). That analysis is included in Appendix F, and the results are summarized in Table 6-3.

Air emissions of criteria pollutants (including nitrogen oxides [NO_x], sulfur oxides [SO_x], and particulate matter [PM_{10}]) generated from all combustion activities (e.g., dredging, residual management backfill, dredge material handling, transportation, and disposal) under Alternatives 3A and 3B are estimated at 76 metric tons and 53 metric tons, respectively. The volume of greenhouse gas generated from all combustion activity is estimated to range from 7,000 (Alternative 3B) to 10,000 (Alternative 3A) metric tons. As recommended by the USEPA green remediation policy (USEPA, 2012b), possible sustainable best-management practices that can be applied to minimize the carbon footprint for construction for all remedial alternatives were also identified (see Appendix F).

6.3.6 Implementability

Technologies associated with the handling, transportation, and off-site disposal of dredged sediment are all considered technically feasible and proven technologies that have been implemented nationwide. Incidental technologies, such as dewatering, and the treatment and discharge of treated decant water, are also considered technically feasible and proven technologies. Section 5.2 describes implementation of common remedy elements associated with removal, such as residuals management, dewatering, dredge water management, transloading, and upland disposal.

Considerations used to evaluate dewatering methods include the volume of water generated by the removal technology and upland or barge staging-area space limitations. Both mechanical and hydraulic dredging are removal technologies that can be implemented for MRC sediments. Dewatering/transloading areas will be designed to accommodate the volume of sediments to be removed during each construction season (Alternative 3A: two to four construction years; Alternative 3B: two to three construction years). If mechanical dredging is used, stockpiling the dredged sediments for dewatering and processing will require an upland area of approximately 2.5 acres for Alternative 3B and 3.5 acres for Alternative 3A. If sediments are hydraulically dredged, additional upland area will be needed to place geotextile tubes (Table 6-3).

Construction of an upland dewatering/transloading area at MRC sufficient to accommodate dredged sediments per construction year is implementable for either hydraulic or mechanical dredging. Water generated at the dewatering pad willl go through a water treatment process that may include pumping through bag filters, sand filters, and carbon adsorbers before being discharged back to surface water. A temporary water treatment system will be installed near the dewatering pad for dredge water management. Water generated during dredging and through dewatering including any excess polymers or other additives if used during dewatering process may need to be treated before it is allowed to be discharged, based on water quality compliance criteria. Water management is a necessary part of dredged-material transloading operations.

If both the Dark Head Cove and Cow Pen Creek contaminated sediments are removed by mechanical dredging, the volume of water generated under Alternatives 3A and 3B is estimated to be 8.7 million gallons and 6.0 million gallons, respectively. If hydraulic dredging is used to remove the sediments from Dark Head Cove, the volume of dredged water to be treated may be as much as 220 million gallons for Alternative 3A and 140 million gallons for Alternative 3B (Table 6-3). A water treatment facility will be designed and constructed to handle the estimated volume of dredged water generated each construction year.

Environmental considerations such as fish windows (construction season limited to October 15 to February 15), climate, weather, hydraulic conditions, and hydrologic conditions can be incorporated into the dredging design and implementation schedule. Dredging success can be verified through multiple methods, including real-time surveys, bathymetric surveys, and sediment sampling. Construction quality assurance/quality control and monitoring are designed to verify dredging performance.

With respect to administrative feasibility, dredging will require compliance with Sections 404 and 401 of the Clean Water Act and the Endangered Species Act. All generator requirements related to off-site transport and disposal of dredged material will be met. Resources for the removal technology are available from multiple vendors and procurable through competitive bidding.

6.3.7 Costs

The estimated total cost to implement Alternatives 3A and 3B is $41.7 and $30.2 million, respectively; costs rise as the dredged area and volume increase. Cost information is summarized in Table 6-1. Detailed cost estimates are provided in Appendix E.

6.3.8 Modifying Criteria

Modifying criteria will be evaluated after the proposed plan has been submitted to and reviewed by the regulators and released for public review. Analysis of any additional public comments on the proposed plan will be considered at that time. Regulator acceptance of Alternatives 3A or 3B is unknown at this time, but community comments were received through Lockheed Martin’s community outreach process during development of this FS (see Section 5.7). Working group members expressed concern over the excessive cost of the remedy compared to its benefits for complete removal alternatives, even though a total cleanup is considered ideal. Other concerns include the long construction period and short-term disruption to the community. Appendix D contains information related to community outreach.

6.4 DETAILED ANALYSIS OF ALTERNATIVE 4: COMBINED ACTION

The combined-action alternatives include various combinations of removal, ENR, reactive ENR, *in situ* treatment, and MNR technologies. Five subalternatives, Alternatives 4F, 4G, 4H, 4I and 4J, are carried forward for detailed evaluation (Figures 5-10 to 5-14). Application of the various technologies for each of the subalternatives is summarized in Table 6-1 and illustrated in Figure 6-1.

6.4.1 Overall Protection of Human Health and the Environment

All retained combined-action alternatives meet RAOs, but vary in the time to reach RAOs following the completion of each remedy. The performance of each alternative in meeting RAOs is summarized in Table 6-2, and discussed in Section 6.4.3 in the long-term effectiveness and permanence evaluation. Alternative 4F will meet RAOs immediately following construction. Under Alternative 4G, site-wide RAO 1 PRGs will be met within the first year after the end of the construction (estimated at 0.3 years), but meeting point-based benthic RAO 3 may take up to 13 years. Alternative 4H would achieve 83% progress towards reaching RAO 1 PRG for PCBs (from mean baseline conditions) at the end of construction; meeting point-based RAO 3 may take up to 26 years. Alternatives 4I and 4J will meet site-wide RAO 1 PRGs at the end of construction, but in areas that undergo MNR, it could take as much as 12 and three years, respectively, to meet point-based RAO 3.

A construction duration of one to two years is estimated for the combined-action alternatives. Risks to workers and the community from the general physical hazards of construction, noise, particulate emissions, and contaminant concentrations in fish and shellfish tissue will all increase with increased removal quantities. Protection of workers and the community from physical injury is manageable with appropriate planning and standard construction practices. In addition to the current regional consumption advisories issued by MDE, short-term institutional controls will likely be required to protect consumers of resident seafood during construction.

Alternatives 4F, 4G, 4I, and 4J meet RAOs associated with human health risks related to fish consumption and direct contact with sediments (i.e., RAOs 1 and 2) at the end, or within the first year, of construction (Table 6-2). Therefore, the re-exposure risk for these alternatives is expected to be negligible, due to the lack of potential exposure mechanisms. Long-term monitoring (to reduce risks to benthic invertebrates) will be required at areas not meeting point-based RAO 3 at the end of construction. Any re-exposure will affect the performance of the remedy in meeting RAO 3 by causing localized short-term disruption to the benthic community in the affected zone.

Alternative 4H will meet the site-wide PCB PRG for human health risks related to fish consumption (RAO 1) within approximately 10 years after the end of construction. Exposure risk that could affect RAOs 1 and 2 following active remediation of Alternative 4H is also considered negligible for Alternative 4H, due to the lack of potential exposure mechanisms. Similar to the other variants of Alternative 4, performance of this remedy in meeting RAO 3 will be affected if re-exposure occurs because of elevated COC concentrations in deeper sediments. A delay in meeting the PCB PRG for RAO 1 is expected to be negligible beyond the estimated time of 10 years needed to meet RAO 1, because localized elevated COC concentrations would have a minor effect on the SWAC. Long-term monitoring of the MNR area will verify any re-exposure and the overall performance effectiveness of the remedy. Post-remedy residual surface contaminant-concentrations will verify the effectiveness of the remedy at the end of the construction.

All combined alternatives will leave subsurface COC concentrations greater than PRGs at depths of six to 30 inches in Dark Head Cove. Potential exposure to this contamination is considered negligible, because sediment disturbance mechanisms (such as high-flow scour, seismic events, and propeller scour) at this location rarely occur. Any exposure to subsurface contamination will therefore be localized, and may cause short-term disruption to the benthic community in the affected zone, but will not pose any risk to human health through fish consumption or direct contact with sediments. These areas will be monitored under the long-term OM&M program, and contingency actions will be taken if necessary. The removal portion of the alternatives may also require short-term fish consumption advisories during remedial construction when sediments with the highest contaminant concentrations are actively dredged. Current institutional controls of informational devices such as education, public outreach, and regional seafood consumption advisories issued by MDE will remain.

6.4.2 Compliance with ARARs

All combined alternatives will comply with the federal and state chemical- and location-specific ARARs and TBCs provided in Table 3-1 to 3-3. Adequate engineering planning, design, and agency review will ensure that the remedy complies with ARARs.

6.4.3 Long-Term Effectiveness and Permanence

The detailed evaluation of alternatives, in terms of long-term effectiveness and permanence, includes an assessment of the magnitude of residual risks, the time to meet RAOs, and the adequacy and reliability of controls. Performance of each alternative in terms of meeting RAOs (i.e., magnitude of surface sediment residual risk) at the end of the construction, time to meet RAOs, and contaminant mass removed, are summarized in Tables 6-1 and 6-2. Alternative 4F will meet RAOs 1, 2, and 3 immediately following construction by removing about 48,800 cubic yards of sediment, containing 40.1 metric tons of contaminant mass over 12.5 acres, and applying reactive ENR over 8.5 acres.

Alternative 4G involves the same amount of sediment removal as Alternative 4F, but *in situ* treatment will be applied over 8.5 acres, instead of using reactive ENR. Site-wide PRGs for RAOs 1 and 2 will be met at the end or shortly after the end of the construction, based on the assumptions made regarding the effectiveness of *in situ* treatment. However, meeting the point-based benthic RAO 3 over approximately 3.5 acres may take up to 13 years.

Alternative 4H has the same removal footprint as Alternatives 4F and 4G, but the rest of the AOPC will not receive any active remedial actions, but will be monitored for natural recovery. At the end of construction, an estimated 83% progress towards reaching RAO 1 PRG for PCBs on a site-wide basis will be achieved compared to mean baseline conditions. Estimates of the rate of natural recovery suggest that meeting the point-based RAO 3 over approximately nine acres of the AOPC may take up to 26 years.

Alternatives 4I and 4J expand the removal volume to about 63,000 cubic yards over 16 acres, with 49.3 metric tons of contaminant mass removed. The rest of the AOPC will be remediated by MNR or *in situ* treatment. Site-wide RAOs 1 and 2 will be met at the end of construction, and MNR to meet the point-based RAO 3 may take up to 12 years for Alternative 4I, and up to three years for Alternative 4J at certain locations.

All combined alternatives will leave subsurface contamination after the remedy completion. Most subsurface COC concentrations exceeding PRGs are between six and 30 inches below the sediment surface, in areas of Dark Head Cove where dredging will not be implemented. Hydrodynamic analysis and a seismic stability assessment of the Dark Head Cove sediments do not indicate any potential re-exposure risks.

Other potential re-exposure mechanisms include propeller wash and some construction activities.. Any re-exposure due to these activities will be localized, and may cause short-term disruption to the benthic community in the affected zone. If this occurs, such re-exposure may adversely affect the ability to meet point-based PRGs associated with RAO 3. These localized exposures will not affect site-wide PRGs for meeting RAO 1. The areas remediated by reactive ENR, *in situ* treatment, and MNR will be monitored to assess occurrence of any subsurface residual re-exposure. Post-removal-action confirmation sampling and analysis will be conducted after construction to directly measure residual conditions. Corrective actions will be taken if dredged areas fail to meet performance requirements.

In situ treatment and natural recovery are considered viable and effective remedial technologies for Dark Head Cove due to its stable sediment environment. Long-term monitoring is needed to verify performance of the remedy at areas remediated by *in situ* treatment and MNR. The operations, maintenance, and monitoring plan (OMMP) developed during design of this remedy will outline the sampling program, performance standards, and associated contingency actions, if needed, based on these monitoring data. Current ICs (regional seafood consumption advisories issued by MDE, public outreach, and education) will remain.

6.4.4 Reduction in Toxicity, Mobility, or Volume

Reduction in COC bioavailability through application of a thin reactive ENR layer or *in situ* treatment is incorporated in Alternatives 4F, 4G, and 4J. Under Alternative 4F, the reactive material (i.e., activated carbon) is mixed with sand and applied over 8.5 acres in a thin reactive ENR layer. This layer reduces contaminant migration by binding contaminants through adsorptive processes. Similarly, *in situ* treatment application under Alternatives 4G (over 8.5 acres) and 4J (over 1.9 acres) reduces the bioavailability of contaminants by applying activated carbon directly to surface sediments.

A conservative assumption based on recent research and pilot studies suggest that *in situ* treatment can effectively reduce total PCBs, BaPEq, and mercury by 50%, and total metal concentrations by 20% (Section 5.2.4). During design, an MRC-sediment treatability study will be conducted to test if the site-specific sediments are amenable to bioavailability reduction. The effectiveness assumptions made in this FS may need to be adjusted based on the treatability study results. The *in situ* treatment is considered irreversible. Long-term monitoring will gauge the effectiveness of the remedy. Institutional controls are required to prevent disturbance of *in situ* treatment areas and the underlying contaminated sediments.

6.4.5 Short-Term Effectiveness

Short-term environmental impacts from the active remedial actions were estimated using the Naval Facilities Engineering Command *SiteWise* tool for assessing the environmental footprint of cleanups (Table 6-3 and Appendix F). As discussed in Section 6.3.5, the general physical hazards of construction, noise, and air emissions associated with construction pose risks to workers and the community. Local transportation impacts will be proportional to the number of truck miles estimated to transport dredged material (Alternatives 4F, 4G, 4H=3,300 truck trips and 815,000 miles; Alternatives 4I, 4J=4,200 truck trips and 1,050,000 miles). Air pollution emissions from all combustion activities correlate to the remedial action construction activities (Alternative 4F=27 metric tons; Alternatives 4G and 4H=26 metric tons; Alternatives 4I and 4J=34 metric tons). Greenhouse gas from all combustion activity is estimated between 3,450 (Alternatives 4G, 4H) and 4,500 metric tons (Alternatives 4I, 4J). Possible sustainable best-management practices that can be applied all the remedial alternatives to minimize the carbon footprint during construction are provided in Appendix F, and will be considered during design.

6.4.6 Implementability

Technologies associated with the handling, transportation, and off-site disposal of dredged sediment, and the application of reactive ENR, are all considered technically feasible and proven technologies. Surface broadcasting of activated carbon for *in situ* treatment of contaminated sediments has been conducted in pilot-scale projects, typically on approximately 2-acre plots. The same technology would be applied over 8.5 acres under Alternative 4G, and over 1.9 acres for Alternative 4J. Technologies incidental to the removal action, such as dewatering and the treatment and discharge of treated decant water, are also considered technically feasible, proven technologies.

Section 6.3.6 contains information regarding the technical implementability of ancillary technologies, environmental considerations, and administrative feasibility aspects of dredging. As part of ancillary removal technologies, a dewatering/transloading area will be designed to accommodate the volume of sediments to be removed during each construction season. Combined-action alternatives are expected to be completed in one to two construction years.

If mechanical dredging is used, combined-action alternatives will require an upland area of approximately one acre for Alternatives 4F, 4G, 4H, and an upland area of 1.5 acres for Alternatives 4I and 4J, to stockpile dredged sediments for dewatering and handling. Additional upland area will be needed to place geotextile tubes if sediments are hydraulically dredged. Construction of an upland dewatering/transloading area at the MRC sufficient to accommodate dredged sediments is implementable. Decant water from the dewatering pad will likely go through water treatment, which will include being pumped through bag filters, sand filters, and carbon adsorbers before being discharged back to surface water. A temporary water treatment system will be installed near the dewatering pad to manage dredge water.

Compliance with water quality criteria may necessitate treatment of water from dredging and dewatering before it can be discharged. As shown in Table 6-3, if contaminated sediments from both Dark Head Cove and Cow Pen Creek are removed by mechanical dredging, the volume of dredged water is estimated at approximately three million gallons (Alternatives 4F, 4G, 4H) to 3.8 million gallons (Alternatives 4I, 4J). If hydraulic dredging is used to remove sediments from Dark Head Cove, the volume of dredged water to be treated would reach 46 million gallons for Alternatives 4F, 4G, 4H, and 71 million gallons for Alternatives 4I and 4J. This volume of dredged water will require the design of a water treatment facility.

The administrative feasibility of Alternative 4F is low because Dark Head Cove is part of the Middle River navigation channel. The United States Army Corps of Engineers (USACE) would not likely allow placement of any material that would reduce the navigation depth. Resources for dredging, reactive ENR, and *in situ* treatment technologies are available from multiple vendors and procurable through competitive bidding.

6.4.7 Costs

The estimated range of total costs to implement Alternative 4F through Alternative 4J is from $18.1 to $22.1 million (Table 6-1). Detailed cost estimates are included in Appendix E.

6.4.8 Modifying Criteria

As discussed in Section 6.3.8, regulator acceptance of any combined action under Alternative 4 is unknown at this time, but community comments have been received during development of this FS through Lockheed Martin's community outreach process. Combined-action alternatives with partial removal, *in situ* treatment, and MNR received supportive comments from the public due to their lower cost and construction time, and because disruption to the environment and the community for these alternatives would be minimal compared to the complete-removal alternatives. The community noted their concerns regarding the length of recovery associated with MNR in certain areas (i.e., Alternative 4H), the introduction of activated carbon into the water, and the effectiveness of activated carbon treatment. The public comments matrix is provided in Appendix D.

