Eagle River Flats

Comprehensive Evaluation Report

Fort Richardson, Alaska
July 1994
Contract No. DACA85-92-D-0007
Delivery Order 0013

Prepared for
U.S. Army Garrison, Alaska
Department of Public Works

Prepared by
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Through contract with
Department of the Army
U.S. Army Engineer District
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William A. Gossweiler, Project Manager

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Abbreviations

ACGIH	American Conference of Governmental Industrial Hygienists
ADEC	Alaska Department of Environmental Conservation
ADFG	Alaska Department of Fish and Game
AEIDC	Alaska Environmental Information and Data Center
AFB	Air Force Base
AFWRC	Alaska Fish and Wildlife Research Center
AOC	area of contamination
ARAR	applicable or relevant and appropriate requirement
BCF	bioconcentration factor
C	Centigrade
CER	Comprehensive Evaluation Report
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980 ("Superfund")
cfs	cubic feet per second
cm	centimeter
ChE	cholinesterase
CNS	central nervous system
COE	U.S. Army Corps of Engineers
CRL	certified reporting limit
CRREL	U.S. Army Cold Regions Research and Engineering Laboratory
CSM	conceptual site model
DNB	dinitrobenzene
DNT	dinitrotulene
DQO	data quality objective
DWRC	Denver Wildlife Research Center
Eh	measure of redox potential
EOD	explosive ordnance disposal
ERF	Eagle River Flats

ESE	Environmental Science and Engineering, Inc.
F	Fahrenheit
FFA	Federal Facility Agreement
FS	feasibility study
GC	gas chromatography
g/cm^3	grams per cubic centimeter
GIS	Geographical Information System
gpm	gallons per minute
GSD	geometric standard deviation
HC	hexachloroethane-zinc mixture
HE	high explosive
HMX	cyclotetramethylenetetranitramine
IRA	interim remedial action
IRIS	Integrated Risk Information System
IRP	Installation Restoration Program
ITC	Interagency Testing Committee
LC_{50}	lethal concentration for 50 percent of a sample population
LD_{50}	lethal dose for 50 percent of a sample population
LOEL	lowest observed effects level
m	meter
m^3/sec	cubic meters per second
MA	methyl anthranilate
µg	microgram
µg/g	micrograms per gram
µg/L	micrograms per liter
mg	milligram
µL	microliter
mg/cm^3	milligrams per cubic centimeter
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mg/m^3	milligrams per cubic meter

mgd	million gallons per day
mL	milliliter
mm	millimeter
MOA	Municipality of Anchorage
msl	mean sea level
mV	millivolt
NEILE	New England Institute of Landscape Ecology
NIOSH	National Institute for Occupational Safety and Health
NOAA	National Oceanic and Atmospheric Administration
NOAEL	no observed adverse effects level
NPL	National Priorities List
NWHL	National Wildlife Health Laboratory
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
P_4	elemental phosphorus
P_4O_{10}	phosphoric oxide
P_4O_6	phosphoric trioxide
PCB	polychlorinated biphenyl
PEL	permissible exposure limit
PETN	pentaerythritol tetranitrate
PWRC	Patuxent Wildlife Research Center
ppb	parts per billion
ppm	parts per million
ppt	parts per thousand
PRG	preliminary remedial goal
QAP_jP	Quality Assurance Project Plan
QA/QC	quality assurance/quality control
QC	quality control
RBC	risk-based concentration
RCRA	Resource Conservation and Recovery Act of 1976
RDX	hexahydro-1,3,5-trinitro-1,3,5-triazine

redox	reduction oxidation
RfD	reference dose
RPM	Remedial Program Manager
smokes	smoke obscurants
tetryl	1,2,4,6-tetranitro-N-metylaniline
TLV	threshold-limit value
TNT	trinitrotoluene
TSCA	Toxic Substances Control Act of 1976
TSS	total suspended sediment
TWA	time-weighted average
USAEC	U.S. Army Environmental Center
USAEHA	U.S. Army Environmental Hygiene Agency
USATHAMA	U.S. Army Toxic and Hazardous Materials Agency
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
USPHS	U.S. Public Health Service
WP	white phosphorus

Section 1
Introduction

1.1 Scope and Purpose of the Comprehensive Evaluation Report

The U.S. Army Corps of Engineers (COE), Alaska District, on behalf of the U.S. Army Garrison at Fort Richardson, Alaska, has contracted with an independent engineering consulting firm to complete a Comprehensive Evaluation Report (CER) for the Eagle River Flats (ERF) area on Fort Richardson. In 1993, Fort Richardson was proposed for inclusion on the National Priorities List (NPL). The NPL is administered by the U.S. Environmental Protection Agency (USEPA) and is used by the USEPA to prioritize contaminated sites across the nation that require action under the federal Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The purpose of the NPL is to inform the public of the most seriously contaminated sites in the nation, through site-specific criteria and a preliminary evaluation of potential contamination that may pose a substantial risk to human health or the environment.

CERCLA requires that federal facilities investigate and clean up contaminated sites according to specific interagency agreements. The U.S. Army is currently negotiating a Federal Facility Agreement (FFA) with the USEPA and the Alaska Department of Environmental Conservation (ADEC) for Fort Richardson. The purpose of the FFA is to ensure that environmental impacts associated with a site are thoroughly investigated and remediated. Work at a Department of Defense NPL site that is carried out under the Installation Restoration Program (IRP) is planned and completed as required by CERCLA according to the terms specified in the FFA.

The ERF site of Fort Richardson is one area that has been investigated under the IRP and is included in the upcoming FFA. The CER is the result of a review and evaluation of the various studies and investigations completed at the ERF since 1982. The CER summarizes and presents the information obtained to date from the ERF investigations. It is designed to assist the U.S. Army and the signatories to the FFA in determining practical, implementable, and effective remedial actions for the ERF.

The CER incudes the following:

- Description of the general site location and environmental setting of the ERF (Section 2)
- Summary of past studies and investigations, including the results and identification of chemicals of concern (Section 3)
- Conceptual site model (CSM) that describes the fate and transport of contaminants and identifies potential data gaps from past studies (Section 4)
- Qualitative assessment of potential risks posed to human health and the environment from the contamination at the site (Section 5)
- Criteria for evaluating treatability studies developed by the USEPA (Section 6)
- Data quality objectives (DQOs) that describe the type, quantity, and quality of existing data and present additional data that may be necessary for evaluating risk, conducting treatability studies, determining cleanup goals and objectives, and completing remedial design (Section 7)

Applicable or relevant and appropriate requirements (ARARs) that must be met during field activities and at the conclusion of remediation are discussed in a separate document. The information presented in the CER will be used to design and implement potential interim remedial actions (IRAs), removals, and treatability studies for the successful remediation of any contamination at the ERF that poses a substantial risk to human health and the environment.

1.2 Background

The ERF is an estuarine salt marsh in the northwest sector of Fort Richardson. Fort Richardson's 55,000 acres include a central cantonment area surrounded by ranges and impact and maneuver areas to the north, east, and south. The Municipality of Anchorage (MOA) and Elmendorf Air Force Base (AFB) lie west of Fort Richardson.

The ERF has been used as the primary ordnance impact area for Fort Richardson since the mid-1940s. The ERF is a 2,165-acre wetland within Fort Richardson at the mouth of Eagle River, adjacent to Upper Cook Inlet (Figure 1-1). The ERF is an important staging ground for several species of waterfowl, including ducks, geese, and swans, during spring and fall migrations. During the peak migration periods, the waterfowl population may total 3,000 to 5,000.

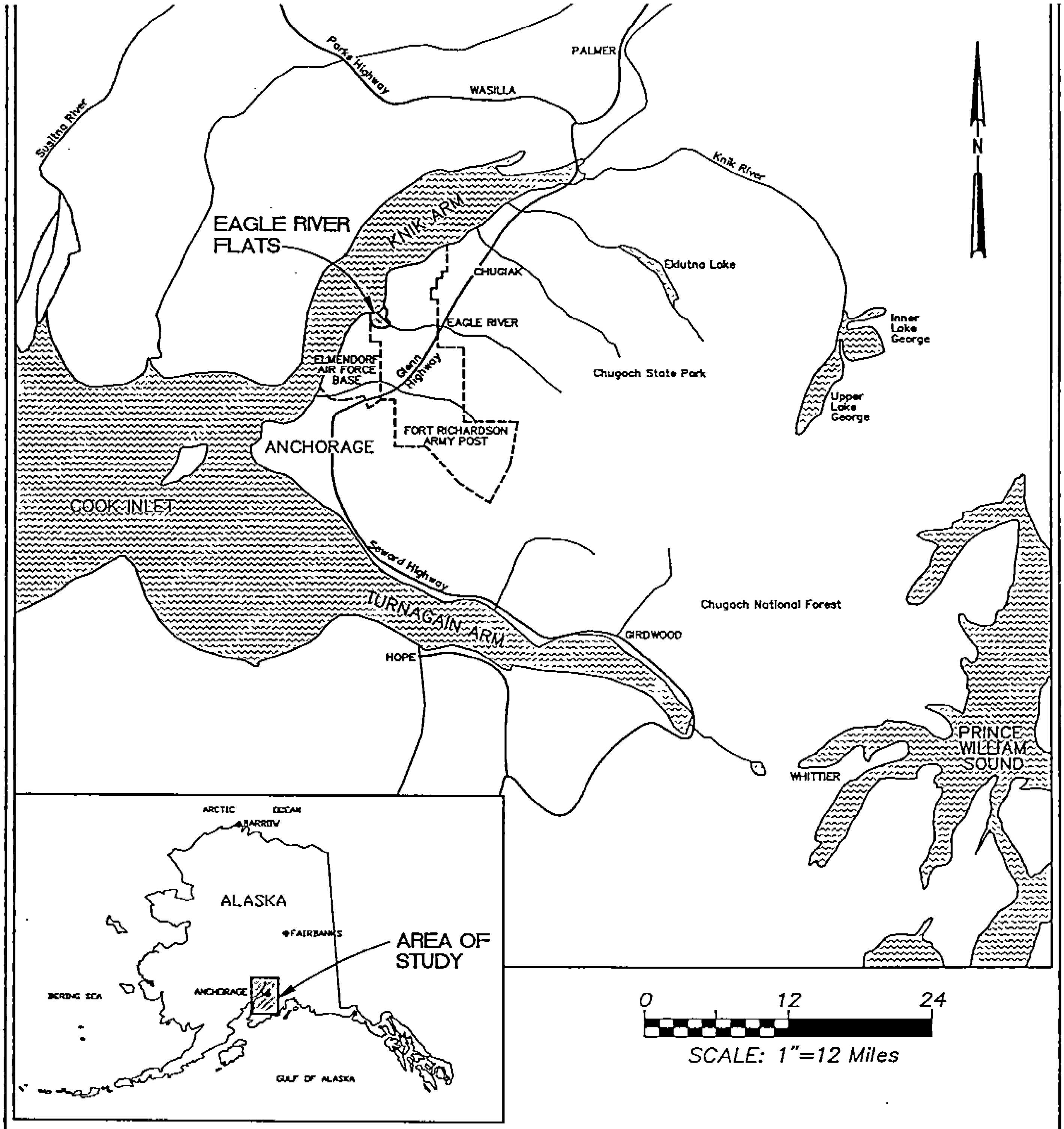
A former explosive ordnance disposal (EOD) pad, where detonation of outdated munitions occurred, adjoins the eastern boundary of the ERF (Figure 1-2). Ordnance fired into the ERF since 1949 include machine gun and rifle rounds, grenades, rockets, and incendiary missiles. Various calibers of artillery and mortar rounds fired into the ERF include smoke obscurants (smokes), illumination flares, and high-explosive rounds.

In 1980, U.S. Army biologists first noticed an unusually high number of waterfowl carcasses, including several dead swans, in the ERF marshes. Between 1982 and 1985, random ground searches were conducted at the ERF by the U.S. Army, the U.S. Fish and Wildlife Service (USFWS), and the Alaska Department of Fish and Game (ADFG). The discovery of abnormally high numbers of dead waterfowl during the searches indicated that a potentially serious problem existed. The dead and dying waterfowl were looked for and observed in several areas, including those referred to as Areas A, B, C, and D (Figure 1-2).

To approach the problem in an organized and scientific manner, an interagency task force was formed in 1987. The ERF Task Force was composed of representatives from the following federal and state agencies:

- U.S. Army
- USEPA
- USFWS
- ADFG
- ADEC

The primary objective of the ERF Task Force was to identify the cause of the waterfowl die-offs and recommend remedial alternatives. Since the formation of the ERF Task Force, several studies and investigations have been conducted to identify contaminants of concern, to characterize the nature and extent of contamination, and to evaluate potential remedial alternatives.



SOURCE: MOA, 1993

FIGURE 1-1
EAGLE RIVER FLATS
LOCATION MAP

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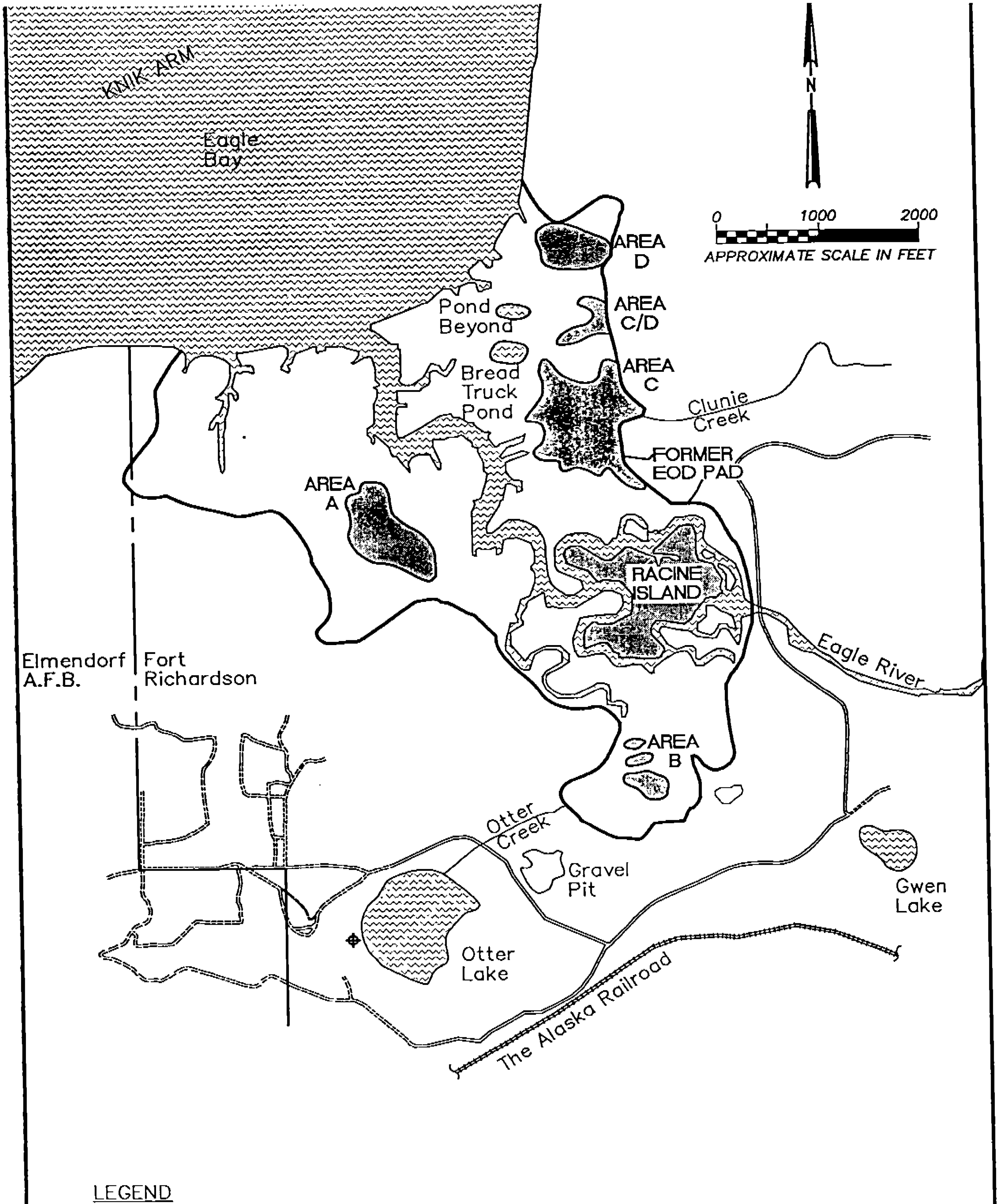


LEGEND

⌖ WATER SUPPLY WELL

SOURCE: RACINE et al., 1992b

FIGURE 1-2
EAGLE RIVER FLATS
SITE MAP

In addition to the ERF Task Force member agencies, other agencies and consultants that have been involved in the investigations at the ERF include the following:

- COE, Alaska District
- U.S. Army Cold Regions Research and Engineering Laboratory (CRREL)
- U.S. Army Environmental Hygiene Agency (USAEHA)
- U.S. Army Environmental Center (USAEC) (formerly U.S. Army Toxic and Hazardous Materials Agency [USATHAMA])
- U.S. Department of Agriculture (USDA)
- Environmental Science and Engineering, Inc. (ESE)

The results of a 1989 study by ESE, under contract to USATHAMA, indicated that chemicals from explosive ordnance were the probable cause for the waterfowl mortality at the ERF. Field and laboratory studies conducted by CRREL between 1990 and 1992 provided evidence that white phosphorus (WP), used in smoke obscurants, was the likely cause of the mortality.

In February 1990, on the basis of the conclusions of the ESE report, the Army temporarily suspended the use of the ERF for live firing until the causative agent of waterfowl mortality was identified. The 1990 CRREL report identified the causative agent to be WP. With this conclusion, the Army initiated a public review process that evaluated alternatives for the resumption of live firing. The ERF was reopened for training uses in January 1992, following a series of test firings, under the following conditions:

- No WP munitions may be used.
- Only point contact detonators may be used.
- A minimum of 6 inches of ice must cover the ERF before it can be used for firing.
- Firing is allowed only between November 1 and March 31.

Section 2

Environmental Setting

2.1 Military Land Uses

The ERF is the only impact area for heavy artillery and mortars on Fort Richardson. Approximately 40 derelict cars and trucks have been placed individually or in groups as targets around the ERF, as shown in Figure 2-1. U.S. Army personnel practice firing at the targets from more than 25 points, located at distances of up to 6-1/4 miles away (Racine, et al., 1992b).

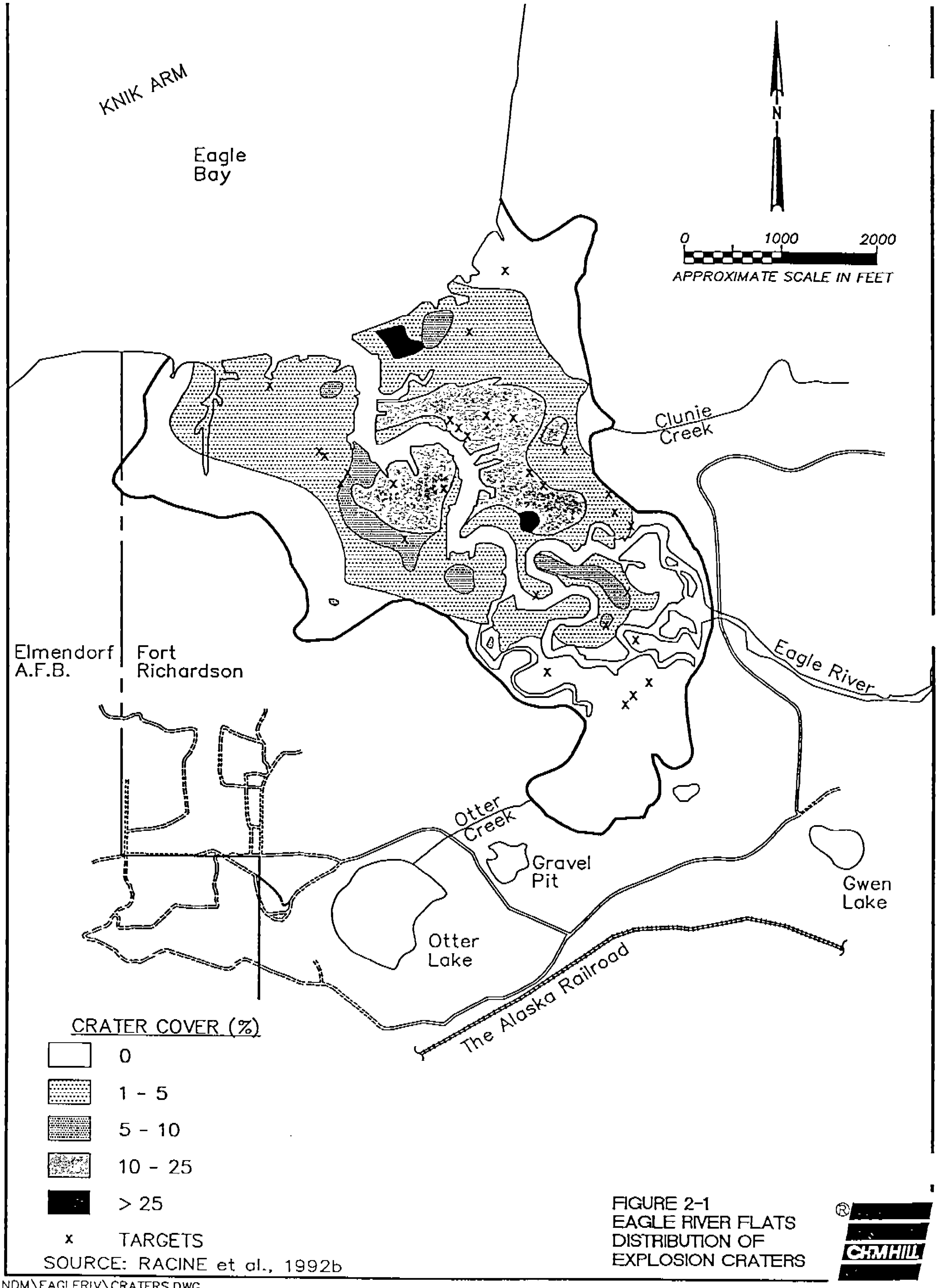
The former EOD pad is a 5-acre gravel pad constructed at least 20 years ago along the east side of the ERF. It is no longer used to detonate outdated munitions, but demolition of propellants on this pad apparently contaminated an area of the salt marsh in the ERF (Racine, et al., 1992b).

Three general types of munitions have been fired onto the ERF. These include high explosives (HEs), smokes, and illumination flares (Racine, et al., 1992b). Table 2-1 lists the munitions and corresponding component filler materials potentially fired onto the ERF.

When an HE projectile is fired at targets in the ERF, it hits the ground, explodes, creates a crater, and spreads fragments of steel (shrapnel) in the vicinity of the impact zone. The HE projectile uses the blast effect and fragmentation to produce casualties. The distribution of explosion craters at the ERF is shown in Figure 2-1.

Smokes are used to obscure or screen the movement of troops and vehicles. Smokes have critical defensive importance in neutralizing enemy sensors and hiding friendly forces and materials. Smoke screens can also be used offensively for immobilizing enemy troops by obscuring their vision (Muhly, 1983; Yon, et al., 1983).

White phosphorus and hexachloroethane-zinc-mixture (HC) smokes are the two most common agents used by the military to produce white smokes in the visible spectrum (Cichowicz, 1983). White phosphorus, consisting primarily of elemental phosphorus, P_4, has been used as a smoke-producing material in munitions since World War I (Yon, et al., 1983). When munitions containing WP are detonated, the phosphorus breaks up into minute



SOURCE: RACINE et al., 1992b

FIGURE 2-1
EAGLE RIVER FLATS
DISTRIBUTION OF
EXPLOSION CRATERS

NDM\EAGLERIV\CRATERS.DWG

Table 2-1
Military Munitions Potentially Fired onto the Eagle River Flats, Fort Richardson, Alaska

Munitions Category	Munitions Description	Filler Material(s)[b]
High Explosives	105mm howitzer, 60mm mortar, 81mm mortar, 107mm mortar, 90mm recoilless rifle, 66mm Light Anti-tank Weapon (LAW), 40mm grenades, 155mm HE artillery[a], Shillelagh missiles[a], 3.5-inch rockets[a]	TNT, RDX, HMX, Comp A3, Comp A5, Comp B, Comp B Grade A, Comp C-4, or Octol
Smokes	105mm howitzer, 60mm mortar, 81mm mortar, 107mm mortar, 40mm grenades	WP (not used since 1990), FS (not used since 1985), and HC
Illumination Rounds	Flares	Mg
Small Arms Ammunition	7.62mm, 5.56mm, and .50 caliber	None

[a] Munitions discovered on an adjacent impact area.

[b] Filler material components:

TNT = Trinitrotoluene
RDX = Cyclotrimethylenetetranitramine
HMX = Cyclotetramethylenetetranitramine
Comp A3 = 90% RDX, 10% wax
Comp A5 = 98.5% RDX, 1.5% stearic acid
Comp B = 60% RDX, 39% TNT, 1% wax
Comp C-4 = RDX, wax
Octol = HMX, TNT
WP = White phosphorus
FS = Sulfur trioxide, chlorosulfonic acid
HC = Hexachloroethane-zinc mixture
Mg = Magnesium

Sources: Tweten, 1989; Racine, et al., 1992b.

particles that disperse over a large area; WP reacts spontaneously with air, forming a pillar of rising smoke. The tendency for the smoke to rise, rather than linger, was considered by the U.S. Army to be a serious inadequacy. In 1944, the problem was solved by plasticizing the WP, and coating the granules with a viscous solution of synthetic rubber in a solvent (Yon, et al., 1983). Another development in WP smoke munitions was to impregnate felt wedges with plasticized WP. Upon deployment, a central burster charge separated the wedges.

The hexachloroethane-zinc mixture is a pyrotechnic smoke-producing composition of aluminum, zinc oxide, and hexachloroethane. It is also used in smoke pots, which produce large volumes of smoke for extended periods of time on land or water.

In 1978, a fire destroyed the ERF range control building. Also lost in the fire were records of munitions fired onto the ERF before 1978. Tables 2-2 and 2-3 summarize the only available documentation of use of WP munitions at the ERF. Table 2-2 lists the rounds fired into the ERF between April and December 1989. Table 2-3 lists the number of WP rounds fired into the ERF between January 1987 and February 1989.

Table 2-2
Summary of White Phosphorus Rounds Fired into the ERF
Between April and December 1989

Projectile	Type	Number of Rounds
60mm mortar	HE WP Illumination	1,983 106 146
81mm mortar	HE WP Illumination	1,520 105 94
105mm howitzer	HE WP Illumination HC	2,173 27 459 132
107mm mortar	HE WP Illumination	96 36 27
Total Rounds		6,904

Source: Racine, et al., 1992b.

Table 2-3
Number of White Phosphorus Rounds Fired onto the ERF between January 1987 and February 1990

Projectile	Number of Rounds per Calendar Year				Average Rounds per Year	Average WP Weight per Round (kg)	Average WP Weight per Year (kg)
	1987	1988	1989	1990			
60mm mortar	187	57	135	29	136	0.35	48
81mm mortar	287	210	120	29	215	1.30	280
105mm howitzer	72	35	38	18	54	1.77	96
Total							424

Source: Racine, et al., 1992b.

The data in Table 2-3, extrapolated to provide an estimate of WP fired into the ERF between 1950 and 1990, indicate that approximately 17,000 kilograms (kg) may have been fired into the ERF. This is considered a conservative estimate for the following reasons:

- Current U.S. Army policy is to discontinue use of munitions if there is higher than a 10 percent dud rate (past practices may not have been so stringent).
- Dud rates tend to be lower when firing onto a hard target such as ice (in the past, training exercises also occurred during the warmer months when the marshes had soft bottom-muds).

Because the quantities and locations of unexploded ordnance in the ERF are unknown and may never be fully neutralized, it is likely that future land uses there will be tied to continued restricted access by the U.S. Army.

2.2 Demographic Characteristics and Water Supply

The community of Eagle River lies within the boundaries of the Municipality of Anchorage, about 4 miles upstream of the nearest point of the ERF (Figure 1-1). At the time of the 1990 census, the Eagle River community had a population of about 6,000 and an average of 3.1 persons per residence (MOA, 1993). Most residential and commercial development in the Eagle River community is on the east side of the Glenn Highway (Figure 1-1) (MOA, 1993). No one resides, works, or attends school within or immediately downstream of the ERF.

The primary source of drinking water for the residents of the Eagle River community is surface water from Eklutna Lake, 15 miles to the northeast. Most residents of the urban/suburban Eagle River area are served by the MOA water system (MOA, 1993). Those residences and businesses outside of the MOA water system service area use private wells for a water supply. However, there is only one water supply well within a 4-mile radius of the nearest point of the ERF (U.S. Geological Survey [USGS], 1993). The well is at Otter Lake Lodge on the west shore of Otter Lake (Figure 1-2) and is either upgradient of or cross gradient to the ERF contamination. Therefore, no present threat appears to exist to human health as a result of groundwater contamination from the ERF.

2.3 Climate, Geology, and Hydrology

2.3.1 Climate

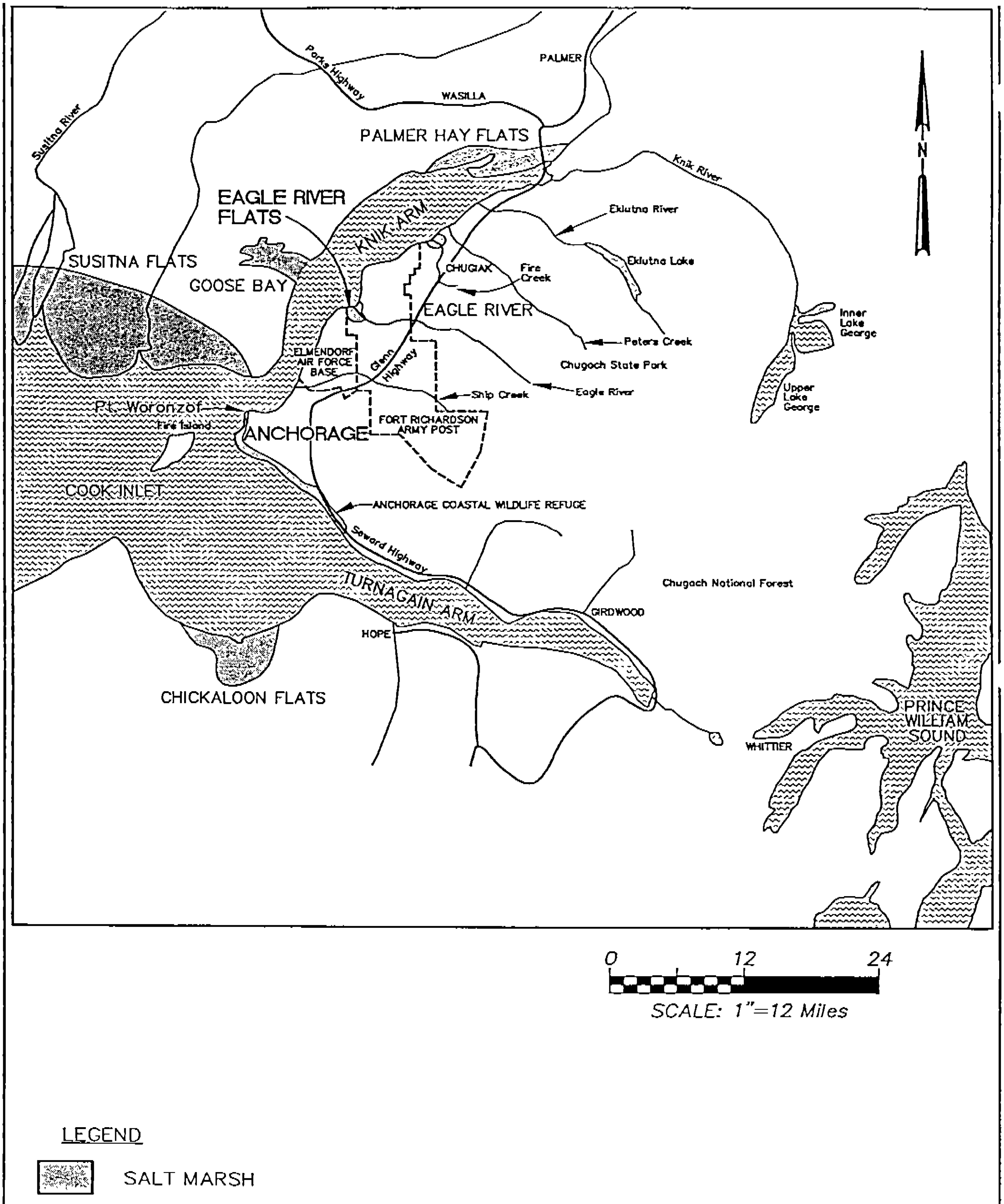
A transitional climate zone provides a relatively moderate climate for the Anchorage area. The Alaska Range, north and northwest of Anchorage, prevents the influx of very cold air from the Interior, and the waters of Cook Inlet, including Turnagain Arm and Knik Arm to the northwest and southwest, help warm the area. Average temperatures recorded for the period 1952 to 1987 ranged from -2°C to 7°C, with an annual mean of 3°C. Extreme temperatures ranged from -18°C to 33°C (Alaska Environmental Information and Data Center [AEIDC], 1989). Air masses from the Gulf of Alaska (to the south) produce relatively heavy rainfall along the Chugach Range and can contribute to high runoff events in the rivers draining the mountains, including Eagle River. The heaviest precipitation occurs between July and September, with an average rainfall of almost 7 inches falling during the 3-month period. Annual average rainfall is between 13 and 20 inches (AEIDC, 1989).