Table 6-1
Remedial Alternatives – Scope, Cost, and Contaminant Mass Removal Summary

		Remedial Alternative							
		1 No Action	3A Removal at CPC, DHC, Dark Head	3B Removal at CPC, DHC	4F Partial Removal, Reactive	4G Partial Removal, *In situ* Treatment,	4H Partial Removal, MNR	4I Partial+ Removal, MNR	4J Partial+ Removal, *In situ* Treatment,
Technology Application Summary									
Actively Remediated Area (Acre)[1/]	Dredge	0	28.0	23.2	12.5	12.5	12.5	16.0	16.0
	MNR	0	0.0	0.0	0.0	3.7	8.5	5.1	3.2
	In situ Treatment	0	0.0	0.0	0.0	8.5	0.0	0.0	1.9
	Reactive ENR	0	0.0	0.0	8.5	0.0	0.0	0.0	0.0
Total Actively Remediated Area[2/]		0	28.0	23.2	21.0	21.0	21.0	21.0	21.0
Dredge Volume (1,000 cy)[3/]		0	143.1	99.5	48.8	48.8	48.8	62.9	62.9
Construction Time (years)[4/]		0	2 to 4	2 to 3	1 to 2	1 to 2	1 to 2	1 to 2	1 to 2
Cost Summary									
Cost (MM$)[5/]	Capital	0	41.7	30.2	20.5	18.4	17.2	21.1	21.5
	ICs, OM&M	0	0.0	0.0	1.0	1.0	0.9	0.6	0.6
	Total Cost	0	41.7	30.2	21.5	19.4	18.1	21.7	22.1
Contaminant Mass Removed (metric ton)[6/]									
COCs	Total PCBs	0	0.088	0.082	0.060	0.060	0.060	0.077	0.077
	BaP Equivalents	0	0.143	0.128	0.096	0.096	0.096	0.108	0.108
	Arsenic	0	1.045	0.699	0.266	0.266	0.266	0.387	0.387
	Lead	0	28.58	22.40	14.10	14.10	14.10	16.24	16.24
	Cadmium	0	3.715	3.049	2.158	2.158	2.158	2.384	2.384
	Copper	0	12.421	8.245	3.565	3.565	3.565	4.948	4.948
	Mercury	0	0.120	0.086	0.033	0.033	0.033	0.050	0.050
	Zinc	0	52.83	37.48	19.86	19.86	19.86	25.12	25.12
	Total	0.0	99.0	72.2	40.1	40.1	40.1	49.3	49.3

Notes:

1/ Actively remediated area is approximate but consitent between the alternatives because the size of the sampling polygon varies by depth.

2/ Remediated area of Alt 3A address AOPC to any depth; Alt. 4s address AOPC to meet RAOs; Alt. 3B adds 2.2. acre in Dark Head Creek confluence to Alt. 4s footprint.

3/ The performance dredge volume is the neat dredge volume increased by 50%.

4/ One construction year is assumed as 180 days. See Appendix F for construction duration estimates.

5/ See Appendix E for detailed cost estimates.

6/ Based on removal volume and COC concentrations by depth.

CPC=Cow Pen Creek; DHC=Dark Head Cove; MNR=Monitored natural recovery; ENR=Enhanced natural recovery; cy = cubic yard; ICs=Institutional controls; MM=Millions; OM&M=Operation, maintenance, monitoring; COC=Contaminant of concern; PCB=Polychlorinated biphenyl; BaP=Benzo(a)pyrene; RAO=remedial action opbjective; AOPC=Area of potential concern.

Table 6-2
Remedial Alternatives - Residual Site-Wide Area Weighted-Average Concentrations and Predicted Outcomes

			RAOs				
			RAO 1: Human Health – Seafood Consumption		**RAO 2: Human Health – Direct Contact**	**RAO 3: Ecological Health – Benthic**	
PRGs			SWAC: **Total PCBs:** 195 ug/kg (Nat. Bkd.) **BaP Equivalents:** 700 ug/kg (Nat. Bkd.) **Arsenic:** 18.3 mg/kg (Nat. Bkd.)		SWAC: **Total PCBs:** 1000 ug/kg **BaP Equivalents:** 700 ug/kg (Nat. Bkd.) **Arsenic:** 18.3 mg/kg (Nat. Bkd.)	Point Base: **Total PCBs:** 676 ug/kg **Lead:** 190 mg/kg (Nat. Bkd.) **Cadmium:** 9.96 mg/kg **Copper:** 298 mg/kg **Mercury:** 1.06 mg/kg **Zinc:** 459 mg/kg	
Remedial Alternative	**Residual Site-Wide Area Weighted-Average Concentration**		**Predicted Outcomes - Reaching RAO PRGs (%)**				
			RAO 1: Human Health – Seafood Consumption [1/]		**RAO 2: Human Health – Direct Contact [1/]**	**RAO 3: Ecological Health – Benthic [2/]**	
	Risk Driver	**Mean**	Percentage Progress to Achieve Site-Wide PRGs	Number of Years to Reach Site-Wide PRGs		Percent Area Meeting RAO 3 PRGs	Number of Years to Reach PRGs by MNR
1 No Action (Baseline)	**Total PCBs (ug/kg):**	945	0%	30	100%	71%	1 to 80
	BaP Equivalents (ug/kg):	763	0%	2	91%	not a COC	-
	Arsenic (mg/kg):	7.8	100%	0	100%	not a COC	-
	Lead (mg/kg):	264	not a COC	-	not a COC	93%	1 to 100
	Cadmium (mg/kg):	9.00	not a COC	-	not a COC	82%	1 to 65
	Copper (mg/kg)	91	not a COC	-	not a COC	0%	0
	Mercury (mg/kg)	0.38	not a COC	-	not a COC	98%	1 to 20
	Zinc (mg/kg):	283	not a COC	-	not a COC	93%	1 to 6
3A Removal at CPC, DHC and Dark Head Creek	**Total PCBs (ug/kg):**	116	100%	0	100%	100%	0
	BaP Equivalents (ug/kg):	327	100%	0	100%	not a COC	-
	Arsenic (mg/kg):	4.9	100%	0	100%	not a COC	-
	Lead (mg/kg):	44	not a COC	-	not a COC	100%	0
	Cadmium (mg/kg):	3.27	not a COC	-	not a COC	100%	0
	Copper (mg/kg)	45	not a COC	-	not a COC	100%	0
	Mercury (mg/kg)	0.16	not a COC	-	not a COC	100%	0
	Zinc (mg/kg):	92	not a COC	-	not a COC	100%	0
3B Removal at CPC and DHC	**Total PCBs (ug/kg):**	125	100%	0	100%	100%	0
	BaP Equivalents (ug/kg):	393	100%	0	100%	not a COC	-
	Arsenic (mg/kg):	5.5	100%	0	100%	not a COC	-
	Lead (mg/kg):	50	not a COC	-	not a COC	100%	0
	Cadmium (mg/kg):	5.14	not a COC	-	not a COC	100%	0
	Copper (mg/kg)	51	not a COC	-	not a COC	100%	0
	Mercury (mg/kg)	0.18	not a COC	-	not a COC	100%	0
	Zinc (mg/kg):	114	not a COC	-	not a COC	100%	0
4F Partial Removal, Reactive ENR	**Total PCBs (ug/kg):**	140	100%	0	100%	100%	0
	BaP Equivalents (ug/kg):	177	100%	0	100%	not a COC	-
	Arsenic (mg/kg):	5.7	100%	0	100%	not a COC	-
	Lead (mg/kg):	54	not a COC	-	not a COC	100%	0
	Cadmium (mg/kg):	2.70	not a COC	-	not a COC	100%	0
	Copper (mg/kg)	57	not a COC	-	not a COC	100%	0
	Mercury (mg/kg)	0.19	not a COC	-	not a COC	100%	0
	Zinc (mg/kg):	145	not a COC	-	not a COC	100%	0

			RAOs				
			RAO 1: Human Health – Seafood Consumption		RAO 2: Human Health – Direct Contact	RAO 3: Ecological Health – Benthic	
PRGs			SWAC: **Total PCBs:** 195 ug/kg (Nat. Bkd.) **BaP Equivalents:** 700 ug/kg (Nat. Bkd.) **Arsenic:** 18.3 mg/kg (Nat. Bkd.)		SWAC: **Total PCBs:** 1000 ug/kg **BaP Equivalents:** 700 ug/kg (Nat. Bkd.) **Arsenic:** 18.3 mg/kg (Nat. Bkd.)	Point Base: **Total PCBs:** 676 ug/kg **Lead:** 190 mg/kg (Nat. Bkd.) **Cadmium:** 9.96 mg/kg **Copper:** 298 mg/kg **Mercury:** 1.06 mg/kg **Zinc:** 459 mg/kg	
Remedial Alternative	**Residual Site-Wide Area Weighted-Average Concentration**		**Predicted Outcomes - Reaching RAO PRGs (%)**				
			RAO 1: Human Health – Seafood Consumption [1/]		**RAO 2: Human Health – Direct Contact [1/]**	**RAO 3: Ecological Health – Benthic [2/]**	
	Risk Driver	**Mean**	Percentage Progress to Achieve Site-Wide PRGs	Number of Years to Reach Site-Wide PRGs		Percent Area Meeting RAO 3 PRGs	Number of Years to Reach PRGs by MNR
4G Partial Removal, *In situ* Treatment, MNR	**Total PCBs (ug/kg):**	198	99.5%	0.3	100%	93%	1 to 13
	BaP Equivalents (ug/kg):	236	100%	0	100%	not a COC	-
	Arsenic (mg/kg):	6.9	100%	0	100%	not a COC	-
	Lead (mg/kg):	61	not a COC	-	not a COC	100%	0
	Cadmium (mg/kg):	3.08	not a COC	-	not a COC	99.5%	1
	Copper (mg/kg)	64	not a COC	-	not a COC	100%	0
	Mercury (mg/kg)	0.21	not a COC	-	not a COC	98%	9
	Zinc (mg/kg):	168	not a COC	-	not a COC	100%	0
4H Partial Removal at DHC, CPC, and MNR	**Total PCBs (ug/kg):**	324	83%	10	100%	82%	1 to 26
	BaP Equivalents (ug/kg):	547	100%	0	100%	not a COC	-
	Arsenic (mg/kg):	7.1	100%	0	100%	not a COC	-
	Lead (mg/kg):	133	not a COC	-	not a COC	100%	0
	Cadmium (mg/kg):	3.42	not a COC	-	not a COC	99%	3
	Copper (mg/kg)	67	not a COC	-	not a COC	100%	0
	Mercury (mg/kg)	0.29	not a COC	-	not a COC	98%	22
	Zinc (mg/kg):	184	not a COC	-	not a COC	100%	0
4I Partial Removal at DHC, CPC, and MNR	**Total PCBs (ug/kg):**	194	100%	0	100%	89%	1 to 12
	BaP Equivalents (ug/kg):	513	100%	0	100%	not a COC	-
	Arsenic (mg/kg):	7.0	100%	0	100%	not a COC	-
	Lead (mg/kg):	64	not a COC	-	not a COC	100%	0
	Cadmium (mg/kg):	3.32	not a COC	-	not a COC	100%	0
	Copper (mg/kg)	59	not a COC	-	not a COC	100%	0
	Mercury (mg/kg)	0.21	not a COC	-	not a COC	100%	0
	Zinc (mg/kg):	162	not a COC	-	not a COC	100%	0
4J Partial Removal at DHC, CPC, *In situ* Treatment, MNR	**Total PCBs (ug/kg):**	168	100%	0	100%	93%	1 to 3
	BaP Equivalents (ug/kg):	493	100%	0	100%	not a COC	-
	Arsenic (mg/kg):	7.0	100%	0	100%	not a COC	-
	Lead (mg/kg):	57	not a COC	-	not a COC	100%	0
	Cadmium (mg/kg):	3.23	not a COC	-	not a COC	100%	0
	Copper (mg/kg)	62	not a COC	-	not a COC	100%	0
	Mercury (mg/kg)	0.20	not a COC	-	not a COC	100%	0
	Zinc (mg/kg):	156	not a COC	-	not a COC	100%	0

Notes:

[1/] Based on calculated mean residual site-wide area weighted-average surface sediment concentrations. Percentage progress towards achieving RAO PRGs from baseline conditions at the end of construction.

[2/] Based on calculated point basis residual surface sediment concentrations. Reported as the ratio of the area of point basis exceedance to total AOPC. Number of years to reach RAO PRGs by MNR was estimated using the results of sediment age-dating and approximation of intrinsic half-time through exponential decay.

SWAC=Site-wide area weighted-average concentration; MRC=Middle River Complex; CPC=Cow Pen Creek; DHC=Dark Head Crek; COC=Contaminant of concern; AOPC=Area of potential concern; RAO=Remedial action objective; PRG=Preliminary remediation goal; ENR=Enhanced natural recovery; MNR=Monitored natural recovery; n/a=Not applicable; Nat. Bkd.=natural background; PCB=Polychlorinated biphenyl, BaP=Benzo(a)pyrene; ug/kg=micrograms per kilogram; mg/kg=milligrams per kilogram.

Table 6-3
Summary of Short-term Effectiveness and Estimates of Implementability Metrics

		Remedial Alternative							
		1 No Action	**3A Removal at CPC, DHC, Dark Head Creek**	**3B Removal at CPC, DHC**	**4F Partial Removal, Reactive ENR**	**4G Partial Removal, *In situ* Treatment, MNR**	**4H Partial Removal, MNR**	**4I Partial+ Removal, MNR**	**4J Partial+ Removal, *In situ* Treatment, MNR**
Remedial Action Construction	Dredge volume at CPC and DHC [a]	0	143,200	99,600	48,800	48,800	48,800	62,900	62,900
	Backfill, reactive ENR volume at CPC and DHC (cy) [b]	0	33,300	25,500	29,000	15,200	15,200	19,300	19,300
	In situ treatment - activated carbon (cy) [c]	0	0	0	0	500	0	0	110
Upland Work Area [d]	Mechanical dredging - Dredged material stockpile (acre)	0	3.3	2.3	1.1	1.1	1.1	1.4	1.4
	Hydraulic dredging - geotubes (acre)	0	3.5 to 10	2.5 to 8.0	1.0 to 2.5	1.0 to 2.5	1.0 to 2.5	1.0 to 4.0	1.5 to 4.0
	Hydraulic dredging - geotubes of 200 feet each (number)	0	80	60	20	20	20	30	30
Water Treatment [e]	Water treatment volume by mechanical dredging (million gallon)	0	8.7	6.0	3.0	3.0	3.0	3.8	3.8
	Water treatment volume by mechanical dredging at CPC and hydraulic dredging at DHC (million gallon)	0	217	138	46	46	46	71	71
Transportation [f]	Backfill material to site - barge trips	0	42	32	38	20	20	26	26
	Dredge material to landfill - truck trips	0	9,550	6,640	3,260	3,260	3,260	4,200	4,200
	Activated carbon to site - truck trips	0	0	0	0	40	0	0	10
	Dredge material to landfill - truck miles	0	2,387,500	1,660,000	815,000	815,000	815,000	1,050,000	1,050,000
Environmental Footprint [g]	Total energy use (MMBTU)	0	135,000	94,000	47,800	46,600	46,400	59,700	59,700
	Greenhouse gas emissions (metric ton)	0	10,000	7,000	3,600	3,500	3,450	4,500	4,500
	Air pollution emissions (metric ton)	0	76	53	27	26	26	34	34

Notes:

a/ Neat dredge volumes were estimated by utilizing Thiessen polygons and increased by 50% for Feasibility Study (FS) analysis to account for the various causes of volume creep.

b/ Reactive ENR volume was estimated assuming 12 inch layer of sand mixed with activated carbon over the footprint to reach minimum 6 inch coverage. Dredge residual backfill material volume was estimated assuming 9 inch layer of sand over the footprint to reach minimum 6 inch coverage.

c/ 35,000 kg granulated activated carbon per hactare (31,230 lb/ha) (Ghosh, 2011), converted to cubic yard.

d/ Assumptions: 1) mechanically dredged material require about 1 sqft/cy; 2) for hydraulically dredged material, approximate capacity of each 200-ft geotube is 1,500 cy; 3) one 200-ft geotube base footprint is approximately 5,500 sqft; 4) range of geotubes upland area depends on geotubes stacked up in 1 to 3 layers.