2.3.2 Topography

A roughly triangular lowland, the Anchorage area lies between Turnagain Arm and Knik Arm, at the head of Cook Inlet (Figure 2-2). The Chugach Mountains rise abruptly east of Anchorage to elevations of more than 3,500 feet. From an elevation of 1,000 feet at the mountain front, the lowland declines into the Anchorage plain and to the coast. The Anchorage plain is a large alluvial fan that extends from the mountain front westward and northwestward. Steep bluffs, broken only by principal streams such as Eagle River, mark the edge of the lowland as it drops abruptly to the sea.

2.3.3 Regional Geology

Bedrock in the Chugach Mountains consists of metamorphic rocks, principally the McHughs Complex, which is composed of weakly metamorphose siltstone, lithic sandstone, arkose, and conglomerate sandstone. Bedrock beneath the Anchorage lowland consists of relatively soft, clastic sedimentary rocks of the Tertiary-period Kenai Formation. These rocks do not crop out on the surface, being covered with younger alluvial and glacial surface deposits, and are in fault contact with the metamorphic rocks of the McHughs Complex. This steeply dipping normal fault, the Border Ranges Fault, forms the abrupt front of the Chugach Mountains. The alluvial fan complex of surficial material that makes up much



SOURCE: RACINE et al., 1992b

FIGURE 2-2
EAGLE RIVER FLATS
AND OTHER COOK
INLET SALT MARSHES

CH2M HILL

of the Anchorage plain starts at the mountain front and slopes downward and thickens to the west and northwest. Thicknesses of material range from zero at the mountain front to greater than 900 feet at Pt. Woronzof. The upper part of this fan is chiefly composed of well-bedded and well-sorted gravels, grading into sand toward the west. These thin surface-gravel deposits are between 30 and 100 feet thick. Underlying the surface gravels is the Bootlegger Cove clay, a 60- to 200-foot layer of clay and silt with interbeds of fine sand. Beneath the clay layer is a 100- to 200-foot layer of sand and gravel that constitutes the main aquifer in the Anchorage area.

The Bootlegger Cove clay serves as a confining layer between the upper and lower gravel layers. It also serves to intercept and attenuate downward-moving pollutants that may be locally present in the shallow groundwater (Brown, et al., 1987). The confining action of the clay produces artesian effects in the lower gravel aquifer as water moves from the recharge area in the foothill downslope through the gravel. The groundwater in this lower gravel layer eventually discharges into Knik and Turnagain Arms. Large-capacity wells drilled into this lower aquifer can produce 700 to 1,500 gallons per minute (gpm) of water. An estimated 75 million gallons per day (mgd) of groundwater enters the confined aquifers of the lowlands (Selkregg, 1972). Beneath the lower gravel layer is a thick layer of poorly sorted glacial deposits, which are, in turn, underlain by sedimentary bedrock.

The northern third of the Anchorage lowland consists of a complex of glacially deposited materials. These materials include morainal deposits of the Elmendorf Moraine, marking the margin of the former glacier occupying Knik Arm. Other glacial deposits consist of diamicton and other unsorted or poorly sorted till material, and glacial alluvium, including glacial outwash gravels, kames, and kame terraces deposited at the edge of the former glacier.

Fort Richardson straddles both the alluvial fan gravels of the Anchorage plain and the moraine and glacial alluvium complex near the shore of Knik Arm. The gravel alluvium of the Anchorage plain underlies the main cantonment. The well-bedded and well-sorted gravels and sands provide good foundation conditions and plentiful construction material. The confined gravel aquifer is from 200 to 400 feet below the surface in this area of the installation (Selkregg, 1972). Groundwater flow in this confined aquifer would be in a generally western to northwestern direction.

Just north of the main cantonment is the southern edge of the Elmendorf Moraine, a hummocky, long series of ridges running east-west across Fort Richardson and Elmendorf AFB, roughly parallel to Knik Arm. Elevations of the moraine rise to more than 300 feet, especially in the west, on Elmendorf AFB. The moraine is chiefly till, including diamicton and poorly sorted gravel. North of the Elmendorf Moraine is a complex of moraine and glacial alluvium deposits in the form of irregularly shaped hills.

The complex of hills just south of the south end of the Eagle River Flats is part of this glacial alluvium deposit. Further north, on either side of the ERF, are more moraine deposits. These deposits are more subdued in topography than the Elmendorf Moraine.

2.3.4 Surface Drainage

The ERF formed as Eagle River eroded through the alluvial deposits of the Anchorage lowland to create a deep valley, which later filled with fine-grained terrestrial and marine sediments. Evidence of the glacial alluvium can be seen as poorly sorted gravels in the steep bluffs surrounding the ERF.

With an average flow rate of 519 cubic feet per second (cfs), Eagle River drains approximately 192 square miles of mountains and lowlands. Glaciers cover 13 percent of the drainage basin. The river reaches peak discharges of more than 70 cubic meters per second (m^3/sec) in July and August, but a particularly heavy rainfall or high runoff from glaciers can generate a discharge greater than 103 m^3/sec (Racine, et al., 1993).

In addition to Eagle River, several small tributary streams enter the ERF. Otter Creek, a small perennial stream, drains Otter Lake and enters the ERF near its southern end (Figure 2-1). Clunie Creek drains several small lakes within the moraines to the east and northeast of the ERF and enters the ERF just north of the former EOD pad (Racine, et al., 1993).

2.3.5 Siltation and Sedimentation

During the summer, Eagle River carries a moderate suspended-sediment load derived from glacial melt and runoff. USGS data collected in the early 1970s indicate that a summer mean daily suspended sediment load for Eagle River ranges between 100 and 300 milligrams per liter (mg/L) but increases to 400 to 700 mg/L during high discharge periods. The maximum recorded sediment load is 1,810 mg/L (USGS, 1990). These sediment loads are fairly low for glacially fed rivers in Alaska. In comparison, the Knik River has a mean daily concentration during the summer of 1,400 mg/L, concentrations near 4,000 mg/L during high discharge periods, and a maximum recorded sediment concentration of 6,290 mg/L.

The waters of Knik Arm also contain a moderate suspended-sediment load derived from the glacially fed rivers emptying into it, such as the Matanuska and Knik rivers. Each time the ERF is inundated, either by water from Eagle River or by tidal water from Knik Arm, silts and clays settle out of the water or ice covering the flats and are deposited, both on the mudflats and in the shallow ponds. In other areas, sediment erosion is occurring. Sedimentation and erosion processes may play a role in the fate and future distribution of WP particles.

The 1964 earthquake caused land subsidence of about 2 feet along the shore of Knik Arm and probably increased flooding and the deposition of sediments at the ERF (Small and Wharton, 1972). Annual net sedimentation rates at the ERF have not been measured, but annual net rates determined on other mudflats in upper Cook Inlet are 0.5 to 1.3 centimeters (cm) per year. Between May 1992 and September 1993, Lawson, et al., conducted studies at several locations around the ERF to measure gross sedimentation rates (Lawson, Bigl, and Bodette, in Racine, et al., 1994). Gross sedimentation rates of 20 to 40 mm were recorded at pond sites and were much higher than rates of 1 to 5 mm recorded at levees.

The deposited sediments become the substrate of the ponds, mudflats, and marshes. Here, organic material is incorporated into the sediments as plants and animals die, causing a series of complex chemical reactions. The highly productive salt marsh produces large amounts of organic carbon, which becomes the basis of oxidation-reduction reactions (respiration). Since oxygen is rapidly exhausted in these flooded, organic-rich sediments, other electron acceptors, such as sulfate, become important. A major product of sulfate reduction is hydrogen sulfide, which exudes a characteristic odor that is pervasive in the ERF. Because WP is highly reducing (it readily donates its electrons), the absence of an electron acceptor (oxygen) in the highly reduced salt marsh sediments means that WP will persist there.

More than 200 measurements of sediment reduction oxidation (redox) potential were made during the 1991 field season (see Subsection 3.1.5) from different vegetation zones, water depths, and sediment types. All redox values (Eh) were negative. In Area C, Eh varied from -100 millivolts (mV) on mudflat samples to -400 mV in the black organic sediments associated with bulrush areas. The sediments have pH values ranging from 7 to 8, or neutral to alkaline, as determined by analysis of 36 water and sediment samples from the ERF.

2.3.6 Salinity

The salinity of the surface water varies seasonally within the ERF, particularly in relation to the distance from freshwater inlet streams along the edge of the ERF. Salinity measurements were made at 20 locations throughout the ERF. Salinity values at these locations ranged from less than 1 to 46 parts per thousand (ppt). The majority of the values were 10 ppt or less, with all but one of the rest being between 20 and 40 ppt. Measurements were made in ponds, gullies, and Eagle River. These data indicate the influence of both saltwater and freshwater inputs and reflect the complexity of the surface water hydrology in the ERF.

2.4 Ecological Characteristics

The most complete available descriptions of the ecological setting of the ERF are provided by Racine, et al. (1993 and 1994). This section summarizes Racine's description, as well as information from earlier reports.

Fort Richardson supports a variety of habitats, including the following (Gossweiler, 1984):

- **Alpine tundra**–Occurring at elevations greater than 600 meters (m) above mean sea level (msl), this zone constitutes 15 percent of Fort Richardson's land area.

- **Sub-alpine habitat**–A transition zone between the forested mountains and the alpine, this zone occurs at elevations of about 450 to 600 m above msl and constitutes 6 percent of Fort Richardson.

- **Forest habitats**–Lying just below the sub-alpine zone, this zone dominates from a few meters above msl to about 450 m above msl, and covers about 62 percent of Fort Richardson.

- **Shrub thickets**–Occurring primarily on disturbed sites, this zone provides the highest quality moose habitat on Fort Richardson.

- **Bogs**–Bogs occur in moist, poorly drained basins or depressions and are characterized by a thick layer of partially decomposed vegetative matter, or peat, in cold, water-logged soils.

- **Marsh**–Although both freshwater and saltwater marshes occur on Fort Richardson, salt marshes are found exclusively within the ERF. Marshes comprise the most critical habitat for waterfowl on the ERF. Two creeks, Clunie and Otter, drain into the ERF and contribute to the marshland there (Figure 2-1). Numerous tidal sloughs also occur on the ERF and dozens of shallow ponds contain water-tolerant plants that root in waterlogged soil. Other salt marshes on Knik Arm include Fire Creek, just north of the ERF, Goose Bay, and Palmer Hay Flats (Figure 2-2). Susitna Flats, at the lower end of Knik Arm, is one of the largest intertidal salt marshes in Cook Inlet. Chickaloon Flats is located south of Anchorage on the Turnagain Arm of Cook Inlet.

Photographs of various habitats and portions of the ERF can be found in recent CRREL reports, including *Remedial Investigation Report: White Phosphorus Contamination of Salt Marsh Sediments at Eagle River Flats, Alaska* (Racine, 1992a; Racine, et al., 1994).

2.4.1 Elevations–Flooding Frequencies and Zones

Landforms, vegetation, and expected tidal flooding frequencies change with elevation (Racine, et al., 1993). A generalized pattern of decreasing elevation creates a series of zones or landforms from levees to mudflats to brackish ponds and marshes. Measured elevations vary from less than 1 m above msl at the river bottom of Eagle River to 5.5 m on top of the highest levees near Eagle River. Distributary channels (or gullies) cut deeply through the mudflats and connect ponds with Eagle River.

Subtle changes in elevation of the channel floors dictate whether tidal flooding occurs daily, occasionally, or rarely. Where bottom elevations of the gullies are 2.2 to 3.75 m, flooding occurs daily during high tides. Between 3.75 and 4.0 m above msl, flooding occurs only with the highest tide of each month; only extreme high tides, in combination with high river discharge levels, flood areas between 4.4 and 5.0 m above msl (Racine, et al., 1993).

2.4.2 Landforms and Vegetation

The landforms associated with different elevations and flooding frequencies include distributaries, levees, mudflats, ponds, and marshes (Racine, et al., 1993). Different types of vegetation are associated with each landform.

Distributaries

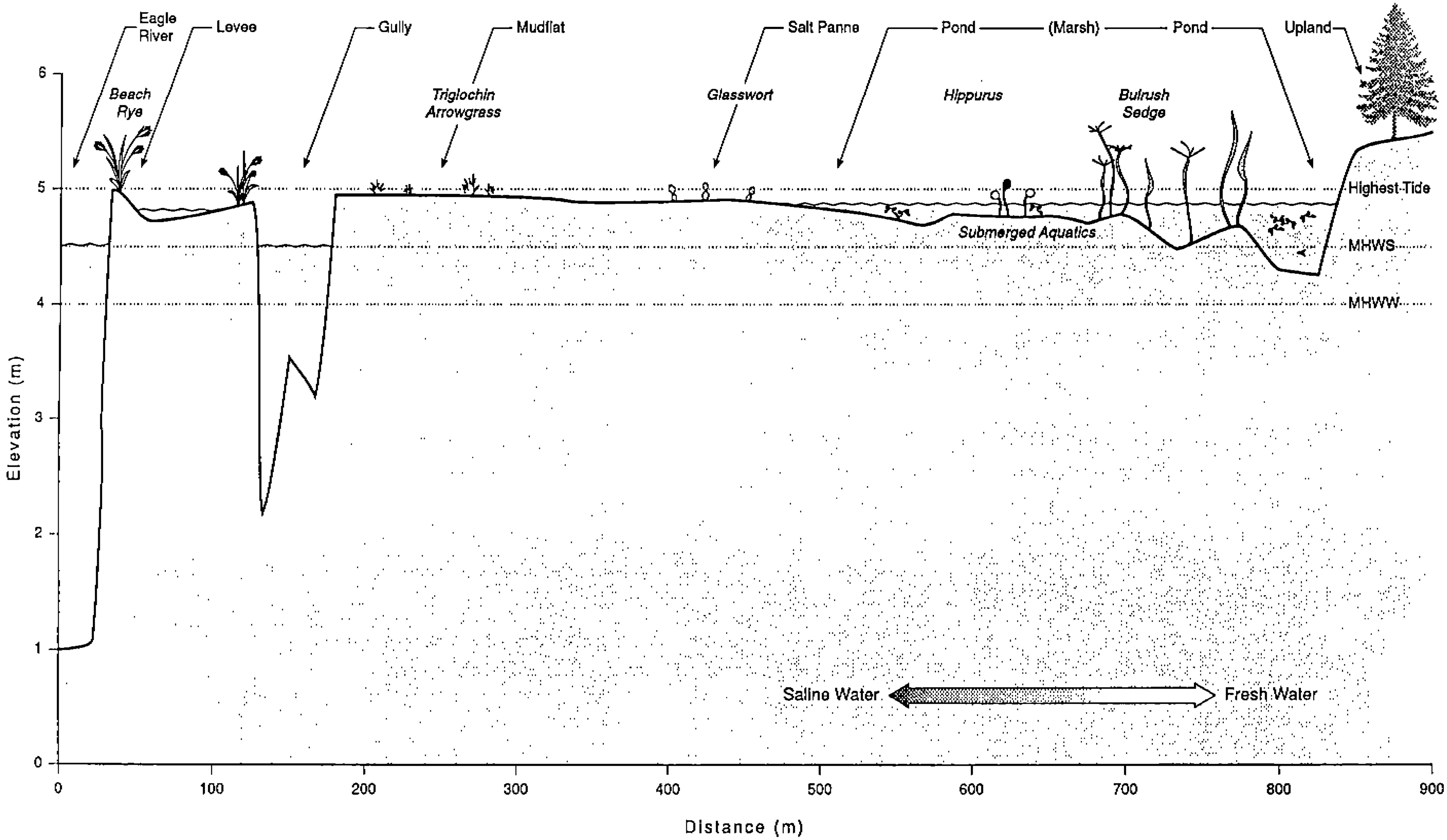
Distributary channels compose an important drainage system for the ERF and connect the ERF ponds to the main channel of Eagle River. These distributaries are probably formed by the movement of tidal water and runoff. While the distributaries near Eagle River have eroded deeply into the sediments to form gullies, farther away they form shallow, vegetated depressions that frequently reach back into ponds (Figure 2-3). The ponds may have formed when the outlet of one of these drainages became dammed by vegetation or shifting sediments. A pond could also drain if headward erosion were to cut back into it (Racine, et al., 1993).

Levees

Natural levees occur along the edge of Eagle River and the larger distributary streams near Eagle River. In the ERF, tall stands of beach rye (*Elymus arenarius*) grow on levees that are higher than 4 m above msl. Old levees, set far back from Eagle River, support dense stands of sedge lawn dominated by the sedge *Carex ramenskii* (Racine, et al., 1993).

Mudflats

Vegetated mudflats in the ERF are dominated by arrowgrass (*Triglochin maritimum*) with occasional patches of goosetongue (*Plantago maritimum*) (Racine, et al., 1993). Sparsely vegetated mudflats occur closer to the shallow ponds; and usually along their edges. Salt-tolerant species such as alkali grass (*Puccinellia hultenii*), glasswort (*Salicornia europea*), and *Atriplex Gmelini* grow there.



Note: Features other than surface profile are not drawn to scale.
Vertical exaggeration is 78x.
SOURCE: Racine, et al., 1993

MHWS = Mean high water summer
MHWW = Mean high water winter

FIGURE 2-3
EAGLE RIVER FLATS
CROSS SECTION FROM AREA C TO UPLAND

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Ponds

As the major feeding areas for dabbling ducks and swans in the ERF, ponds have become the focus for the wildlife mortality studies there (Racine, et al., 1993). Shallow mudflat ponds (3 to 15 cm deep) frequently become dry during certain times of the summer; deeper, permanent ponds that vary in depth from a few centimeters to more than 50 cm and are near the upland edge of the ERF are fed by freshwater streams or springs. Salinity in the permanent ponds varies from as much as 20 ppt on the shallow outer edge to less than 5 ppt near freshwater streams or springs. Beavers and muskrats live in the permanent ponds, near the inflows. Dense stands of grasses (*Calamagrostis* sp.), sedges (*Carex aquatilis*), and shrubs (*Myrica gale*) grow on pond banks. The deeper soils there are highly organic and reduced.

Submerged aquatic vegetation in the permanent ponds includes horned pondweed (*Zannichellia palustris*), pondweed (*Potamogeton pectinatus*), and ditch grass (*Ruppia spiralis*) (Racine, et al., 1993). Emergent vegetation includes clumps of sedge, bulrush, and mares tail (*Hippurus tetraphylla*). Islands and raised ridges of sedge lawn are vegetated with *Carex ramenskii*.

Marshes

Two types of marsh dominate the ERF: the tall, coarse sedge marsh and the bulrush marsh. The sedge *Carex lyngbyaei* dominates tall, coarse sedge marsh and grows to 1 m tall. Its roots form a very dense and tight mat under shallow, standing water. Racine, et al. (1993) notes, "A well-developed stand of this type borders the former EOD pad and extends to the south end of the Area C ponds. It is also well developed around Otter Pond, a small pond located at the south end of Area A (Figure 1-2). This tall, coarse sedge zone is by far the most heterogeneous zone and varies greatly within the ERF."

Marshes composed mostly of bulrushes (*Scirpus* sp.) are also numerous in the ERF. Water depth and elevation of the pond bottom dictate the species of bulrush present. The bulrush marshes are particularly extensive between the semi-permanent intertidal ponds and the permanent ponds east of Eagle River. Racine, et al. (1993) notes that:

> In Area A, bulrush (*S. paludosus*) occurs extensively in the ponds but appears to be dying. These stands may have been buried by silt because of

> ground subsidence caused by the 1964 earthquake. Neiland (1971) noted that in Chickaloon Flats the bulrush community was once far more extensive than at present. As in ERF, Neiland also found the most vigorous bulrushes at the edges of the wettest areas with coarse sedge marsh.

The ERF can be divided into five generalized geomorphic and vegetation zones on the basis of features described above (Racine, in Racine, et al., 1994). These zones are illustrated in Figure 2-4 and are summarized in Table 2-4. They include (1) a mudflat/distributary zone covering about 30 percent of the marsh; (2) a sedge meadow zone (10 percent); (3) a pond/marsh zone (30 percent); (4) an inner marsh complex (20 percent); and (5) a bordering shrub/tree zone (5 percent). The broad channel of Eagle River covers the remaining 5 percent. The various zones of the ERF can be further divided into 18 general habitat types, as listed in Table 2-4 (for example, arrowgrass-vegetated mudflats).

Vegetation zones in the ERF are relatively well defined and oriented in relation to both the long estuarine channel of Eagle River and the Cook Inlet coastline (Racine, in Racine, et al., 1994). In contrast, vegetation zones in both nearby Susitna Flats and Chickaloon Flats tend to form bands that run roughly parallel to the Cook Inlet shore (Quimby, 1972). Those salt marshes have a high width-to-length ratio, and zonation may therefore be dominated by coastal-tidal rather than riverine flooding influences (Racine, in Racine, et al., 1994).

Species and vegetation types typical of other Cook Inlet salt marsh floras also occur in the ERF with some conspicuous differences (Racine, in Racine, et al., 1994). *Puccinellia phryganodes*, a major salt marsh species of Alaska, is absent or rare in the ERF, but is described as a major part of the mudflat vegetation at Goose Bay (Hanson, 1951), Chickaloon Flats (Quimby, 1972), and Susitna Flats (Vince and Snow, 1984). Because it is a primary colonizer of exposed muds in salt marshes, its absence from the ERF may result in greater rates of erosion. However, other mudflat species such as arrowgrass form well-developed stands on portions of the mudflat. *Glaux maritima* is another species that is common in these other Cook Inlet marshes but rare at the ERF. In the ERF, annual species such as *Atriplex* and glasswort are relatively abundant, possibly because of the past frequent disturbance of the mudflat sediments created by high-explosive shell impact craters (Racine, in Racine, et al., 1994).

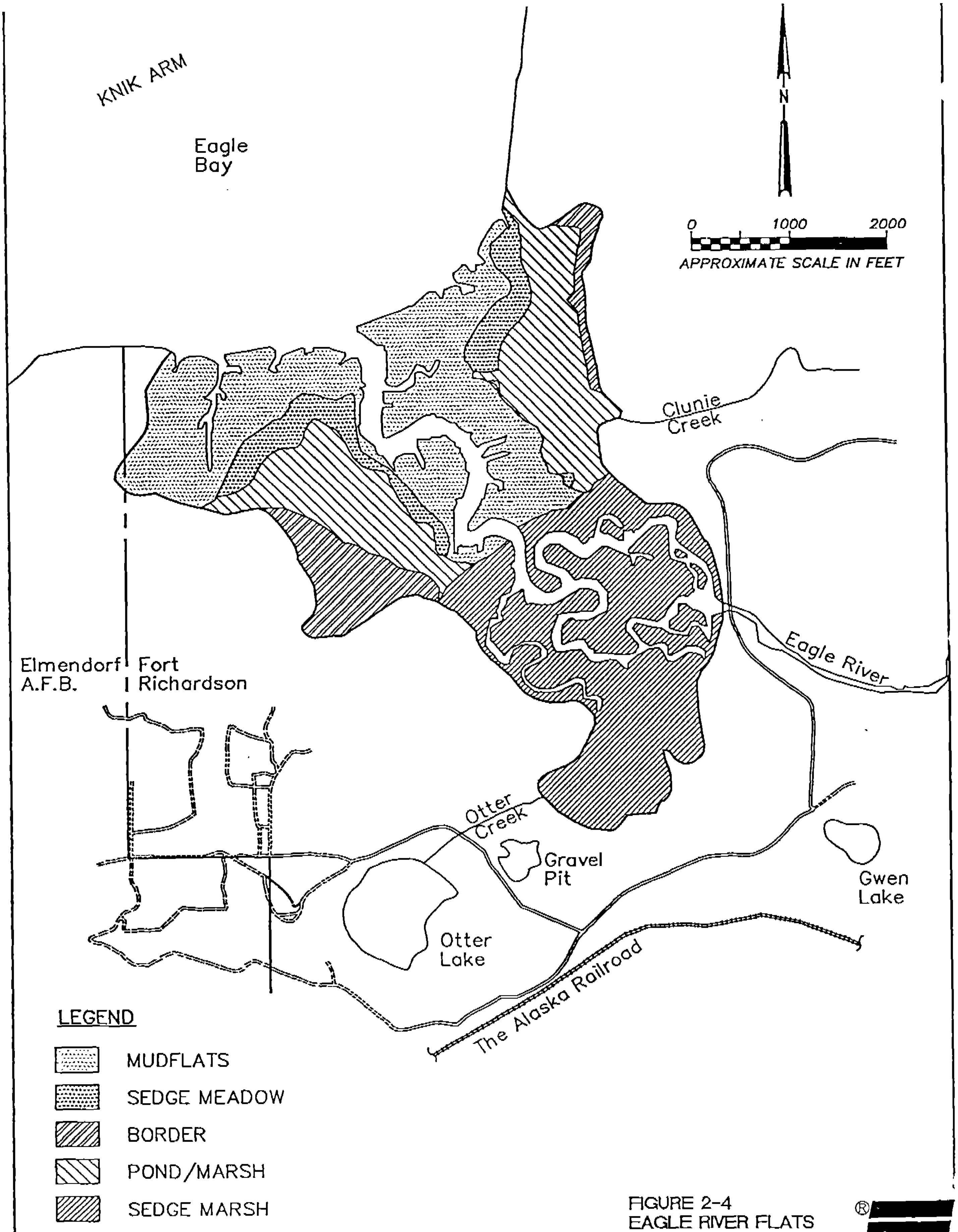

FIGURE 2-4
EAGLE RIVER FLATS
MAJOR VEGETATION
LANDFORM ZONES

CH2M HILL

SOURCE: RACINE et al., 1994

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Table 2-4
Hierarchical Classification of Vegetation and
Landforms in the Eagle River Flats

I. Mudflat/Distributary Zone
  1. Unvegetated Mudflat
     (*Puccinellia Hultenii, Salicornia europea, Atriplex Gmelini*)
  2. Vegetated Mudflat
     a. Arrowgrass (*Triglochin maritima*)
     b. Plantain (*Plantago maritima*)
     c. Beach rye (*Elymus arenarius, Potentilla egedii*)
  3. Gully Banks
  4. Shallow Ponds

II. Sedge Meadow Zone (old levees, pond borders)
  1. Ramenski's sedge (*Carex Ramenskii, Triglochin maritima*)

III. Pond/Marsh Zone
  1. Deep Ponds (>10 cm deep)
     a. Submerged aquatics (*Zannichellia palustris, Potomogeton sp., Ruppia spiralis*)
     b. *Hippurus tetragona*
  2. Shallow Ponds (<10 cm)
     a. No aquatic vegetation
     b. *Salicornia europea, Triglochin maritima* (during drying cycle)
  3. Bulrush Marsh
     a. Tall bulrush (*Scirpus validus*)
     b. Low bulrush (*Scirpus paludosus*)
  4. Sedge marsh (*Carex Lyngbyaei*)

IV. Inner Marsh Zone Tall-coarse Sedge Marsh (*Carex Lyngbyaei*)
  1. Deep Ponds
  2. Bulrush marsh

V. Bordering Shrub/Spruce Zone
  1. Shrub-grass (*Myrica gale, Calamagrostis sp., Carex sp.*)
  2. Black spruce-sedge
  3. Floating sedge mat (*Carex pleuroflora, C. mackenziana, C. Lyngbyaei*)

Source: Racine, in Racine, et al., 1994.

The abrupt transition from mudflat to Ramenski's sedge meadow seen at the ERF (mainly on the west side of the river [Racine, in Racine et al., 1994]) was also noted at Susitna Flats and Chickaloon Flats (Vince and Snow, 1984; Quimby, 1972). However, this zone, while well developed along the coastal reach of the ERF, is fragmented or missing further inland along the Eagle River portion of the salt marsh (Racine, in Racine, et al., 1994). At Chickaloon Flats, Neiland (1971) also mentions that the Ramenski's sedge community often surrounded the heads of drainage ditches and their feeder streams as broken patches.

A pond/marsh complex similar to the marsh communities at Chickaloon Flats described by Neiland (1971) occurs inside the Ramenski's sedge meadow at the ERF. It is a combination of the Bulrush and Coarse Sedge Community (Racine, in Racine, et al., 1994). At Sustina Flats, an "inner sedge marsh" composed of Lyngbyaei's sedge, *Scirpus paludosus*, and the tall dark-green *S. validus* is recognized by Vince and Snow (1984). In Susitna Flats, Vince and Snow (1984) noted that both bulrush species occur in association with deeper ponds (>10 cm) as they do in the ERF. Neiland (1971) noted that in Chickaloon Flats, *S. paludosus* marsh is not as extensive as it was. The degeneration of many bulrush stands may be related to increased sedimentation following the 1964 earthquake. This senescing of bulrush vegetation was also observed in the ERF, particularly in ponds on the west side of the river, where it occurs as sparse stunted plants (Racine, in Racine, et al., 1994). The earthquake induced lowering of the marsh surface, and saltwater incursion may also reduce the extent of bulrush marsh but may increase the extent of the open-water pond areas. Other forces following the earthquake, such as increased sedimentation and headward erosion of drainage channels, also may have reduced the area of ponds. As new sediment is deposited in the ponds, primary succession may occur.

Waterfowl surveys have not been conducted in other Cook Inlet salt marshes as intensively as those at the ERF, but available data suggest that waterfowl use in two such marshes (Goose Bay and Fire Creek) is less than that at the ERF (Racine, et al., 1993; Rosenberg, ADFG, pers. comm.).

2.4.3 Artillery Impact Features

Thousands of craters occur in the ERF as 1- to 2-m-diameter depressions that are 20 to 40 cm deep (Racine, et al., 1993). Projectiles from 60-, 81- and 107-mm mortars and 105-mm howitzers made the craters, which are generally concentrated around the firing targets in the ERF. Depending on the tidal cycle and season, the craters may or may not be filled with water. However, numerous examples of underwater and "off-target" craters can be found almost anywhere in the ERF. Zones of high and low crater density were mapped in 1990 to help identify areas where munition residues would most likely occur (Figure 2-1).

2.4.4 Fish and Wildlife Use

The interspersion and zonation of bulrush and sedge marsh, open water ponds, and mudflats within the ERF provide ideal habitat for large numbers of waterfowl, shorebirds, gulls and terns, raptors, and other birds and mammals (Racine, et al., 1993). Studies conducted by CRREL in 1991 and 1992 documented diversified avian species (Table 2-5), but because the field sessions were limited, a complete species list has not yet been developed. The USFWS has surveyed the waterfowl species on the ERF during April to October for 4 years; thus, more information has been collected about the seasonal populations of these species.

Fish and aquatic macroinvertebrate populations have not been well characterized, but some information is available. In addition, ongoing studies may provide further characterization of the aquatic biota.

Although peregrine falcons are occasionally observed as migrants, resident-threatened or endangered species are not known to occur on Fort Richardson (Garrett, 1991; Quirk, 1991). The probability of occurrence of threatened or endangered species is considered low because of the lack of prime habitat and nesting sites.