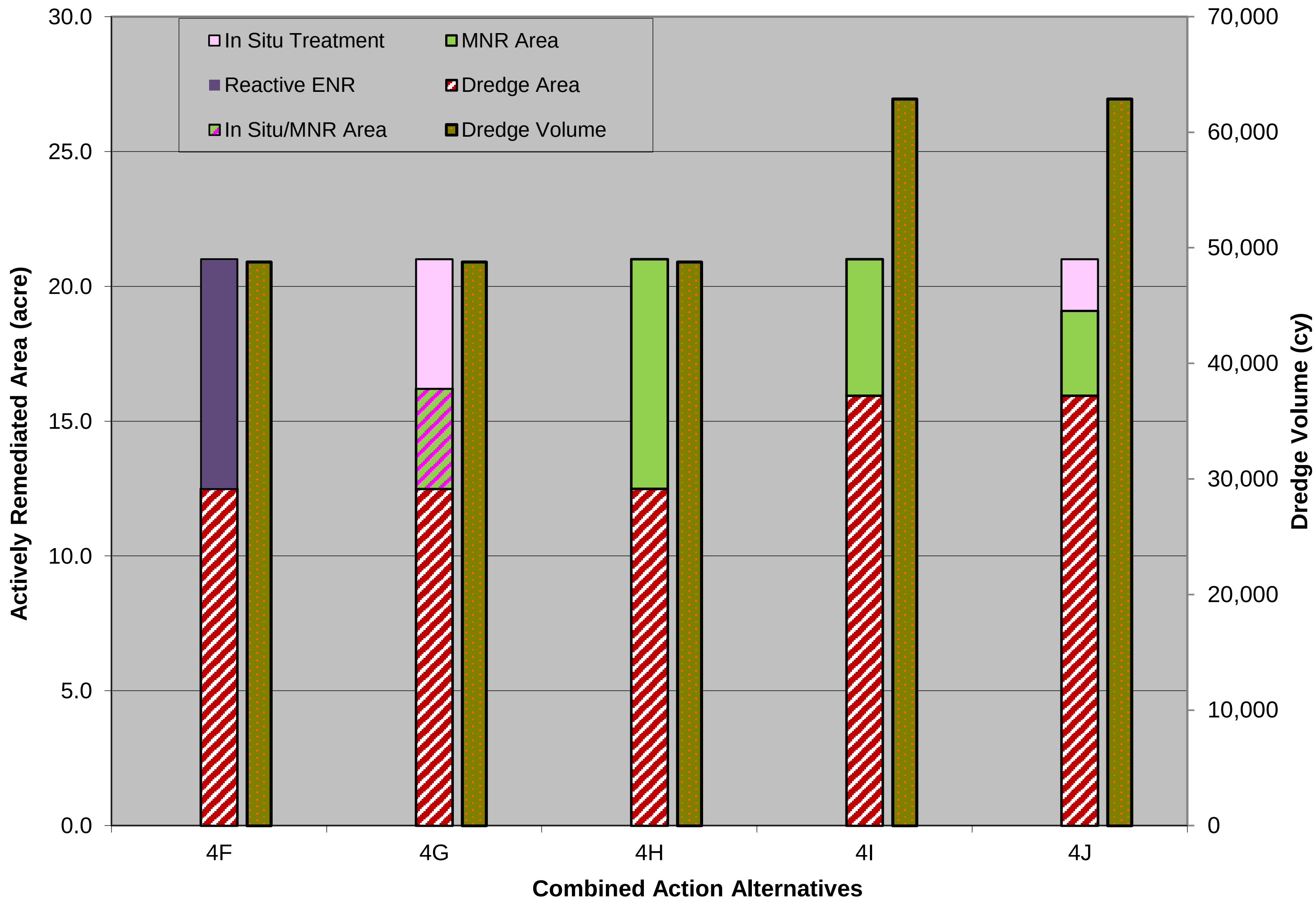
e/ Assumptions: 1) assume dewatered volume of dredged material is same as in-situ FS level dredge volume; 2) water to be treated collected by mechanical dredging is 30% of dredged material including additional stormwater that may need to be collected at dewatering area; 3) hydraulically dredged material is 10% slurry mixture therefore 9x dredge vol. of water treatment required.

f/ Assumptions: 1) dredged material will be transported by trucks from the transloading area to Grows North landfill in Morrisville, PA (15 cy/truck, 250 mile/round trip) and from landfilll offloading site to the disposal cell (15 cy/truck); 2) Activated carbon will be delivered by trucks (10 cy/truck); 3) ENR and backfill material will be delivered by barge (barge capacity: 1,600 cy); 4) trucks and barge trips are round trips.

g/ Greenhouse gas emissions include carbon dioxide, methane, and nitrous oxide emissions. Air polllution emissions include nitrogen oxide, sulfur oxide, particulate matter emissions. See Appendix F for detailed environmental footprint estimates.

cy=cubic yard; ENR=Enhanced natural recovery; MNR=monitored natural recovery; gal=gallon; CPC=Cow Pen Creek; DHC=Dark Head Cove; MMBTU=Million metric British Thermal unit; sqft=square feet; ft=feet.

Figure 6-1. Alternative 4 - Technology Application Summary



ENR=Enhanced Natural Recovery; MNR=Monitored Natural Recovery

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Section 7

Comparative Analysis of Remedial Alternatives

This section provides a comparative evaluation of the Middle River Complex (MRC) site remedial alternatives developed in Section 5 and evaluated individually in Section 6 to assess the relative performance of each alternative with respect to each of the evaluation criteria (e.g., threshold, balancing, and modifying criteria) under the Comprehensive Environmental Resource, Compensation and Liability Act (CERCLA, or Superfund), and to identify key tradeoffs among them. In this feasibility study (FS), the remedial alternatives evaluated were assembled as the No Action alternative (Alternative 1), removal alternatives (Alternatives 3A and 3B) and combined-action alternatives (Alternatives 4F, 4G, 4H, 4I, and 4J). Figure 7-1 illustrates actively remediated areas and how these various technologies have been applied for each of the alternatives.

7.1 COMPARATIVE ANALYSIS METHODOLOGY

The candidate alternatives are first evaluated for whether or not they meet the threshold criteria (i.e., overall protection of human health and the environment and compliance with applicable or relevant and appropriate requirements [ARARs]). These are threshold determinations, in that any alternative must meet them to be eligible for selection. The balancing criteria (i.e., long-term effectiveness and permanence; reduction of toxicity, mobility, and volume through treatment; short-term effectiveness; implementability; and cost) are then considered. They generally require more discussion because the major tradeoffs among alternatives are typically related to these criteria (USEPA, 1988).

A comparative evaluation of MRC remedial alternatives was conducted using both a qualitative comparative analysis and a more quantitative multi-criteria comparative analysis. The methodology for each type of analysis is discussed below. Details of the multi-criteria comparative analysis are included in Appendix G.

7.1.1 Qualitative Comparative Analysis

A qualitative comparative analysis evaluated the relative overall ranking of each remedial alternative based on the detailed evaluation conducted in Section 6. A five-star ranking system (corresponding to low, low-medium, medium, medium-high, and high levels) assessed the relative performance of each alternative. The evaluation framework follows the CERCLA threshold, balancing, and modifying criteria, which are represented by one or more individual metrics. Two levels of evaluation criteria were established to incorporate those metrics: Level 1 criteria are the major threshold, balancing and modifying criteria; Level 2 criteria include factors considered in evaluating the Level 1 criteria.

This qualitative framework and the evaluation are presented in Table 7-1, along with a discussion regarding performance of the alternatives under each CERCLA criterion. Some Level 2 criteria were evaluated based on the metrics for each alternative (e.g., estimated time to meet remedial action objectives [RAOs], removal volume, years of construction, depleted resources of backfill materials and landfill). A qualitative comparison was performed and a star ranking was assigned for each Level 1 criterion. A summary at the bottom of the table shows the overall star ranking of each alternative. The general outcome of the qualitative comparison is that the combined-action alternatives scored better than removal alternatives and the No Action alternative, and Alternativers 4F, 4G, and 4J scored the best among the combined-action alternatives (See discussion in Section 7.5).

The qualitative comparison produces a fairly similar ranking for many of the alternatives, and does not provide enough detail to distinguish similarities and dissimilarities among the alternatives, specifically within the combined-action alternatives. A more quantitative analysis method (i.e., multi-criteria decision analysis) provided a basis for further evaluation and distinguishing differences among the alternatives. This method allowed consideration of multiple factors under each CERCLA criterion by assigning scores and weightings to these metrics. The methodology for the multi-criteria decision analysis and detailed discussion of the comparative analysis are presented in the following sections.

7.1.2 Multi-Criteria Comparative Analysis

A multi-criteria comparative decision analysis was performed to support selection of the recommended alternative. Multi-parameter analysis tools were developed based on the multi-criteria decision analysis, which offer a scientifically sound decision framework for managing contaminated sediments. This method is useful because criteria such as environmental benefits, impacts, risk, economics, and stakeholder participation cannot be easily condensed into simple evaluation matrices. Other benefits associated with a multi-parameter analysis tool include having the decision criteria for remedy selection, the weighting of each criterion considered, and the score applied to each remedial alternative clearly defined and readily available for review when using this method.

In this FS, the multi-parameter analysis tool Criterium Decision Plus® (CDP) was used to weight and score remedial alternatives for the MRC site. Criterium Decision Plus® is a decision analysis tool that uses decision-making techniques such as the analytical hierarchy process, the Multi-Attribute Utility Theory, and the simple multi-attribute rating technique that is incorporated into the tool (InfoHarvest, 2001). To build the decision hierarchy and incorporate all the decision factors, each CERCLA evaluation criterion is represented by one or more individual metrics. To account for those metrics, up to three levels of evaluation criteria were established: Level 1 criteria are the major balancing and modifying criteria; Level 2 criteria have factors considered in evaluation of Level 1 criteria; and Level 3 has further subcomponents with which to evaluate the Level 2 criteria. The framework for comparative evaluation of alternatives is summarized in Table 7-2, and an illustration of the decision analysis framework and interactions among the various levels of criteria is in Figure 7-2.

Overall protection of human health and the environment and compliance with ARARs are threshold criteria, and all alternatives would meet these criteria; they were therefore not included in the CDP evaluations. The contribution of the balancing and modifying CERCLA criteria to the overall evaluation was calculated by applying a weighting factor to each criterion. An environmental criterion was also added to support short-term effectiveness metrics among the alternatives where the differences in energy use, air emissions, and impacts to water resources of a remedy were evaluated. The criterion was added to be consistent with Lockheed Martin's policy to implement green and sustainable remediation, and the USEPA green remediation policy to enhance the environmental benefits of federal cleanup programs by promoting sustainable technologies and practices.

For the primary balancing criteria, a 20% weight was assigned to the criteria of long-term effectiveness, permanence, and implementability. A weight of 10% was assigned to the reduction of toxicity, mobility, or volume through treatment, short-term effectiveness, and environmental concerns criteria. A weight of 15% was given to costs and a weight of 15% is associated with regulator and community acceptance. The overall sum of weighting factors for the primary balancing criteria is 100%. These weights are subjective but provide an initial basis for comparative evaluation of the alternatives. A sensitivity analysis was also performed after the initial CDP analysis. Appendix G contains the CDP analysis framework and CDP scoring guidelines.

Metrics were developed for the scoring criteria in Table 7-2, based on a zero to 10 rating scale; they are presented in Table 7-3. The rating scale is a linear relationship, with a minimum performance receiving a rating of zero and the maximum performance (with full achievement) receiving a rating of 10. The input data and information for each Level 2 and Level 3 criterion used to calculate a score are provided in non-shaded rows. The scoring input to the CDP analysis for each evaluation criteria is shown in the shaded rows. When a criterion has multiple metrics, the individual metric scores were averaged to give an overall score for the criterion. For example, two individual metrics were evaluated to assess prevention of human health risks under the long-term effectiveness of an alternative, which are achievement of RAO 1 and RAO 2. The data for these two metrics are entered into the first and second rows of Table 7-3. Based on the input data, the scores of each alternative to meet RAO 1 and RAO 2 were calculated, then these two scores were averaged to provide an overall average score for prevention of human health risks criterion shown in the third (shaded) row, which then is entered to the CDP analysis. The bases for each of the metrics used to develop the scores in Table 7-3 are described under the evaluation of each criterion in the following sections.

After calculating an average for each criterion, an overall score was calculated for the overall comparison and for input to the CDP tool. Regulator acceptance is unknown at this time, so it was not incorporated into the evaluations. Community input received during this FS process led to two sets of CDP evaluations being conducted: one incorporating community input, the other not incorporating community input.

In the following sections, a comparative evaluation of the alternatives is based on the detailed evaluation in Section 6, and the information in Tables 7-1 and 7-3.

7.2 THRESHOLD CRITERIA

USEPA (1988) guidance and the NCP (40 CFR 300.430[e][9][iii]) require evaluation of remedial alternatives in terms of their ability to satisfy two threshold criteria: (1) overall protection of human health and the environment and (2) compliance with ARARs.

7.2.1 Overall Protection of Human Health and the Environment

Alternative 1, the No Action alternative, takes no measures to protect human health and the environment. Other alternatives meet the threshold criterion of overall protection of human health and the environment and achieve RAOs by implementing an engineered remedy and monitoring to ensure that the PRGs associated with the RAOs are achieved. Complete-removal alternatives would meet RAOs immediately following construction.

The time for combined-action alternatives to achieve RAOs upon completion of each remedy varies. The performance of alternatives in meeting RAOs is compared in the first two rows of Table 7-1, under the achievement of RAOs and time to achieve RAOs evaluation criteria. The alternatives were also compared using the same categories listed in the first two rows of Table 7-3, under the “prevent human health risks” and “minimize ecological risks” criteria.

Time to meet RAOs for Alternative 4 and its variants are estimated in Table 6-2, and summarized in Tables 7-1 and 7-3. For achieving the remedial objectiverelated to mitigating human health risks associated with consumption of fish (RAO 1), Alternative 4H scored 9.2 due to the extended time (approximately 10 years) it takes to reach the RAO PRGs when compared to the other active remedial alternatives, all of which scored 10 (Table 7-3). At the end of construction, all alternatives would achieve remedial objective RAO 2 (except the No Action alternative), which addresses human health risks associated with direct-contact exposure to contamination.

Removal alternatives 3A and 3B and Alternative 4F achieve the benthic-related remedial objective RAO 3 by the end of the construction. Other combined-action alternatives meet RAO 3 within 82% (Alternative 4H) to 93% (Alternative 4J) of the AOPC area by the end of construction. The period to meet RAO 3 is up to three years for Alternative 4J, up to 13 years for Alternative 4G, up to 12 years for Alternative 4I, and up to 26 years for Alternative 4H. With respect to achieving the benthic-related remedial objectives of RAO 3, Alternative 4H scored the lowest (8.2), Alternative 4I scored

8.9, Alternative 4G and 4J scored 9.3, Alternatives 3A, 3B, and 4F scored 10, and No Action alternative scored 7.1; all scores are based on the time to reach RAO 3 PRGs and the area affected.

Graphical presentations of RAO achievement, as related to removal volumes, are presented in Figures 7-3 and 7-4. Consistent with the discussion above and scoring of the alternatives, Figure 7-3 shows that the human health RAO 1 is achieved at the end of the construction under the combined-action alternatives 4F, 4G, 4I, and 4J, with a smaller removal volume than the complete-removal alternatives. Figure 7-4 shows the benthic RAO 3 achievement in terms of the percentage of the area within the AOPC for which each alternative meets the RAO at the end of construction. This graph illustrates that 100% of the AOPC would meet RAO 3 under Alternatives 3A, 3B, and 4F at the end of construction, and 82 to 93% of AOPC would meet RAO 3 under Alternatives 4G, 4H, 4I, and 4J at the end of construction.

7.2.2 Compliance with Applicable or Relevant and Appropriate Requirements

All alternatives except No Action comply with federal and state chemical- and location-specific ARARs and TBCs. Adequate engineering planning, design and agency review will ensure that these remedies would comply with ARARs.

7.3 PRIMARY BALANCING CRITERIA

The primary balancing criteria weigh effectiveness and cost tradeoffs among alternatives. The alternatives were compared with regard to how well they satisfy the five CERCLA balancing criteria, presented below.

7.3.1 Long-Term Effectiveness and Permanence

The general analysis factors considered during the comparative evaluation of alternatives for their long-term effectiveness and permanence are preventing human health risks, minimizing ecological risks, the residual potential risk of each alternative, and technology reliability. Other factors evaluated under long-term effectiveness and permanence in Section 6 include time to meet RAOs (which measures the performance of alternatives in meeting RAOs) and the adequacy and reliability of controls to manage any remaining contamination. These factors are incorporated into metrics for achieving RAOs and technology reliability.

The performance of each remedial alternative in terms of preventing human health risks (RAOs 1 and 2) and to minimize ecological risks (RAO 3) is summarized in Section 7.2.1. The residual potential risk of alternatives is compared in the third row of Tables 7-1 and 7-3, under the long-term effectiveness criterion. In Table 7-3, residual potential risk was evaluated based on the Level 3 criteria of achieving RAOs and residual exposure risk, where the risk is also correlated to the reliability of the remedial technologies.

Technology reliability of the alternatives was also evaluated in Tables 7-1 and 7-3. In Table 7-3, the technology reliability score of each alternative was calculated based on the areas where the technologies would be applied, and a technology reliability weighting assigned to each technology. A weighting of 9 was assigned to removal technologies due to issues of resuspension and contaminant release during dredging, and remaining residuals.

MNR received a weighting of 5 because recovery depends on the natural deposition of clean sediments. *In situ* treatment received a weighting of 8, based on the research and field applications of activated carbon in reducing COC bioavailability. A weighting of 8 was also assigned to reactive ENR because it reduces the migration of contaminants by binding through adsorptive processes.

The area of each technology was multiplied by its reliability-weighting factor and divided by the total area to compute a score under the technology reliability criterion. The area the technologies would be applied to and the weighting assigned to them led to Alternative 4H receiving the lowest reliability score (7.4), due to its reliance on MNR. This was followed by Alternatives 4I, 4G, 4J, and 4F in ascending order (with scores of 8.0 to 8.6). Alternatives 3A and 3B were assigned a score of 9 in the technology reliability evaluation (Table 7-3).

Under the “residual potential risk” criterion, the No Action alternative poses the greatest potential of residual risk. The magnitude of surface contamination remaining at the end of construction of each remedial alternative was evaluated under the “achievement of RAOs” criterion. Complete-removal alternatives would leave no residual surface or subsurface contamination, so no risk of exposure would be expected. Combined-action alternatives would leave subsurface contamination at levels higher than PRGs in areas that are not subject to removal.

Alternative 4F is considered as protective as Alternatives 3A and 3B through application of reactive ENR in non-removal areas. For the other combined-action alternatives, exposure of remaining subsurface contamination is negligible due to lack of sediment disturbance mechanisms in Dark Head Cove (e.g., high-flow scour, seismic events, and propeller scour). Residual potential risk also correlates with technology reliability. Alternative 4H therefore ranks lowest (8.1) due its reliance on MNR, followed by Alternative 4I (8.8), which is the other combined-action alternative with removal and MNR components. Alternative 4J (9.0) is ranked slightly higher than 4G (8.9) because of its larger removal volume and lower remaining contaminant mass. Alternatives 4F, 3A, and 3B score higher than the other alternatives with respect to the residual potential risk criterion (9.3 to 9.5) because they leave no residual contamination and due to the reliability of removal and reactive ENR technologies.