2.4.4.1 Waterfowl

Table 2-5 lists the species of waterfowl that have been seen using the ERF. The area is an important feeding and resting point for birds migrating in the spring and fall. Mallards, American wigeons, northern pintails, green-winged teals, and sandhill cranes use the ERF as a breeding and nesting area as well (Racine, et al., 1993; Edridge, in Racine, et al., 1994).

The USFWS has conducted aerial waterfowl surveys of the ERF annually since 1988 (Tweten, 1989; Eldridge, 1990, 1991, and 1992). The results of these censuses indicate that most waterfowl use the ERF predominantly during late April to early June and mid-August to mid-October (Racine, et al., 1993; (Eldridge, in Racine, et al., 1994). During most years there are more waterfowl at the ERF in the fall than in the spring. A small population of ducks, cranes, and shorebirds remains to breed in the ERF throughout the summer. Male American wigeons also stage on the ERF in small numbers prior to molt migration in late June (Eldridge, USFWS, pers. comm.). The number and species of waterfowl using each

Table 2-5
Bird Species Observed During Field Studies in May and August 1991-1992

Page 1 of 2

Common Name	Species Name
Waterfowl	
Common loon	*Gavia immer*
Red-necked grebe	*Podiceps grisegena*
Horned grebe	*Podiceps auritus*
Tundra swan	*Cygnus columbianus*
Trumpeter swan	*Cygnus buccinator*
Greater white-fronted goose	*Anser albifrons*
Snow goose	*Chen caerulescens*
Canada goose	*Branta canadensis*
Mallard	*Anas platyrhynchos*
Green-winged teal	*Anas crecca*
American wigeon	*Anas americana*
Eurasian wigeon	*Anas penelope*
Northern pintail	*Anas acuta*
Northern shoveler	*Anas clypeata*
Blue-winged teal	*Anas discors*
Cinnamon teal	*Anas cyanoptera*
Canvasback	*Aythya valisineria*
Ring-necked duck	*Aythya collaris*
Greater scaup	*Aythya marila*
Lesser scaup	*Aythya affinis*
Barrows goldeneye	*Bucephala islandica*
Common goldeneye	*Bucephala clangula*
Bufflehead	*Bucephala albeola*
Common merganser	*Mergus merganser*
Gulls and Terns	
Herring gull	*Larus argentatus*
Mew gull	*Larus canus*
Glaucous-winged gull	*Larus glaucescens*
Bonapart gull	*Larus philadelphia*
Arctic tern	*Sterna paradisaea*
Raptors	
Bald eagle	*Haliaeetus leucocephalus*
Northern harrier	*Circus cyaneus*
Merlin	*Falco columbarius*
Peregrine falcon	*Falco peregrinus*
Red-tailed hawk	*Buteo jamaicensis*
Rough-legged hawk	*Buteo lagopus*
Sharp-shinned hawk	*Accipiter striatus*
Northern goshawk	*Accipiter gentilis*
American kestrel	*Falco sparverius*

Table 2-5
Bird Species Observed During Field Studies in May and August 1991-1992

Page 2 of 2

Common Name	Species Name
Short-eared owl	*Asio flammeus*
Shorebirds	
Sandhill crane	*Grus canadensis*
Semipalmated plover	*Charadrius semipalmatus*
Killdeer	*Charadruis vociferus*
Blackbellied plover	*Pluvialus squatarola*
Lesser golden plover	*Pluvialis dominica*
Hudsonian godwit	*Limosa haemastica*
Whimbrel	*Numenius phaeopus*
Greater yellowlegs	*Tringa melanoleuca*
Lesser yellowlegs	*Tringa flavipes*
Solitary sandpiper	*Tringa solitaria*
Spotted sandpiper	*Actitis macularia*
Wilson's phalarope	*Phalaropus tricolor*
Red-necked phalarope	*Phalaropus lobatus*
Short-billed dowitcher	*Limnodromus griseus*
Long-billed dowitcher	*Limnodromus scolopaceus*
Common snipe	*Gallinago gallinago*
Ruddy turnstone	*Arenaria interpres*
Surfbird	*Aphriza virgata*
Semipalmated sandpiper	*Calidris pusilla*
Western sandpiper	*Calidris mauri*
Least sandpiper	*Calidris minutilla*
Bairds sandpiper	*Calidris bairdii*
Pectoral sandpiper	*Calidris melanotos*
Dunlin	*Calidris alpina*
Other Birds	
Belted kingfisher	*Ceryle alcyon*
Tree swallow	*Tachycineta bicolor*
Violet-green swallow	*Tachycineta thalassina*
Bank swallow	*Riparia riparia*
Rough-winged swallow	*Stelgidopteryx serripennis*
Cliff swallow	*Hirundo pyrrhonota*
Common northern raven	*Corvus corax*
Northern shrike	*Lanius excubitor*
Savannah sparrow	*Passerculus sandwichensis*
Lincoln's sparrow	*Melospiza lincolnii*
Lapland longspur	*Calcarius lapponicus*
Rusty blackbird	*Euphagus carolinus*

Source: Racine, et al., 1993.

area within the ERF also varies. Swans were observed mainly in Areas A, B, and D. Canada geese are numerous in Areas A and D; whereas snow geese use Areas A and B more. Use of Areas A, B, C, and D by ducks depends on water levels, ice conditions, and human disturbance. Areas A and D are consistently important to ducks (Eldridge, USFWS, pers. comm.).

Eldridge (1992) observed that tundra and trumpeter swans used the ERF less in 1992 than in previous years and use in 1993 was similar to use in 1992 (Eldridge, in Racine, et al., 1994). Fall swan numbers did not build up on the ERF or Cook Inlet, similar to 1991. The smaller swan population likely was a result of an early freezeup and clear weather, which allowed swans to push through Cook Inlet without stopping, or stopping for short periods (Eldridge, USFWS, pers. comm.). As in 1991, most of the migrating swans observed in the fall flew over the ERF, as well as Cook Inlet, without stopping.

Geese, on the other hand, occurred in larger numbers on the ERF during 1991 and 1992 than in prior years or in 1993. Goose numbers on the ERF were higher in 1992 than 1991 because melting conditions caused good feeding habitat to be available sooner on the ERF than on other Cook Inlet marshes (Eldridge, USFWS, pers. comm.). Canada goose fall number peaks were lower in 1992 than in previous years, maybe because of hazing and human activity in 1992, and because of an early fall freezeup. Compared to other species, the white-fronted goose numbers were low in 1992, but similar to other years.

The number of birds on the ERF probably is higher in those years when there is heavy snow and ice cover on the west side of Cook Inlet or in years with late breakup in spring (Rosenberg, ADFG, pers. comm.). The ERF becomes snow- and ice-free earlier than the more westerly marshes and this effect is more pronounced in late winters or those with heavy snow and ice cover on the west side. For geese, snowmelt is more important than open water ponds.

Eldridge (1992) also observed that the duck species using the ERF were similar to previous years, but spring numbers were higher than fall and peaked in early May. The rise in spring populations was mostly because of more northern pintails than usual. Mallard, American wigeon, green-winged teal, northern shoveler, and northern pintail were the most common species observed.

Like goose numbers, the number of ducks in the ERF dropped noticeably after September 1 and was probably caused by hazing and the beginning of hunting season, which generally depletes duck numbers in Cook Inlet from mortality and disturbance. The duck numbers then gradually increased on the ERF through late fall until freezeup (Eldridge, 1992).

2.4.4.2 Shorebirds

As many shorebird species as waterfowl are represented on the ERF. Table 2-5 details this variety. Shorebirds inhabit the mudflats and shallow water at the ERF and occur in abundance. Field observations by CRREL during May in 1991 and 1992 documented that phalaropes, yellowlegs, pectoral sandpipers, and common snipe exhibit mating behaviors or appear to use the ERF for breeding (Racine, et al., 1993). Many shorebirds migrate south before the last 2 weeks in August. As with waterfowl, species abundance of shorebirds was dependent on migration habits, but the abundance of mating birds and the overall diversity of species show that the ERF is important habitat for shorebirds.

2.4.4.3 Gulls and Terns

Racine, et al. (1993) reports that 5 to 10 herring gull nests and 10 mew gull nests have been seen in the ERF, mostly in Area D, on hummocks of bulrush; but some herring gull pairs use the artillery targets as nesting platforms. Non-breeding herring gulls are abundant on the ERF, where they feed on salmon in Eagle River and on duck carcasses and aquatic organisms in the small ponds. Gull species were combined for the USFWS aerial surveys (Eldridge, 1992; Racine, et al., 1994). They include glaucous-winged gulls, in addition to mew and herring gulls. Numbers increased from fewer than 10 gulls before mid-April in 1992 and 1993 to about 200 to 345 gulls in late April or early May (varying by year). Numbers decreased after mid-May with 50 to 100 gulls in mid-June and less than 25 after mid-July.

Arctic terns feed on small fish in the open water of the ERF. Racine, et al. (1993) notes that Arctic terns are most common in May, when they can be seen displaying courtship behavior. About 20 to 50 were seen during aerial surveys in 1992 and 1993 (Eldridge, 1992; Eldridge, in Racine, et al., 1994). There were commonly 10 to 40 terns counted during June and July.

2.4.4.4 Raptors

Although a few bald eagles use the ERF year round, they are most abundant in May (as many as 58 have been seen), before salmon become a major food source. In mid- to late-May, eulachon *Thaleichthys pacificus* migrate to upper Cook Inlet streams and provide a food source for eagles before the salmon runs (Rosenberg, ADFG, pers. comm.). The eagles often perch on artillery targets and driftwood and on trees along the margins of the ERF. Racine, et al. (1993) points out that during 1991 and 1992 field observations, an unusually high number of bald eagles were attracted to the ERF, probably because of the dead and dying ducks there. According to Racine, "USFWS aerial surveys of surrounding marshes indicates two times the number of eagles at ERF than at all other flats combined."

Northern harriers use the ERF during spring and fall. Harriers feed primarily on rodents in wet grassy areas, but Racine states that the birds have been seen feeding on dead ducks at the ERF. During 1991 and 1992 field observations, merlins were seen regularly, feeding on dragonflies. Peregrine falcons were seen during fall migration, presumably attracted by the abundant shorebirds (Racine, et al., 1993). Other raptor species are listed in Table 2-5.

2.4.4.5 Other Birds

Other bird species that use the ERF are listed in Table 2-5. Racine, et al. (1993) notes that several species of swallows were observed in the ERF during 1991 and 1992 field observations. Such species include violet-green, rough-winged, tree, bank, and cliff swallows, in abundance. Observers saw belted kingfishers fishing in the pools on the margins of the ERF and rusty blackbirds in the bulrushes in May and August. According to Racine, et al., the blackbirds may also breed in the ERF. During the studies, savannah sparrows were common throughout the summer, and flocks of Lapland longspurs were common in August.

Common northern ravens also occur in abundance (Racine, et al., 1993). Six to eight ravens use the ERF regularly. Ravens use dead ducks as their primary food resource, although they are subordinate to the eagles and are often chased away from carcasses.

2.4.4.6 Fish and Aquatic Invertebrates

About 300 to 500 naturally occurring king and red salmon pass through the ERF annually on their way to spawn in small clear tributaries of the north and south forks of Eagle River. In 1990, the ADFG released 100,000 king salmon fingerlings into the upper stretches of

Eagle River in the hopes of establishing a king salmon sport fishery in Eagle River. This is likely to produce about 3,000 returning salmon each year, which will also travel through the ERF to return to Eagle River spawning grounds. The new sport fishery is currently restricted to sections of Eagle River east of the Glenn Highway (Quirk, 1991).

Dolly Varden trout also occur in Eagle River. Although the lower portion of Eagle River that passes through the ERF supports limited rearing activity for salmon and Dolly Varden, it serves primarily as a migration corridor for adult salmon moving upstream (June to September) and juvenile salmon running to the ocean (mid-April to June) (Quirk, 1991).

Fish were sampled for WP analysis during 1993, but species were not identified in the report by Sparling (in Racine, et al., 1994). However, sticklebacks and sculpins were shown as potential food-chain components for fish-eating birds such as terns and kingfishers that feed in the ERF. Overall, information on the distribution and abundance of fish in the ERF is limited.

Benthic macroinvertebrates (bottom-dwelling aquatic insects, crustaceans, and other invertebrates) were collected during 1993 at several pond locations on the ERF and at two reference locations in Goose Bay (Sparling, in Racine, et al., 1994). Macroinvertebrates also were collected from ERF distributaries where ponding occurred at low tide. The organisms were sorted, identified to species when possible, and counted to determine diversity (H), species richness, percent contribution of dominant species, and similarity between samples. The benthic macroinvertebrate populations included six or fewer species at each sample site. Typical benthic macroinvertebrates found at the various sampling locations included annelid worms (Oligochaeta), amphipods, and insects including mainly dipterans (Chironomidae, Ceratopogonidae, Ephydridae, and Muscidae). Other sampling for macroinvertebrates to be analyzed for WP during 1993 included collection of dragonflies and damselflies (Odonata), midges, and brineflies (Diptera), beetles (Coleoptera), snails (Gastropoda), and amphipods (Amphipoda) that were sufficiently abundant for analysis. Odonates were more frequently caught, followed by midge larvae and snails.

2.4.4.7 Other Wildlife

Besides birds, moose and coyotes frequent the ERF. Black bears are occasionally observed in the ERF in the summer. Smaller mammals that use the flats also include beaver, muskrat, mink, weasel, wolverine, red fox, lynx, and numerous rodents (Quirk, 1991). In

August, wood frogs thrive in the ERF, where they comprise a major food source for sandhill cranes (Racine, et al., 1993).

Beluga whales have been observed entering the mouth of a drainage slough in the northwest corner of the ERF, near the mouth of both Eagle River and a large drainage slough to the north, as well as close to the shoreline throughout Eagle Bay, and approximately 1-1/4 mile up Eagle River. Sightings have occurred from June to the end of October. Whales have been observed vigorously chasing salmon up drainages along the river bank (Gossweiler, undated).

2.4.4.8 Summary of Fish and Wildlife Use

The abundance of birds at the ERF reflects a productive food chain, providing resources to support the higher trophic levels (Racine, et al., 1993). The great diversity of species results from the diversity of habitats. The ERF contains large shallow ponds, sparse sedges, mudflats, craters, and expansive bulrush stands interspersed with small ponds. Derelict trucks, placed as targets, provide perches that are not present in other marshes. Consequently, the ERF has more diverse habitat features than other marshes in the area. Ground censuses conducted in two such marshes (Goose Bay and Fire Creek) suggest less waterfowl use of neighboring flats, although few comparable surveys have been conducted in Goose Bay (Rosenberg, ADFG, pers. comm.).

Each group of animals, considered alone, represents a valuable wildlife resource; together, they indicate that the ERF has significant value to wildlife. Not only do large populations occur on the flats, but many species are represented. Thus, Racine, et al. (1993) concluded that the ERF is an important wildlife resource for this part of Alaska.

Section 3

Summary of Past Investigations

Biological and chemical investigations have been ongoing at the ERF for the past decade. The objective of virtually all of these studies has been to determine the cause of the acute mortality of waterfowl there. This section summarizes the studies and is organized into five major subsections. Subsection 3.1 provides a chronological overview of the studies. Subsection 3.2 discusses the avian bird mortality studies, which served to highlight the significant effects that were occurring at the ERF. Subsections 3.3 and 3.4 discuss the chemical concentration studies that have been performed on the physical environment (sediment and water) and the biological environment (birds). The section concludes with the identification of studies performed during the 1993 field season.

3.1 History of Investigation

A list of studies conducted and the types of data obtained at the ERF since the waterfowl die-offs were first discovered in 1980 is presented in reverse chronological order in Table 3-1. In general, the studies have focused on five areas of the ERF: Areas A, B, C, and D and Bread Truck Pond (Figure 1-2). These areas correspond to the larger ponds where waterfowl have consistently been observed (dead and alive).

Following is a summary of events at the ERF since 1980.

3.1.1 1980 to 1987 Investigations

In August 1980, a U.S. Army wildlife biologist discovered an unusually high number of duck carcasses (exact quantity not documented), including several dead swans, at the ERF, primarily in the vicinity of Area A. During subsequent ground searches conducted in September 1983, U.S. Army and USFWS biologists found 368 waterfowl carcasses, including about 35 fresh carcasses (Gossweiler, 1987). The biologists sent 22 of the carcasses to the National Wildlife Health Laboratory (NWHL) in Madison, Wisconsin, for analysis.

Table 3-1
Summary of Previous Investigations at the Eagle River Flats

Investigation/Report	Investigators	Field Date(s)	Chemical Data Obtained[1]		Biological Data Obtained			Monitoring/ Aerial Survey
			Soil/ Sediment	Surface Water	Fat/ Tissue	Plants & Seeds	Bioassay	
Contaminant Inventory	AEHA	12-23 Jul 1993	Area A - 2 Area C - 3 Area C/D - 2 BT Pond - 3 ER Distributaries - 7 ER - 2 Goose Bay - 2 (Control)	Area A - 2 Area C - 3 Area C/D - 2 BT Pond - 3 ER Distributaries - 7 ER - 2 Goose Bay - 2 (Control)				
Treatability Study - Hazing Waterfowl in ERF	USDA ADC	May, Sep-Oct 1993						Areas A & C, BT Pond, Racine Island
Treatability Study - Laboratory Evaluation of a Methyl Anthranilate Bead Formulation	USDA DWRC	1993					Laboratory - 8 mallards	
Treatability Study - Field Behavioral Response and Bead Formulations for Methyl Anthranilate	USDA DWRC	Jun, Aug 1993			Area C - 24 mallards		Area C - 72 mallards	
Treatability Study - Field Evaluation: Mortality of Mallards Feeding in Areas Treated with Methyl Anthranilate	USDA DWRC	Jun 1993	Area C - 5				Area C - 72 mallards	
Waterfowl Mortality at ERF	CRREL	Apr-May, Aug-Oct 1993						Areas A & C and BT Pond - 642 waterfowl estimated 1993 mortality

Table 3-1
Summary of Previous Investigations at the Eagle River Flats

Investigation/Report	Investigators	Field Date(s)	Chemical Data Obtained[1]		Biological Data Obtained			Monitoring/ Aerial Survey
			Soil/ Sediment	Surface Water	Fat/ Tissue	Plants & Seeds	Bioassay	
Distribution and Concentrations of White Phosphorus in ERF	CRREL	1991 - 1993 (See Note 1)	Area A - 152 Area B - 38 Area C - 253 Area C/D - 37 Area D - 43 BT Pond - 33 Pond Beyond - 14 Racine Island - 29	Area C - 12				
Waterfowl Distribution and Movements in ERF	USDA DWRC	Apr-Jun, Aug-Oct 1993						39 ducks fitted with backpack transmitters 23 ducks tagged 8 dead ducks on ERF 3 dead ducks off ERF
White Phosphorus Poisoning of Waterbirds in ERF	USFWS PWRC	May-Sep 1993			ERF - 30 ducks, 57 misc. waterbirds, eggs from 10 nests Susitna Flats - 15 misc. waterbirds (Control)		Area C - 16 mallards	
Toxicological Studies of White Phosphorus in Waterfowl	USFWS PWRC	1993			Laboratory - 70 adult mallards, 50 juvenile mallards			
Physical System Dynamics (Sedimentation and Erosion at ERF)	CRREL	May 1992 - Sep 1993	Area C & BT Pond - 14 erosion sites, 12 sedimentation transects	Area C & BT Pond - TSS, turbidity, WP particle transport				

Table 3-1
Summary of Previous Investigations at the Eagle River Flats

Investigation/Report	Investigators	Field Date(s)	Chemical Data Obtained[1]		Biological Data Obtained			Monitoring/ Aerial Survey
			Soil/ Sediment	Surface Water	Fat/ Tissue	Plants & Seeds	Bioassay	
Food Chain Invertebrates and Fish: Sediment Bioassay	AEHA	12 - 23 Jul 1993			Areas A, C, C/D, BT Pond, ER Distributaries, Goose Bay (Control) - Benthic macroinvertebrates Areas A, C, C/D, BT Pond, Goose Bay (Control) - Fish		Laboratory - Racine Island sediment toxicity studies	
White Phosphorus in Invertebrates and Fish	USFWS PWRC	Jun 1993			Invertebrates: Area B - 5 Area C - 6 Area D - 4 BT Pond - 10 Fish: Area B - 4 Area C - 6 Area C/D - 6 Area D - 4 BT Pond - 4			
Habitat and Vegetation in ERF	CRREL	1993	180 surface sediment samples around ERF		180 sample points around ERF (1m x 1m)			Aerial photos were geocorrected to produce orthophotos
White Phosphorus in Plants at ERF	CRREL	Jun 1993				Area C - 7 sites aquatic plants		
Waterbird Utilization of ERF	USFWS	Apr-Oct 1993						Areas A, B, C, & D - misc. waterfowl Spring: 7,070 Summer: 2,410 Fall: 15,850

Table 3-1
Summary of Previous Investigations at the Eagle River Flats

Investigation/Report	Investigators	Field Date(s)	Chemical Data Obtained[1]		Biological Data Obtained			Monitoring/ Aerial Survey
			Soil/ Sediment	Surface Water	Fat/ Tissue	Plants & Seeds	Bioassay	
Treatability Study - Pond Draining	CRREL	Jun-Aug 1993	Area C, BT Pond, Pond Beyond - level and coord. surveys, soil moisture analyses					
Treatability Study - Air Drying Contaminated Sediments	CRREL	Jun-Aug 1993	Area C - 1,070 kg sediment in 6 test plots					
Treatability Study - Geosynthetic Covering of Contaminated Sediment	CRREL	Jul 1993	Area B - 4 geotextiles at 16 sites Area D - 4 geotextiles at 12 sites					
Treatability Study - Evaluation of Concover and BentoBalls on Contaminated Sediments to Reduce Mortality of Foraging Waterfowl	USDA DWRC	Jun 1993					Area C - BentoBalls, 36 mallards	
U.S. Army Eagle River Flats: Protecting Waterfowl from Ingesting White Phosphorus	USDA DWRC	1992					Areas B&C - 84 ducks Laboratory - 36 ducks Laboratory - 840 fish Laboratory - 100 water fleas	
Rapid Uptake and Disappearance of White Phosphorus in American Kestrels	CRREL and Dartmouth Medical School	1992			Laboratory - 15 kestrels			

Table 3-1
Summary of Previous Investigations at the Eagle River Flats

Investigation/Report	Investigators	Field Date(s)	Chemical Data Obtained[1]		Biological Data Obtained			Monitoring/ Aerial Survey
			Soil/ Sediment	Surface Water	Fat/ Tissue	Plants & Seeds	Bioassay	
Draft Report - Preliminary Assessment of Sedimentation and Erosion in the Eagle River Tidal Flats, Ft. Richardson, Alaska	CRREL	May-Sep 1992	Area C & BT Pond - 156					
Hazardous Waste Consultation No. 37-66-JR11-92, Soil Sampling Results, Ft. Richardson, Alaska, July 6-7, 1992	USAEHA	July 6-7 1992	EOD Pad - 48					
Draft Report - Waterbird Utilization of Eagle River Flats, April - October 1992	USFWS	Apr-Oct 1992						Areas A, B, C, & D - misc. waterfowl Spring: 14,000 Summer: 1,070 Fall: 34,740
Draft Report - White Phosphorus Contamination of Salt Marsh Sediments at Eagle River Flats, Alaska, February 1993	CRREL	1991-1992	Area A - 160 Area B - 38 Area C - 506, Area C/D - 35 Area D - 43 BT Pond - 131 Pond Beyond - 7 Mudflats - 83	Area C - Field particle suspension studies	Area C - 2 gulls, 24 misc. waterfowl, 7 shorebirds Area C/D - 9 ducks Area D - 1 shorebird, 3 gull eggs Gwen Lake - 2 ducks Otter Lake - 1 loon Clunie Lake - 1 duck EAFB - 1 swan			
Waterbird Utilization of Eagle River Flats, April - October 1991, December 1991	USFWS	Apr-Oct 1991						Areas A, B, C, & D - misc. waterfowl Spring: 10,440 Summer: 1,3560 Fall: 26,000

Table 3-1
Summary of Previous Investigations at the Eagle River Flats

Investigation/Report	Investigators	Field Date(s)	Chemical Data Obtained[1]		Biological Data Obtained			Monitoring/ Aerial Survey
			Soil/ Sediment	Surface Water	Fat/ Tissue	Plants & Seeds	Bioassay	
Waterfowl Mortality in Eagle River Flats, Alaska, The Role of Munitions Residues. May 1992	CRREL	1990	Area A - 16 Area B - 5 Area C - 193 Area D - 5	Area A - 16 Area B - 5 Area C - 21 Area D - 5	Area C - 14 misc. waterfowl Susitna Flats - 5 ducks (Control)		Laboratory - 5 ducks	
Waterbird Utilization of Eagle River Flats, April - October 1990. December 1990.	USFWS	Apr-Oct 1990						Areas A, B, C, & D - misc. waterfowl Spring: 2,360 Summer: 850 Fall: 35,950
Eagle River Flats Expanded Site Investigation, Ft. Richardson, Alaska. Final Technical Report, June 1990	ESE	Jul-Oct 1989	Upgradient ER - 1 Area A - 4 Area B - 1 Area C - 15 Area D - 3 Mouth of ER - 1 Cottonwood Slough - 1 (Control)	Upgradient ER - 1, Area A - 4 Area B - 1 Area C - 15 Area D - 4 Mouth of ER - 1 Cottonwood Slough - 1 (Control)	ERF - 58 misc. waterfowl	Blue-green and red algae diversity Area B - 1 Area C - 2 Area D - 1	Sentinel birds: Area A - 34 Area B - 4 Area C - 64 Area D - 4 Cottonwood Slough - 4 (Control) Laboratory - 36 ducklings Laboratory - 5 mice	Field monitoring associated with sentinel bird studies
Eagle River Flats Waterfowl Mortality Progress Report, August 1989	As noted below							
Laboratory Investigations	ADEC	Sep 15, 1988	Area C (EOD Pond) - 1 Area C/D (Beaver Pond) - 1 Potters Marsh (Control) - 1	Area C (EOD Pond) - 1 Area C/D (Beaver Pond) -1 Potters Marsh (Control) - 1	ERF - 1 duck			

Table 3-1
Summary of Previous Investigations at the Eagle River Flats

			Chemical Data Obtained[1]		Biological Data Obtained			
Investigation/Report	Investigators	Field Date(s)	Soil/ Sediment	Surface Water	Fat/ Tissue	Plants & Seeds	Bioassay	Monitoring/ Aerial Survey
Laboratory Investigations	USEPA	Jul 11, 1988		Area C (EOD Pond) - 1 Area C/D (Beaver Pond) - 1 Area D (OP Vital Pond) - 1				
Laboratory Investigations	USEPA	Jul 22, 1988					Laboratory - 9 ducklings & EOD, Beaver, OP Vital pond water	
Bird Utilization of ERF During Spring, Summer, and Fall, and Associated Mortality	USFWS	Apr-Oct, 1988			ERF - 15 bird carcasses			Areas C & C/D - 358 bird carcasses 573 feather piles
Investigations of Waterfowl Mortality, ERF	USFWS	1983-88			ERF - 80 bird carcasses			
Laboratory Investigations	AEHA	1985	Upgradient ER - 2 Area A - 1 Area B - 1 Area C - 1 Area D - 1 Goose Bay - 2 (Control)	Upgradient ER - 3 Area A - 1 Area B - 1 Area C - 1 Area D - 1 Goose Bay - 2 (Control)				
Field Investigations	USFWS	1982-85						Misc. bird carcasses: Area A - 328 Area B - 21 Area C - 141 Area D - 117

[1] Numbers indicate sample quantity.

Notes:

1. Partial duplication of samples enumerated in earlier CRREL reports.

ADC = Animal Damage Control

ER = Eagle River

In August and September 1984, about 175 carcasses were discovered; 21 were sent to the NWHL for analysis. At that time, the U.S. Army estimated the number of waterfowl deaths to be between 1,500 and 2,000 per year (Tweten, 1989).

Early studies at the ERF focused on identifying a causative agent for the waterfowl mortality. The waterfowl carcasses sent to the NWHL were analyzed for three common waterfowl diseases (avian botulism, bacterial pathogens, and viral pathogens) and metals (zinc, mercury, magnesium, lead, and phosphorus). The results of the analyses for diseases were negative. Concentrations of zinc, mercury, and magnesium were within normal limits. Lead concentrations in one bird were elevated, but typical lesions were not detectable. The results of the analyses for phosphorus were inconclusive.

Brain tissue samples were sent to the Patuxent Wildlife Research Center (PWRC) for analysis for cholinesterase inhibition (to indicate the presence of organic esters of phosphoric acid derivatives). Brain cholinesterase inhibition was not detected (Alaska Fish and Wildlife Research Center [AFWRC], 1988). The condition of most carcasses indicated that the birds were in a good nutritional state and that death was relatively sudden. Lesions, such as hemorrhages or ruptured organs, were not evident, indicating that death by concussion was unlikely.

In 1985, the USFWS Regional Director formally requested U.S. Army authorization to continue monitoring and sampling the ERF. The study was to be conducted under the terms of the *Cooperative Agreement for Management of Fish and Wildlife Resources on Army Installations in Alaska,* a plan of cooperation and coordination between the U.S. Army, the USFWS, and the ADFG (Gossweiler, 1987; U.S. Army, 6th Infantry Division, 1986). Authorization was granted, and on May 16, 1985, more than 70 carcasses were collected during a 2-1/2-hour period. Three days before the carcass search, munitions containing WP had been fired onto the ERF (Gossweiler, 1987).

Also during 1985, USAEHA collected sediment and surface water samples from seven locations in the ERF and from two control sites at Goose Bay, across Knik Arm from the ERF. The results of analyses for pesticides, polychlorinated biphenyls (PCBs), and explosives were negative, and the concentrations of metals detected were within normal background ranges. No other samples were collected or analyses conducted until 1988.

3.1.2 1987 to 1988 Investigations

With the formation of the ERF Task Force in late 1987, a more organized interagency approach to studying waterfowl mortality was implemented. The following were objectives for the 1988 field season:

- Determine whether a waterfowl die-off was still occurring
- Complete an inventory of the ERF fauna
- Document and collect dead birds for laboratory analysis

U.S. Army and USFWS wildlife biologists conducted several aerial surveys and more than 30 systematic ground searches in Area C/D during the 1988 field season, meeting all three study objectives (Gossweiler, 1989). A total of 358 bird carcasses and 573 feather piles were counted during the ground searches. Of those, 25 bird carcasses were collected by the USFWS for analysis at the NWHL. The results of analyses ruled out the probability of bacterial, viral, and parasitic diseases, predation, and trauma as the primary cause of death (Tweten, 1989). The results of analyses conducted at the PWRC indicated that the cause of waterfowl death also could not be linked to the organic compounds (organochlorine and aromatic hydrocarbons) or trace and heavy metal analytes.

During the 1988 field season, ADEC personnel collected surface water and sediment samples from three locations in the ERF and one control site in Potter Marsh, south of Anchorage. Toxic compounds were not detected in the water or sediment samples in concentrations expected to cause waterfowl deaths, and chemicals from explosive ordnance were not detected.

As part of the 1988 fieldwork, the USEPA conducted bioassays with mallard ducklings, dosing the ducklings with water samples collected from three locations in the ERF. No deaths occurred during the bioassay period. However, some birds did develop diarrhea.

3.1.3 1989 Investigations

In 1989, ESE, under contract to USATHAMA and in coordination with the ERF Task Force, conducted an expanded site investigation at the ERF. The objective of the investigation was to determine the cause and probable source of the ERF waterfowl mortality. The study included the following elements:

- Necropsy, hematology, histopathology, and bacterial culture studies of affected waterfowl
- Integrated sampling and analysis of sediment, surface water, and waterfowl tissue
- In situ and ex situ bioassays

Clinical studies eliminated the possibility of infectious disease, concussion, and inhalation of toxic substances as causes of waterfowl mortality. The results of laboratory analyses also indicated that algal toxins were probably not the cause of the waterfowl mortality (ESE, 1990).

The results of the laboratory bioassay studies indicated that contaminants in water and possibly sediment from some locations in the ERF were the cause of the waterfowl mortality, and that the causative substance was not transferred through plants in the food chain (ESE, 1990). This result was further substantiated by subsequent in situ sentinel bird experiments, which produced similar results.