The long-term effectiveness and permanence evaluation of alternatives is illustrated in Figures 7-5a and 7-5b, where contaminant mass removals versus dredge volumes are graphed for each alternative. These graphs also show the ratio of relative contaminant mass versus dredge volumes, and show which alternatives are optimized for the most contaminant-mass removal per volume of material removed. Alternatives 4F, 4G and 4H would remove 48,800 cubic yards of sediments from Cow Pen Creek and in front of the Dark Head Cove bulkhead. These alternatives have the most optimized contaminant mass removal as compared to the other alternatives. Alternatives 4I and 4J also have a better contaminant mass removal ratio than complete removal Alternatives 3A and 3B.

7.3.2 Reductions in Toxicity, Mobility, and Volume through Treatment

No reduction of toxicity, mobility, or volume through treatment would be achieved under the No Action, complete removal, and combined-action alternatives of 4H and 4I because no treatment would be implemented. Alternatives 4F, 4G and 4J were given credit because they incorporate *in situ* treatment (Table 7-1 and 7-3). Under Alternative 4J, up to 10% of contaminants would be expected to be treated by reducing bioavailability, and a score of 1 is given; Alternatives 4F and 4G are scored 2 (20–40% of contaminants would be expected to be managed by *in situ* treatment). The treatment is considered non-reversible, so Alternatives 4F, 4G, 4J are scored 10. The rest of the alternatives scored 0 under the irreversibility of treatment criterion (Table 7-3).

7.3.3 Short-Term Effectiveness and Environmental Criteria

Alternatives with longer construction times and those that handle larger amounts of contaminated material present proportionately larger risks to workers, the community, and the environment. Longer construction periods increase equipment and vehicle emissions, noise, and the use of various resources. Larger actively remediated footprints increase the short-term disturbance of the existing benthic community and other resident aquatic life and generate more releases of bioavailable chemicals over a longer period. The comparative ranking of each alternative for the short-term effectiveness criterion is based on differences in construction time and the quantity of contaminated sediment removed. The nature of dredging and its ancillary technologies contribute the most to impacts associated with short-term effectiveness and the environmental metrics of energy use, air emissions, and impacts to water resources (e.g., the volume of decant water to be treated).

In Table 7-1, protection of community and worker exposure and ecological disturbance are correlated to construction duration where removal alternatives (two to four construction years) rank less than the combined-action alternatives (one to two construction years). Depleted natural resources (through use of sand and gravel backfill, and reactive ENR placement) and landfill capacity use correlated to dredge volumes are also considered in the comparative evaluations. In Table 7-3, Level 3 metrics of the criteria related to relative impacts to human health and ecological receptors are subjectively ranked as low (8.0), low to moderate (7.0), moderate (6.0), and high (0).

Alternative 1, No Action, received the highest score of 10 in this category, since no actions would be taken and no short-term impacts would be produced. Alternatives 3A and 3B received the lowest score (0) due to high short-term impacts. The combined-action alternatives scored higher (6.0 to 8.0) due to their shorter construction periods and smaller removal volumes and associated dredge components (Table 7-3).

Time to achieve RAOs is also incorporated under the short-term effectiveness evaluation criterion to balance the short-term impacts to the benefits of each alternative. Under the "time to achieve RAOs" criterion, Alternatives 3A, 3B, 4F scored 10, followed by Alternative 4J (9.9), Alternatives 4G and 4I (9.7), and Alternative 4H, which gets the lowest score (8.2) due to the areas that require a longer period of MNR.

In Table 7-3, environmental criteria are also incorporated into the comparative evaluation (i.e., the fifth Level 1 criteria). Energy use, greenhouse gas and air pollution emissions, and impacts on water resources due to treating decant water are considered as Level 2 and Level 3 criteria in the evaluation. These metrics are estimated in detail in Appendix F, and are discussed in the detailed evaluation of alternatives in Section 6. These metrics were used to calculate a linear scoring for each alternative, where No Action (Alternative 1) received 10 and the most extensive removal alternative (3A) received zero.

In this category, Alternative 3B scored 3, Alternatives 4F, 4G, and 4H scored 6.2 to 6.6, and Alternatives 4I and 4J scored 5.6 (Table 7-3). To visualize potential environmental impacts, Figure 7-6 compares the alternatives' environmental metrics (i.e., greenhouse gas emissions versus air pollution emissions) correlated to the number of construction days. Consistent with the discussion above, environmental impacts are directly correlated to the extent of removal volume; therefore, the impacts of the alternatives with the same removal volume would be similar (Alternatives 4F, 4G, 4H; and Alternatives 4I, 4J). The most impacts would be expected under Alternatives 3A and 3B (Figure 7-6).

7.3.4 Implementability

This evaluation criterion considers the technical and administrative feasibility of implementing the remedial alternatives and the availability of services and materials. The evaluation is based on technical and administrative implementability, because resources for the remedial technologies are available from multiple vendors and procurable through competitive bidding nationwide. In general, the potential for technical problems and schedule delays increases in direct proportion to the duration and complexity of the alternatives. Complete-removal alternatives have more complex technical and administrative (e.g., coordination with agencies) implementability issues due to the complexity of dredging and ancillary technologies (i.e., transloading, transporting, water management, disposal, monitoring, and residuals management).

Similarly, Alternatives 4I and 4J would remove a greater volume of material and require a longer construction period, and would have a comparatively higher potential for problems and delays than would Alternatives 4H and 4G, which are designed to remove smaller volumes of material and have shorter construction times. Alternative 4F has low administrative implementability due to the federal navigation channel status of Middle River. In Table 7-1, implementability of alternatives was evaluated qualitatively; Alternative 3A scored the lowest, followed by Alternatives 3B and 4F. Alternatives 4G and 4H rank higher than Alternatives 4I and 4J due to a smaller removal volume.

In Table 7-3, implementability of alternatives was evaluated under the Level 2 criteria of obtaining other approvals, constructability, availability of experts and technology, availability to modify and update as necessary, and effectiveness of monitoring. Under constructability, Level 3 criteria were considered based on the area to which each remedial technology would be applied, the weighting assigned to each technology, and the estimated construction period. An implementability weighting factor of five was assigned to implementability of dredging, ten was assigned to MNR, and seven was assigned to *in situ* treatment and reactive ENR. The area of each technology was multiplied by the weighting factor and then divided by the total area to compute a score under the constructability criterion. The other Level 2 criteria (obtaining other approvals, availability of experts and technology, availability to modify and update as necessary, and effectiveness of monitoring) are evaluated as moderate, moderate to high, or high, and a score was given to each alternative reflecting the discussion above (Table 7-3).

7.3.5 Cost

This assessment evaluates the capital costs (engineering, construction, and supplies) and annual or periodic costs (operation and maintenance [O&M] costs, monitoring, institutional controls, and ongoing administration) of each alternative. Capital cost for the alternatives range from $17.2 million (Alternative 4H) to $41.7 million (Alternative 3A). Operation, maintenance, and monitoring (OM&M) costs for the alternatives range from $0 (Alternative 3A, 3B) to $1.06 million (Alternative 4G). Alternatives are scored linearly to reflect their cost. The No Action alternative received the highest score (10), and is the least expensive alternative. Alternative 3A scored zero. Detailed cost estimates for each remedial alternative are included in Appendix E and summarized in Tables 7-1 and 7-3.

7.4 MODIFYING CRITERIA

Evaluation of the modifying criteria will be completed after the proposed plan has been submitted to the regulators and released for public review, and following analysis of public comment on the proposed plan. As an initial evaluation of community acceptance, community input on remedial alternatives received through Lockheed Martin's community outreach process during development of this FS was incorporated into the evaluation matrix (Tables 7-1 and 7-3). The CDP decision analysis model was then built for two cases: one with community acceptance metrics incorporated and one without them incorporated. Community acceptance of the recommended alternative will be reevaluated by the agencies after the public hearing of the proposed plan. The No Action alternative is regulatorily unacceptable and gets a score of zero. Alternative 4H gets a score of three due to concerns about longer natural recovery times to reach benthic RAOs. Alternatives 3A and 3B are scored five due to their cost and short-term impacts. Alternative 4F is scored seven due to concerns regarding placement of a thin layer of reactive ENR in a navigation channel. Alternatives 4I, 4G, and 4J get the highest score of eight. Alternatives 4I, 4G, and 4J all meet RAOs in a reasonable period, with lower cost and fewer short-term impacts than the complete-removal alternatives. These alternatives would remove the most contaminant mass, and manage the rest of the contaminated sediments by *in situ* treatment and MNR.

7.5 COMPARATIVE ANALYSIS SUMMARY AND CDP DECISION ANALYSIS

A qualitative comparative analysis and a multi-criteria comparative analysis compared the suite of MRC remedial alternatives considered in this FS. The methodology of each evaluation and the detailed comparative analyses of the alternatives are discussed above. The qualitative comparative analysis is summarized in Table 7-1. The last row of Table 7-1 incorporates all CERCLA evaluation criteria and provides an overall summary.

The analysis shows that Alternatives 4F, 4G and 4J would be the best performing alternatives, closely followed by Alternatives 4H and 4I. Alternative 3B ranked lower than the combined-action alternatives. Alternatives 3A and No Action are the lowest performing alternatives. This simple qualitative comparison makes Alternatives 4F, 4G, and 4J candidates for the best performing alternatives. Multi-criteria decision analysis was also performed using the CDP tool, because the qualitative comparison produces similar rankings for the alternatives and does not incorporate factors that distinguish similarities and dissimilarities among them. The analysis methodology and the comparative evaluation based on that analysis are discussed in the sections above.

Once the framework for the evaluation criteria was established, the alternatives were scored for each factor under the evaluation criteria (Table 7-3). Using the metric scores as an input, a CDP decision analysis model was built for two cases: one with community acceptance metrics incorporated (Figure 7-7) and one without community acceptance criteria incorporated (Figure 7-8). The reason for running the model using two cases is that modifying criteria are usually considered after the proposed plan has been accepted by the regulators and reviewed by the public, not during the FS process.

In this FS, community input was received during the FS process and used in the comparative analysis. Both cases of CDP analyses identified Alternative 4G as the most robust alternative, followed by Alternatives 4J and 4F. Below these three alternatives, a difference in the order of alternatives occurs when community input is considered: Alternative 4I scores higher than Alternative 4H, and Alternative 3B scores higher than the No Action alternative. The range of decision scores when community input is included is 0.459 to 0.655; when community input is not included, it is 0.491 to 0.692. Alternative 3A gets the lowest score, and Alternative 4G gets the highest score in both analyses.

Multi-criteria comparative analysis outputs of the CDP model are also graphed by including the cost trend-line to visualize the overall-benefit ranking of each alternative as compared to its cost (Figures 7-9 and 7-10). Another way of assessing cost/benefits is presented in Figure 7-11, which provides a benefits-to-cost ratio trend-line. Figures 7-9 through 7-11 indicate that Alternative 4G offers the best performance for its cost as compared to the other combined-action alternatives. Complete-removal alternatives do not perform well because they have higher FS-level cost estimates as compared to the combined-action alternatives. The No Action alternative performs similarly or better than the complete-removal alternatives.

After completion of the initial CDP analysis, sensitivity analyses were performed to assess the robustness of the scoring and ranking. Sensitivity curves are used to identify any cases where only slight changes (i.e., under 10%) in criteria weights would cause a change in the score sufficient to change the ranking of alternatives. If that were the case, the weighting of that particular criterion was revisited and the ranking of the alternatives re-assessed. Sensitivity analysis was performed based on the difference in decision scores between Alternatives 4G and 4J, the highest scoring alternatives, and by identifying the criteria that would produce difference in the scores. The analysis shows that Alternative 4G is a robust alternative. A slight change in criteria weights does not change the decision score enough to change the ranking of the alternatives. The sensitivity analysis is in Appendix G.

7.6 RECOMMENDED ALTERNATIVE

This section discusses the rationale for identifying and selecting the recommended alternative and provides a general description. The determination is based on both the individual evaluations of the remedial alternatives against the CERCLA evaluation criteria (Section 6) and the comparative evaluation of the remedial alternatives presented above.

7.6.1 Rationale for Recommendation

The No Action alternative was retained for comparative purposes as the baseline condition. Considering all rating criteria presented in Table 7-3, the decision score of alternatives falls into a fairly narrow range of 0.459 to 0.692 (Figures 7-7 and 7-8). However, the results demonstrate fundamental differences among the alternatives.

More dredging does not necessarily result in higher overall scores because of higher short-term impacts to workers, the community, and environment; lower technical and administrative feasibility; relatively similar time to achieve RAOs compared to combined-action alternatives; and high cost. The complete-removal alternatives actually result in a decision score below or slightly above the No Action alternative, because the benefits-to-impacts balance of complete removal is similar to conditions under no further action. Managing contaminated sediments through thin layer placement, *in situ* treatment, and MNR results in higher scores due to the benefits in meeting RAOs, reduced short-term impacts, and high technical and administrative feasibility.

Figures 7-9 and 7-10 show decision scores for each alternative, with an overlay of cost. These figures indicate that the higher cost alternatives show little or no increase in overall benefit over lower cost alternatives. These figures also show that the combined-action alternatives, specifically Alternatives 4F, 4G, 4I, and 4J, perform very similarly from an overall benefit and cost standpoint. Figure 7-11 includes the benefit-to-cost ratio trend-line. The comparative analyses summarized in Figures 7-9 to 7-11 demonstrate that Alternative 4G is the most cost-effective and protective remedy for MRC sediments.

7.6.2 Description of the Recommended Alternative

The detailed comparative evaluation of the remedial alternatives identified Alternative 4G as the recommended alternative for the MRC site. Figure 7-12 illustrates the remedial actions comprising the recommended alternative. The remedial footprint associated with the selected alternative would likely be refined in the design phase through a refined exposure map (i.e., an interpolated surface of sediment COC concentrations at the specific depth intervals) and through design of constructable dredge prisms. The recommended alternative involves the following:

- removal of about 48,800 cubic yards of contaminated sediments targeting the high contamination areas over 12.5 acres of the AOPC, targeting Cow Pen Creek and in front of the Dark Head Cove bulkhead

- *in situ* treatment of contaminated sediments over 8.5 acres (the rest of the AOPC)

- monitored natural recovery of about four acres of the *in situ* treatment area

- shoreline stabilization, habitat enhancement, and riparian planting after the remedial construction (if necessary)

- long-term monitoring O&M program of *in situ* treatment areas to verify the remedy

- institutional controls, including public outreach, education, and seafood consumption advisories (in conjunction with regional Middle River advisories issued by Maryland Department of the Environment).

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Table 7-1
Qualitative Comparative Analysis of Remedial Alternatives

Evaluation Criteria			Remedial Alternative							
Level 1	Level 2		1 No Action	3A Removal at CPC, DHC, Dark Head Creek	3B Removal at CPC, DHC	4F Partial Removal, Reactive ENR	4G Partial Removal, *In situ* Treatment, MNR	4H Partial Removal+MNR	4I Partial+ Removal, MNR	4J Partial+ Removal, *In situ* Treatment, MNR
Overall Protection of Human Health and the Environment	Achievement of RAOs		The RAOs would not be achieved in a reasonable timeframe	All remedial alternatives achieve RAOs at varying performance						
	Time to Achieve RAOs	Time to Achieve Human Health RAOs after the completion of construction (RAO 1 and RAO 2)	30	0	0	0	0	10	0	0
			All remedial alternatives achieve RAO 2 at baseline conditions							
		Time to Achieve Benthic RAOs after the completion of construction (RAO 3)	100	0	0	0	13	26	12	3
	Potential for exposing remaining contamination		Greatest potential for re-exposure	None - no surface and subsurface residual contamination remains within AOPC		Negligible - non-removal areas would be protected by reactive ENR	Negligible - higher risk than Alternative 4J due to less removal volume	Negligible - higher risk than other Alt. 4s due to reliance on MNR	Negligible - similar risk to 4G due to larger removal volume but MNR the rest	Negligible - lower risk than 4G due to larger removal volume
	Adequacy and reliability of controls	Institutional Controls, Monitoring and Maintenance	Current regional ICs remain, no OM&M	Current regional ICs remain, no OM&M		Current regional ICs remain, OM&M over 8.5 acre			Current regional ICs remain, OM&M over 5.1 acre	
	Summary of Short-term Effectiveness		None	Short-term impacts are higher for removal-focus alternatives and increase with increased removal volume		Short-term impacts are less than Alts.4I and 4J due to less removal volume		Least short-term impacts within Alt. 4s due to MNR over 8.5 acre	Short-term impacts are higher than Alts. 4F, 4G, 4H due to larger removal volume	
Comply with ARARs	Compliance with ARARs		Not expected to comply	All remedial alternatives comply with ARARs						
Summary of Threshold Criteria (Overall Protection of Human Health and the Environment and Compliance with ARARs)			*	*****	*****	*****	***	**	***	****
Long-term Effectiveness	Prevent Human Health Risks	Level of risk mitigation to protect human health	Not protective of human health	High level of risk mitigation to protect human health		High level of risk mitigation to protect human health		Moderate to high level of risk mitigation	High level of risk mitigation to protect human health	
	Minimize Ecological Risks	Level of risk mitigation to protect ecological receptors	Not protective of environment	High level of risk mitigation to protect ecological receptors		High level of risk mitigation to protect ecological receptors	RAO 3 exceedance in 7% of area, up to 13 years to meet RAO 3	RAO 3 exceedance in 18.4% of area, up to 26 years to meet RAO 3	RAO 3 exceedance in 10% of area, up to 12 years to meet RAO 3	RAO 3 exceedance in 7% of area, up to 3 years to meet RAO 4
	Residual Potential Risk	Potential exposure pathways to remaining COCs	Highest potential risk	None - no surface and subsurface residual contamination remains within AOPC		Negligible - higher risk than Alts. 4I and 4J due to less removal volume		Negligible - higher risk than other Alt. 4s.	Negligible - less risk than Alts. 4F, 4G, 4H due to larger removal volume	
	Technology Reliability	Success in achieving RAOs	The RAOs would not be achieved in a reasonable timeframe	High	High	High	Moderate to high	Moderate	Moderate to high	Moderate to high
	Summary of Long-term Effectiveness		*	*****	*****	****	***	***	****	****
Reduction of Toxicity, Mobility, or Volume through Treatment	Destruction or Immobilization of Hazardous Constituents	Estimated amount of destruction or stablization of COCs	No treatment	No treatment		Treatment over 8.5 acre		No treatment	No treatment	Treatment over 5.1 acre
	Irreversibility of Treatment	Potential of COCs to reoccur after remedy implementation	No treatment	No treatment		Irreversible		No treatment	No treatment	Irreversible
	Summary of Reduction of Toxicity, Mobility, or Volume through Treatment		*	*	*	*****	*****	*	*	****
Short-Term Effectiveness	Environmental	Energy consumption, greenhouse gas (GHG), air pollution emissions (NOx, SOx, PM10)	0	High short-term environmental impacts compared to Alt. 4s due to large volume to be dredged		Less short-term impacts than Alts.4I and 4J due to less removal volume		Least short-term impacts within Alt. 4s due to MNR over 8.5 acre	Higher short-term impacts than Alts. 4F, 4G, 4H due to larger removal volume	
	Protection of community exposure worker exposure and ecological disturbance	Years of construction	0	2 to 4	2 to 3	1 to 2	1 to 2	1 to 2	1 to 2	1 to 2
	Depleted natural resources	Sand, gravel for in-water placement (backfill, ENR) (cy)	0	33,300	25,500	19,000	15,200	15,200	19,300	19,300
	Landfill capacity used	1.2 times dredge volume (cy)	0	171,800	119,500	58,600	58,600	58,600	75,500	75,500
	Summary of Short-Term Impacts		*****	*	**	****	****	****	***	***
Implementability	Technical Implementability	Levels of sophistication of construction oversight and planning	No potential for technical/ administrative difficulties, availability of services and materials	Less than Alt. 4s. Potential for technical difficulties increase with the dredge volume associated construction activities		Moderate	Moderate	Moderate to high	Moderate	Moderate
	Administrative Implementability	Number and difficulty in obtaining permits and approvals from agencies		Less than Alt. 4s. Potential for administrative difficulties, schedule delays increase with the dredge volume		Low administrative implementability due to navigation channel status of Middle River	Moderate	Moderate	Moderate	Moderate
	Availability of Services and Materials	Accessibility of special expertise and equipment that is required		Resources for the removal technology are available from multiple vendors and procurable through competitive bidding		Resources for the removal, reactive ENR, *in situ* treatment technologies are available from multiple vendors and procurable through competitive bidding				
	Summary of Implementability		*****	*	**	**	****	****	***	***
Costs	Capital and OM&M (MM$)	NPV $s	0	41.7	30.2	21.5	19.4	18.1	21.7	22.1
	Summary of Costs		*****	*	**	***	***	****	***	***
Modifying Criteria	Regulatory Agency	Level of acceptability relative to the least acceptable alternative	Not known, not evaluated							
	Community		Not preferred	Concerns over the excessive cost of the remedy compared to the benefits, long construction period and short-term disruption to the community		Supportive comments due to their less cost, less construction time, and less disruption to the environment and the community compared to complete removal alternatives while meeting all RAOs. Concerns on the length of recovery in certain areas through MNR (i.e., Alternative 4H), introduction of activated carbon to the water, and the effectiveness of activated carbon treatment				
	Summary of Modifying Criteria		*	**	***	*****	*****	***	****	*****
Overall Summary			**	**	***	*****	*****	****	****	*****

RAO=Remedial action objective; COC=Contaminant of concern; ARARs=Applicable or relevant and appropriate requirements; ICs=institutional controls; AOPC=Area of potential concern; ENR=Enhanced natural recovery; MNR=Monitored natural recovery; cy=cubic yard; CPC=Cow Pen Creek; DHC=Dark Head Cove; GHG=Greenhouse gas; NOx= Nitrogen oxides; SOx=Sulfur oxides; PM10 = particulated matter with diameter 10 µm or less; OM&M=Operation maintenance and monitoring; MM$=Million Dollar; NPV=Net present value.

Ranking Index =	*	**	***	****	*****
	Low	Low-Medium	Medium	Medium-High	High

Table 7-2
Framework for Multi-Criteria Comparative Evaluation of Remedial Alternatives

Evaluation Criteria Levels and Typical Weights			
Level 1	**Level 2**		**Level 3**
Long-term Effectiveness 20%	Prevent Human Health Risks	Level of risk mitigation to protect human health	Achievement of RAO 1: Human Seafood Consumption at the end of construction (%)
			Achievement of RAO 2: Human Health Direct Contact at the end of construction (%)
	Minimize Ecological Risks	Level of risk mitigation to protect Ecologiocal Receptors	RAO 3: Benthic Organisms at the end of construction (%)
	Potential exposure pathways to remaining COCs	Potential exposure pathways to remaining COCs	Achievement of RAOs
			Residual reexposure risk
	Technology Reliability	Success in achieving RAOs	Total dredge area (acres)
			Total MNR area (acres)
			Total *in situ* treatment area (acres)
			Total reactive ENR area (acres)
Reduction of Toxicity, Mobility, or Volume through Treatment 10%	Destruction or Immobilization of Hazardous Constituents	Estimated amount of destruction or stablization of COCs	
	Irreversibility of Treatment	Potential of COCs to reoccur after remedy implementation	
Short-Term Effectiveness 10%	Time to Achieve RAOs (years)		Time to Achieve RAO 1
			Time to Achieve RAO 2
			Time to Achieve RAO 3
	Un-mitigable Adverse Impacts During Construction and OM&M	Relative impacts to Human Health and Ecological Receptors (i.e. compared to Alternative with the highest impact)	Protect Community (Relative impacts to Human Health - compared to Alternative with the highest impact)
			Protect Construction Workers (Relative impacts to Human Health - compared to Alternative with the highest impact)
			Minimize Environmental Impacts (Relative impacts to Ecological Receptors - compared to Alternative with the highest impact)
Implementability 20%	Obtain Other Approvals	Number and difficulty in obtaining permits and approvals from agencies not related to the remedy approval (e.g. from local cities and counties, transportation agencies, water purveyors, etc.), relative to the most difficult Alternative	
	Constructability	Levels of sophistication of construction oversight and planning relative to the most complex Alternative	Total dredge area (acres)
			Total MNR area (acres)
			Total *in situ* treatment area (acres)
			Total reactive ENR area (acres)
			Construction Period (days)
	Availability of Experts and Technology	Accessibility of special expertise and equipment that is required	
	Availability to Modify/Update, as necessary	Ease with which changes can be made compared to the least adaptable Alternative	
	Effectiveness of Monitoring	Reliability of assessing Alternative performance by monitoring	
Environmental 10%	Energy Use (MMBTU)		
	Air Emissions	Toxic and GHG emissions	GHG emissions (tons)
			NO_x emissions (tons)
			SO_x emissions (tons)
			PM_{10} Emissions (tons)
	Impacts on Water Resources		
Costs 15%	Capital (MM$)	NPV $s	
	OM&M (MM$)	NPV $s	
Acceptance 15%	State and Local Agency	Level of acceptability relative to the least acceptable Alternative	
	Community	Level of acceptability relative to the least acceptable Alternative	

RAO=Remedial action objective; COC=Contaminant of concern; ENR=Enhanced natural recovery; MNR=Monitored natural recovery; OM&M=Operation maintenance and monitoring; MMBTU=Million metric British thermal units; GHG=Greenhouse gas; NOx= Nitrogen oxides; SOx=Sulfur oxides; PM10 = particulated matter with diameter 10 µm or less; MM$=Million Dollar; NPV=Net present value.

Table 7-3
Multi-Criteria Comparative Analysis of Remedial Alternatives - CDP Input Scoring

Evaluation Criteria				Remedial Alternative							
Level 1	Level 2		Level 3 [1/]	1 No Action	3A Removal at CPC, DHC, Dark Head Creek	3B Removal at CPC, DHC	4F Partial Removal, Reactive ENR	4G Partial Removal, *In situ* Treatment, MNR	4H Partial Removal+MNR	4I Partial+ Removal, MNR	4J Partial+ Removal, *In situ* Treatment, MNR
Long-term Effectiveness	Prevent Human Health Risks	Level of risk mitigation to protect human health	Achievement of RAO 1: Human Seafood Consumption at the end of construction (%) [2/]	0	100.0	100.0	100.0	99.5	83.0	100.0	100.0
			Achievement of RAO 2: Human Health Direct Contact at the end of construction (%)	91	100	100	100	100	100	100	100
				4.6	10.0	10.0	10.0	10.0	9.2	10.0	10.0
	Minimize Ecological Risks	Level of risk mitigation to protect Ecologiocal Receptors	RAO 3: Benthic Organisms at the end of construction (%) [3/]	71.0	100.0	100.0	100.0	92.7	82.1	89.4	93.4
				7.1	10.0	10.0	10.0	9.3	8.2	8.9	9.3
	Residual Potential Risk	Potential exposure pathways to remaining COCs	Achievement of RAOs [4/]	5.4	10.0	10.0	10.0	9.7	8.8	9.6	9.8
			Residual reexposure risk [5/]	0	9.0	9.0	8.6	8.1	7.4	8.0	8.3
				2.7	9.5	9.5	9.3	8.9	8.1	8.8	9.0
	Technology Reliability	Success in achieving RAOs [6/]	Total dredge area (acres) 9	0	27.51	21.01	12.49	12.49	12.49	15.95	15.95
			Total MNR area (acres) 5	0	0.00	0.00	0.00	3.46	8.52	5.06	3.15
			Total *in situ* treatment area (acres) 8	0	0.00	0.00	0.00	8.52	0.00	0.00	1.91
			Total reactive ENR area (acres) 8	0	0.00	0.00	8.52	0.00	0.00	0.00	0.00
				0	9.0	9.0	8.6	8.1	7.4	8.0	8.3
Reduction of Toxicity, Mobility, or Volume through Treatment	Destruction or Immobilization of Hazardous Constituents	Estimated amount of destruction or stablization of COCs		No treatment	No treatment	No treatment	Immobilization of COCs in 8.5 acres	Immobilization of COCs in 8.5 acres	No treatment	No treatment	Immobilization of COCs in 2 acres
				0	0	0	2	2	0	0	1
	Irreversibility of Treatment	Potential of COCs to reoccur after remedy implementation		No treatment	No treatment	No treatment	Non-reversible	Non-reversible	No treatment	No treatment	Non-reversible
				0	0	0	10	10	0	0	10
Short-Term Effectiveness	Time to Achieve RAOs (years)		Time to Achieve RAO 1	30	0	0	0	0	10	0	0
			Time to Achieve RAO 2	0	0	0	0	0	0	0	0
			Time to Achieve RAO 3 [7/]	100	0	0	0	13	26	12	3
				0	10.0	10.0	10.0	9.7	8.2	9.7	9.9
	Un-mitigable Adverse Impacts During Construction and OM&M	Relative impacts to Human Health and Ecological Receptors (i.e. compared to Alternative with the highest impact)	Protect Community (Relative impacts to Human Health - compared to Alternative with the highest impact)	n/a	High	High	Low to moderate	Low to moderate	Low	Moderate	Moderate
				10	0	0	7.0	7.0	8.0	6.0	6.0
			Protect Construction Workers (Relative impacts to Human Health - compared to Alternative with the highest impact)	n/a	High	High	Low to moderate	Low to moderate	Low	Moderate	Moderate
				10	0	0	7.0	7.0	8.0	6.0	6.0
			Minimize Environmental Impacts (Relative Impacts to Ecological Receptors - compared to Alternative with the highest impact)	n/a	High	High	Moderate	Low	Low	Low to moderate	Low to moderate
				10	0	0	6.0	8.0	8.0	7.0	7.0
Implementability	Obtain Other Approvals	Number and difficulty in obtaining permits and approvals from agencies not related to the remedy approval (e.g. from local cities and counties, transportation agencies, water purveyors, etc.), relative to the most difficult Alternative		No construction period. No potential for technical/ administrative difficulties.	Moderate to high	Moderate to high	High	Moderate	Moderate	Moderate	Moderate
				10	5	5	2.5	7.5	7.5	7.5	7.5
	Constructability [8/]	Levels of sophistication of construction oversight and planning relative to the most complex Alternative	Total dredge area (acres) 5	0	27.51	21.01	12.49	12.49	12.49	15.95	15.95
			Total MNR area (acres) 10	0	0.00	0.00	0.00	3.46	8.52	5.06	3.15
			Total *in situ* treatment area (acres) 7	0	0.00	0.00	0.00	8.52	0.00	0.00	1.91
			Total reactive ENR area (acres) 7	0	0.00	0.00	8.52	0.00	0.00	0.00	0.00
			Construction Period (days)	0	230	170	100	110	90	110	120
				10	5.0	5.7	6.8	7.0	7.0	6.9	6.7
	Availability of Experts and Technology	Accessibility of special expertise and equipment that is required		n/a	High	High	High	Moderate to high	High	High	Moderate to high
				10	10	10	10	8	10	10	8
	Availability to Modify/Update, as necessary	Ease with which changes can be made compared to the least adaptable Alternative		n/a	High	High	Moderate to high	Moderate	High	High	Moderate
				0	10	10	8	6	10	10	6
	Effectiveness of Monitoring	Reliability of assessing Alternative performance by monitoring		n/a	High	High	Moderate to high	Moderate	Moderate to high	Moderate to high	Moderate
				0	10	10	8	6	8	8	6

Table 7-3
Multi-Criteria Comparative Analysis of Remedial Alternatives - CDP Input Scoring

Evaluation Criteria				Remedial Alternative							
				1 No Action	3A Removal at CPC, DHC, Dark Head Creek	3B Removal at CPC, DHC	4F Partial Removal, Reactive ENR	4G Partial Removal, *In situ* Treatment, MNR	4H Partial Removal+MNR	4I Partial+ Removal, MNR	4J Partial+ Removal, *In situ* Treatment, MNR
Level 1	Level 2		Level 3 [1/]								
Environmental	Energy Use (MMBTU)			0	135,000	94,000	47,800	46,600	46,400	59,700	59,700
				10	0.0	3.0	6.5	6.5	6.6	5.6	5.6
	Air Emissions [9/]	Toxic and GHG emissions	GHG emissions (tons)	0	9,995	6,964	3,573	3,462	3,441	4,425	4,430
				10	0.0	3.0	6.4	6.5	6.6	5.6	5.6
			NO_x emissions (tons)	0	27.70	19.30	10.60	9.81	9.65	12.40	12.40
				10	0.0	3.0	6.2	6.5	6.5	5.5	5.5
			SO_x emissions (tons)	0	8.37	5.83	2.87	2.86	2.86	3.68	3.68
				10	0.0	3.0	6.6	6.6	6.6	5.6	5.6
			PM_{10} Emissions (tons)	0	40.10	27.90	13.80	13.70	13.70	17.60	17.60
				10	0.0	3.0	6.6	6.6	6.6	5.6	5.6
	Impacts on Water Resources			None	8,672,000	6,032,000	2,956,000	2,956,000	2,956,000	3,811,000	3,811,000
				10	0	3.0	6.6	6.6	6.6	5.6	5.6
Costs	Capital (MM$)	NPV $s		0	41.7	30.2	20.5	18.4	17.2	21.1	21.5
				10	0.0	2.8	5.1	5.6	5.9	4.9	4.8
	OM&M (MM$)	NPV $s		0	0.00	0.00	1.01	1.06	0.95	0.62	0.59
				10	10.0	10.0	0.4	0.0	1.1	4.2	4.4
Acceptance	State and Local Agency	Level of acceptability relative to the least acceptable Alternative									
	Community	Level of acceptability relative to the least acceptable Alternative		0	5	5	7	8	3	8	8

Notes:

1/ The alternatives are scored on a linear scale between the high and low points within Level 3 criteria. A score of 0 represents a low ranking and a score of 10 represents a high ranking for a given metric. Level 3 sublevels are scored individually and averaged to compute Level 2 scores presented in shaded rows as input into the CDP analysis.

2/ Percentage performance towards achieving RAO 1 PRGs from the baseline (no action) conditions.

3/ Percentage area within the area of concern achieving RAO 3 PRGs.

4/ Average performance of RAO 1, RAO 2, and RAO 3.

5/ Residual reexposure risk is scored based on the reliability of remedial technology.