Field observations made during the ESE investigation provided information on the seasonal distribution of waterfowl in the ERF, the locations of dead and dying birds, and the behavior of wild birds. The results indicated that dabbling duck species comprised most of the affected waterfowl, and that the causative substance did not appear to produce secondary effects in predators or scavengers that fed on the affected waterfowl (ESE, 1990).

Although specific chemicals were not identified by ESE during the 1989 investigation, the results of the integrated sampling program indicated a statistically significant relationship between chemicals from explosive ordnance and the waterfowl mortality at the ERF (ESE, 1990). As a result, the U.S. Army temporarily closed the ERF as an impact area in February 1990. Despite the closure, large numbers of waterfowl continued to die at the ERF during the spring and fall migrations.

3.1.4 1990 Investigations

In 1990, CRREL was asked by USATHAMA to explore the theory that chemicals from explosive ordnance were the cause of waterfowl mortality at the ERF. The following were the primary objectives during the 1990 field season:

- Conduct chemical and physical analyses of sediment, surface water, and waterfowl tissue
- Determine the field behavior of affected waterfowl in relation to feeding and death
- Conduct controlled feeding experiments with the use of suspected contaminants
- Determine the background environmental conditions at the ERF
- Determine the effect of military land use at the ERF on the type, location, storage, and movement of the munition compounds in the environment

The approach to the CRREL investigation was based on three primary assumptions (Racine, et al., 1992a):

1. Contaminants reside in sediments (Dabbling ducks comprise the majority of the affected waterfowl.)
2. Distribution of the contaminants is heterogeneous (Only a small percentage of the ducks that enter and feed in the ERF die.)
3. Contaminant degradation rate is slow (Ducks continued to die despite the closure of the ERF impact area.)

In May 1990, CRREL initiated a sediment and surface water sampling program at the ERF. Several 100-meter-long sampling transects were laid out within four of the ERF areas (Areas A through D). Water and sediment samples were collected from craters or other features at recorded distances between the transect endpoints. The locations of the sampling sites and selected surface features in the salt marsh were surveyed, and the data were entered into a geographical information systems (GIS) database (Racine, et al., 1992a).

Samples were field screened for hexahydro-1,3,5-trinito-1,3,5-triazine (RDX) and 1,3,5-trinitrotoluene (1,3,5-TNT), with confirmation samples sent to a laboratory for analysis for a suite of 14 explosive compounds, including several forms of nitramines, nitrobenzenes, and nitrotoluenes (Racine, et al., 1992a). Neither RDX nor TNT was detected in any of the 93 samples collected. However, 2,4-dinitrotoluene (2,4-DNT) was detected in three sediment samples collected from the former EOD pad adjacent to Area C. To reconfirm the presence of 2,4-DNT near the former EOD pad, three more samples were collected for analysis in late June 1990; but only trace amounts were detected.

One of the samples, however, emitted a vapor cloud when opened and stirred (Racine, et al., 1992a). The behavior was recognized as a characteristic of smoke-producing compounds, such as WP, used in munitions. A portion of the sample was air-dried and analyzed for orthophosphate, an oxidation product of WP. The concentration of phosphate exceeded the range for the procedure (greater than 225 milligrams per kilogram [mg/kg]). The analytical program for the fall 1990 sampling was augmented to include phosphate analysis.

Because the analytical results for the samples collected in May 1990 indicated the presence of munitions compounds only in the vicinity of the former EOD pad, the second round of samples, collected in August 1990, was concentrated along the interface between Area C and the former EOD pad. Additionally, only sediment samples were collected because the contaminant source appeared to be in the sediments.

Of the 172 sediment samples collected, 62 contained 2,4-DNT. Most samples that contained at least 1 mg/kg of 2,4-DNT also had detectable concentrations of TNT (Racine, et al., 1992a). Phosphate was detected in 42 of the sediment samples. Of the 17 samples analyzed for WP, 8 contained detectable concentrations.

Field observations of the ERF waterfowl were conducted by CRREL personnel from a blind in Area C in mid-September 1990. The symptoms associated with the death of six ducks were observed during a 5-day period. The general progression of symptoms included the following (Racine, et al., 1992a; Coburn, et al., 1950):

- Lethargy
- Hiding in dense vegetation
- Head rolling back and forth across the back
- Swimming in tight circles
- Violent convulsions followed by death

CRREL personnel also conducted laboratory WP toxicity studies. The behavior of the dying ducks observed at the ERF was consistent with the observations of the ducks dosed with WP in the laboratory. Concentrations of WP in tissues were also similar.

The results of the 1990 CRREL investigations provided strong evidence that WP was the primary cause of the waterfowl mortality at the ERF. Further, it was suggested that the water and sediment conditions at the ERF were conducive to long-term storage of the WP in the sediments (Racine, et al., 1992a).

3.1.5 1991 Investigations

In March 1991, the U.S. Army conducted test firing to determine if they could resume using ERF as an impact range. Routine use of the ERF as an impact range began again in January 1992, with the restriction that there must be sufficient ice cover to prevent disturbance to sediments upon munitions impact and detonation.

CRREL continued investigations at the ERF in 1991, focusing on WP as the primary cause of waterfowl mortality. The main objectives for the 1991 fieldwork were to obtain sufficient data to substantiate the hypothesis of WP as the causative agent, determine the effects of WP contamination on the ERF avian species, and characterize the extent of WP contamination in the ERF sediments. As in 1990, the 1991 fieldwork was carried out in May and August to coincide with the peak waterfowl migration periods. The fieldwork included the following elements (CRREL, 1991):

- Avian field study program to observe and document waterfowl behavior, feeding habits, movement patterns, predation, and mortality

- Sediment sampling and analysis program to characterize WP distribution and compare WP distribution with observed patterns of mortality
- Field laboratory to provide quick-turnaround screening results for WP in sediment and tissue samples collected
- Remote sensing program to obtain aerial photographic imagery and eight-band multispectral scanner tape information for mapping vegetation and habitat types, as well as sampling locations

More than 400 sediment samples and 60 carcasses were collected for analysis. Because there was no standard method of analysis available for WP in soil, sediment, or bird tissue, it was necessary for CRREL to develop the procedures.

The results of the 1991 fieldwork indicated that two ponded areas in the ERF, Area C and Bread Truck Pond, accounted for most of the WP poisoning of dabbling ducks (CRREL, 1991). White phosphorus was detected in pond sediments to depths of 20 cm. The areal extent of WP contamination in non-ponded areas was not determined because only ponded areas were sampled.

During the 1991 fall hunting season, ADFG and USFWS staff collected 305 gizzards from hunter-harvested ducks at Goose Bay, Palmer Hay Flats, Susitna Flats, and the Anchorage Coastal Wildlife Refuge (Figure 2-2). The gizzards were analyzed for WP to evaluate the potential for offsite transport of WP by the waterfowl. White phosphorus was not detected in any of the birds (CRREL, 1991). However, it was observed that waterfowl can fly short distances after ingestion of WP and may be contributing to distribution of the contaminants, as evidenced by the following:

- White phosphorus was detected in a dead duck found 500 m from the ERF and in four ducks harvested while flying in the ERF (Racine, et al., 1992a).
- Dead ducks were found in some uncontaminated ponds and ponds too deep for dabbling ducks to feed.
- Tissue samples collected from floating duck carcasses in advanced stages of decomposition still contained significant concentrations of WP.

Remedial technologies tested by CRREL in the laboratory during the 1991 field season included oxidation of WP by sediment drying, aeration, and the use of hydrogen peroxide (CRREL, 1991). Some success was achieved, but implementation of the strategies on a full-scale basis may not be applicable at the ERF because of the unknown quantity and locations of unexploded ordnance. Additionally, a test detonation of an HE projectile charge in WP-contaminated sediments did not reduce WP concentrations; such detonations would likely only aggravate the problem (CRREL, 1991).

3.1.6 1992 Investigations

In 1992, CRREL conducted the following field studies at the ERF (Racine, et al., 1993):

- Pond sediment surface and subsurface sampling and analysis to further characterize areal and vertical distribution of WP contamination
- Treatability studies to evaluate the effectiveness of geotextiles in limiting waterfowl exposure to WP, chemical oxidation of WP, and drying of wet, contaminated sediments to promote oxidation (A geotextile is a permeable textile material, usually synthetic, used with soil, rock, or any other geotechnical engineering-related material to enhance the performance or cost of a human-made product, structure, or system.)
- Sedimentation-rate measurements at various locations in the ERF

The results of CRREL's sampling program generally confirmed the 1991 findings that the highest concentrations of WP were in the vicinity of Area C and Bread Truck Pond, in a densely cratered area east of Eagle River. Localized "hot spots" were suspected in Area A because a high number of carcasses were consistently observed on one of the Area A ponds. However, this hypothesis was not confirmed by the results of the sample analyses.

The scope of the geotextile treatability studies did not include placing geotextile in areas of the ERF known to have WP contamination. The studies were designed to determine sediment deposition rates on the geotextiles and methods of anchoring the geotextiles, and to measure the maximum WP particle size retained and released by the geotextiles. Further studies were recommended for the 1993 field season. Several types of geotextiles were placed on pond bottoms to evaluate the effectiveness of geotextiles in limiting waterfowl exposure.

Concentrations of WP in sediments collected from Area C were reduced by 99 percent through use of hydrogen peroxide and mechanical mixing. It was suggested that this method may be effective for treatment of dredge spoils (Racine, et al., 1993). Air drying of sediments in the laboratory also resulted in a 99 percent reduction in WP concentrations (as indicated by the median concentrations of four replicates from each of three samples). The remedial technology experiment was conducted over a 2-month period, with the greatest decrease in WP concentrations occurring during the first 2 weeks (Racine, et al., 1993).

CRREL, in conjunction with Dartmouth Medical School, in Hanover, New Hampshire, conducted laboratory experiments in 1992 to evaluate the ability of WP to bioaccumulate in the tissues of waterfowl predators at the ERF. American kestrels were used to simulate the predator population. When fed a diet containing WP, rapid uptake of WP into bird tissues was observed. However, rapid disappearance of WP in tissues was observed when exposure to WP was reduced. The results indicated that the ability of WP to bioaccumulate in the food chain is very limited (CRREL, undated). However, the kestrel experiments were only accomplished with one level of WP dissolved into the fat content of the food. Thus, it cannot be assumed that at other concentrations or for longer times of exposure WP would not bioacumulate (Roebuck, 1994). Also, WP exposure to predators/scavengers is in the forms of both WP dissolved into biological material and WP particles. The kestrel experiments only refer to exposure through dissolved particles. It is difficult to predict how exposure to particles of WP would affect tissue levels of WP in a receptor without additional studies.

Four studies were conducted in 1992 by the USDA Denver Wildlife Research Center (DWRC) to evaluate the effectiveness of methyl anthranilate (MA) as a bird repellant, the acute toxicity to fish of MA, and the bioaccumulation and life cycle effects of MA on water fleas. The results of the duck-feeding studies indicated that MA is an effective bird repellant, if provided in the proper form; encapsulated formulations were significantly more effective than beaded formulations (USDA, 1993). High concentrations of MA (>1,000 mg/L) were found to be toxic to fish; however, MA appeared to be safe at concentrations of 5 to 10 mg/L (the concentration at which MA partitioned from food into water under test conditions). Concentrations of 5 to 10 mg/L MA also appeared to be safe for the water fleas (USDA, 1993).

During the 1992 field season, USAEHA collected 48 soil samples at the former EOD pad to analyze for explosives, including cyclotetramethylenetetranitramine (HMX), RDX, 2,6-DNT, 2,4-DNT, and TNT. All the analytes were detected in at least one sample, with

2,4-DNT and 2,6-DNT detected most frequently. The maximum concentration of 2,4-DNT was 76 mg/kg; maximum 2,6-DNT was 2.6 mg/kg.

3.1.7 1993 Investigations

Field investigations conducted in 1993 focused primarily on the east side of the ERF in the vicinity of Area C and Bread Truck Pond. The results of the 1993 investigations are summarized in a document prepared by CRREL (Racine, et al., 1994). The titles, responsible agencies, and brief descriptions of the studies follow:

- Habitat and Vegetation (CRREL)–identified five zones and 18 habitat-vegetation types in the ERF
- Physical System Dynamics (CRREL)–measured erosion and sedimentation rates around the ERF
- Contaminant Inventory (AEHA)–collected sediment and surface water samples and analyzed for WP, explosives, nutrients, target analytes, and target compounds
- Review of Chemical and Physical Properties of WP (CRREL)–reviewed literature to evaluate the factors that influence the persistence of WP in the environment
- Toxicological Studies of White Phosphorus in Waterfowl (USFWS)–conducted laboratory studies to determine acute lethal doses for adult and juvenile mallards
- Distribution and Concentrations of WP in ERF (CRREL)–collected and analyzed sediment and surface water samples; report includes data from 1991 and 1992 field seasons
- Waterbird Utilization of ERF April through October 1993 (USFWS)–conducted 42 aerial surveys during spring, summer, and fall

- Waterfowl Mortality at ERF (CRREL)–estimated waterfowl mortality to assess future changes in mortality rates resulting from decreased exposure to WP following remedial activities

- Waterfowl Distribution and Movements in ERF (USDA)–tagged 23 ducks, fitted 39 ducks with radio transmitters to track movements

- White Phosphorus Poisoning of Waterbirds in ERF (USFWS)–collected 35 carcasses and 52 fresh waterbird specimens for laboratory analysis for WP

- Invertebrates and Fish (USAEHA)–collected stickleback fish for WP tissue analysis, collected invertebrates for effects of WP on community integrity, and conducted WP sediment toxicity studies on invertebrates

- Invertebrates and Fish (USFWS)–collected macroinvertebrates and fish for laboratory analyses

- White Phosphorus in Plants at ERF (CRREL)–collected plant samples from areas where WP had previously been detected in sediments

- Hazing Waterfowl in ERF (USDA)–used several standard hazing methods including propane cannons, scarecrows, mylar tape, and helium-filled balloons

- Laboratory Evaluation of a Methyl Anthranilate Bead Formulation for Reducing Mallard Mortality and Feeding Behavior (USDA)–evaluated two methyl anthranilate bead formulations using captive wild mallards in the laboratory

- Field Behavioral Response and Bead Formulations for Methyl Anthranilate Encapsulated Bird Repellents (USDA)–evaluated two formulations of methyl anthranilate using captive wild mallards at the ERF

- Field Evaluation: Mortality of Mallards Feeding in Area Treated with Methyl Anthranilate (USDA)–determined mortality of captive wild mallards feeding in pens treated with a methyl anthranilate formulation

- Geosynthetic Covering of Contaminated Sediment (CRREL)–tested four geosynthetics to determine potential effectiveness of providing a barrier to waterfowl dabbling in pond sediments
- Evaluation of Concover and BentoBalls on Contaminated Sediments to Reduce Mortality of Foraging Waterfowl (USDA)–tested effectiveness of two products at forming a physical barrier to waterfowl dabbling in pond sediments
- Field Study of Air-Drying Contaminated Sediment (CRREL)–tested effects of covering and tilling sediments in landfarming treatability study
- Pond Draining Treatability Study (CRREL)–surveyed potential pond drainage routes to evaluate feasibility of draining ponds
- Preliminary Literature List and Review for Salt Marsh Restoration as Applied to ERF (CRREL)–reviewed literature to determine if methods of salt marsh restoration exist and how other marshes have responded to major alterations such as draining or dredging

3.2 Mortality Studies

Areas A, B, C, and D, where most of the waterfowl mortality has been concentrated, have been correlated with crater impact zones (Racine, et al., 1993). Over time, four other areas of potential concern have also been identified: Area C/D (between Areas C and D), Bread Truck Pond, Pond Beyond, and the mudflats (Figures 1-2 and 2-1).

Area A consists of open-water ponds (covering up to about 15 hectares) scattered throughout 50 hectares on the west side of Eagle River. The eastern section of Area A consists of shallow, flooded mudflats; water is typically less than 10 cm deep with high salinity (10 to 25 ppt) and dries up in summer when flooding tides do not occur. The western section of Area A consists of deeper ponds (10 to 30 cm deep) in bulrush marsh with a lower salinity (less than 5 ppt).

Area B, at the extreme south end of the ERF, includes about 7 hectares of 0.1- to 0.5-m-deep ponds, pools with bulrush, and shallow ponds in sedge vegetation. Salinity is generally less than 4 ppt. There are no crater zones or targets in Area B.

Area C includes a single large pond (10 hectares in size) with several connected smaller ponds to the north, and inlets (such as Clunie Creek) along the east edge of the ERF. The total pond area is about 18 hectares. Mudflats to the west are less than 10 cm deep and are barren because of high soil salinities from the drying, shallow edge of the pond. Bulrush and sedge occur to the east and south. Water depth is 35 cm in the eastern area where freshwater enters the pond from Clunie Creek. Craters cover 15 to 25 percent of the mudflats in Area A where underwater craters are fairly common; craters cover 3 to 7 percent of the sections to the north and south of the main pond (Figure 2-1).

Area D consists of permanent, fairly deep ponds with about 10 hectares of open water that has a salinity of 7 ppt. Patches of bulrushes and islands occur in the northeast corner of Area D; the northwest section grades to shallow ponds and mudflats. Swans use Area D heavily during fall migration. Although Area D is not an impact area, artillery-caused craters cover 1 to 3 percent of the area's western section.

Area C/D is a small area of narrow ponds along the east side of the ERF. The ponds are generally more than 40 cm deep. Open water covers about 3 hectares of the ponds; freshwater input contributes to a low salinity (less than 4 ppt). Bulrush and sedge vegetation surround the channels between the ponds. The water depth in the ponds is believed to limit duck feeding, but provides good bulrush habitat for the ducks to hide in. No craters appear in Area C/D, but some exist to the west toward the Bread Truck Pond area (Figure 2-1).

Bread Truck Pond was targeted as a study area because observers noted an unusually dense eagle population there, possibly scavenging duck carcasses. The pond is highly saline (10 to 20 ppt), very shallow along mudflats on one end (1 cm deep), and deeper (30 cm) near a bulrush marsh along the east side. This 6.5-hectare, semi-permanent pond was the main component of an impact zone and, thus, is densely covered by craters (15 to 25 percent coverage).

Pond Beyond encompasses about 3 hectares of shallow mudflat ponds approximately 200 m north of the Bread Truck Pond area, and has 7 to 10 percent crater coverage. The western edge of Pond Beyond has a target and numerous submerged craters.

Mudflats occur on more than 25 percent of the ERF and are used by feeding shorebirds and geese, particularly during the spring migration. Although some shorebirds have been found dead in the mudflats, no goose mortality has been observed to occur there. The mudflats between Area C, the Bread Truck Pond, and Eagle River have 25 to 30 percent crater coverage.

As summarized in Subsection 3.1, several studies to count and tabulate the number and species of bird carcasses were conducted between 1982 and 1990. Until 1989, mortality counts were conducted on a single day over limited areas of the ERF during the fall or spring. Table 3-2 summarizes mortality counts made between 1982 and 1988. The most intensive count of dead birds during that period involved foot searches by 34 searchers in Area C (and part of D) between April and October 1988.

Table 3-2
Summary of Waterfowl Mortality Counts
Conducted Between 1982 and 1988

Date	**Number of Searches**	**Number of Searchers**	**ERF Area**	**Number of Carcasses**
August 1982	1	1	Fox Point	ND[a]
September-October 1983	5	5	A B C D **Total**	159 21 71 117 **368**
August 1984	4	2-11	A	140
September 1984	1	1	A	29
May 16, 1985	1	8	C	70
April 20-October 7, 1988	26	34	C,C/D	358[b]

[a] ND = not determined.
[b] 573 feather piles also found.

Source: Racine, et al., 1993.

Nearly 1,000 dead waterfowl were found during this survey. Species composition of carcasses and feather piles is shown in Table 3-3. In 1990, the Fort Richardson wildlife

Table 3-3
Numbers of Carcasses and Feather Piles Either Observed or Collected Between April 20 and October 7, 1988

Species	Fresh Carcasses	Feather Piles
Northern pintail	117	118
Mallard	113	46
Green-winged teal	97	62
Northern shoveler	13	28
American wigeon	1	5
Gadwall	1	0
Least sandpiper	1	0
Semipalmated sandpiper	1	0
Dowitcher sp.	1	0
Yellowlegs	1	0
Swans	10	2
Bald eagle	1	0
Mew gull	1	0
Raven	0	1
Canada geese	0	2
Unknown ducks	0	254
Unknown shorebirds	0	14
Unknown gull	0	1
Total	**358**	**573**

Source: Racine, et al., 1993.

biologist (William Gossweiler) made occasional counts of feather piles and carcasses from an Army helicopter that further documented the continuing mortality.

For several studies, transects were established to count dead birds and feather/bone piles, and to mark carcasses to monitor decomposition and removal rates. In Areas A, C, and Bread Truck Pond, two types of transects were established. Edge transects were placed in areas of high mortality to obtain gross mortality counts. Density transects, 10 m wide, were placed through vegetation typical of the area; density transects were walked every 3 days, and carcasses were marked with metal tags. Two other transect types have been used in the marsh/pond area between areas C, C/D and Bread Truck Pond (Racine, et al., 1993).

Results from counts conducted in 1990 are shown in Table 3-4.

Table 3-4
Numbers of Carcasses and Feather Piles Observed
Between May 11 and October 18, 1990

Date	Area	Carcasses/Feather Piles
May 11	C and D	17 feather piles
May 16	C	7 duck carcasses
July 31		6 duck carcasses
August 8-9	C	2 teal carcasses, 4 mallard carcasses
August 16		111 (mallard, teal, widgeon) carcasses
September 10		7 duck carcasses
September 24		6 swan carcasses
September 28		2 swan carcasses
October 15		18 swan carcasses

Source: Racine, et al., 1992b.

Documented swan carcasses had quadrupled since the last carcass count, in 1988 and 1989 (CRREL, 1991). Tissue samples were collected in the fall of 1990 from dead waterfowl and were analyzed for WP. In addition, gizzard contents and fat tissue were analyzed from five ducks collected in Susitna Flats (as "controls"). The results are listed in Table 3-5.

Studies conducted in 1991 set up a repeatable census of waterfowl mortality by establishing density transects and edge transects that could be walked at set time intervals each year in Areas A, C, C/D, and D and the Bread Truck Pond (Racine, et al., 1993). The density transects were established with fixed widths so that total mortality could be extrapolated. Edge transects were set up in areas presumed to have high numbers of carcasses so that sample sizes would be greater to allow year-to-year comparisons.

In 1992, a woodland quadrat (50 by 200 m, or 1 hectare) was added east of Area C and north of Clunie Creek, and four transects (50 by 400 m each) were established running perpendicular to the edge of the flats and into the woods on the eastern border north of the former EOD pad.

Estimated mortality rates in the spring were found to be different from mortality rates in the fall because of a higher number of predators and scavengers in the spring who removed carcasses before they could be counted. Hazing and an increase in human activity in Area C may also have decreased the number of birds exposed to the WP. Carcass counts therefore underestimated mortality.

Table 3-6 provides a summary of waterfowl mortality along the transects in 1991 and 1992. Although the studies in 1992 were not designed to estimate total duck mortality, the extensive woodland surveys, large samples of feather piles left by predators of ducks, and predation observations enabled the investigators to estimate total mortality during the spring migration (Racine, et al., 1993). They estimated that 2,301 feather piles were located in the woodland between the former EOD pad and the blind at Area D, and that these feather piles in the woods represent 64 percent of the dead ducks; an additional 36 percent, or approximately 1,295, were eaten on the flats.

Total estimated mortality was 3,595 ducks, with pintails, green-winged teals, and mallards being represented in greater numbers than expected on the basis of their occurrence on ERF and shovelers and wigeons occurring less frequently than expected on the basis of their presence on ERF. The investigators concluded that almost all of the poisoned ducks are removed by predators while still alive or shortly after death. Thus, counting the number of feather piles is a more effective way to measure mortality than counting carcasses alone.

Table 3-5
Concentrations of White Phosphorus Detected in Various Tissues and Organs of Dying and Dead Ducks and Swans Collected in the ERF During the 1990 Fall Migration

Page 1 of 2

Specimen (date collected)	Sample No.	Type of Tissue	Mass of Tissue (wet weight)(g)	Mass of White Phosphorus (µg)	Concentration of White Phosphorus in Tissue (µg/g)
ERF Samples					
Pintail	60	Heart	1.7	0	0
	61	Liver	7.1	0.35111	0.049
	66	Gizzard contents	1.5	1	74
	71	Intestinal contents	1.3	1.07	0.82
Green-winged teal–male (9/11/90)	73	Liver	4.6	0.047	0.010
	74	Kidney	2.9	0	0
	78	Gizzard contents	0.53	0.295	0.56
	83	Intestinal contents	not weighed	0.081	NA
	84	Intestines	10.4	9.8	0.94
Green-winged teal–female (9/12/90)	96A	Blood	1.7	0	0
	96B	Liver	6.3	0.91	0.144
	96C	Heart	2.1	0.159	0.076
	96D	Kidney	1.1	0.015	0.014
	97	Gizzard contents	0.15	0.012	0.08
	98	Intestines	not weighed	6.16	NA
Green-winged teal–male (9/12/90)	99	Heart	2	0.389	0.19
	99A	Blood	4.4	0	0
	100	Liver	8.7	0.411	0.049
	101	Kidney	2.2	0.043	0.019
	110	Gizzard contents	0.17	0.022	0.13
	111	Intestines	16	7.9	0.494
Green-winged teal–collected live, survived 9.5 hours (9/15/90)	112	Pectoral muscle	35.6	0.059	0.0016
	113	Heart	4	0	0
	114	Liver	10.4	0	0
	115	Intestines	14.7	0.08	0.005
	116	Kidney	3.5	0	0
	117	Brain	2	0	0
	118	Fat	8.8	0.4	0.045
	119A	Gizzard muscle	11.8	trace	trace
	119B	Gizzard contents	0.67	0.08	0.12
Tundra swan–adult	1A	Gizzard contents	4.4	0.24	0.054
Tundra swan–immature	2A	Gizzard contents	10.7	0.24	0.022
	2B	Fat	6.3	2.03	0.32

Table 3-5
Concentrations of White Phosphorus Detected in Various Tissues and Organs of Dying and Dead Ducks and Swans Collected in the ERF During the 1990 Fall Migration

Page 2 of 2

Specimen (date collected)	Sample No.	Type of Tissue	Mass of Tissue (wet weight)(g)	Mass of White Phosphorus (µg)	Concentration of White Phosphorus in Tissue (µg/g)
Tundra swan–immature	3A 3B	Gizzard contents Fat	53.1 6.6	11,000 19.2	206 2.9
Tundra swan adult	4A 4B	Gizzard contents Fat	1.4 9.1	0.085 0.93	0.061 0.102
Mallard–male	5A 5B	Gizzard contents Fat	3.1 0	60.5 NA	19.5 NA
Mallard–male	6A 6B	Gizzard contents Fat	5.4 2.6	1.5 0	0.28 0
Controls (Collected from Susitna Flats)					
Green-winged teal–male		Gizzard contents Fat	1.34 4.99	0 0	0 0
Green-winged teal–female		Gizzard contents Fat	1.68 6.35	0 0	0 0
Green-winged teal–male		Gizzard contents Fat	2.13 2.95	0 0	0 0
Green-winged teal–male		Gizzard contents Fat	1.95 3.21	0 0	0 0
Green-winged teal–female		Gizzard contents Fat	1.55 4.05	0 0	0 0

Notes: µg = Micrograms
g = Grams
NA = Not applicable

Source: CRREL, 1991.

Table 3-6
Summary of Mortality Transect Counts in 1991 and 1992, Including Numbers of Carcasses Plus Feather Piles

Transect	August 1991[a]	May 1992	August 1992[a]
A-density	6 (9.4)	26	12 (13.3)
A-edge	20	4	72
C-density	15 (10.7)	28	11 (9.3)
C-edge	41	24	11
Bread Truck Pond	17 (16.2)	20	14 (14.7)
Subtotals	99	102	120
BT rectangle		15	4
CD rectangle		28	5
Woodland quadrat		117	

[a] The numbers in parentheses are densities of dead ducks per Hectare.
Source: Racine, et al., 1993

The peak number of ducks observed during aerial surveys in spring is about 2,500 (see Subsection 5.2.5.2); thus, the mortality estimates may be too high or there may be a high turnover within the ducks passing through the ERF in the spring.

In the fall, few ducks were removed by predators (Racine, et al., 1993). Fewer eagles occupied the ERF, and vegetation in late summer provided greater cover for concealment of carcasses. The number of feather piles on transects was reported to relate more to the availability of perch and/or eating sites on the transects, rather than to the location of poisoning.

During 1993, field studies further indicated that eagle predation and scavenging of carcasses is much more prevalent in spring than in fall, and that evidence of dead waterfowl is almost entirely in the form of feather piles in spring and carcasses in the fall (Reitsma and Steele, in Racine, 1994). Consequently, different measures were developed for quantifying mortality in spring and fall, which are described in Section VI-2 of that report. Overall, duck mortality in 1993 decreased at about the same rate as duck use of the study areas. The total estimated mortality at the ERF was 570 ducks in 1993. However, when exposure rate is considered, spring mortality rate was similar between years. Fewer ducks used the ERF in fall 1993 compared to fall 1992 but that difference was not enough to explain the dramatic difference in carcasses found on transects. This resulted in a statistically significant lower mortality rate in 1993 compared to 1992, with total estimated mortality of 144 ducks in fall 1993.

Hazing of waterfowl during the fall seems to have been an important factor in reducing mortality during fall.

In summary, studies conducted to date estimate that annual waterfowl mortality exceeds 3,500 individuals without hazing, and suggest that tainted carcasses may pose a risk to avian scavengers (Racine, et al., 1993). Results of mortality surveys indicate that certain species of dabbling waterfowl are the primary victims. Green-winged teal, mallard, and northern pintail carcasses account for 97 percent of the mortalities, while wigeon and northern shoveler appear much less susceptible to poisoning, as mentioned above. Species found dead include northern pintail, mallard, green-winged teal, northern shoveler, American wigeon, gadwall, least sandpiper, semipalmated sandpiper, dowitcher, swans, bald eagle, mew gull, raven, Canada goose, unknown ducks, shorebirds, and gulls.

3.3 Chemicals in the Physical Environment

This section first addresses the chemicals of concern by considering the activities in individual study areas, and then addresses specific chemicals analyzed for during previous investigations. Because of the previous focus on WP as a poisoning agent, this chemical is discussed first, for both the sediment and surface water. Discussions of other chemicals follow the discussion of WP.

3.3.1 Chemicals of Concern

Initial investigations at the ERF focused on finding the causative agents of the waterfowl mortality. Past practices at the site indicate that the following chemicals might be expected to be present:

- High explosives: TNT, RDX, HMX, tetryl, and pentaerythritol tetranitrate (PETN). By-products of explosives include 2-Am-4,6-DNT, 4-Am-2,6-DNT, DNB, nitrates, and phosphates.
- Chemicals associated with smoke projectiles: WP and hexachloroethane-zinc mixture (HC). By-products of HC smokes include hexachloroethane, hexachlorobenzene, phosgene, and zinc.
- Propellants: composed of 2,4-DNT and trace amounts of 2,6-DNT, TNT dibutylphthalate, and diphenylamine.

Samples of sediment, soil, surface water, and waterfowl tissues were collected and analyzed for a suite of compounds, including those listed above. Groundwater at depth and air have not been sampled.

3.3.2 White Phosphorus

By the end of 1990, evidence showed that the cause of the annual waterfowl die-off was the ingestion of WP particles deposited in the sediments during artillery training (Racine, et al., 1992b). Subsequent investigations led to a better understanding of the distribution of WP particles in sediment and surface water at the ERF. Two groups have investigated WP distribution at the ERF: CRREL in 1990 through 1993 and USAEHA in 1993. The following summary is based on four reports: Racine, et al., 1992a, 1992b, 1993, and 1994.

3.3.2.1 Sediments

Sampling Strategy: The initial objective was to determine the cause of the waterfowl mortality. Since chemicals associated with the artillery activities were suspected, most of the sediment and water samples collected during the May 1990 field program were from explosion craters. As in all the ERF investigations, difficulty in access, and concern about unexploded ordinances, helped to direct the selection of collection sites.