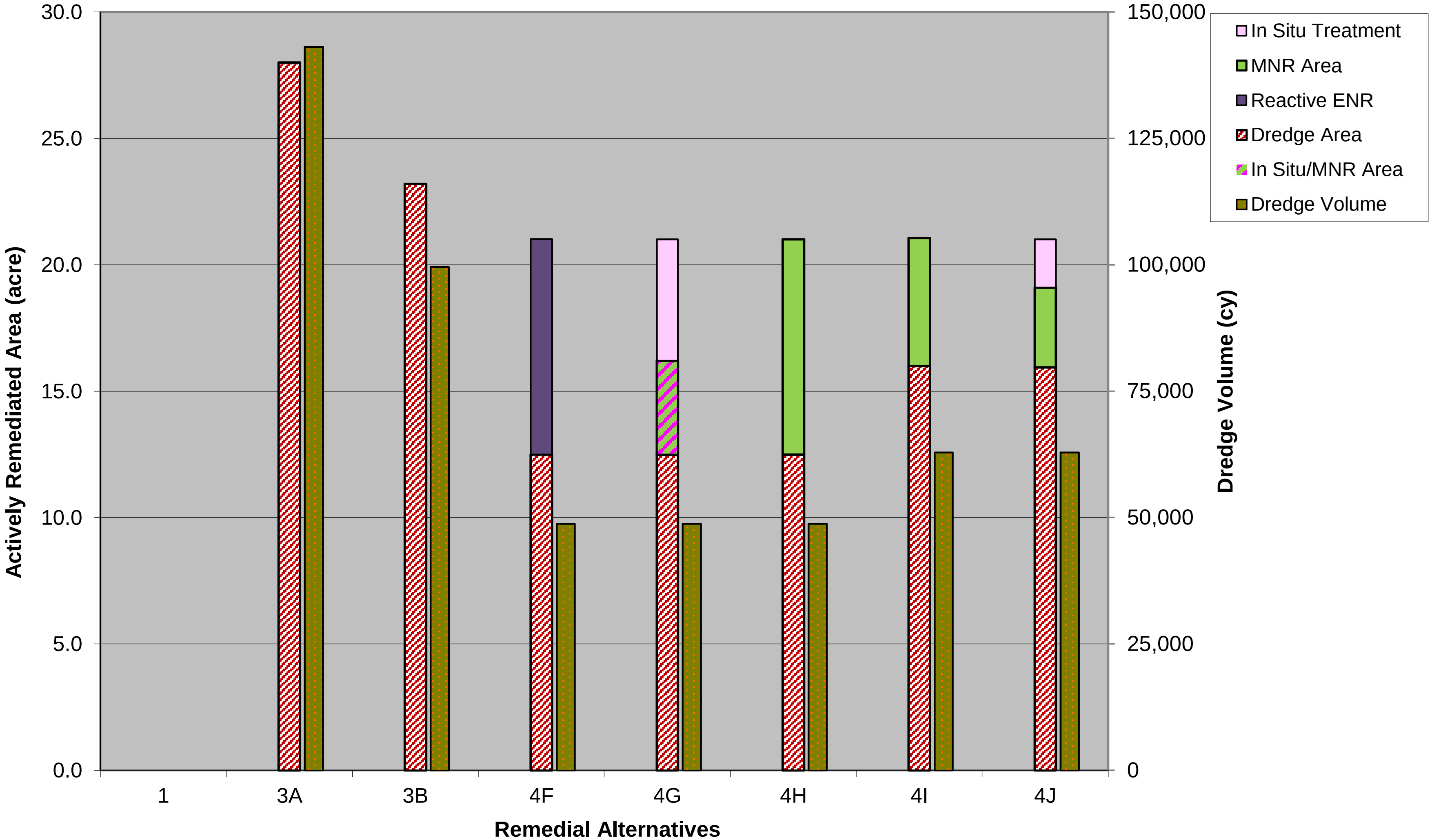
6/ Success in achieving RAOs is scored based on the area of each technology applied multiplied by the assigned technology reliability weighting divided by acreage of the study area.

7/ Maximum number of years to achieve point base RAO 3 is reported and scored for each alternative.

8/ Constructability scoring is based on the average of scores computed for the area over which the technology is applied multiplied by the technology constructability factor divided by the acreage of the construction area and the number of construction days.

9/ Level 3 sublevels in air emissions are scored individually as an input to the CDP analysis.
RAO=Remedial action objective; COC=Contaminant of concern; PRG=Preliminary remedial goal; CDP= Criterium decision plus; ARARs=Applicable or relevant and appropriate requirements; ICs=institutional controls; AOPC=Area of potential concern; ENR=Enhanced natural recovery; MNR=Monitored natural recovery; cy=cubic yard; CPC=Cow Pen Creek; DHC=Dark Head Cove; GHG=Greenhouse gas; NOx= Nitrogen oxides; SOx=Sulfur oxides; PM10 = particulated matter with diameter 10 µm or less; OM&M=Operation maintenance and monitoring; MMBTU= Million British thermal unit; MM$=Million Dollar; NPV=Net present value.

Figure 7-1. Comparative Analysis - Technology Application Summary



MNR=Monitored Natural Recovery; ENR=Enhanced Natural Recovery

Figure 7-2. Criterium Decision Plus Analysis Model

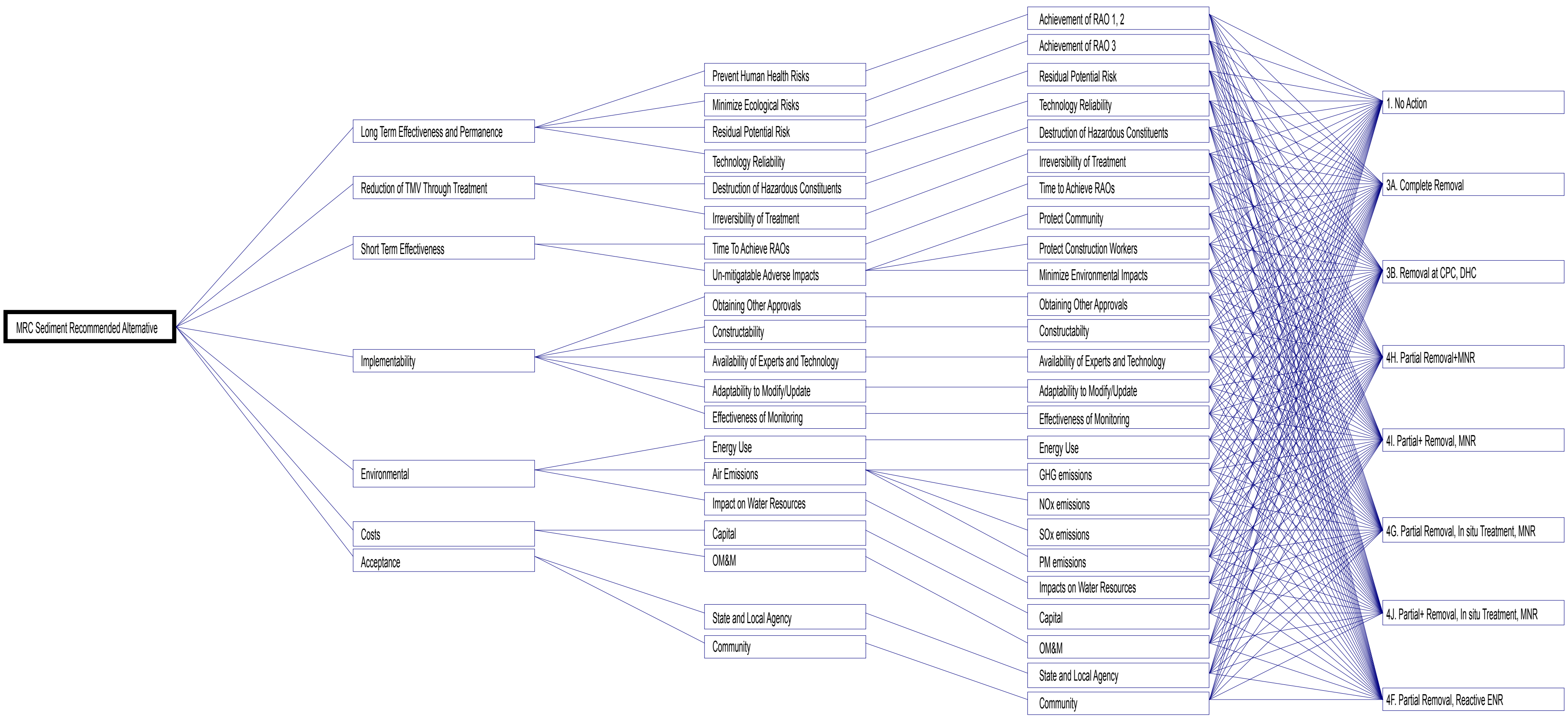
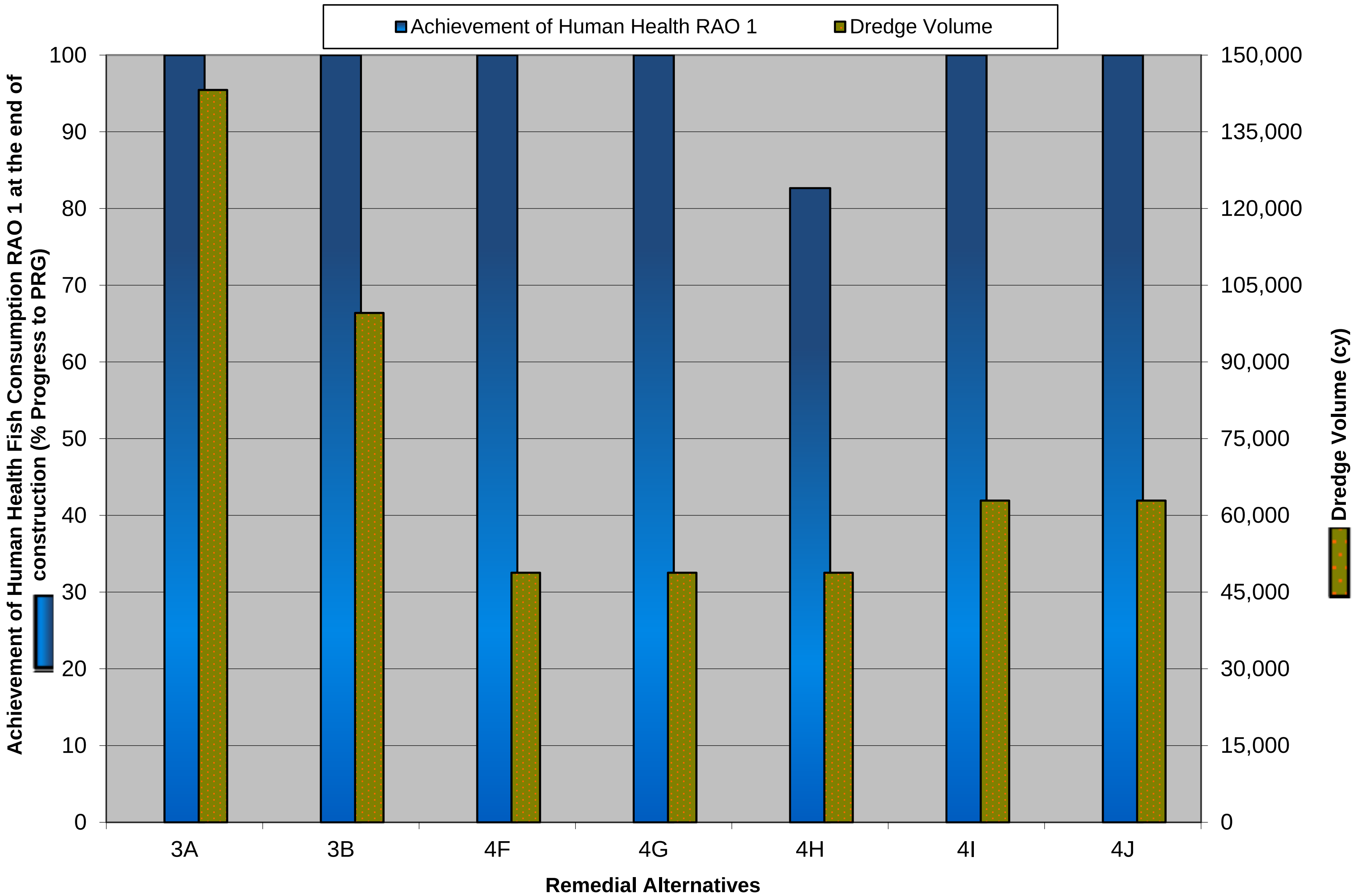
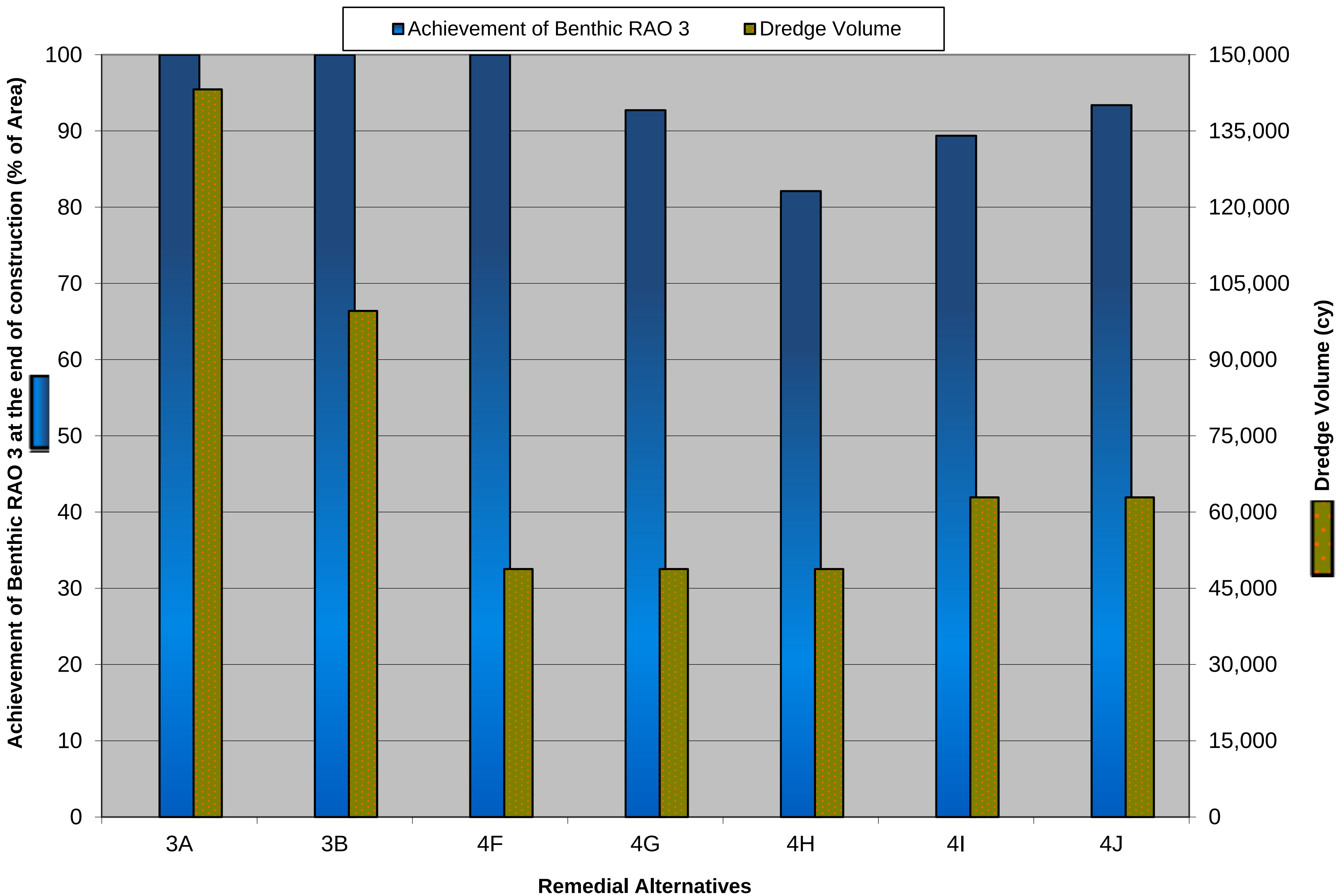


Figure 7-3. Comparative Analysis - Achievement of RAO 1 at the End of Construction to Dredge Volume



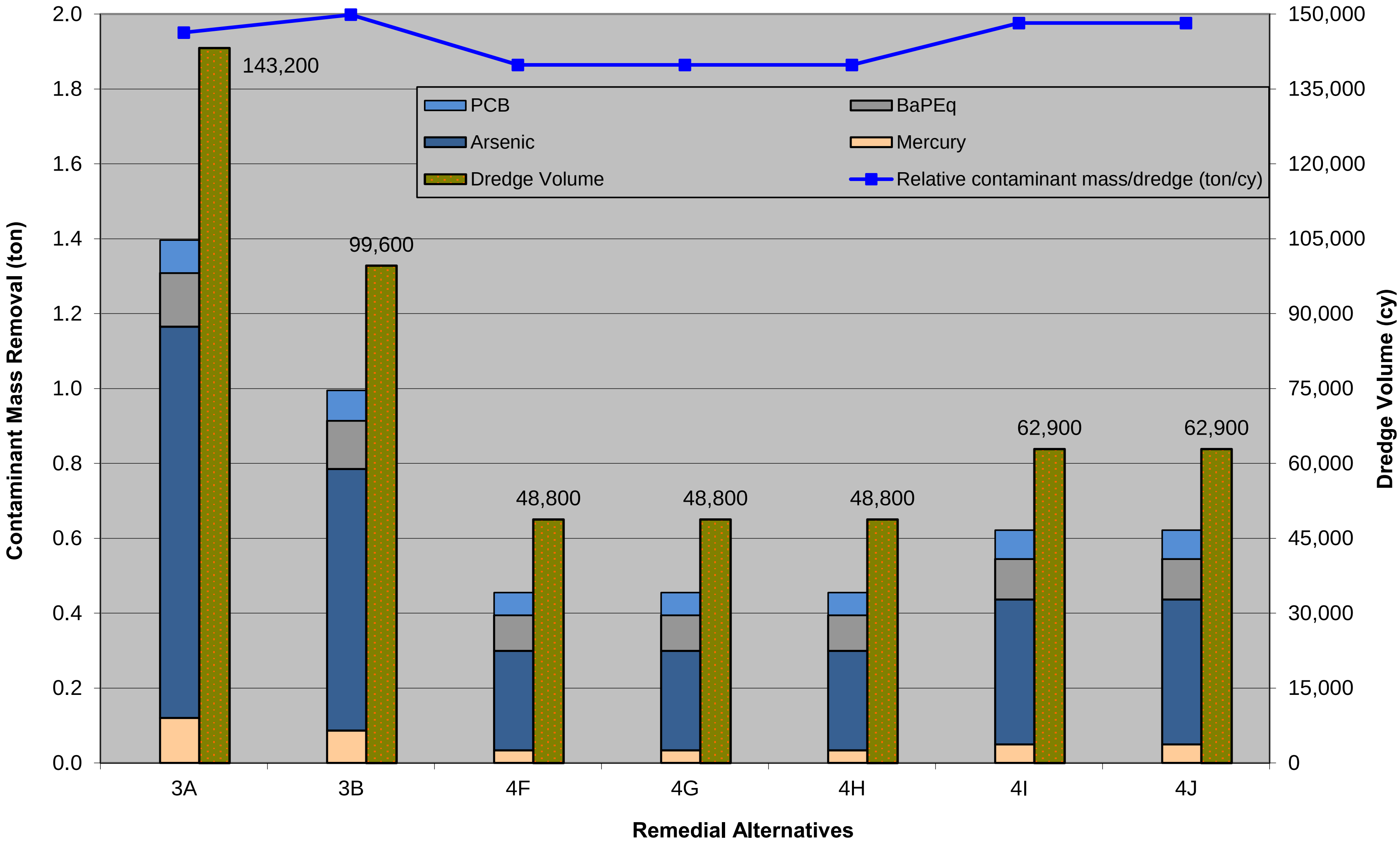
PRG=Preliminary Remediation Goal; RAO=Remedial Action Objective