Several 100-m-long sampling transects were laid out within Areas A, B, C, and D. Transect endpoints and sampling points were marked and later surveyed so that any sample point could be relocated and resampled in the future. Because the May sampling of sediments and water indicated that munitions residues (2,4-DNT; 2,6-DNT; 2,4,6-TNT; and aminodinitrotoluenes) occurred only adjacent to the former EOD pad, the August 1990 sampling concentrated on intensive sediment sampling along the former EOD pad and into the salt marsh in Area C. By the end of 1990, the presence of WP in both sediments and waterfowl carcasses led investigators to suspect that WP was the cause of the waterfowl mortality.

The next investigation objectives were to determine where in the ERF the waterfowl were ingesting the WP and what concentrations of WP were present. The 1991 field sediment sampling was concentrated in ponded areas where waterfowl feed, carcasses had been found, and/or intense spring predation had been observed. Because dabbling ducks feed mainly in open water areas, sediment samples were collected from areas that had less than 25 percent vegetation cover. In addition, sampling was restricted to the top 5 cm of pond bottom sediments where dabbling ducks feed and where a particulate such as WP is most likely to be ingested along with seeds, invertebrates, and other food items.

In each pond area, CRREL collected sediment samples from transects radiating along compass coordinates from a central observation tower. The transect lines up to 300 m long ended at the edge of the ponds or, on occasion, extended a short distance into the adjoining mudflats. The towers served as a platform for surveying and for waterfowl observation studies. The sampling-transect was designed to minimize human movement (for safety reasons) and integrate waterfowl observations with sediment-contamination studies.

In 1991, surface sediment samples were collected along each transect at 25-m intervals, which corresponded to the "burst area" for WP rounds. Each interval sediment sample collection site was marked and surveyed.

In 1992, sampling of sediments was extended onto other landscape units or habitats on the ERF where dabbling ducks or swans do not feed, but where other species (geese, shorebirds, invertebrates) could be exposed. These habitats included the heavily cratered mudflats and eroded gullies between the Bread Truck Pond and Area C ponds. Gully sediment samples were obtained to determine whether WP might be transported out of the ponds through the drainages that connect these ponds with Eagle River.

During 1992, "close-interval" sampling was conducted at sites previously determined to be contaminated. The purpose of the sampling was to better define the small-scale distribution pattern of WP contamination. In addition, sediment cores were collected to determine the depth of WP contamination. The cores were obtained from Areas A, C, and the Bread Truck Pond, all known to contain WP in surface sediments.

In 1992-1993, CRREL also sampled sediments in isolated "new" ponds (such as Lawson Pond and on Racine Island) where high waterfowl carcass densities had been observed during previous investigations. In 1993, USAEHA sampled sediments from ponds, gullies, and Eagle River. USAEHA analyzed the sediment samples for USEPA priority pollutants in addition to WP. The results of the other test methods are discussed in subsequent subsections.

CRREL investigators also attempted to characterize the physical sizes, shapes, and properties of the WP particles in the sediments to determine how feeding waterfowl are exposed to the risk of poisonings. To determine how the sizes of WP particles compare with the various food items in the ERF sediments, a size analysis was conducted of the particulate items in sediments and in gizzards. Of particular concern was whether smaller WP particles could become suspended in the water column, where they could be ingested by filter-feeding species, or transported in water.

Additional physical data were collected in 1991-1993 to determine if the presence or concentration of WP was related to environmental variables such as water depth, vegetation cover, salinity, redox, pH, or temperature of sediments.

Collection of Sediment Samples and Analytical Methods: At each sample point, researchers donned rubber gloves to scrape a surface sediment sample from the pond bottom. An area about 0.5 m square was scraped to a depth of 2 to 5 cm. The sample was then packed into a sample jar to exclude all air and the jar was tightly capped.

In 1993, CRREL (Racine and Walsh, 1994, in Chapter V-1 of Racine, et al., 1994) tested a WP composite sampling method to simulate feeding by dabbling ducks in a pond. A large, long-handled spoon was used to scoop small "dabs" of sediment at many random locations in each pond. As each dab was collected, it was placed in a #30 mesh (0.59 mm) bucket sieve and washed and stirred while walking through the sample pond while holding the bottom of the bucket underwater. This removed the fine-grained silt particles leaving larger organic materials and particles of WP larger that the 0.59 mm mesh size. Depending on the size of the pond, from 5 to 15 spot sediment samples would be collected and washed. The remaining material was placed in a 500-milliliter (mL) jar for analysis. During 1993, this composite sampling technique was tested in Area A, the Pond Beyond, Bread Truck Pond, and Racine Island.

Two types of coring devices were used in 1992 to obtain cores from the soft bottom sediments in the ponds: one type was designed to collect saturated cores and one was for firmer sediment horizons. Cores were taken from a maximum depth of 30 cm and were transported to the field laboratory in rigid plastic sleeves. At the laboratory, the cores were sampled in 5-cm increments.

Total sediment samples to date include 483 interval pond samples, 190 close interval samples, 58 sediment cores (with 272 subsamples analyzed), 87 gully samples, and 104 mudflat samples.

During 1991, CRREL developed an analytical method for WP in wet sediment. The method was certified as described in the USATHAMA (1990) report, *Installation Restoration Quality Assurance Program*, and was assigned Method Number KN01. The certified reporting limit was 0.00088 microgram per gram (µg/g). The analysis uses gas chromatography (GC) and calls for preparation of an iso-octane extract on a known weight of wet sediment. A WP standard is analyzed daily to ensure that the sensitivity of the GC remains constant and to determine the mass of WP in the extracts. For each sample, the mass of WP is divided by the wet sediment weight, and the concentrations are expressed as µg/g wet weight.

In addition to the GC laboratory analysis for WP, a field screening technique for WP particles was developed during 1993. This method involves smearing a thin layer of the sediment sample on an aluminum pie dish and heating the dish over a small portable propane stove. Burning of the larger WP particles leaves an orange or black spot easily seen against the dry gray sediment. The number of particles on each dish can be counted to give a semiquantitative measure of WP particle density in the sample. The composite samples described previously were analyzed by both this field screening and the laboratory GC method. Of 33 samples, 12 did not contain detectable levels of WP by either method, 17 samples tested positive for WP by both methods, and only 4 samples tested positive by one method but not the other.

Sampling and Analysis Plans: The documents available for review did not include a Quality Assurance Project Plan (QAP_jP) for the data gathering activities. Such plans are typically required for environmental sampling and analysis programs conducted under CERCLA or the Resource Conservation and Recovery Act (RCRA). A QAP_jP describes the planned project objectives, the data required to meet these objectives, and the procedures that will be followed to obtain the data. A QAP_jP also includes planned sampling locations and details the analytical methods that will be used to analyze the samples. Procedures to review the quality of the analytical data and assess whether they meet the project objectives are also included in a QAP_jP.

Although quality data can be generated without a QAP_jP, the absence of documentation to demonstrate the adequacy and quality of the data can limit their usability in meeting regulator concerns and requirements under CERCLA or RCRA programs.

The following USEPA CERCLA guidance documents discuss in more detail the contents of QAP_jPs, project planning to ensure that quality data are obtained, and the evaluation of data for usability in risk assessments:

- *Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans.* Office of Monitoring Systems and Quality Assurance, Office of Research and Development. QAMS-005/80. December 1980.
- *Guidance for Data Usability in Risk Assessment.* Office of Emergency and Remedial Response. EPA/540/G-90-008. October 1990.
- *Guidance on Implementing the Data Quality Objectives Process for Superfund.* Interim Final Guidance. Office of Emergency and Remedial Response. EPA/540-4-93-071. September 1993.

Data Quality Review: The study reports offer no discussion of analytical performance or data validation of the available analytical data, and the raw data were not available for review or validation during preparation of this CER. The reports also do not interpret any results from field or laboratory quality control (QC) samples that may have been analyzed. Without some data validation or data quality review, it is not possible to develop an independent assessment of the data quality, or to judge their adequacy to meet project objectives.

Because the WP was present in sediment as small particles that had not burned after the rounds burst, it was difficult to obtain representative samples through the small subsamples analyzed for this project.

White phosphorus analysis was carried out with Method Number KN01. The analytical method for WP in wet soil or sediment has been validated, and method performance information, including detection limits studies, recovery studies, and precision studies, is presented in the CRREL 1994 report (Walsh and Taylor, in Racine, et al., 1994) and has been published recently by CRREL (Walsh and Taylor, 1993). The method includes laboratory QC requirements for calibration, blanks, and control samples to monitor precision and accuracy.

The certified reporting limit (CRL) for WP in sediments for using USATHAMA KNO1 is 0.000881 µg/g. This is the lowest level at which reproducible results with a certain amount of precision and accuracy can be obtained. To obtain that value, a spike-recovery study was conducted following the method of Hubaux and Vos (1970) as described in the USATHAMA Installation Restoration Quality Assurance Program (USATHAMA, 1990). The CRL is similar to the practical quantitation limit found in the USEPA Contract Laboratory Program. The WP method for sediment does not indicate a method detection limit; however, the lowest spike concentration used to certify the method was 0.000845 µg/g. Any reported values under the CRL should be considered estimated values. The method is capable of detecting and quantifying the amounts of WP present in sediment samples and should be capable of producing quality data when performed under a defined QAP_jP.

The field screening method developed in 1993 appears to provide a rapid visual method of identifying sediment samples that contain WP particles. When duplicate samples (obtained from larger composite samples) were also analyzed by the laboratory method, the two methods gave the same result (presence or absence of WP) approximately 90 percent of the time. The lack of identical correlation between the two methods may be a result of non-homogeneous samples (related to the particulate nature of WP) or the inability of observer to visually identify the smaller particles in the field sample. The screening method gives a semiquantitative measure of the density of WP particles in the sample; while the laboratory method states the result as a wet weight concentration. The use of the two methods in the future should take into consideration the measurement endpoint required. For example, if ingestion of particles of a certain size (rather than sediment concentration) is determined to trigger the threshold level of WP for waterfowl mortality; then the screening method may be a more appropriate measurement providing the method can detect the presence of the appropriate size ranges of particles.

Concentrations and Distribution of WP in Sediments: Table 3-7 summarizes the WP contamination in sediments by study area.

As stated earlier, WP analysis of more than 1,000 sediment samples from ponds shows that the major WP contamination occurs in Area C and the Bread Truck Pond, as well as in the mudflats adjacent to these areas. The following are major areas of contamination in Area C:

- A large area about 300 by 200 m along the northern half of the pond
- A bulrush area in the northeast part of the pond and the deeper waters areas near the Clunie Creek inlet
- The shallow pond area to the west and southwest of the tower

Major contamination was also discovered on Racine Island in 1993.

The sampling confirmed that WP contamination correlates with areas of high crater impact coverage. CRREL investigators (Racine and Walsh, in Racine, et al., 1994) hypothesized that WP found in other areas of the ERF may have been transported there by sick ducks or by water during high tides or runoff periods. High tides could potentially move contamination from the Bread Truck Pond and Racine Island into Eagle River.

Numerous sediment cores 20 to 30 cm deep showed that WP can occur as deep as 30 cm. A few cores taken to a maximum depth of 60 cm showed that contamination existed to a depth of at least 55 cm.

Particle-size studies showed that WP occurs in the sediments as soft, waxy particles ranging in size from less than 0.15 millimeters (mm) to 3.5 mm diameter. The shapes of the particles varied from angular to globular. The particle masses ranged from less than 0.1 microgram (µg) to 3.4 milligrams (mg), and the particle lengths ranged from 0.26 mm

Table 3-7
Summary of Sediment Samples Collected in the Eagle River Flats in 1991, 1992, and 1993

Page 1 of 2

Area	Crater Cover Percentage	Type of Sample	Number of Samples	Positive for WP		Concentration Range (µg/g)	Mean Concent-ration (µg/g)	Median Concent-ration (µg/g)
				Number	Percentage			
A	1-10	Interval–ponds	156	15	10	<det-0.038	0.01	0.002
		Close interval	6	4	67	<det-0.053	0.01	0.004
		Cores (8)	27	2	7.4	0.0019-0.024	0.01	0.01
		AEHA	2	0	0	–	–	–
B	0	Interval–ponds	15	0	0	–	–	–
		Close interval	23	0	0	–	–	–
		Cores	0	–	–	–	–	–
C	15-25	Interval–ponds	160	60	37.5	<det-219	3.9	0.002
		Close interval	153	105	68.6	<det-85.7	2.6	0.01
		Cores (32)	163	71	43.6	<det-198	9.7	0.03
		AEHA	3	2	66.6	0.43-1.60	–	–
C/D	0	Interval–ponds	35	2	5.7	<det-0.012	0.007	0.007
		AEHA	2	0	0	–	–	–
D	0	Interval–ponds	43	0	0	–	–	–
Bread Truck Pond (BTP)	15-25	Interval–ponds	33	24	72.7	<det-57.6	4.3	0.009
		Close interval	8	8	100.0	0.0013-7.7	1.5	0.05
		Cores (18)	89	24	27.0	<det-7.7	0.48	0.01
		AEHA	3	1	33.3	0.079	–	–
Pond Beyond (PB)	7-10	Interval–ponds	7	1	14.3	0.02	–	–
		Composite	8	0	0	–	–	–
Mudflats	25-30							
• Northeast of A		Surface sediments	12	1	8.3	0.062	–	–
• West of C		Surface sediments	59	6	10.2	<det-0.14	0.07	0.009
• Between C and PB		Surface sediments	12	1	8.3	0.15	–	–
• Knik	0	Surface sediments	3	0	–	–	–	–

Table 3-7
Summary of Sediment Samples Collected in the Eagle River Flats in 1991, 1992, and 1993

Area	Crater Cover Percentage	Type of Sample	Number of Samples	Positive for WP		Concentration Range (µg/g)	Mean Concentration (µg/g)	Median Concentration (µg/g)
				Number	Percentage			
Racine Island	0-15	Main pond	23	8	34	<det-3071	469.9	44.12
		Pond to north	4	4	100	0.001-0.41	0.11	
		AEHA	2	2	100			
Distributary Gullies (C & BTP)	0	Sidewall/bottom	87	3	3.4	<det-0.049	0.02	0.01
		AEHA	7	0	0	–	–	–
Eagle River	0	AEHA	2	0	0	–	–	–

Concentrations are in micrograms per gram (µg/g) wet weight.
det = detection limit. Reporting limit is 0.00088 µg/g.
Source: Racine and Walsh, in Racine, et al., 1994.

to 2.9 mm. The number of WP particles in the various size classes varied greatly from one sediment sample to the next or from place to place within a pond. Consequently, a "plume" of contamination will probably not be found on the ERF. This also means that the presence or absence of WP particles may be a more reliable index of contamination than concentration of WP in a sample.

Figure 3-1 summarizes the locations where surface sediment samples were collected from 1990 through 1993 (Racine and Walsh, in Racine, et al., 1994). Figures 3-2 through 3-8 summarize the WP sampling locations by area and concentration. It is easy to see the radial nature of the sampling locations. Sampling to date has focused on specific areas of waterfowl activity, with the effort to document the cause of acute mortality. However, this has left substantial areas without any sampling.

In Figures 3-2 through 3-8, the concentrations at specific locations are shown for each major sampling area in the ERF. The numbers in the parentheses within each of the concentration legends indicate the number of samples with concentrations that fell in that range. For example, 157 samples in Figure 3-2 had concentrations in the range of 0.0008 to 0.001 µg/g. From this summary, it is easy to see that Area C has the largest number of locations with the highest concentrations. Areas C/D, Bread Truck Pond, Racine Island, and Pond Beyond also have some high concentrations. White phosphorus concentrations in the other areas tend to be near or below the certified reporting limit.

3.3.2.2 Surface Water

Sampling Strategy: In 1991-1992, laboratory and field investigations of WP in surface water focused on whether small WP particles could become suspended in the water column. During 1993, CRREL and USAEHA collected surface water samples from ponds, gullies, and Eagle River to determine whether WP was present in the water column. Contamination of the water column with WP presents a hazard to animals that feed in the area. Also, the water column provides a means by which WP may be transported within or out of ponds by currents or tides.

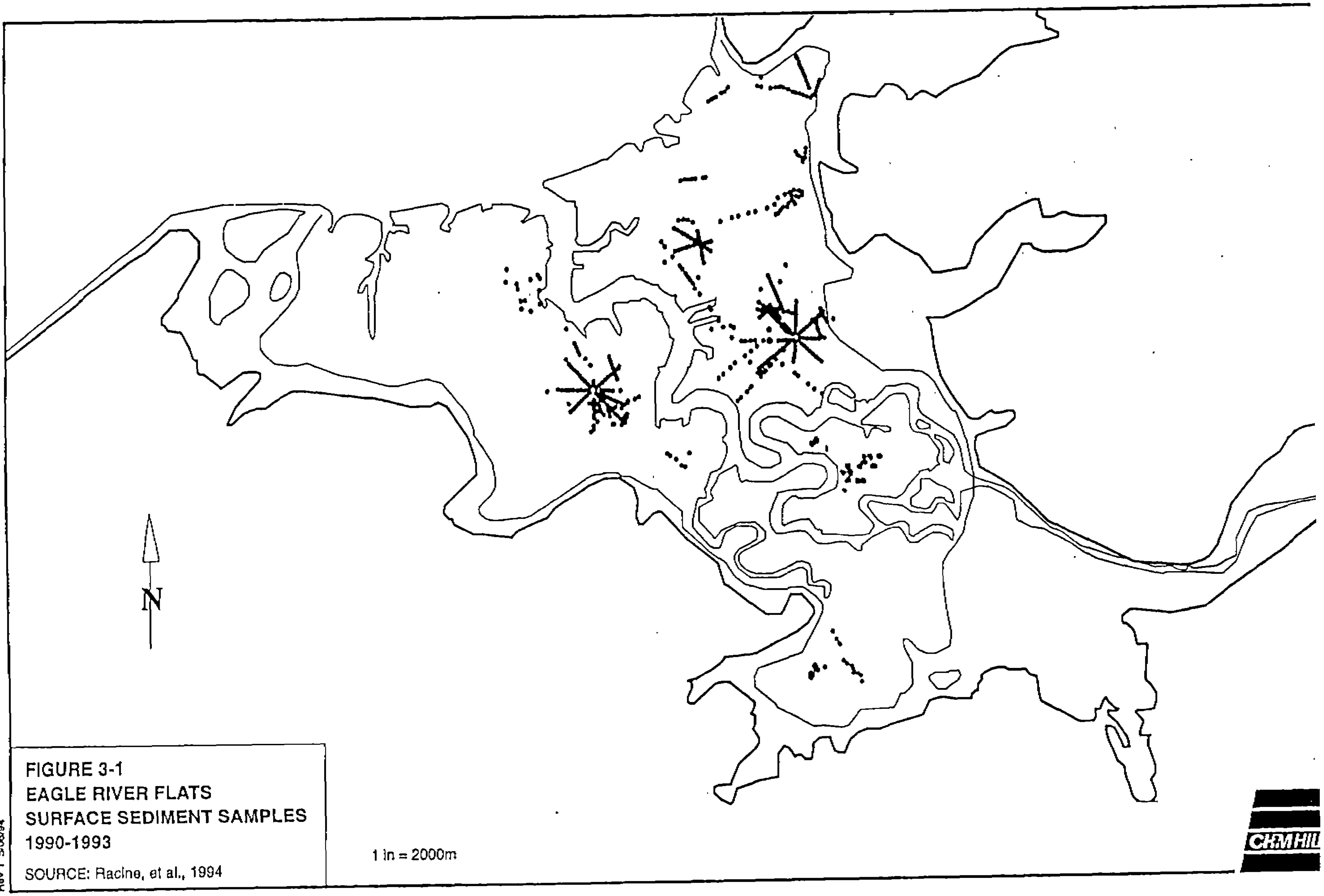

FIGURE 3-1
EAGLE RIVER FLATS
SURFACE SEDIMENT SAMPLES
1990-1993

SOURCE: Racine, et al., 1994

NPE70024.M0.20 Fig 3-X
Rev 1 5/06/94

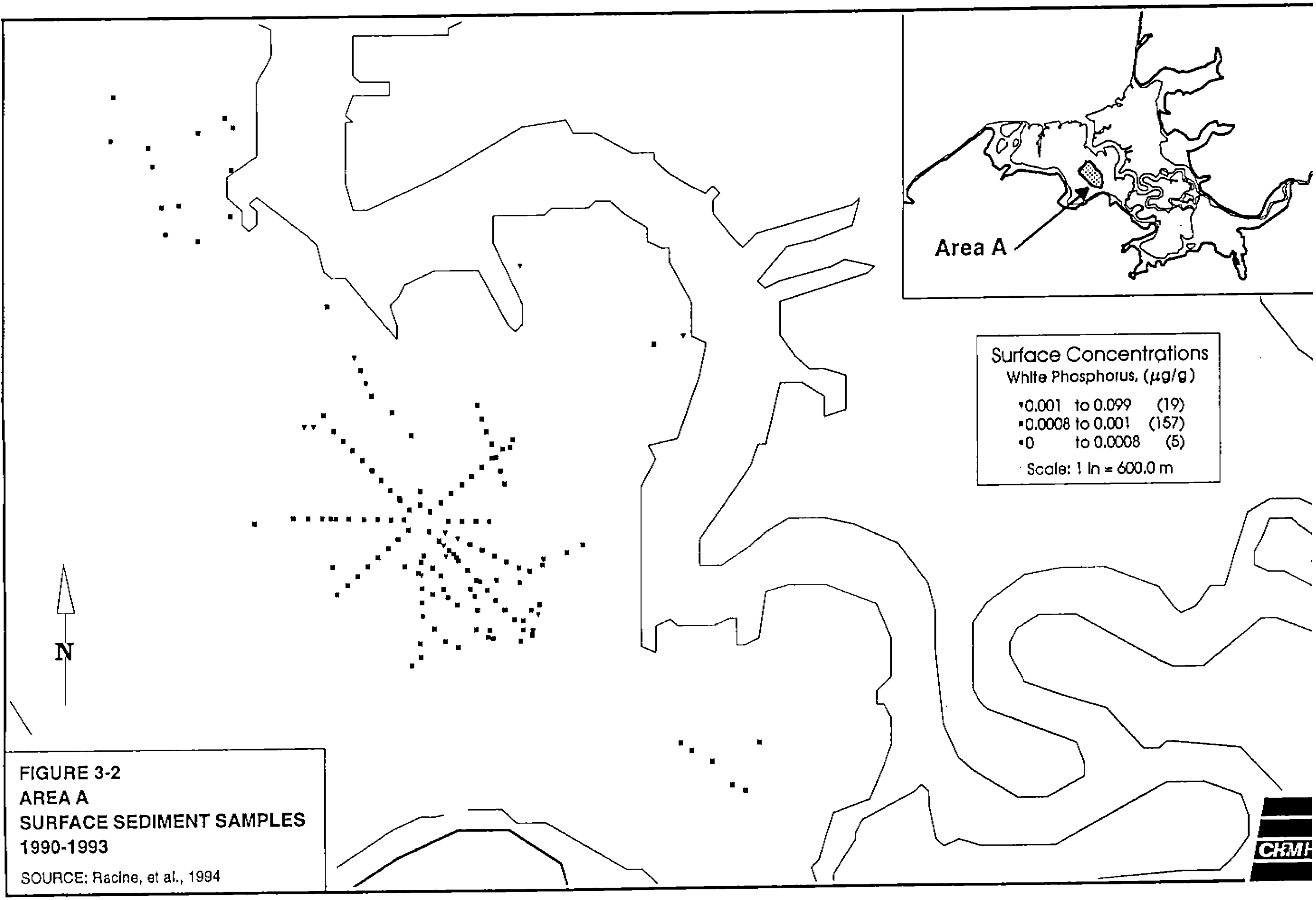

FIGURE 3-2
AREA A
SURFACE SEDIMENT SAMPLES
1990-1993

SOURCE: Racine, et al., 1994

NPE70024.M0.20 Fig 3-X
Rev 1 5/06/94

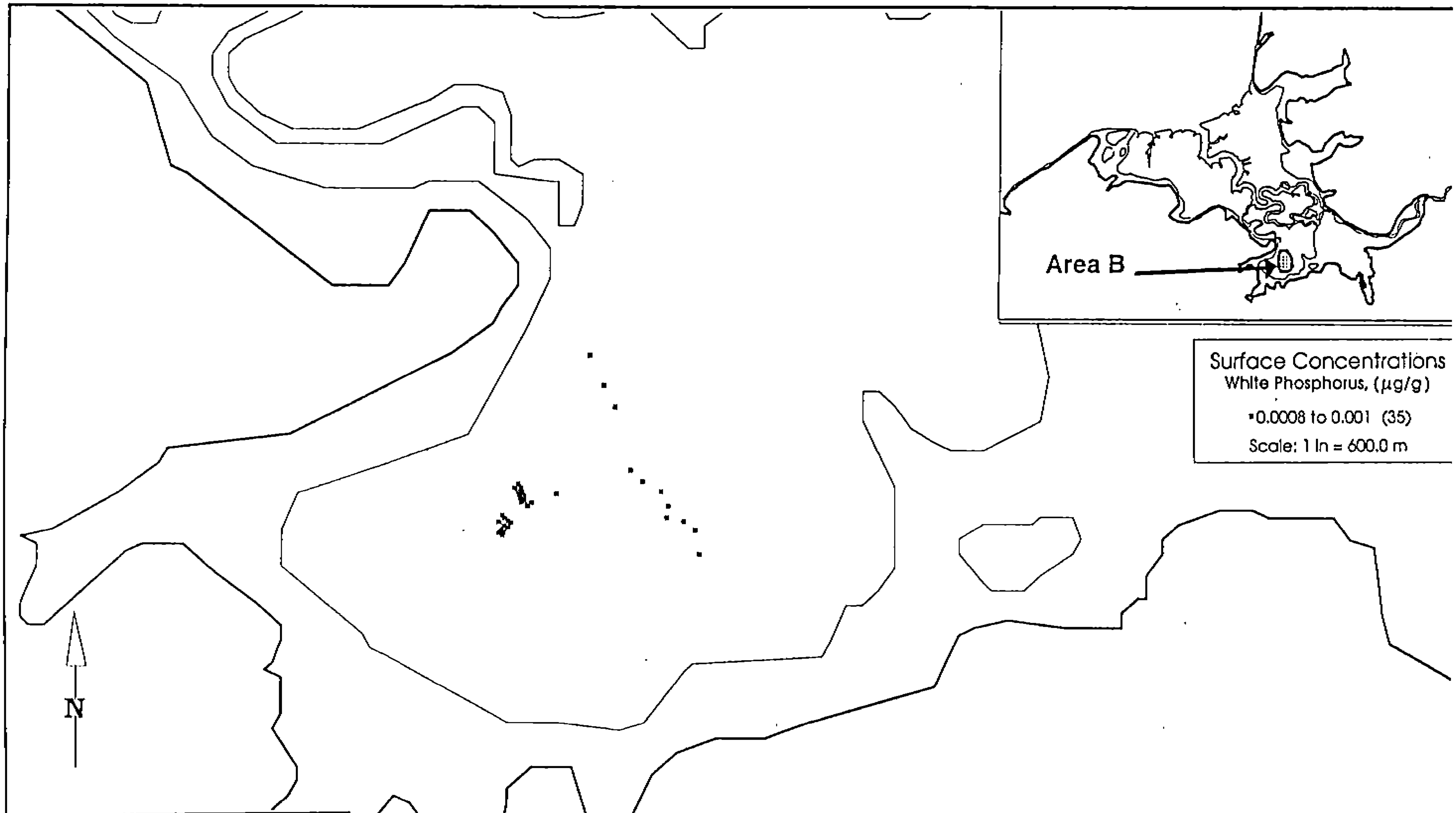

FIGURE 3-3
AREA B
SURFACE SEDIMENT SAMPLES
1990-1993

SOURCE: Racine, et al., 1994

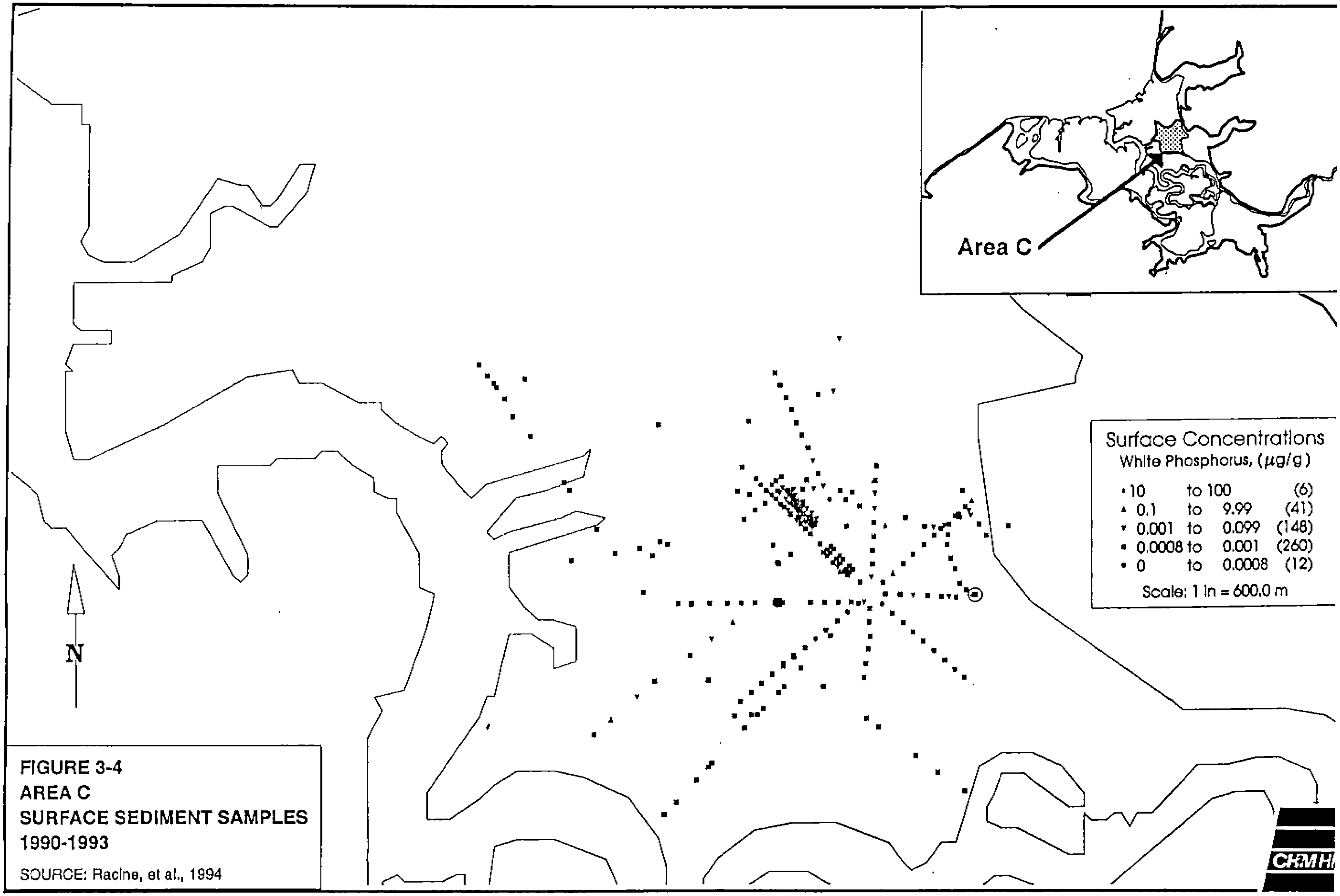

FIGURE 3-4
AREA C
SURFACE SEDIMENT SAMPLES
1990-1993

SOURCE: Racine, et al., 1994

NPE70024.M0.20 Fig 3-X
Rev 1 5/06/94

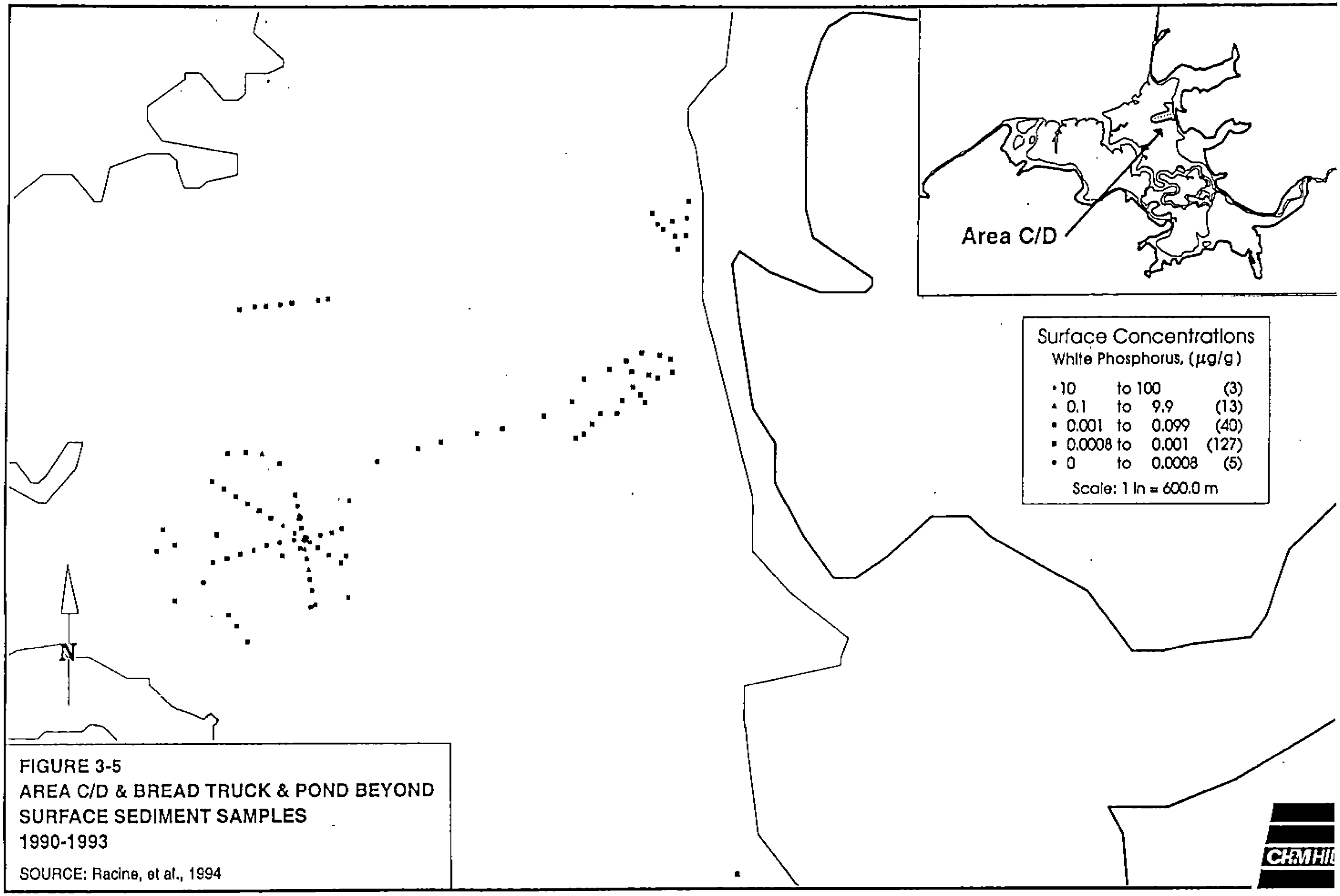

FIGURE 3-5
AREA C/D & BREAD TRUCK & POND BEYOND
SURFACE SEDIMENT SAMPLES
1990-1993

SOURCE: Racine, et al., 1994

NPE70024.M0-20 Fg 3-X
Rev 1 5/06/94

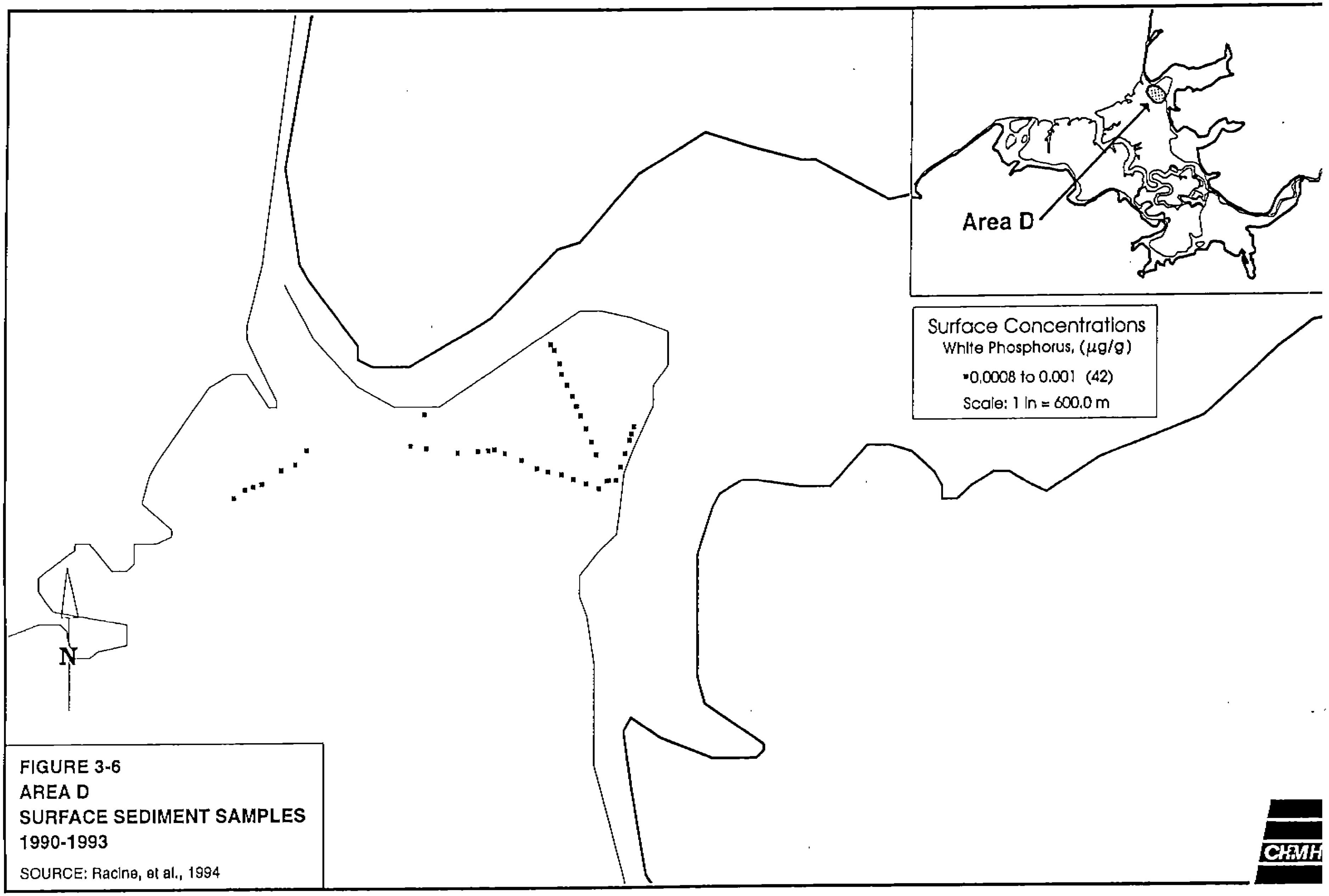

FIGURE 3-6
AREA D
SURFACE SEDIMENT SAMPLES
1990-1993

SOURCE: Racine, et al., 1994

NPE70024.M0.20 Fig 3-X
Rev 1 5/06/94

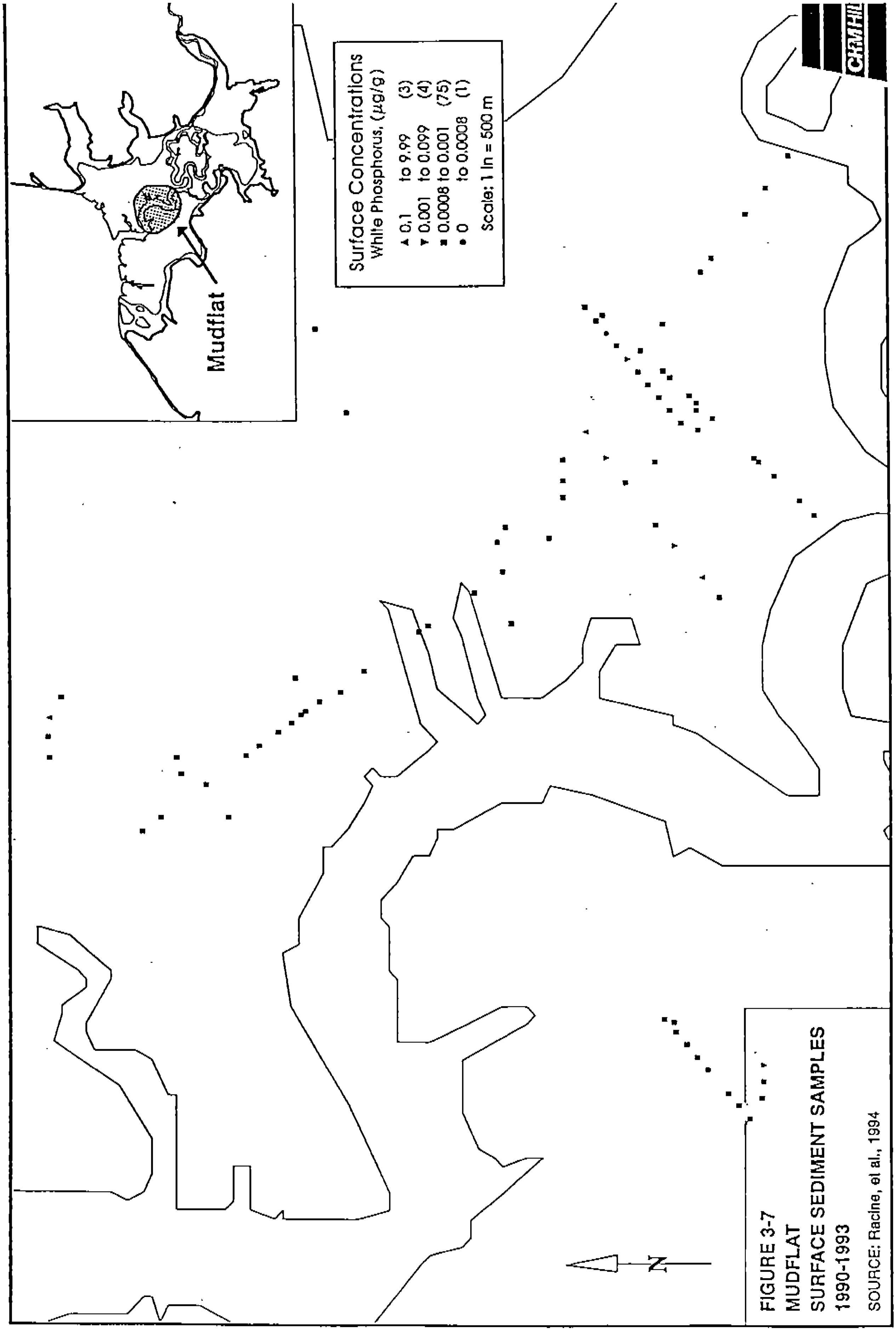

FIGURE 3-7
MUDFLAT
SURFACE SEDIMENT SAMPLES
1990-1993

SOURCE: Racine, et al., 1994

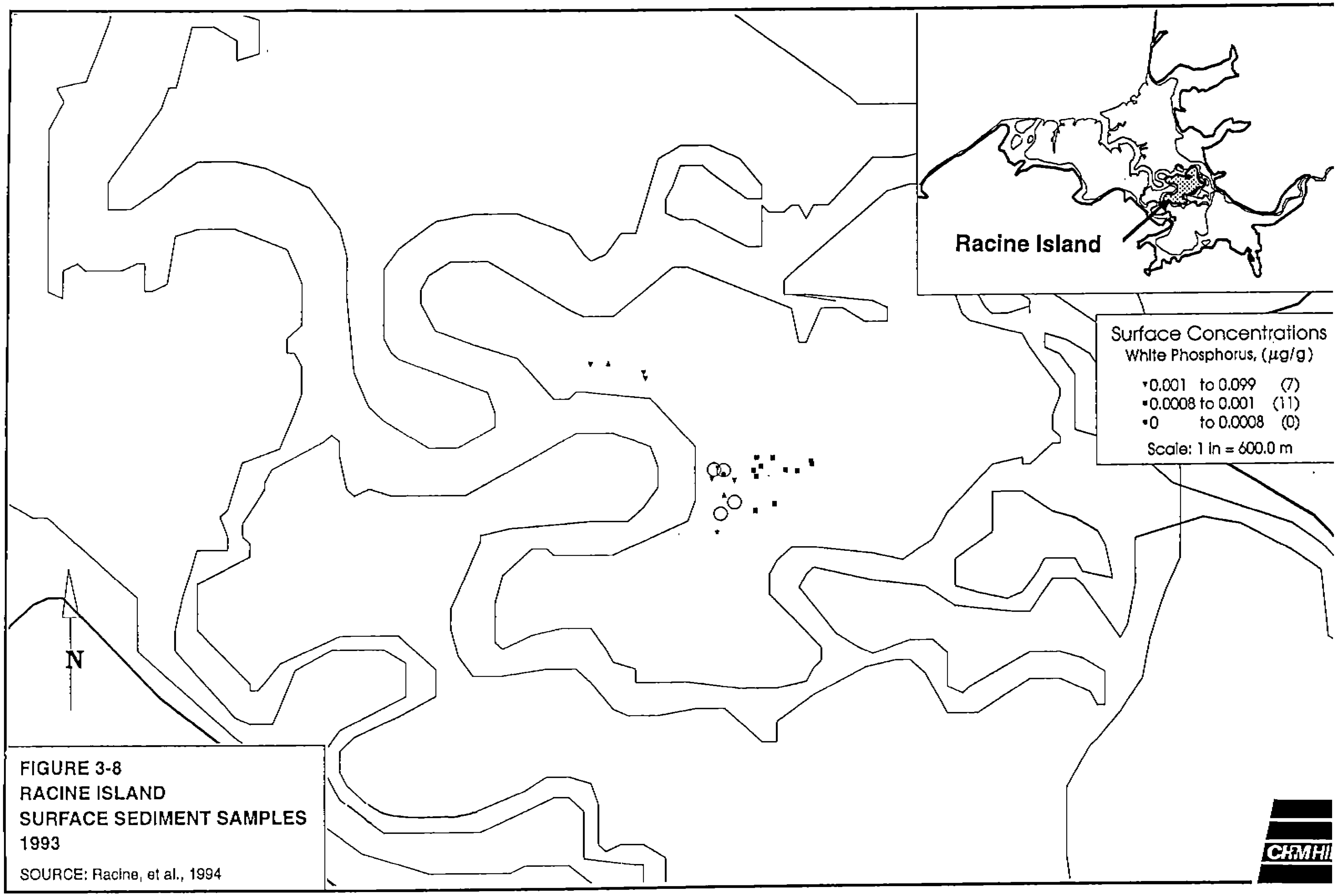

FIGURE 3-8
RACINE ISLAND
SURFACE SEDIMENT SAMPLES
1993

SOURCE: Racine, et al., 1994

NPE70024.M0.20 Fig 3-X
Rev 1 5/06/94

USAEHA collected surface water samples along with associated sediments and macroinvertebrates, and subjected the water samples to tests for USEPA priority pollutants in addition to the WP. The intent was to determine if other contaminants might also be a problem on the ERF. Surface water was sampled for WP at 17 locations in ERF and two areas in Eagle River. A control sample was taken from Goose Bay, where no WP was expected.

CRREL collected water samples from five locations. Three sites in Area C were chosen on the basis of the following criteria:

- Well characterized by several sediment samples, all of which were positive for WP
- Represented different habitats (shallow pond, deep pond, sedge marsh) with different salinities
- Easy access

At least two of the USAEHA collection points were the same as those used by CRREL. CRREL collected two additional surface water samples from Area C in conjunction with the study of WP in plant tissue.

Collection of Water Samples and Analytical Methods: The WP suspension studies were conducted in a shallow pond just north of the Area C tower in August 1991. Before disturbing the pond sediment, researchers first dragged a plankton tow net equipped with a 0.076-mm mesh through the pond and collected a water sample from within the submerged net. They then collected one water sample over undisturbed sediments. Finally, one water sample was collected after researchers walked through the pond to disturb the sediment.

Laboratory experiments were also conducted on bulk sediment samples collected from Area C. The samples were covered with a saline solution to simulate water conditions at ponds in Area C, and then subjected to three levels of agitation to simulate high-level disturbance from a duck feeding in the pond sediment, low-level disturbance from wind or a duck swimming in the water column, and no disturbance (control). Water samples were collected immediately after the sediment was disturbed and at 15-minute intervals thereafter for up to 1 hour.

Sieved sediment samples (<0.150-mm particle size) were also suspended in water and the water columns sampled for WP after zero, 2, 4, and 20 hours of settling.

Both CRREL and USAEHA collected water samples directly into the required containers. Some samples were filtered in the field using a portable pump (ISCO) and a high-rate filter (0.45 micron). All samples were analyzed for WP by CRREL.

The water samples for the sedimentation studies (1991-1992) were analyzed by GC for WP using an iso-octane extraction developed by Addison and Ackman (in 1970). The method detection limit for WP in water is listed as 0.2 microgram per liter (µg/L). The water samples collected in 1993 were also taken with iso-octane extraction methods. However, the USAEHA water samples were also subjected to a new preconcentration method involving ether extraction followed by GC analysis. The ether extraction procedure resulted in a lower method detection limit of 0.011 µg/L. The documentation available from CRREL on the water methods does not indicate a practical quantitation limit. The ether extraction procedure provides a technique to measure WP at levels low enough to meet the water quality criteria for the protection of aquatic organisms (Walsh, 1994, in Appendix A of Racine, et al., 1994).

Sampling and Analysis Plans: The documents available for review did not include a QAP_jP for the data gathering activities. Although quality data can be generated without a QAP_jP, the absence of documentation to demonstrate the adequacy and quality of the data can limit their usability in meeting regulatory concerns and requirements under CERCLA or RCRA programs.

Data Quality Review: The study reports offer no discussion of analytical performance or data validation of the available analytical data, and the raw data were not available for review or validation during preparation of this CER. Without data validation or data quality review, it is not possible to develop an independent assessment of the data quality and to judge its adequacy to meet project objectives.

The information presented in the CRREL report (Walsh, in Racine, et al., 1994) indicates that the analytical method is capable of detecting and quantifying WP present and should be capable of producing quality data when performed under a defined QAP_jP.

A major problem with analyzing WP in water appears to be a short holding time because of volatilization. A preliminary study (Walsh, 1994, in Appendix A of Racine, et al., 1994) showed that if precautions were taken to minimize losses to volatilization, surface water samples maintained at 4°C remained stable for at least 6 days. The samples CRREL collected were apparently analyzed at a field laboratory and presumably had a short holding time. Samples collected by USAEHA were shipped overnight to CRREL in New Hampshire. Because holding times were not indicated for any of the samples analyzed from the ERF, it is not possible to determine the effect on the resulting data.

To distinguish between dissolved and suspended WP as well as that sorbed to the sediment, filtration of water samples was tested in the field. However, filtration causes turbulence in the filtered water and facilitates mass transfer of WP from the water to the air. CRREL is investigating the magnitude of this effect.

Concentrations and Distribution of WP in Surface Water: The tow sample taken before sediments were disturbed by walking, contained very low, but measurable, concentrations of WP (0.0008 µg/g in suspended sediments). The tow sample taken in the same place after disturbance of the bottom sediments yielded a concentration of 0.0224 µg/L, suggesting that small particles of WP become suspended in the water column along with the sediment.

In the laboratory particle-suspension experiments, some samples showed WP at detectable levels in the water columns, even in undisturbed controls. White phosphorus was most easily detected from the sediment sample that had the largest number of particles and the highest concentration of WP. The greatest concentration of WP in the water was on the order of 50 µg/L. In bulk sediment samples with smaller WP particle-size, WP remained in suspension for the entire 1-hour experiment. In sieved sediment samples, WP remained in suspension up to 24 hours if a large number of small particles were present in the original sediment sample.

The fact that WP particles may remain suspended for several hours is significant since, once suspended, these particles could be consumed by animals feeding in the water column or could be transported by currents to other areas of the ERF.

In 1993, WP was detectable in the water column above contaminated sediments. Disturbed sites had more suspended WP than undisturbed sites. For the disturbed, unfiltered water samples, concentrations were highest (290 µg/L) in "cratered" areas where water flow is restricted by the sides of the holes or craters. With WP sediment concentrations greater than 2,000 µg/g (parts per million), WP water concentrations were around 7 µg/L (parts per billion) over undisturbed sediments. In holes, the contaminated water is less susceptible to the dilution that may occur in open water areas.

White phosphorus was detected in open area waters at concentrations two orders of magnitude lower than concentrations found in confined sites. For open water areas over undisturbed sediments with WP concentrations of 1 µg/g, the WP water concentrations were only 0.01 µg/L. Disturbance caused by excavating the contaminated sediments increased WP water concentrations to more than 1 µg/L. Filtered samples contained less WP than unfiltered samples, which may be a function of decreased sediment or increased volatilization of WP during the collection process.

No WP was detected in the water column above the uncontaminated sediments in the USAEHA investigation.

CRREL concluded that because areas with high WP concentration were chosen for the surface water investigation, the results represented the highest WP water concentrations that may be expected in the ERF. Given the potential for dilution by flooding high tides in the ERF, the concentration of WP in water away from localized hot spots is likely to be insignificant.

3.3.2.3 Summary and Conclusions about WP in the Physical Environment

Four years of investigations of WP in the physical environment by CRREL and collaborators have led to the following conclusions (Racine, et al., 1993; Racine, et al., 1994):

- Particles of WP in pond-bottom sediments are the cause of the mortality of thousands of waterfowl at the ERF.

- White phosphorus enters pond sediments as a result of detonation of smoke projectiles.

- White phosphorus occurs in the sediments as soft, waxy particles ranging in size from less than 0.15 mm to 3.5 mm. The number of particles in the various size classes from small to large varies greatly from one sediment sample to the next or from place to place within a pond.

- Analysis of more than 1,000 sediment samples for WP suggests that the major contamination and hypothesized source of most waterfowl poisonings in the ERF occurs in ponds on three areas: Area C, Racine Island, and Bread Truck Pond.

- Sediment cores showed that WP can occur in sediments to depths of 30 cm, and probably deeper.

- Disturbance of contaminated sediments (from traffic, wind, or feeding) results in the suspension of WP particles in the water column above contaminated sediments, particularly where most of the particles are 0.15 mm or less in size.

- The concentration of WP in water away from localized hot spots is likely to be insignificant.

- White phosphorus particles in the sediment may be transported to other areas of the ERF and former EOD pad by surface water or by dying, but still mobile, waterfowl. However, WP was not detected in water in distributaries draining the Bread Truck Pond and Area C.

3.3.3 Other Munitions Residues

Several studies at the ERF and former EOD pad have looked for munitions residues in the physical environment. Unlike WP, other munitions residues do not appear to cause acute mortality in waterfowl. The following compounds have been detected at low concentrations in either surface sediments, soils, or surface water.

- HMX (cyclotetramethylenetetranitramine)
- RDX (hexahydro-1,3,5-trinitro-1,3,5-triazine)
- TNT (2,4,6-trinitrotoluene)
- Tetryl (1,2,4,6-tetranitro-N-methylaniline)
- PETN (pentaerythritol tetranitrate)
- 2,4-DNT (2,4-dinitrotoluene)
- 2,6-DNT (2,6-dinitrotoluene)
- 2-Am-4,6-DNT (2-amino-4,6-dinitrotoluene)

- 4-Am-2,6-DNT (4-amino-2,6-dinitrotoluene)
- Dinitrobenzene (DNB) (1,3-dinitrobenzene)
- Nitrates
- Phosphates

The chemicals HMX, RDX, TNT, tetryl, and PETN are components of high explosives; 2,4-DNT is a component of the propellant M1 composition; TNT and 2,6-DNT are by-products of the manufacture of 2,4-DNT. The amino compounds are breakdown-products of TNT–they form when a nitro group on the TNT molecule is reduced (Racine, et al., 1992b). Nitrates and phosphates may be elevated because of breakdown products of explosive components.

3.3.3.1 Sediment and Soils

Sampling Strategy: The initial hypothesis was that munitions residues, if present, should occur in, or next to, explosion craters. Consequently, investigators in 1989 (ESE, 1990) and 1990 (Racine, et al., 1992b) sampled sediments in the ponds where craters occurred.

Initial results from sampling in 1989 and May 1990 indicated that munitions analytes were only found in Area C, adjacent to the former EOD pad. The hypothesis then centered on the former EOD pad as a potential source of contaminants. Additional sediment samples were collected in August 1990 from transects starting at the edge of the former EOD pad and extending into the salt marsh in Area C (Racine, et al., 1992b). Only sediment samples were collected in August 1990 because the investigators reasoned that bottom feeding by dabbling ducks would be the most likely pathway for ingestion of toxic compounds.

In 1992, USAEHA (Holdsworth, 1993) collected surface soil samples from the former EOD pad. Sample points were approximately equally spaced along transect lines that extended from the edge of the marsh upland to the tree line.

In 1993, as part of a broad contaminant inventory, USAEHA again tested for munitions residues in sediments collected from Eagle River, its distributaries, and ponded areas at the ERF. The sediments were also sampled for microinvertebrates so that concentrations of contaminants could be compared to the condition of the benthic macroinvertebrate populations. Samples in the distributaries were collected shortly before a low tide that followed an ERF-inundating high tide. The timing was required to get the worst-case scenario for the amount of contaminants leaving the flats and entering Eagle River.

Collection of Sediment and Soil Samples and Analytical Methods: ESE (1990) collected 25 composite sediment samples from the ERF and one sample from the Cottonwood Slough control site in 1989. Table 3-1 shows the distribution of the samples over the areas of the ERF. Each sediment sample was composed of three subsamples collected with stainless-steel spoons and placed in a sample jar. Samples were placed in ice chests and maintained at or below 4°C during shipment to the laboratory. Samples were handled under strict chain-of-custody procedures. The sediment samples were analyzed for explosives/munitions residues (USATHAMA Certified Method LW12), nitrate plus nitrite (USATHAMA Certified Method KF10), and total phosphate (Method KF14). The results were expressed in dry weight.

In May 1990, CRREL collected 47 sediment samples. Table 3-1 shows the distribution of the samples over the areas of the ERF. In August 1990, CRREL (Racine, et al., 1992b) collected 172 sediment samples in Area C near the former EOD pad. Soft pond sediment was collected by scraping to a depth of 10 cm into the sediment over as wide an area as possible (1 square m). Where there was an overlying layer of sod, a shovel was used to cut through the sod to reach the underlying sediment, and a representative sample of sediment and organic material was collected along the length of the shovel-cut from a depth of 30 cm to the surface. Samples were analyzed for munitions residues by a modified USATHAMA Standard Method SM02.

In 1992, USAEHA (Holdsworth, 1993) collected 48 soil samples from the former EOD pad. Four of the samples were field duplicates. Although no method number is listed for the report, it was probably USATHAMA Standard Method SM02. The analytes tested for included HMX, RDX, 2,6-DNT, 2,4-DNT, and 2,4,6-TNT.

In July 1993, USAEHA collected sediment samples from 23 sites, two of which had duplicate samples collected. Samples were collected by scooping the top 3 to 4 inches of sediment into a stainless steel bucket and thoroughly mixing the sediment with a stainless steel spoon before placing it into the sample containers. The samples were cooled with ice, packed and shipped overnight to a laboratory for analysis. Analysis for explosives was by a standard USAEHA method (American Industrial Hygiene Association, 1984). Analyses for total nitrogen were by a standard method of the American Society of Agronomy (Methods of Soil Analysis, Method 31-7.1, 1981). American Public Health Association

(Standard Methods for the Examination of Water and Wastewater, 17th ed., 1989) Methods 417B and 424C and F were used to determine ammonia-nitrogen and total phosphate phosphorus, respectively.

Sampling and Analysis Plans: The documents available for review did not include a QAP_jP for the data gathering activities. Although quality data can be generated without a QAP_jP, the absence of documentation to demonstrate the adequacy and quality of the data can limit its usability in meeting regulatory concerns and requirements under CERCLA or RCRA programs.

Data Quality Review: The study reports offer no discussion of analytical performance or data validation of the available analytical data, and the raw data were not available for review or validation during preparation of this CER. Without some type of data validation or data quality review, it is not possible to develop an independent assessment of the data quality and to judge its adequacy to meet project objectives.

The ESE report (1990) presents limited QC data, including some field duplicates and field and laboratory blanks; however, there is no discussion of the results, nor is there any discussion of the results of the QC samples on the quality and usability of the data. For example, acetone and phthalates are reported as present at the site in numerous samples. These two compounds are common laboratory contaminants whose presence, at low levels, in samples should be carefully evaluated before the analytical results are used in the project. No such discussion or evaluation of potential contamination of laboratory blanks is present.

The analytical methods referenced in the ESE report (1990) for organic compounds, metals, and explosives are standard USATHAMA methods that have been validated, have an extensive performance history, and should be capable of producing quality data when performed under a defined QAP_jP. Standard USEPA methods were referenced for other organic compounds and metals analyses in the CRREL report (1991), and USATHAMA Method SM02 was used for the analysis of explosives.

The analytical findings reported by CRREL (1991) indicate that 2,4-DNT contamination was primarily present in particulate form. The 2,4-DNT was present in propellant particles near the former EOD pad. The particulate nature of 2,4-DNT makes it difficult to obtain representative samples, because the contaminant either is or is not present in a small subsample, such as those analyzed for this project.

The USAEHA report (Bouwkamp, 1993) on the 1993 samples shows the results of field duplicate samples. Because no explosive residues or by-products were detected in any sediment sample, those duplicate results are completely comparable. The duplicate results for total nitrogen, ammonia-nitrogen, and total phosphate phosphorus were also comparable, considering the heterogeneity of the matrix. No laboratory QC data were presented in the report.

A possible concern with the 1993 USAEHA data may be that a sediment sample was mixed thoroughly before being distributed to sample jars. This procedure may have resulted in the loss of volatile compounds.

Concentrations and Distribution of Munitions Residues in Sediments and Soils: Table 3-8 shows the maximum concentrations of munitions residues in sediment and soil samples. All samples were collected from Area C or the former EOD pad. No munitions residues were detected in other ERF locations. Of the 172 sediment samples collected by CRREL in 1990, 62 were contaminated with 2,4-DNT. In most samples with concentrations of 2,4-DNT greater than 1 µg/g, 2,6-DNT and TNT were also confirmed, but at much lower concentrations. Also present in some samples were trace amounts of TNT biotransformation products 2-Am-4,6-DNT and 4-Am-2,6-DNT. The most prevalent compound detected in the soil samples on the former EOD pad was 2,4-DNT (present in 23 of the 48 samples collected by USAEHA in 1992 [Holdsworth, 1993]).

Nitrogen (nitrate plus nitrite) and total phosphate concentrations exceeded background concentrations in three sediment samples collected by ESE from Area C. (Sample concentrations were compared to the background geometric mean times one geometric standard deviation [1GSD], which was equal to 2.58 µg/g for nitrogen and 1,435 µg/g for total phosphate.)