Figure 7-4. Comparative Analysis - Achievement of RAO 3 at the End of Construction to Dredge Volume



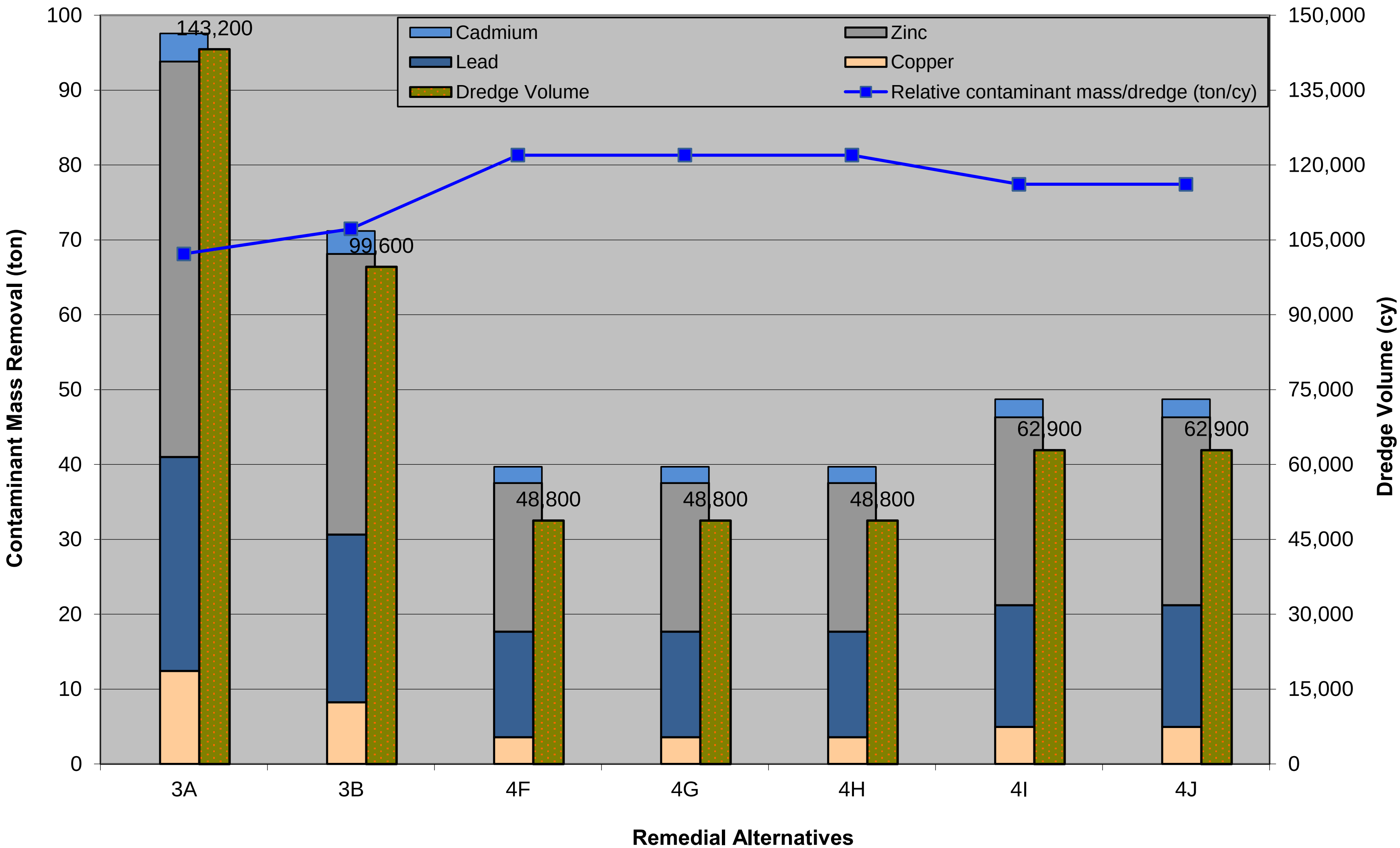
RAO=Remedial Action Objective

Figure 7- 5a. Contaminant Mass Removal of COCs (PCB, BaPEq, As, Hg) to Dredge Volume



Note: Relative contaminant mass/dredge scale: 2.0 = 1E-05 ton/kg or 0.01 kg/cy

Figure 7- 5b. Contaminant Mass Removal of COCs (Cd, Zn, Pb, Cu) to Dredge Volume



Note: Relative contaminant mass/dredge scale: 100=0.001 ton/cy or 1 kg/cy

Figure 7-6. Comparative Analysis - Environmental Metrics

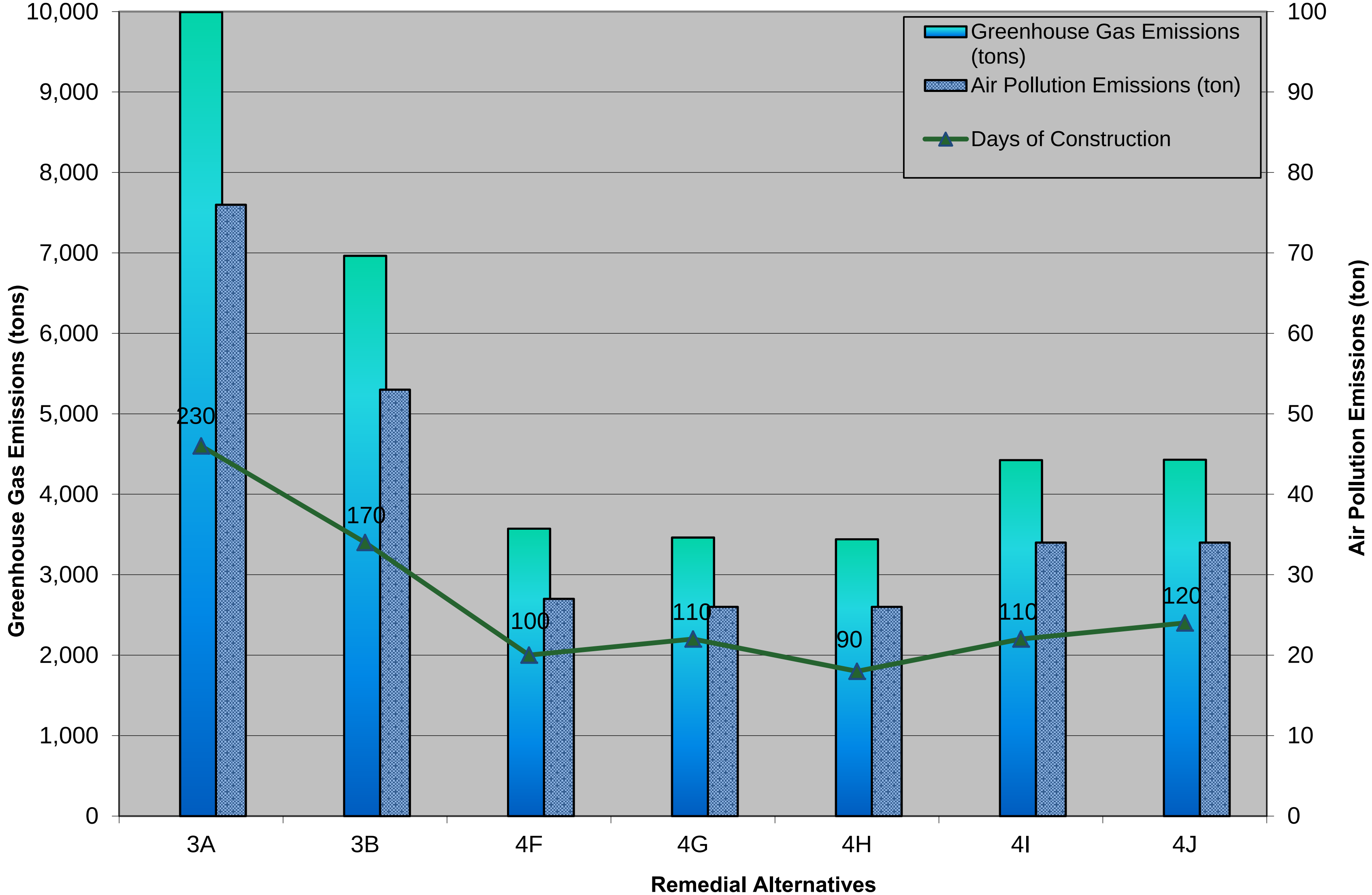
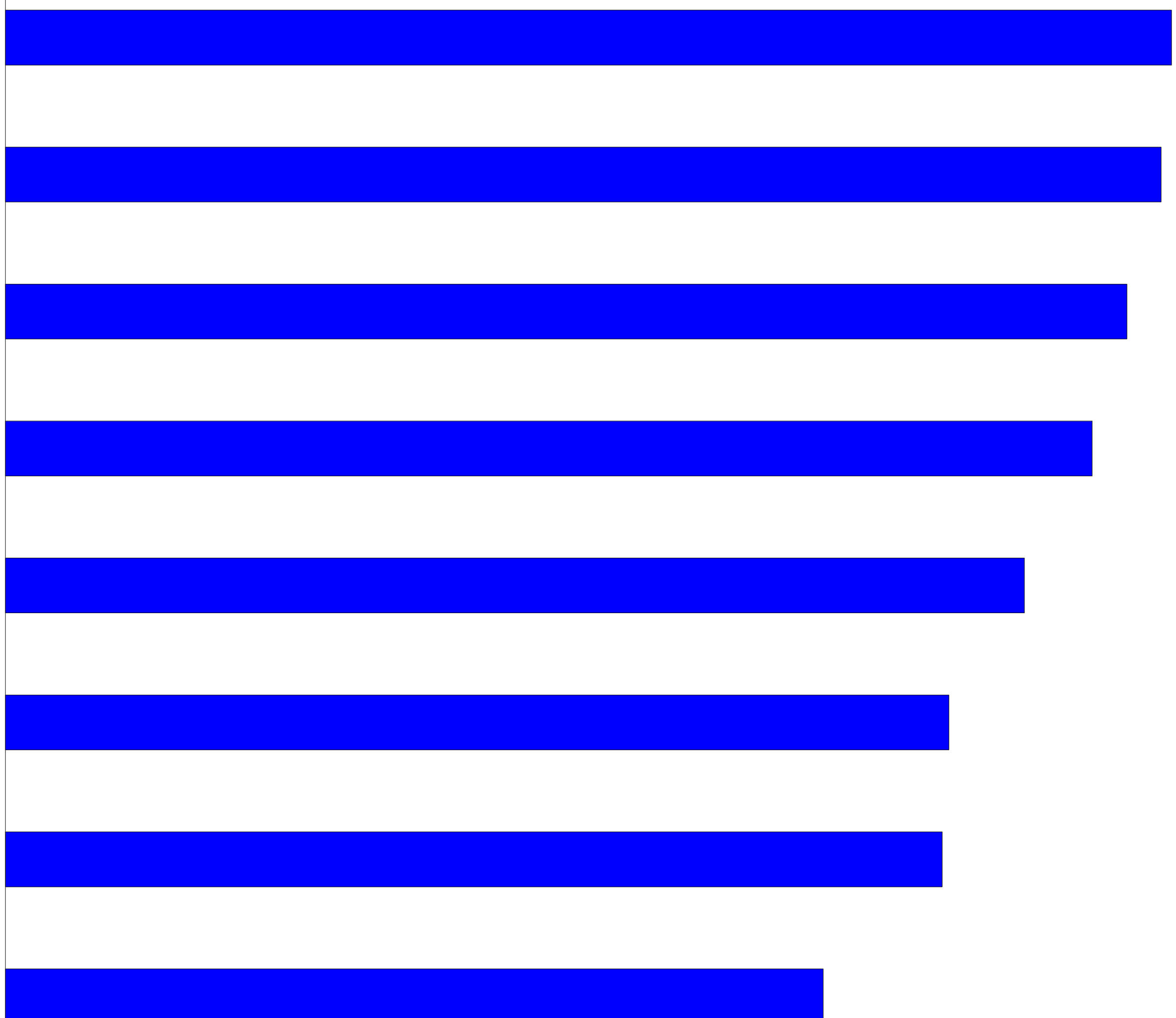


Figure 7-7. Multi-Criteria Comparative Analysis by CDP Model with Community Acceptance

Alternatives	Value	Decision Scores
4G. Removal, Insitu, MNR	0.655	
4J. Removal+, Insitu, MNR	0.649	
4F. Removal, R.ENR	0.630	
4I. Removal+, MNR	0.611	
4H. Removal, MNR	0.572	
3B. Removal at CPC, DHC	0.530	
1. No Action	0.526	
3A. Complete Removal	0.459	

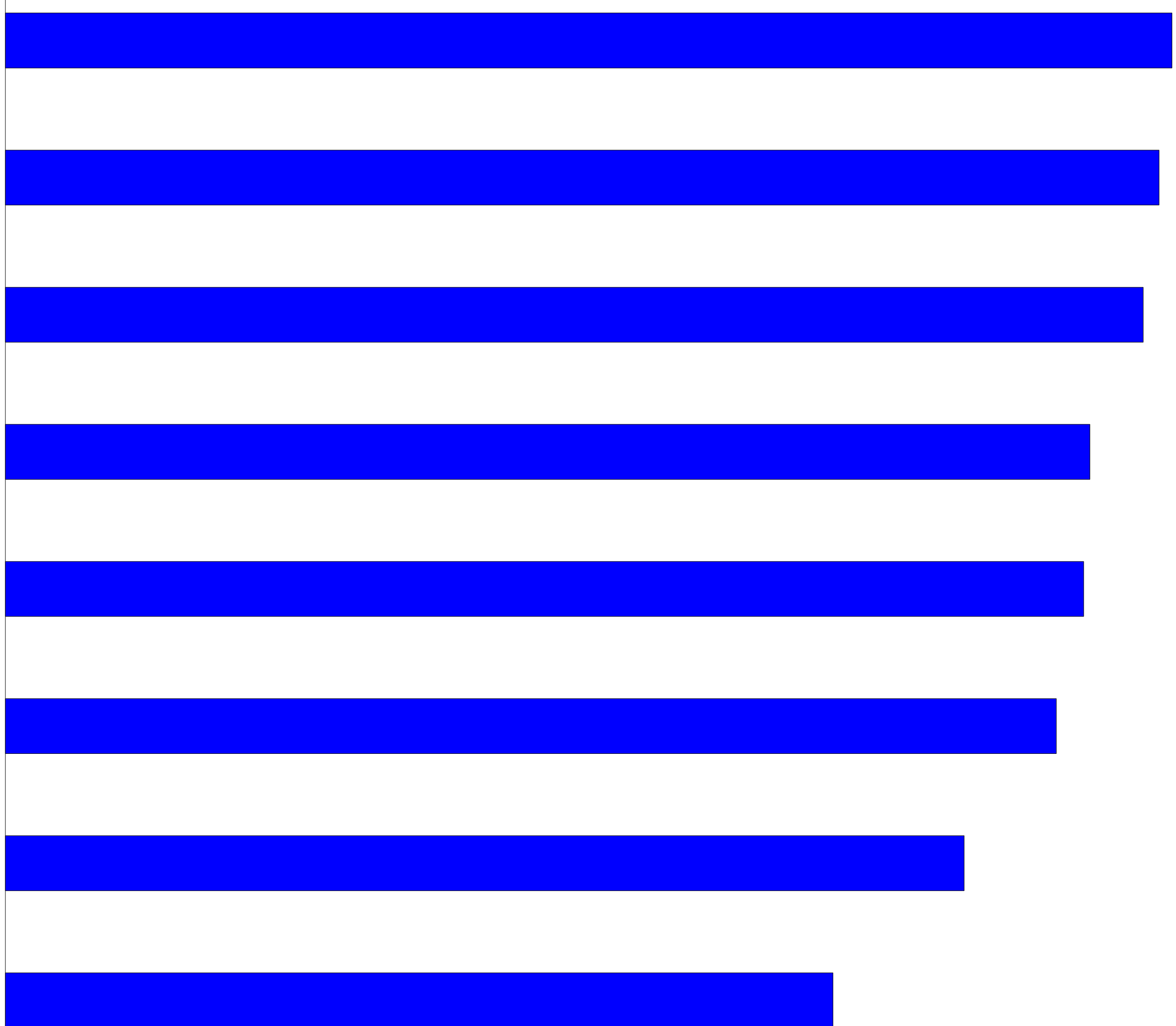


MNR=Monitored Natural Recovery; R.ENR=Reactive Enhanced Natural Recovery; CPC=Cow Pen Creek; DHC=Dark Head Cove