In the USAEHA samples collected in 1993, the maximum ammonia-nitrogen concentrations detected in the ERF at Area C (71 mg/kg, dry weight), Area C/D (40 mg/kg), Bread Truck Pond (86 mg/kg), and Racine Island (23 mg/kg) exceeded maximum background (Goose Bay, 17 mg/kg). The maximum total nitrogen concentrations in Area C (2,800 mg/kg), Area C/D (2,300 mg/kg), Bread Truck Pond (1,600 mg/kg), Racine Island (1,335 mg/kg), and one distributary sample (980 mg/kg) exceeded background (Goose Bay, 660 mg/kg). Total phosphate phosphorus concentrations were more uniform throughout the investigation area, with only one Racine Island sample (2,700 mg/kg) greatly exceeding background

Table 3-8
Munition Residues Detected in Sediments and Soils at the Eagle River Flats

Munition Residue	Surface Sediments[a]		Surface Soils[b]	
	Maximum Concentration[c] (µg/g)	Reference	Maximum Concentration (µg/g)	Reference
HMX	ND	Racine, 1992a	1.4	Holdsworth, 1993
RDX	0.076	Racine, 1992a	12	Holdsworth, 1993
TNT	115[d]	Racine, 1992a	16	Holdsworth, 1993
PETN	34.7	ESE, 1990	NR	Holdsworth, 1993
2,4-DNT	84	Racine, 1992a	76	Holdsworth, 1993
2,6-DNT	4.47	Racine, 1992a	2.6	Holdsworth, 1993
2-Am-4,6-DNT	0.73	Racine, 1992a	NR	Holdsworth, 1993
4-Am-2,6-DNT	0.93	Racine, 1992a	NR	Holdsworth, 1993

ND = Not detected. NR = Not reported.
[a] All surface sediment samples were located in Area C.
[b] All surface soil samples were located on the former EOD pad.
[c] All concentrations are in dry weight.
[d] The second highest concentration of TNT was 0.467 µg/g.

(940 mg/kg). USAEHA (Bouwkamp, 1993) stated that the inorganic results above were "typical of what would be expected in a dynamic tidal wetland with a glacial-fed river and ... estuarine tides."

CRREL investigators concluded that 2,4-DNT is not the cause of waterfowl mortality in the ERF for the following reasons:

- Sick waterfowl in the field did not exhibit characteristics of 2,4-DNT poisoning.
- The area where 2,4-DNT was found is mostly tall sedge marsh with few ponds suitable for waterfowl habitat.

3.3.3.2 Surface Water

Sampling Strategy: The sampling strategy for surface water was similar to that used for sediment sampling. Areas with craters were screened for munitions residues in the water column. In 1989, ESE collected 27 water samples. In May 1990, CRREL collected water samples throughout the ERF. In July 1993, USAEHA collected water samples from the same locations at which sediments and benthic macroinvetrebrates were collected.

Collection of Water Samples and Analytical Methods: ESE, CRREL, and USAEHA collected water samples directly into precleaned sample containers, preserved as required for the analysis to be performed. Samples were maintained at 4°C until analysis. ESE collected and tested 27 water samples for munitions/explosives (USATHAMA Standard Method UW14), nitrate plus nitrite (USATHAMA Method K8), and total phosphates (USATHAMA Method TF27). CRREL collected and field-screened 47 water samples for TNT and RDX by colorimetric methods (Jenkins, 1990; Walsh and Jenkins, 1991). CRREL also tested for munitions residues (USATHAMA Method SM02) at an analytical laboratory. USAEHA collected and tested water samples from 20 locations (plus two duplicate samples) for munitions residues (USATHAMA method), ammonia-nitrogen (USEPA 350.1), total nitrogen (nitrate plus nitrite, USEPA 353.2), total Kjeldahl-nitrogen (USEPA 351.1), and total phosphate phosphorus (USEPA 365.2).

Sampling and Analysis Plans: The available documents did not include a QAP_jP for the data gathering activities, and there is no discussion of analytical performance or data validation of the available analytical data. No raw data were available for review or validation during preparation of this CER.

Data Quality Review: The study reports offer no discussion of analytical performance or data validation of the available analytical data, and the raw data were not available for review or validation during preparation of this CER. Without some type of data validation or data quality review, it is not possible to develop an independent assessment of the data quality and to judge its adequacy to meet project objectives.

The analytical methods referenced for inorganics and explosives are standard USATHAMA or USEPA methods that have been fully validated, have an extensive performance history, and should be capable of producing quality data when performed under a defined QAP_jP.

The field duplicate results for the water samples collected by USAEHA in 1993 were all comparable within the variation expected by the method or expected with nonhomogeneous samples.

Concentrations and Distribution of Munitions Residues in Surface Water: Table 3-9 shows the maximum concentrations of munitions residues detected in surface water samples collected by ESE. Only two of the samples in Area C showed detectable levels of munitions residues (both near the former EOD pad). None of the samples collected by CRREL or USAEHA showed detectable levels of munitions residues.

Table 3-9
Munition Residues Detected in Surface Water at the Eagle River Flats

Munition Residue	Maximum Concentrations[a] (µg/L)	Reference
Tetryl	6.5	ESE, 1990
2,4-DNT	2.86	ESE, 1990
2,6-DNT	2.45	ESE, 1990
DNB	1.17	ESE, 1990
Nitrobenzene	3.48	ESE, 1990

[a] In surface water samples collected in Area C.

ESE (1990) used the geometric means times 1GSD to compare background samples to site samples for inorganic parameters. Total phosphate exceeded the background comparison in surface water samples from Area C. Nitrogen (nitrate plus nitrite) exceeded the background comparison in surface water samples in Area C and Area D.

USAEHA (Bouwkamp, 1993) interpreted the phosphate and nitrogen results in the surface water samples to be "typical of what would be expected in a dynamic tidal wetland with a glacial-fed river and ... estuarine tides."

3.3.3.3 Summary of Munitions Residues in the Physical Environment

Low levels of munitions residues have been found in both sediment and surface water in Area C of the ERF, and in soils at the former EOD pad. A propellent component, 2,4-DNT, is the most frequently observed contaminant in all media. Production by-products (TNT and 2,6-DNT) of 2,4-DNT are also found in soils and sediments, but at generally lower levels. Degradation products of TNT, the amino-dinitrotoluenes, are also present in the sediments in low levels.

Generally, researchers have concluded that the munitions residues discussed in this section are not responsible for the acute mortality found among the waterfowl of the ERF. A review of toxicological data as presented in ERF documents is presented in the risk assessment discussion in Section 5.

3.3.4 Other Organic Compounds and Metals

The investigations at the ERF from 1985 through 1988 (summarized in Tweten, 1989) analyzed sediment and surface water samples for a long list of target compounds, including volatile organics, semivolatile organics, and metals, to determine the nature and extent of contamination (Table 3-1). The studies had few total samples, and sample locations were not precisely documented. The results were generally negative, or were inconclusive because of sampling or analytical problems. The early studies also lack adequate documentation of quality control procedures, so the overall quality of the data cannot be evaluated.

The first study to systematically look for contaminants at the ERF was conducted by ESE in 1989. Organic compounds at low levels and inorganic compounds above background levels were found in both sediment and surface water.

In July 1993, USAEHA (Bouwkamp, 1993) collected surface water and sediment samples from ERF ponds and distributaries, as previously described in the sections on WP. The samples were collected in conjunction with a study on the condition of the benthic macroinvertebrate populations. Samples were preserved as required by the method, stored on ice at 4°C, and shipped overnight to laboratories.

The USAEHA samples were tested for acid/base/neutral extractable organic compounds (USEPA 625/8270), volatile organic compounds (USEPA 624/8260), pesticides/PCBs (USAEHA SOP # 37.1 and Report, Pesticide Monitoring Special Study No. 44-0131-77), mercury (USEPA 245.1), and metals (USEPA 200). Both dissolved (filtered) and total (unfiltered) metals and mercury were determined in the surface water samples. One QC concern might be that the sediment samples were thoroughly mixed before being placed in sample containers. Agitation of the sample could result in loss of volatile organics by volatilization. The USAEHA report indicates that two low-level detections of bis(2-ethylhexyl) phthalate and one methylene chloride detection were obtained. However, USAEHA considered their detections questionable because of possible laboratory contamination. No QC results from trip blanks or laboratory method blanks were available to confirm laboratory contamination.

Table 3-10 shows additional organic compounds, excluding munitions residues, detected in sediments and surface water at the ERF by ESE. A few other organic compounds have been tentatively identified, but not confirmed. Tentative identifications include 1,1,2,2-tetrachloroethane and 1,1,2-trichloroethane in surface water samples from Area C. None of the organic compounds appeared widespread, in terms of study areas, or abundant, in terms of concentrations or number of samples. No organic compounds were found by USAEHA.

Table 3-10
Other Organic Compounds Detected in Surface Water and Sediment Samples at the ERF

Organic Compound	Surface Sediment		Surface Water	
	Maximum concentration (µg/g)	Location	Maximum concentration (µg/L)	Location
Acetone	0.5	Area C	17	Area C
bis(2-ethyhexyl) phthalate	9.0	Area C	>100	Area B
Carbon disulfide	0.06	Area A	ND	--
4-Methyl phenol	4.4	Area C	3.6	Area C
Toluene	0.062	Area C	ND	--
Xylenes	3.0	Area A	ND	--

ND = Not detected.
Source: ESE, 1990.

The concentrations of each type of metal detected in sediment and surface water samples were compared to background levels. The background concentrations were derived from regional data or local background samples. In many of the samples from the ERF, metal concentrations were above background levels. To delineate those samples in which inorganic element concentrations were elevated well above background, the geometric mean times 1GSD for each element was calculated. Those sample sites that exceeded the geometric mean times 1GSD occurred within the upper 16 percent of all the ERF samples for the element. Sample sites thus identified were considered to contain inorganic elements in concentrations higher than most of the samples. Table 3-11 shows the study areas of the ERF that had at least one sample elevated for a specific inorganic element. Area C had the most inorganic elements elevated for both surface water and sediment samples.

Racine, et al. (1993) indicates that additional metal samples were obtained from the ERF and four control areas (Cottonwood Slough, Fire Creek, Goose Bay, and Susitna Flats) in 1990 and the samples were analyzed for inorganic compounds. The analytical results for the ERF samples were not significantly different from the control areas.

USAEHA (Bouwkamp, 1993) summarized their metals results as follows:

> Metals in water were within freshwater criteria based on site-specific hardness. Because of large amounts of metals that could be contributed by the suspended solids from the glacial flour, dissolved metals (form biologically available) were measured and used for criterion comparison. Several metals in the sediment were at concentrations slightly higher than they were in Goose Bay samples (reference site). Except for sodium (salinity related), all sediment metal concentrations were within the upper 95th percentile of the sediments from Goose Bay and within the level of variance seen in the duplicate samples.

ESE (1990) and USAEHA (Bouwkamp, 1993) concluded that the levels of organic and inorganic compounds in the sediments and surface water at the ERF were not high enough to cause waterfowl mortality.

Despite some QC concerns (for example, occasional improper sample collection procedures, lack of documentation and chain of custody, and unavailability of laboratory QC results), an overall review of the accumulated data shows that most organic and inorganic compounds, other than some munitions residues and WP, are not chemicals of concern at the ERF. This view is supported by several investigations using standard laboratory analytical methodology for a suite of possible compounds. It is also supported by a review of

Table 3-11
Elevated Inorganic Analyte Detections in Surface Sediment Samples and Surface Water Samples

Inorganic Analyte	Surface Sediment				Surface Water			
	Area A	Area B	Area C	Area D	Area A	Area B	Area C	Area D
Al			X				X	
Ag		X						
As			X				X	
Ba							X	
Ca		X	X				X	
Co			X					
Cr							X	
Cu							X	
Fe			X				X	
K			X	X			X	
Mg	X		X				X	
Mn	X		X				X	
Na			X	X			X	
N			X				X	X
Ni	X		X				X	
Pb	X		X				X	
PO_4			X				X	
Sb					X		X	
Se								
V		X		X				
Th							X	X
Zn			X				X	
Hg	X	X	X	X				

Source: ESE, 1990

historical practices at the ERF indicating that the presence of volatile organics, acid/base/ neutral organics, metals, pesticides and PCBs in the environment is unlikely.

3.4 Biota Chemical Analyses

In 1983, the gastrointestinal tracts of four birds found dead in the ERF were analyzed for total phosphorus; the concentrations were abnormally high (1,730 to 8,500 parts per million [ppm] dry weight). In 1984, the gastrointestinal tracts of four birds from the ERF and four control birds were analyzed for total phosphorus; concentrations in the ERF birds were 920 to 1,190 ppm wet weight, compared to 750 to 900 ppm in the control birds (CRREL, 1991). Tissue samples from a dead eagle and a gull egg were found to contain WP, and WP was found in the gizzard contents of 74 dabbling duck and 12 swan carcasses collected in the ERF. No WP was detected in 305 ducks shot by hunters outside Fort Richardson (Racine, et al., 1993). Other analyses found no evidence of bacterial, viral, or parasitic disease or trauma; cholinesterase inhibition; or lead, mercury, zinc, magnesium, or arsenic at levels associated with toxicity.

In 1988, kidney and liver tissue from 15 specimens (5 mallards, 5 northern shovelers, 1 pintail, 2 green-winged teals, 1 trumpeter swan, 1 bald eagle) were analyzed for 14 trace elements (aluminum, arsenic, beryllium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, thallium, and zinc). The resulting CRREL report (1991) states that "The concentration of these elements in the waterfowl tissue were less than those associated with acute or chronic mortality." Toxicity resulting from heavy metals, pesticides, or diseases was eliminated during early studies (USFWS, 1993).

In August 1990, tissues from three poisoned ducks were preserved in formalin and, later, thin-section prepared for light-microscope study. In September, five ducks were autopsied immediately after death, and organs (heart, liver, intestines, kidney, gizzard contents, fat, brain, and muscle) put on dry ice for later analysis. In October, the gizzards from two dead mallards and four dead swans were removed and analyzed; five green-winged teals from offsite (Susitna Flats) were analyzed as controls (CRREL, 1991). To analyze the samples, gizzard contents were scraped into vials, and iso-octane was added to extract the WP by homogenizing under nitrogen, shaking overnight, and centrifuging. Iso-octane was analyzed using flame photometric detection gas chromatography/mass spectrometry.

Tissues from the eleven birds (seven ducks and four swans) were analyzed for WP. Gizzard contents and fat tissue from the five Susitna Flats ducks were also analyzed. White phosphorus was found in the gizzard contents of all ducks from the ERF, in the livers of four ducks that died soon after convulsing, and in the fat of one duck that survived 9.5 hours. No WP was found in the Susitna Flats ducks (Table 3-4). White phosphorus was not found in any blood samples, but did occur in 50 percent of the heart and kidney samples from the ERF birds. White phosphorus was found in the gizzard extracts of all swans collected in the ERF and in the fat of three of these swans. In one swan, the mass of WP in the gizzard was 11 mg and the concentration in fat was 2.0 mg/kg. No obvious histopathologic differences were noted between the teals from the ERF and those collected from the Susitna Flats (CRREL, 1991).

In 1990, a laboratory toxicity study was conducted in which acute doses of WP and 2,4-DNT were fed to domestic mallard ducks. The ducks were fed a 50:50 mixture of Agway cracked corn and layer pellets while housed in connected rooms bedded with wood shavings; a wading pool filled with water was also available for the ducks (CRREL, 1991). The procedures for and findings from administering each of the two doses are discussed below.

White Phosphorus Dosing Study. The ducks were treated by gavage with 12 mg of WP per kg body weight (5 to 6 mL) dissolved in tricaprylin. After violent convulsive behavior was observed, ketamine was injected into breast tissue to anesthetize the bird. The bird was sacrificed and immediately autopsied and the tissues analyzed for WP.

Observations included normal activities for the first 75 minutes post-dosing, when one duck exhibited violent shakes with open beak for 15 minutes. This was followed by 3 hours of normal behavior with mild head shakes. Four-and-one-half-hours post-dosing, uncontrollable head shaking with an open beak and constant dipping of the bill occurred, followed by languid behavior. The duck apparently showed photophobia by hiding its head and closing its eyes. At 5.25 hours post-dosing, the duck convulsed twice violently (arched neck and tail with the top of the head resting on the back of the duck and the beak pointing dorsally, wings spread out along its side, open eyes, and chest exposed), at which point it was anesthetized and sacrificed.

The behavior of the other laboratory ducks was similar to field observations of ducks poisoned at the ERF; however, time between onset of symptoms, convulsions, and death varied. The most characteristic behavior of sick ducks involved neck-writhing or rolling while the top of the head touched the back of the bird, swimming in tight circles, and convulsions; earlier signs of sickness were difficult to detect. Some early symptoms of poisoning included strong head shaking, or shaking the head in association with preening behavior. Table 3-12 lists the behavioral patterns in laboratory studies. Table 3-13 lists the concentrations of WP detected in various tissue and organ samples from the sacrificed laboratory ducks (CRREL, 1991). In laboratory and field ducks, WP was found in the body fat. Gross pathology indicated dark congested livers, kidneys, and other visceral organs (CRREL, 1991).

Table 3-12
List of Distinctive Behavior Characteristics Observed in Ducks Treated with White Phosphorus and 2,4-DNT

Domestic Mallards Treated With White Phosphorus (12 mg/kg)	Domestic Mallards Treated With 2,4-DNT (1,000 mg/kg)
Agitation Frequent drinking Uncontrolled head shaking Vomiting Seeking seclusion Lethargy Loss of coordination of head and legs Rearing back and swaying of head Convulsions: wings extended, tail upward, head thrust back Death	Frequent drinking Panting/heavy breathing with the bill open Shivering Inactivity Wobbly gait Sedation and death

Source: Racine, et al., 1993

Table 3-13
White Phosphorus Concentrations in Tissues of Two Domestic Mallards dosed with 12 mg of White Phosphorus Per Kilogram of Body Weight

Mallard	White Phosphorus Concentration (μg/g)			
	Liver	Fat	Breast Muscle	Brain
1	0.029	1.22	0.013	0.000
2	0.009	0.39	0.052	0.007

Source: CRREL, 1991

Lethality could not be correlated to the level of WP in the gizzard, nor in the fatty tissues. The mechanism by which WP causes sickness and death of ducks is unknown. It has been suggested that the absence of WP in brain tissue indicates that it does not act on the central nervous system, although a product of *in situ* phosphorus oxidation or metabolism may be responsible.

2,4-DNT Dosing Study. In two separate experiments, a mallard was gavaged with 1,000 mg of 2,4-DNT and observed. Blood samples were drawn every hour beginning at the second hour after dosing and were assayed for percent methemoglobin (Table 3-14). One to 2 hours after dosing, ducks exhibited inactivity, panting, or heavy breathing with the bill open. A wobbling gait and shivering occurred at about 4 hours; no convulsions occurred and the ducks died quietly 5 to 6 hours post-dosing. Analysis of the blood showed methemoglobin had risen to 35 percent and 51 percent in the two ducks tested within 2 hours post-dosing; the background level was 6 and 14 percent. At all times when blood was examined after treatment with 2,4-DNT, it was chocolate brown. This coloration is considered diagnostic (CRREL, 1991).

Table 3-14
Methemoglobin in the Blood of a Domestic Mallard Dosed With 1,000 mg of 2,4-DNT per Kilogram of Body Weight

Time After Dosing (hrs)	Methemoglobin (% of total heme)	
	First Mallard	Second Mallard
0	6	14
2	35	51
3	50	59
4	63	43
5	48	41
6	42	Died

Source: CRREL, 1991.

The field and laboratory studies concluded that WP is the primary cause of the ERF waterfowl mortality (CRREL, 1991). Supporting data are listed below:

- White phosphorus is highly toxic to ducks at an acute dose of only 1.5 to 3.9 mg/kg; in acute poisonings, ducks die over a few hours. The lethal dose of 2,4-DNT, however, is grams per kilogram of body weight.

- White phosphorus was found in all 11 waterfowl carcasses collected in the ERF during one study, but in none of the 5 wild ducks collected from the Susitna Flats. White phosphorus was found in the gizzards of 4 of 6 teals shot on the wing and in 2 carcasses collected less than 1/2 mile from the ERF (Racine, et al., 1993). Ducks poisoned at the ERF exhibited levels of WP ranging from 0.08 to 3,140 μg in their gizzards.

- Ducks dosed with WP exhibited symptoms similar to affected waterfowl in the ERF. Behavior of ducks dosed with 2,4-DNT was not similar to the dying wild ducks.

- Concentration and distribution of WP in duck tissue was similar in both laboratory ducks and dead ERF ducks. The highest levels of WP were usually found in the gizzard contents, but rapidly accumulated in fatty tissues such as adipose and skin tissue. Dead ducks from the ERF did not exhibit the 2,4-DNT toxicity symptoms of high methemoglobin blood levels and very brown coloration of the blood.

- White phosphorus was found in a shallow pond used intensively by waterfowl for feeding; however, 2,4-DNT was found in tall sedge marsh, habitat not used by feeding ducks.

Uptake of WP was determined to occur through a combination of feeding behavior and opportunistic grit ingestion; this accounts for the differences in mortality between the species (Reitsma and Steele, 1993, in Racine, et al., 1994). Ducks may ingest WP as grit for their gizzards; sizes of particles found in the gizzards support this hypothesis, except for the small particles found in green-winged teals. Smaller body size of the green-winged teal may mean that a smaller dose is lethal for them. Shovelers have the finest lamellae and should catch particles of all sizes, but they do not appear as susceptible to WP poisoning as other species. Wigeons, which showed lower mortality rates than other species, have lower exposure to WP because they feed primarily on plants.

When American kestrels (*Falco sparverious*) were fed a diet containing WP (P_4), detectable quantities of P_4 were found only in fatty tissues (Racine, et al., 1993; Nam, et al., 1994). The P_4 was found in fat deposits and skin as early as 24 hours post-dosing, but not in brain, heart, intestine, liver, kidney, or muscle. After 7 days of continuous exposure to a P_4-containing diet (6.4 µg/g), the skin but not fat deposits showed significant accumulation of P_4. A cyclic dosing regimen of feeding diets containing varying amounts of P_4 caused skin and fat to have measurable concentrations when the diet contained 6.4 µg/g, but not when the diet contained 0.7 µg P_4/g. This indicates that tissue levels are sensitive to dietary levels of P_4.

In dosing studies with mallards, investigators could not detect a linear relationship between P_4 residues in tissues and the dosage administered (Sparling, in Racine, et al., 1994). White phosphorus levels in acutely dosed birds that died during the study ranged from below detection level to 1.776 µg/g for fat, 0.959 µg/g in skin and 0.027 µg/g in liver. Birds that survived for a week had residue levels that were <1/100 of those in birds that died on the same dosage. White phosphorus in fat of dead birds, however, remains the most reliable indicator of exposure although its instability diminishes its value to determine exposure in living birds. Carcasses of a phalarope, lesser yellowlegs, three pintails, a blue-winged teal, 14 green-winged teals, and 14 mallards were collected in the ERF. They were necropsied and analyzed for P_4. All the ducks tested positive for WP, but the phalarope and lesser yellowlegs did not test positive. Skin and crop contents of 11 Arctic terns, 16 mew gulls, 5 lesser yellowlegs, 3 greater yellowlegs, 9 dowitchers, and 8 northern phalaropes that were collected by shooting on the ERF and three each of arctic terns, mew gulls, northern phalaropes, dowitchers, and lesser yellowlegs collected at Susitna Flats (as reference specimens) also did not have detectable levels of P_4.

Nine taxa of macroinvertebrates (most commonly including odonates, chironomids, and snails) were collected with dipnets in four ponded areas of the ERF during 1993 (Sparling, in Racine, et al., 1994). These invertebrates (as well as fish from the sampled areas) were identified to species or genus, minced, mixed with isooctane, and analyzed for P_4. Detectable levels of P_4 were not found in any of the 16 invertebrate samples collected from Bread Truck Pond or the samples of fish from 16 sites.

Plant samples (including *Zannichellia palustris, Carex lyngbyaei, Scirpus paludosus, Hippurus tetraphylla, Potamogeton pectinatus* and *Triglochin maritima*) were collected from sites in Area C where WP was previously detected in the sediment (Walsh, in Racine, et al., 1994). These samples were minced in isooctane and the extract was analyzed by gas chromatography. White phosphorus was detectable in the roots of *Carex Iyngbyaei* (2.27 µg/g) and *Zannichellia palustris* (0.16 µg/g), both of which were growing at sites with WP sediment concentrations exceeding 2,000 µg/g. It is unlikely that plant materials (especially seeds and leaves) represent a major food-chain pathway of exposure to WP for herbivores, but the sorption of WP to organic plant detritus (dead plant tissues in sediments) may provide a pathway to invertebrate detritivores.

Section 4
Conceptual Site Model

4.1 Introduction

A conceptual site model (CSM) provides a visualization of the surface and subsurface features at a site. This model details the nature of the surfaces themselves; it identifies the nature, extent, relationships, and movement of contaminants within them, and the exposures and risks caused by those contaminants. To understand the form, distribution, and movement of WP in the environmental media at the ERF, the chemical and physical behaviors of WP are also examined. The CSM has been developed based on WP contaminations, because WP appears to be the principal chemical of concern (other than the former EOD pad). Other fate and transport mechanisms, exposure pathways, and potential receptors may be associated with additional chemicals present at the ERF, however. The CSM for the ERF is presented in Figure 4-1 and is described below. The sources, releases, fate and transport in sediment and water, exposure routes and receptors, and bioaccumulation and bioconcentration potential of WP are examined. Where WP has not been measured in environmental media, modeling would be required to estimate WP concentrations at potential exposure points.

4.2 Sources of White Phosphorus in the Eagle River Flats

White phosphorus is one of the three forms of elemental phosphorus formerly used in matches, fireworks, and rat poison (Yon, et al., 1983). White phosphorus obscurants are set to burst in the air or upon impact. If the charge explodes in the air, the WP particles melt and burn. Portions of WP particles that are not fully oxidized hit the sediment or water surface and are extinguished. Because the density of the WP (1.8 grams per cubic centimeter [g/cm^3]) is greater than that of water, any unreacted WP sinks through the water column to the bottom sediment.

In the case of smoke projectiles that are set to explode upon impact, less of the WP is expected to burn. Projectiles that land on soft surfaces, like mud, snow, or water, will penetrate the surface before exploding. Under such circumstances, the area over which the

WP spreads is reduced, and the charge may displace significant volumes of sediment, as evidenced by the number of craters in areas where the most WP has been detected.

The range of the WP deposits would be expected to vary with the type of munitions. At the ERF, sediment containing high concentrations of WP has been found immediately surrounded by areas of much lower WP concentrations, suggesting that there is significant WP deposition at the point of impact. The portion of WP in a smoke projectile that is not oxidized following impact has been estimated based on laboratory tests and field observations; estimates range from 1 to 30 percent of the WP fired (Racine, et al., 1992b; CRREL, 1991).

4.3 Releases

The release of chemicals, particularly WP, from exploding ordnance is discussed in Section 2. Measured chemical concentrations, which are described in Section 3, are highlighted below to summarize the form and extent of WP contamination.

The sampling reported in Section 3 demonstrated that small distances between WP samples can present substantial differences in WP concentrations. This heterogeneous environment is extremely difficult to model. White phosphorus concentrations between measured points and in ponds that have not received any sampling should therefore be considered to be very uncertain.

Crater cover has been used to predict potential WP contamination (Racine, et al., 1993; Racine and Walsh, in Racine, et al., 1994), based on the assumption that WP was fired at the same targets or into the same areas as the HE projectives that formed the craters. Because a variety of shells were fired into the ERF over the past 40 years, this assumed correlation requires another assumption: that the distribution of WP shells was the same as that of the crater-producing shells. Although this assumption has not been explicitly tested, a high density of craters has generally indicated a great likelihood for WP to exist.

As discussed in Section 3, the highest frequencies and concentrations for WP detection in sediment were found in Area C, Bread Truck Pond, and Racine Island. Area A had a low frequency (10 percent) of detections and low concentrations (up to 0.053 µg/g); Area B had no detections in 15 samples; Area C/D had only two detections in 37 samples; Area D had

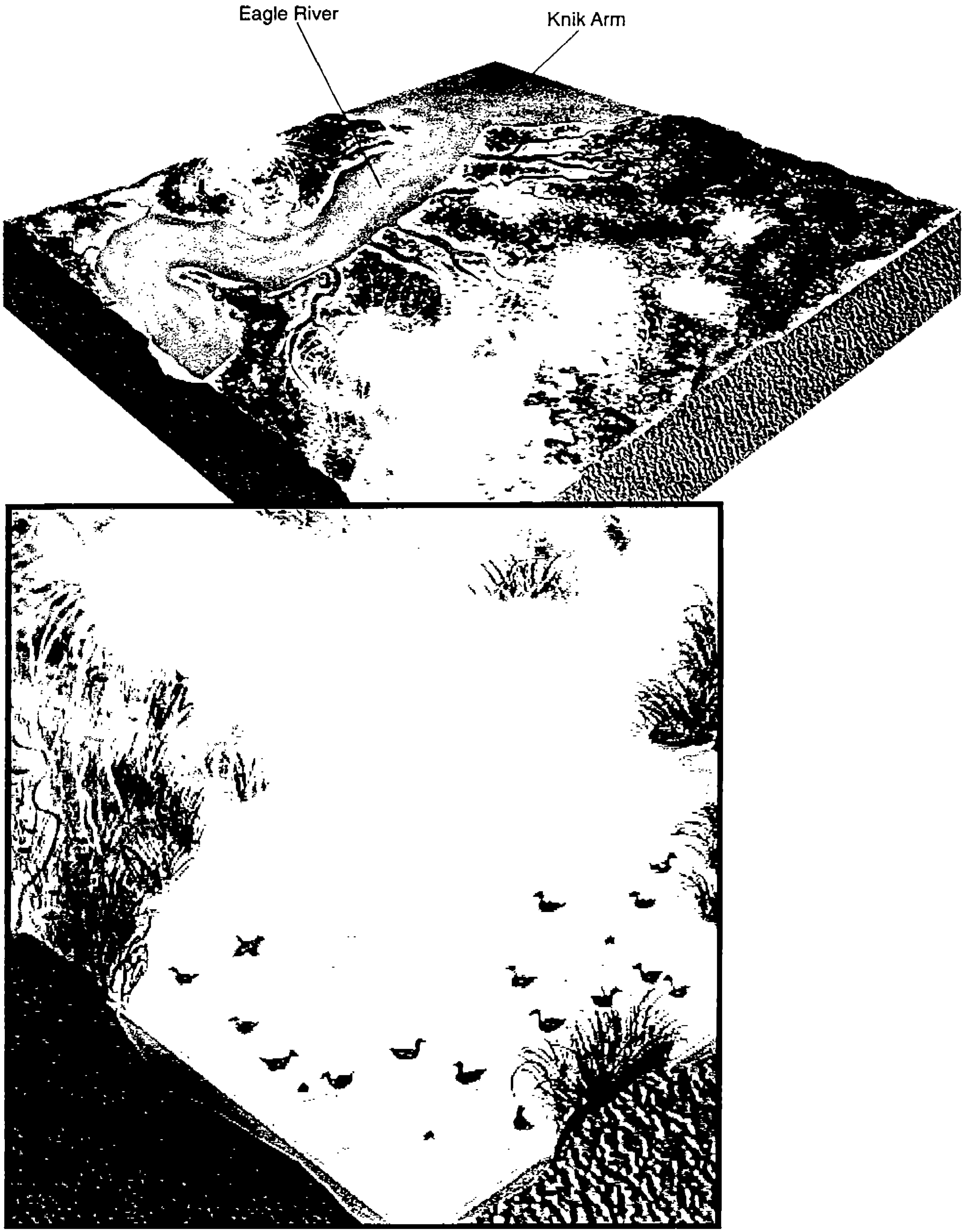

FIGURE 4-1
CONCEPTUAL SITE MODEL FOR
WHITE PHOSPHORUS AT
EAGLE RIVER FLATS, ALASKA

ANC70024 M0 2X Site Model/White Phos Sarah Richards ROY 11-19-93

no detections in 43 samples; and the Pond Beyond had only one detection in 14 samples. Detections were found in only 10 percent of 104 mudflat samples in Areas A and C, Bread Truck Pond, and the Knik Arm, which had the highest concentration of 0.15 μg/g (Racine and Walsh, in Racine, et al., 1994).

Core samples were taken in the Area C pond in 1991 and 1992 and were analyzed for WP. Nine samples were negative at all depths. Seven samples contained WP in the top 10 cm, seven down to 20 cm, and four down to 30 cm. Two samples had WP detection down to 50 to 55 cm.

Three of 37 samples from gully sediment tested positive for WP in 1992, but all 50 samples tested in 1993 were negative. Concern was expressed that the negative 1993 results might have resulted from inadequate sampling techniques (Lawson, Bigl, and Bodette, in Racine, et al., 1994).