Figure 7-8. Multi-Criteria Comparative Analysis by CDP Model without Community Acceptance

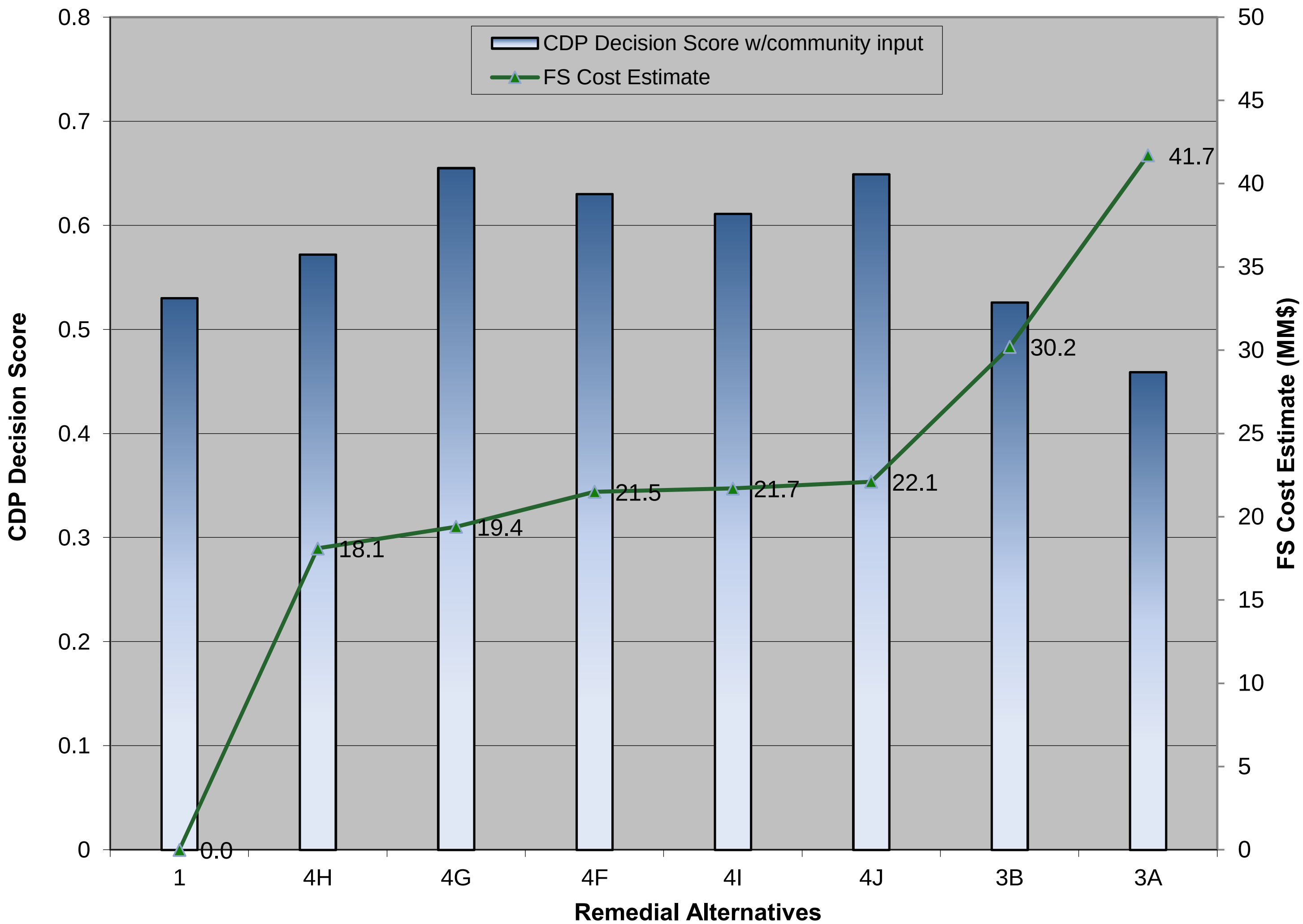
Alternatives	Value
4G. Removal, Insitu, MNR	0.692
4J. Removal+, Insitu, MNR	0.684
4F. Removal, R.ENR	0.675
4H. Removal, MNR	0.643
4I. Removal+, MNR	0.640
1. No Action	0.624
3B. Removal at CPC, DHC	0.569
3A. Complete Removal	0.491

Decision Scores



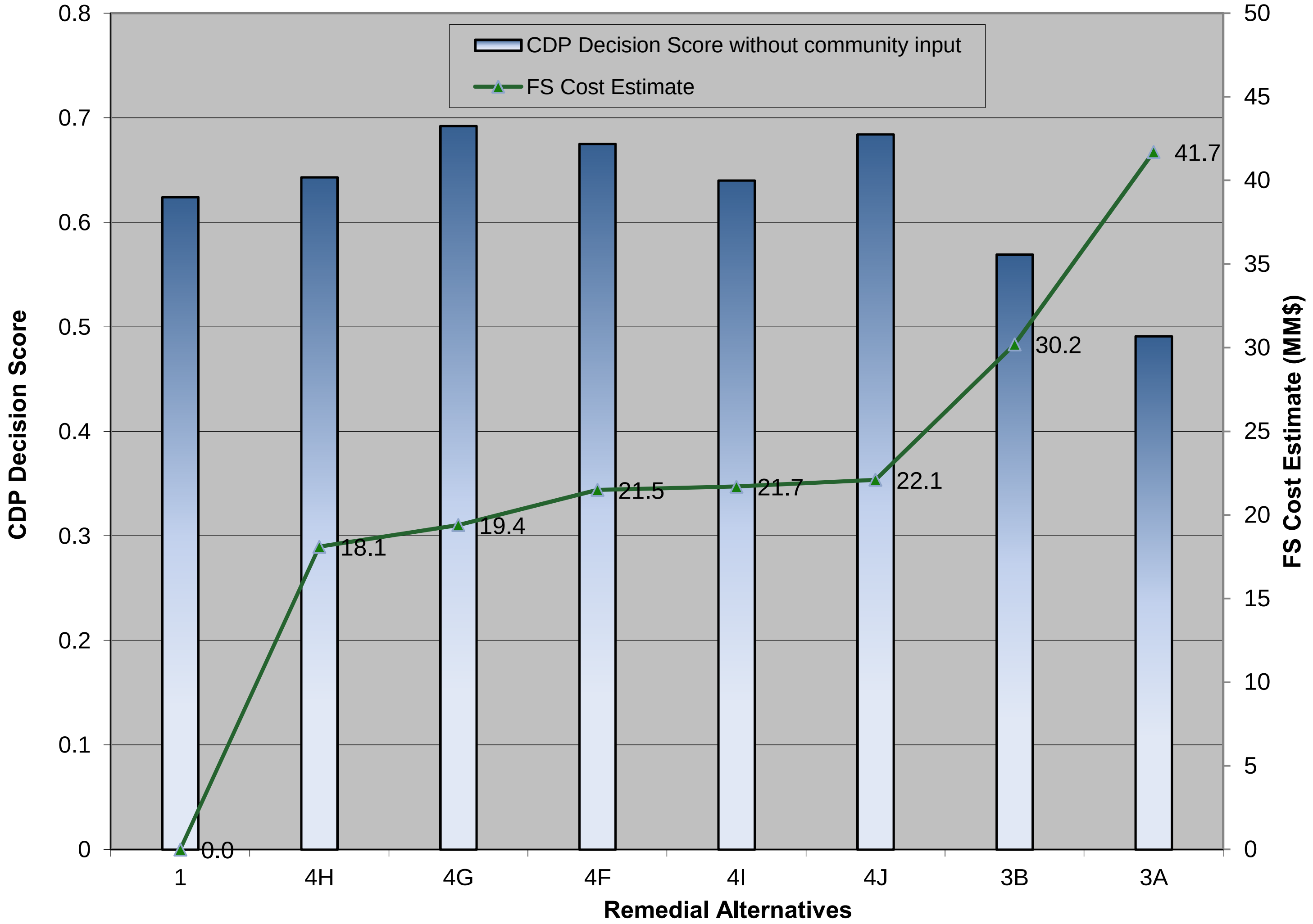
MNR=Monitored Natural Recovery; R.ENR=Reactive Enhanced Natural Recovery; CPC=Cow Pen Creek; DHC=Dark Head Cove

Figure 7-9. Comparative Analysis - CDP Decision Score with Community Input



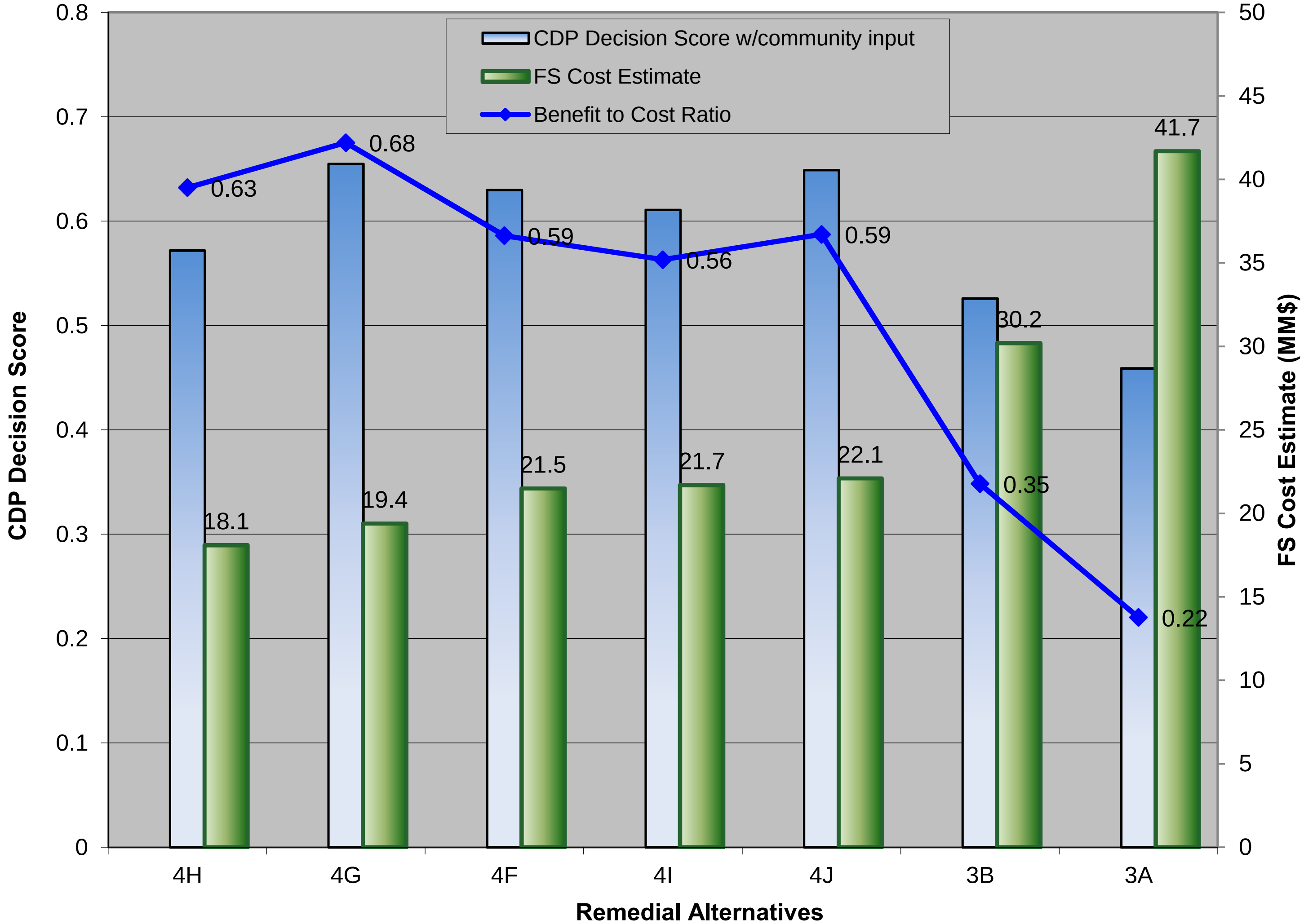
CDP=Criterium Decision Plus; FS=Feasibility Study; MM$=Million Dollar

Figure 7-10. Comparative Analysis - CDP Decision Score without Community Input

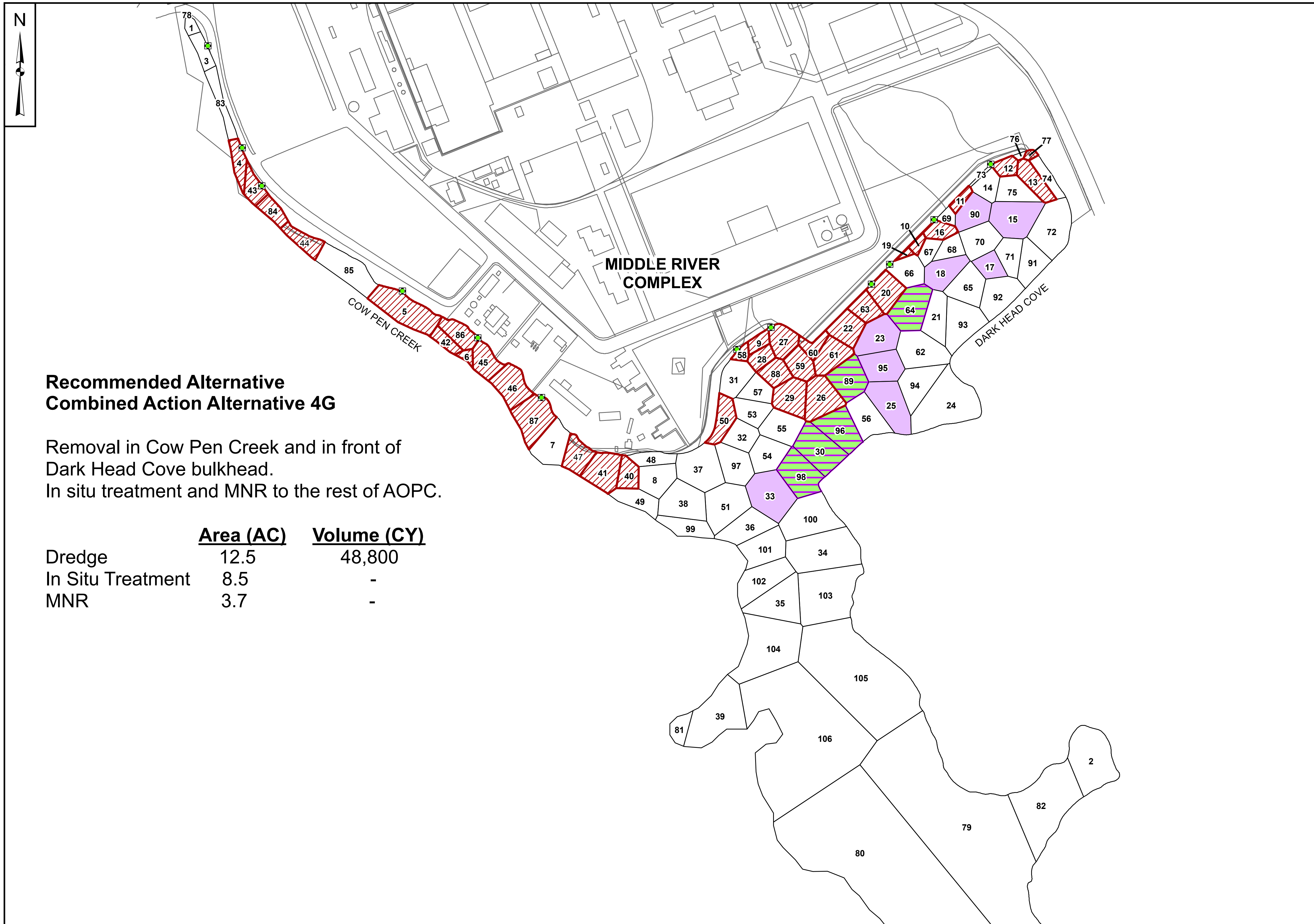


CDP=Criterium Decision Plus; FS=Feasibility Study; MM$=Million Dollar

Figure 7-11. Comparative Analysis - CDP Decision Score with Benefits to Cost Ratio



CDP=Criterium Decision Plus; FS=Feasibility Study; MM$=Million Dollar



Recommended Alternative
Combined Action Alternative 4G

Removal in Cow Pen Creek and in front of Dark Head Cove bulkhead.
In situ treatment and MNR to the rest of AOPC.

	Area (AC)	Volume (CY)
Dredge	12.5	48,800
In Situ Treatment	8.5	-
MNR	3.7	-

TETRA TECH

Figure 7-12
Recommended Alternative
Alternative 4G
Combined Action
Lockheed Martin Middle River Complex (MRC)
Middle River, Maryland

Legend

- Stormwater Outfall Locations
- No Action (Polygon < PRG/RAL)
- In Situ Treatment
- In Situ Treatment + MNR
- Removal
- Buildings/Roads
- 101 Thiessen Polygons and Sample Location Number

PRG = Preliminary Remediation Goal
RAL = Remedial Action Level
MNR = Monitored Natural Recovery
AOPC = Area of Potential Concern

500 250 0 500 Feet

Drawn By: T. WHEATON 07/05/11
Checked By: S. OZKAN 11/19/12
Approved By:

Contract Number: 112IC02903

PGH:P:\GIS\MIDDLE_RIVER\MAPDOCS\MXD\AUG2010_THIESSEN\COMBINEDCOC_THIESSEN_AUG2010_SS_ALT4_CDPRG_ALT4G_REVISED1.MXD 11/19/2012 JN

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