White phosphorus was detected in water above contaminated sediments in Area C. In an open-water area where the sediment WP concentration was about 1 μg/g, the undisturbed and disturbed water concentrations were 0.01 and 1 μg/L, respectively. In a confined water area where the sediment concentration was as high as 2,000 μg/g, water concentrations were about 7 μg/L. These concentrations represent expected high-water concentrations because of the chosen locations (Walsh, in Racine, et al., 1994).

4.4 Fate and Transport

The fate and transport of chemicals in the environment is determined by the physical characteristics of the site, as well as by the physical properties of WP and other contaminants present. Sediment and surface water are the primary sources of WP and other contaminants at the ERF.

4.4.1 Overview of Physical Environment

Information for this summary was obtained from Lawson, Bigl, and Bodette (in Racine, et al., 1994).

Aerial photographs available from the past 40 years have demonstrated the large-scale dynamics of hydrology and sedimentology at the ERF, a complex and physically active area. For example, the primary river channel entering the flats was abandoned sometime between 1950 and 1967. The channel meanders have changed their positions substantially over the past four decades. The drainage pattern on the flats suggests that an active and a relic system are present, perhaps affected by earthquakes.

The tides have a maximum height of 11 m and are an important source of sediment. Tidal flooding begins at the coast, moving progressively up the Eagle River channel and gullies. It then spills across the inner mudflats into the ponds. The water level drops first at the coastal mudflats during the ebb, and then progresses into the gullies.

Eagle River bisects the flats with its discharge, which can vary substantially from spring meltwater and rainstorms. The water quality and discharge volume of the river are influenced by the glaciers in its watershed (13 percent of the area), winter snowmelt, and rainstorms. The average daily discharge from 1966 to 1981 was 14.7 m^3/sec. The maximum and peak discharges occurred in July and August, and ranged from 65 to 76 m^3/sec, respectively. Sediment concentration does not apparently depend on the discharge rate.

The combination of tides and river discharge cause variable levels of flooding across the flats. The levees flood less frequently than the ponds because of their higher elevation. High river discharges will produce a higher flood than one predicted by using high tide elevations listed in the tide tables.

During flood tides, waters slowly flood through gullies into ponds. As water drains out of the ponds during ebb tides, erosion occurs in the gullies. Sediment is deposited during slack high tides in events that are extensive enough to cover the mudflats and ponds. Data from the summer of 1993 suggest that the tides have a greater suspended sediment concentration than the river (about 1,200 versus 23 to 275 mg/L).

In the summer, there is frequently a long period between flooding tides, and parts of the flats become relatively dry. During the winter, Eagle River continues to flow, but ice thickens over the flats with succeeding flood events during cold temperatures. Ice breakup typically occurs in April. It appears that the hydrology and sedimentology of the upper third of the flats is dominated by the river, with the remainder dominated by the tides. This dynamic environment is extremely complex, and predictions will be difficult and uncertain.

4.4.2 Sediment

Unless otherwise cited, information in this section was obtained from Lawson, Bigl, and Bodette (in Racine, et al., 1994).

The gully headwalls are typically characterized by a headwall with a near vertical face of 1.2 to more than 2 m, with a plunge pool 0.5 to more than 1 m deep. The bed becomes progressively shallower until a steep decline to the river occurs. Frequently, for a short segment, the gradient becomes much steeper between the river and the headwall.

Erosion occurs as a natural process during spring thaws, tidal events, and river flows. The erosion of gully headwalls was measured at 14 sites in Area C and the Bread Truck Pond area in 1993. At each site, stakes were driven into the ground in a line at known distances. The distance from a hub stake across each of the linear stakes to the crest of the gully scarp was measured, and the difference in distance over time provided a measure of gully erosion. Accuracy was probably limited to ±10 cm.

The recession rates were highly variable, both within and between gullies. Maximum seasonal rates ranged from 0.0 to 9.8 m in the 1992 summer, 1992-1993 winter, and 1993 summer. One new network of shallow gullies extended 45 m into the mudflats during the 1992-1993 winter. The variability relates to the erosional process. The uppermost 20 to 30 cm of consolidated, root-bound soil is undermined by current erosion, and fails after a 0.5 m or deeper cut is made below it. Lateral walls of gullies fail mostly by retrogression-slump flow.

If these recession rates are representative, the gullies will produce increased pond drainage in 10 to 15 years, particularly in a pond on the western side of Bread Truck Pond, and in the pond complex between Bread Truck and C ponds.

Several methods were used in 1992 and 1993 to measure the rate of sedimentation and resedimentation from naturally resuspended sediments at 10 sites within the ponds around Area C and the Bread Truck Pond. Resuspension occurs because of wind currents and waves, bottom-feeding waterfowl, and other disturbances (Racine, et al., 1993). Gross deposition was measured with a 4-inch-diameter PVC "cup" glued to one end of a short length of 2-inch-diameter pipe. This device was inserted into the pond bottom sediments until the bottom of the cup was in contact with the bed. Net sedimentation was measured from deposits that accrued on a thin, flat plate placed gently on the bottom. A third method, a meter stake, was used briefly, but because accurate measurements proved to be difficult, it was discontinued. Readings in the first two methods were to the nearest 0.5 mm. In some areas, algae and vegetation growth made accurate readings difficult.

Deposition and erosion rates were measured in the mudflats, levees, and gullies with sedimentation stakes and pavement marking paint applied on ground surfaces along surveyed transects in Area C and near Bread Truck Pond. The ice cover destroyed the sedimentation stakes during the winter of 1992-1993, suggesting that the paint method may provide better long-term measurements.

Net sedimentation rates vary with an overall trend of an increasing rate eastward from the levees (1 to 5 mm each season), across the mudflats (3 to 12 mm each season), and into the ponds (8 to 38 mm each season). The differences are believed to be largely related to the number of flooding events, which is a function of their elevation. During the period of the summer of 1992 through the summer of 1993, 110 tides exceeded the height apparently necessary to enter the ponds, but only 15 tides exceeded the height to flood the levees. In the ponds, approximately an equal amount of resuspended and new sediments were deposited.

Sediment samples were taken in 1993 for grain size measurement, but results were unavailable. Studies of 15 sediment samples collected in 1990 found 13 to 27 percent clay fraction in Area A and 30 to 47 percent in Area C. Area C is closer to Eagle River, which may increase the amount of fine "glacial flow" or clay particles it receives. Sand content remained below 3 percent, and silt varied from 52 to 85 percent (Lawson and Brockett, 1993).

White phosphorus has become integrated into the ERF sediments as a result of incomplete oxidation of the compound following its release into the environment (USAEHA, 1993). The fate and transport of WP in sediment is discussed below.

4.4.2.1 Fate of White Phosphorus in Sediment

The unreacted WP at the ERF is not evenly distributed in the ERF sediment, but is present as discreet particles (Figure 4-2). The individual particles are surrounded by sediment. The particles and the sediment continuously or at least frequently are saturated with water.

FIGURE 4-2
WHITE PHOSPHORUS
PARTICLES IN SEDIMENT

ANC70024 M0 20 s Particls in Sedmnt Sarah Richards ROY 11.19.93

When WP particles from the Bread Truck Pond and Area C sediments were isolated and characterized, their lengths ranged from 0.26 to 2.9 mm and shapes were described as angular to globular (Racine, et al., 1992a). Very small WP particles were found suspended in the water column as colloidal particles. Concentrations of the suspended WP particles increased after the sediment was disturbed.

Particle shapes and sizes have a significant impact on the fate of a contaminant. The WP particles that were originally deposited in water and sediment have apparently remained relatively unchanged. This is partially attributable to particle size. Because the surface area of a given mass of particles decreases with increasing particle size, contaminants that are present as large particles (macro scale) will have less surface area than the same mass of material dispersed throughout a medium as microscopic particles. The difference in surface area may be several orders of magnitude. Low surface area means that only a small portion of the WP is available for oxidation; therefore, the WP is preserved. It appears that sublimation may be another important loss mechanism for WP in unsaturated sediments (Walsh, in Racine, et al., 1994).

The persistence of WP at the ERF also results from the characteristics of the tidal flats environment. White phosphorus reacts violently with air (oxygen) because it is a strong reducing agent and oxygen is a powerful oxidizer. In the absence of oxygen (or other strong oxidizers such as hydrogen peroxide), WP will persist. One measure of the oxygen concentration is the redox potential (Eh); the lower the Eh, the less oxidized and the more reduced the environment. In Area C, Ehs ranged from -100 mV to -400 mV, extremely low values, which means WP will persist. These low values are attributable to the abundance of organic material decomposing in the water and sediments of a salt marsh environment.

The frequent flooding of the tidal flats also contributes to WP persistence. Because so much of the area is frequently submerged, the sediments remain saturated, oxygen cannot diffuse through them to reach the WP, and the WP cannot sublimate. White phosphorus is also resistant to photolysis and anaerobic biodegradation, making it stable in oxygen-deficient sediments (USAEHA, 1993).

4.4.2.2 Transport of White Phosphorus in Sediment

The active tidal forces cause significant sediment erosion, transport, and deposition; these dynamic conditions affect the location and availability of WP for ingestion by waterfowl and other organisms. Sediment transport occurs in both the flood and ebb stages of the tidal cycle. Deposition onto the mudflats occurs during slack high tide and during the initial period of the ebb cycle, but water in the ponds and marshes continues to mix and exchange; sediment in the pond bottoms may be resuspended before settling occurs.

Sediment deposition buries WP (Figure 4-3). Particles that were accessible to waterfowl and other organisms become unavailable; this mechanism has a significant impact on the risks posed by WP. The sediment deposition in ponds occurs when the tidal ponds are flooded, primarily during late summer (Racine, et al., 1993). Erosion may uncover WP that was previously buried (Figure 4-3). White phosphorus that currently poses no immediate risk to waterfowl could pose a risk when uncovered.

Movement of WP is dependent on the physical features of the tidal area. Erosion, suspension, and deposition will vary with the terrain, primarily through the water flowpaths. Vegetation also affects material transport. Plants such as grasses may act as filters, trapping suspended solids. In marshes, mats of vegetation will hold existing sediment in place and provide a physical barrier to waterfowl ingestion of WP.

White phosphorus transport in gullies was measured by multiple methods in the gully including Parachute Pond, which drains the Area C pond, and in the gully draining Bread Truck Pond. Composite water samples were collected at 1 cm (four samples) and 30 cm (eight samples) above the channel bottom. Sediment in bedload transport (three samples) and recently deposited material on channel bars (35 samples) were also sampled. Sediment samples were also taken from other gullies and from the silt beach near the tide gauge. Standard laboratory method was used to analyze for WP. All sample analyses were negative for WP (Lawson, Bigl, and Bodette, in Racine, et al., 1994), in contrast to the 1992 studies, which found WP in some distributaries (Bouwkamp, 1993). It is thought that the 1993 field sampling procedure was inappropriate (Lawson, Bigl, and Bodette, in Racine, et al., 1994). White phosphorus was not detected in two sediment and water samples collected at the mouth of the Eagle River in 1993 (Bouwkamp, 1993). White phosphorus in the gullies could make its way to Eagle River and perhaps to Knik Arm. (Note that

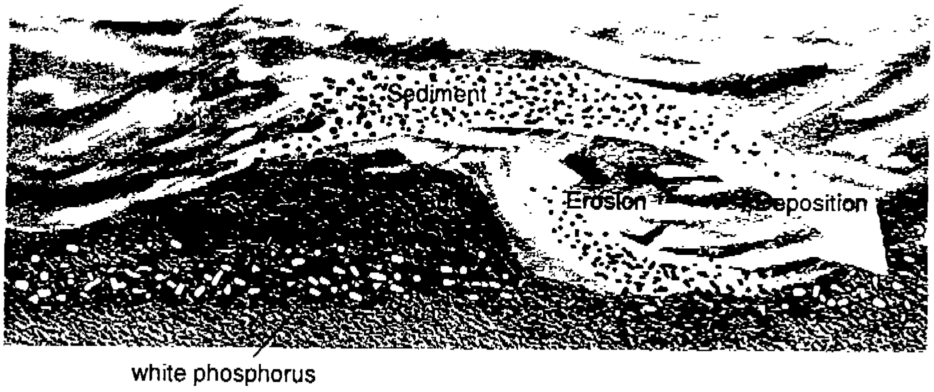

FIGURE 4-3
TRANSPORT OF SEDIMENT

FIGURE 4-4
TRANSPORT OF WHITE PHOSPHORUS WITH DYING DUCKS

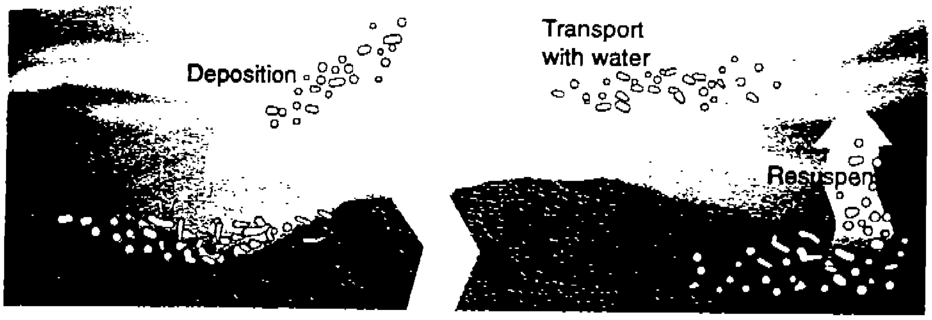

FIGURE 4-5
TRANSPORT OF WHITE PHOSPHORUS

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transport to the river and Knik Arm will be assessed in more detail during the 1994 field season.)

An additional mode of WP transport discovered at the ERF is flight by waterfowl that have ingested the WP, flown to other areas, and have died there. Upon death of the waterfowl, the WP may be introduced to previously uncontaminated sediments by decomposition. Also, it is suspected that WP is redeposited in pond sediments during carcass decomposition (Figure 4-4) (USAEHA, 1993).

4.4.3 Surface Water

Peak water velocities during ebb tide were estimated at 5.8 m/sec for the Bread Truck drainage and 4.3 m/sec in the Parachute Pond (Area C) drainage based on survey data and hydraulic equations. Discharge values were calculated as 504 m^3/sec for the Bread Truck drainage and 36 m^3/sec for the Parachute Pond drainage during peak flows (Lawson, Bigl, and Bodette, in Racine, et al., 1994).

Total suspended sediment (TSS) in the gullies varied during a tidal cycle, with low values through a rising tide, increasing with the flood waters and decreasing as the ebb tide occurs. In the two events when the flats were loaded to a depth of 0.4 m in September 1993, the maximum TSSs were 1,700 and 1,900 mg/L in the Parachute Pond gully and about 300 mg/L lower in the gully draining Bread Truck Pond. This general pattern of increases and decreases was also observed with the optical backscatter equipment, but the correlation was low (Lawson, Bigl, and Bodette, in Racine, et al., 1994).

White phosphorus concentrations have persisted over time in the sediment, and there is potential for particle resuspension, transport, and redeposition into surface water. Laboratory and field experiments indicate that small particles of WP are readily suspended in the water column following agitation of the underlying substrate (USAEHA, 1993). The fate and transport of WP in surface water is discussed below.

4.4.3.1 Fate of White Phosphorus in Surface Water

White phosphorus may be present in surface waters in two forms: as suspended particles or dissolved. The fate of the WP in each of these forms is primarily controlled by the availability of oxygen (Spanggord, et al., 1985).

In particulate form, the WP is introduced into the water column following physical disturbance of the sediment. Larger particles will settle with the sediment, but very small particles remain suspended in the water phase for long periods. The half-life of the particulate WP in aerated water is estimated to be between 1.7 to 3.0 years, but will increase as oxygen concentration decreases (Spanggord, et al., 1985). In surface waters at the ERF, oxygen concentrations will generally be low because of high organic material content. Aeration of waters will occur from tidal mixing or waterfowl disturbances.

In dissolved phase, WP concentrations will decrease as a result of oxidation, volatilization, and hydrolysis (Spanggord, et al., 1985); however, the mass of WP disappearance through these mechanisms will be small because of the low solubility of WP in water. The overall half-life for soluble WP in aerobic water is estimated at 42 hours from hydrolysis and oxidation, but drops to 48 minutes in shallow, turbulent water from increased volatilization (Spanggord, et al., 1985). The volatilization rate will be controlled by transport of the WP to the water surface (through diffusion or mixing). Oxidation rates will be controlled by oxygen availability, and hydrolysis to acids will occur with or without oxygen present. Overall, these loss mechanisms will be insignificant when compared with the total mass of WP present at the ERF.

4.4.3.2 Transport of White Phosphorus in Surface Water

White phosphorus particles could be resuspended and transported through drainage channels on the ERF without undergoing complete oxidation (Figure 4-5). Mechanisms for particle suspension include waterfowl activity, wind, and severe tidal movements. Moving waters on the flats, such as the network of drainage gullies that flow toward Eagle River, act as a transport medium for suspended material (USAEHA, 1993).

Particles are resuspended by tidal currents, waves propagated by wind, rain events, and physical disturbances such as waterfowl swimming and feeding. Once the small WP particles are suspended, they may be transported with the water phase. Sampling of water in ponds at the ERF indicated that small particles remain suspended for at least several hours following physical disturbances. This finding is significant because suspension makes WP available in the water for potential consumption, and allows time for transport of the WP to other areas of the ERF.

4.4.4 White Phosphorus Transformations

White phosphorus is the most reactive of the three phosphorus allotropes (white, red, and black) and does not occur naturally. In unreacted WP, four phosphorus atoms form a tetrahedral-shaped molecule that forms a waxy solid at room temperature. Pure WP is colorless, but it is usually slightly yellow from trace amounts of red phosphorus, an impurity. Table 4-1 lists some of the characteristics of white phosphorus. It is nonpolar and does not dissolve readily in water.

Table 4-1
Chemical and Physical Properties of White Phosphorus

Molecular Structure	P_4
Molecular Weight	124 atomic mass unit
Solid–Melting Point	44°C
Auto Ignition Temperature	20-40°C
Appearance	Waxy Transparent Colorless (pure)
Density (20°C)	1.8 g/cm^3
Vapor Pressure	0.026 mm Hg at 20°C
Solubility– in water (15°C)	2.4 or 3 mg/L
in olive oil	12.5 g/L
in mineral oil	14.5 g/L
Henry's Law Constant	2.1×10^{-3} at m^3/mole at 25°C
Octanol-Water Partition Coefficient	1,200
Oxidation States	
(Fully Oxidized)	+5 P_4O_{10} (solid)[a]
	+3 P_4O_6[b]
	0 P_4
	-2 P_2H_4
(Fully Reduced)	-3 PH_3 (gas)

[a] Forms H_3PO_4, H_3PO_{4-}, $H_2PO_4^{2-}$, or PO_4^{2-} in water, depending on pH.
[b] Forms H_3PO_3, H_3PO_{3-}, or HPO_3^{2-} in water, depending on pH.
References: CCREL, 1991, 1993, and Walsh, in Racine, et al., 1994.

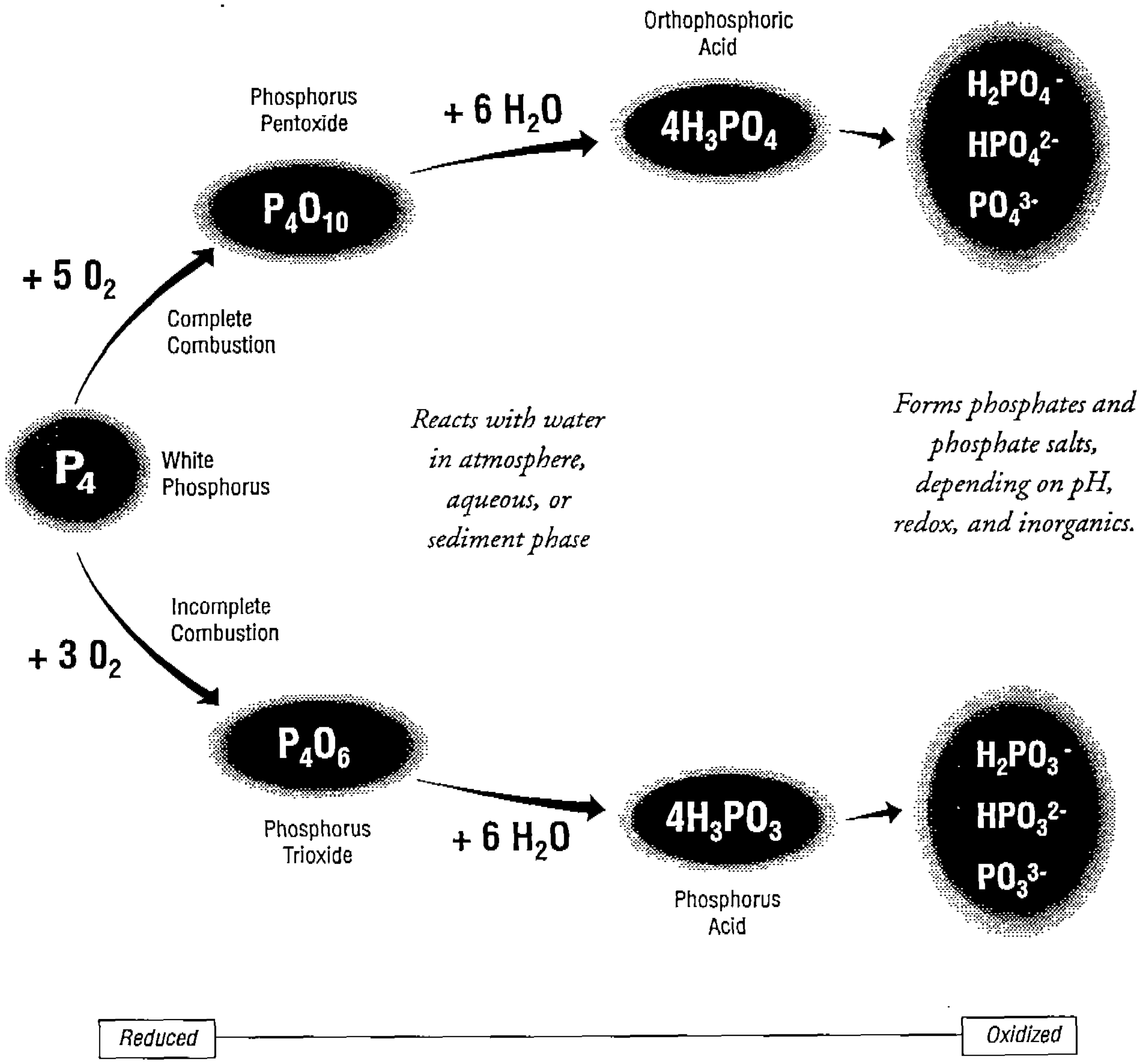
Above 30°C, WP will ignite when exposed to the atmosphere. Because WP has a high burning temperature and low melting point, WP particles will melt and burn in liquid form following ignition. They continue to burn until the WP is depleted or the material comes in contact with water or is buried in sediment.

When WP burns in excess oxygen or air, it forms phosphoric oxide, P_4O_{10} (Figure 4-6). This is the reaction that produces white smoke. In this state, the phosphorus is in its most oxidized form. If excess oxygen is not available, but some oxygen is present, the phosphorus may undergo incomplete combustion to form phosphorus trioxide, P_4O_6. Both phosphoric acid and phosphorus trioxide are acid anhydrides that will react with moisture in the air or water phase to form orthophosphoric acid or phosphorus acid. White phosphorus forms a cloud of white smoke when in contact with oxygen to produce phosphorus oxides (P_4O_2, P_2O, P_2O_3, P_2O_4, P_2O_5, P_2O_6), which react with water vapor to form various phosphoric acids. Rapid oxidation of WP particles generates heat, and smoke (primarily P_2O_5) rises. Combustion of WP in a confined space can produce an oxygen-deficient atmosphere incapable of supporting life (Yon, et al., 1983).

The acid forms of phosphorus are water soluble, and in the water or air phases, the phosphorus will form salts with available inorganic compounds. In an aqueous medium, the solubility of these salts depends on the redox potential of the environment and the inorganic compounds that are present. Insoluble phosphates are not available for uptake by organisms, but some microorganisms are capable of converting the phosphates to soluble and mobile forms. The main oxidation products of WP in water are H_3PO_4 and H_3PO_3 (Yon, et al., 1983). Soluble phosphates are available for plant and microorganism uptake, conversion to organic phosphates, and assimilation into the food chain.

At ambient temperatures and pressures, WP is relatively insoluble and stable in water. It will react with the small amount of oxygen present in the water, but this is very quickly depleted and only a negligible reaction occurs. It is estimated that a 1-mm-diameter particle would take 8 years to dissolve at 25°C in slowly flowing water, and even longer in saltwater (Walsh, in Racine, et al., 1994).

Suspended particles and dissolved phosphorus are readily oxidized to lower states of phosphorus in aerated water. The rate of oxidation can be significantly increased in the present of oxidizing agents (such as ozone and sodium hypochlorite) (USEPA, 1992b).



Reacts with water in atmosphere, aqueous, or sediment phase

Forms phosphates and phosphate salts, depending on pH, redox, and inorganics.

FIGURE 4-6
WHITE PHOSPHORUS
TRANSFORMATIONS

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Phosphoric acids in water are organically bound (greater than 90 percent) and eventually concentrated in the sediment and complexed with metals such as aluminum or calcium. Phosphoric acids can lower pH in systems with low water-hardness, or cause algal blooms, which are detrimental to fish populations; fish kills can occur over winter because of low oxygen in the system from excess algae degradation (Yon, et al., 1983).

Phosphorus combustion products (phosphoric acids) deposited on soils are rapidly complexed and immobilized by metals such as aluminum, adsorbed to soil particles, or absorbed by biota. Unreacted WP burns vegetation in localized areas (Yon, et al., 1983). Oxidized forms of phosphorus reportedly have low toxicity and rapidly form cation complexes in the soil. Both P_4O_{10} (a powerful dehydrating agent) and P_4O_6 are physiologically and chemically hazardous. In atmospheric moisture, P_4O_{10} forms orthophosphoric acid and P_4O_6 forms phosphoric acid (Yon, et al., 1983).

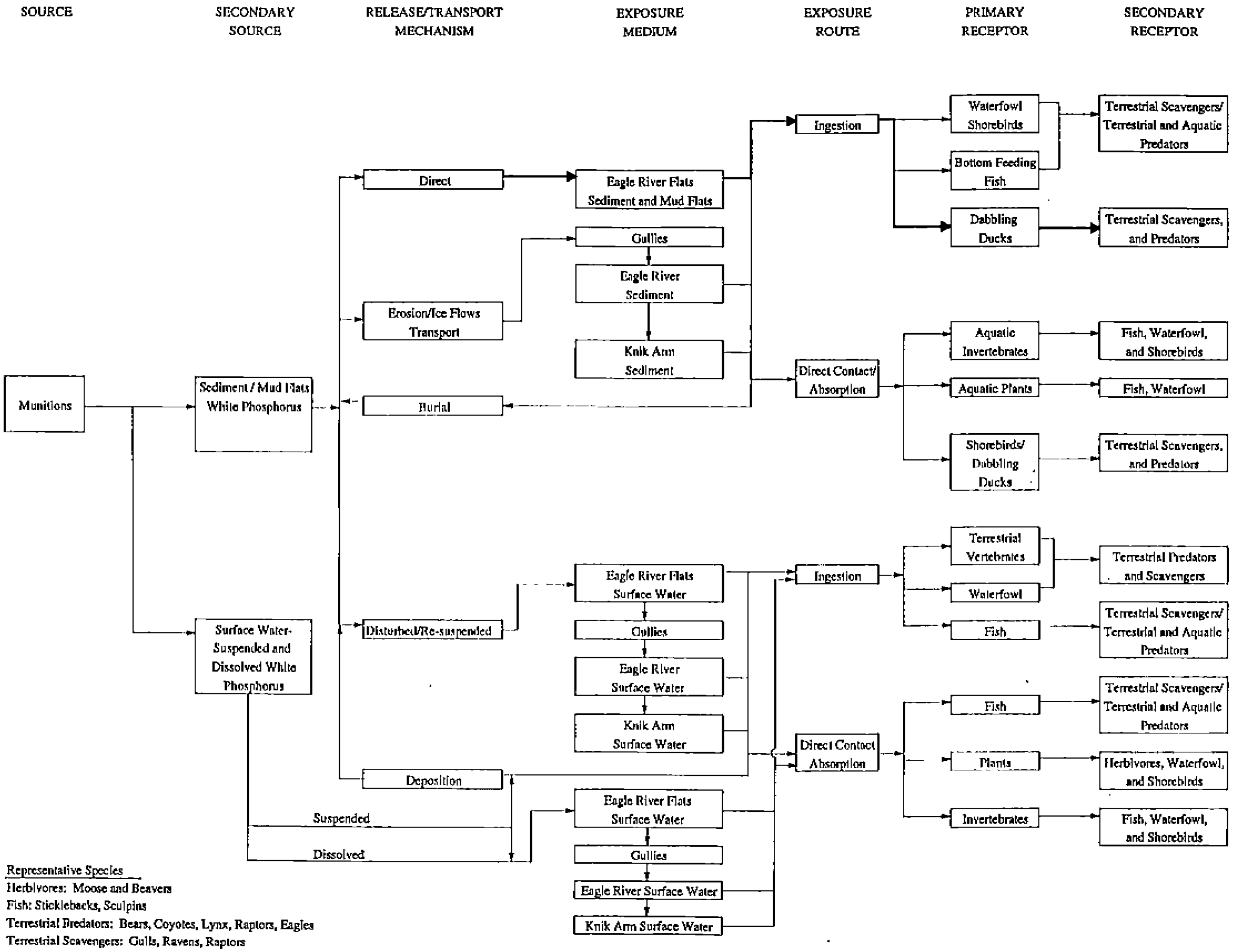
The reactions of WP in the environment affect the distribution and transport of WP (Figure 4-1). The exposure mechanisms are described below.

4.5 Potential Exposure Pathways, Routes, and Receptors

The fate and transport mechanisms described above have resulted in the introduction of WP into the sediment and water at the ERF. Once in these media, the WP is available for potential uptake by plants, waterfowl, and other organisms. To help identify potential exposure pathways and receptors, the conceptual site model is displayed as a flowchart in Figure 4-7.

An exposure pathway describes how a contaminant may move from its source to a receptor (a potentially exposed organism). A complete exposure pathway has five primary elements:

- A chemical source (munitions, for example)
- A mechanism of release and transport (such as deposition from explosion)
- An environmental medium (such as sediment)
- An exposure point (ponds at the ERF, for example)
- Current or potential receptors and feasible routes of exposure (such as ingestion)



Representative Species
Herbivores: Moose and Beavers
Fish: Sticklebacks, Sculpins
Terrestrial Predators: Bears, Coyotes, Lynx, Raptors, Eagles
Terrestrial Scavengers: Gulls, Ravens, Raptors
Aquatic Predators: Beluga Whales, Terns, Kingfishers

⟶ Principal route of concern

FIGURE 4-7
POTENTIAL EXPOSURE ROUTES AND PATHWAYS FOR SEDIMENT

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An exposure pathway is complete if there is a reasonable likelihood that a receptor may take in contaminants through contact with contaminated media. No exposure (and thus no risk) exists unless the exposure pathway is complete.

4.5.1 Sediment

Sources, releases, and WP concentrations were discussed in earlier sections. Unreacted WP is present in the ERF sediment as discreet particles. Reacted phosphorus may also be present in its oxidized form as soluble or insoluble phosphates, depending on the inorganic compounds present, redox potential, and pH. If WP particles of less than 0.1 mm exist, they could be toxic to fish, shorebirds, and other filter-feeders (USATHAMA, 1992). White phosphorus particles sieved from sediment samples ranged from 0.26 to 2.9 mm in length, with masses from less than 0.1 to 3.4 mg. The number of particles ranged from none to more than 100 in volume of sediment samples from 202 to 430 mL (Racine, et al., 1993). This material is available for ingestion or dermal contact.

It is possible that WP has migrated through Eagle River to Knik Arm, but limited sampling failed to detect it in 1993.

4.5.2 Water

Sources, releases, and WP concentrations were discussed in earlier sections. The content of WP in the water phase will change, as small particles are deposited and resuspended. Like sediment, the water phase may also contain soluble or insoluble phosphates. If oxygen is introduced into the water through mixing, acids may form, but this process is not expected to occur at significant rates.

Very small WP particles in the sediment can become suspended in the water column and could provide another source of exposure to waterbirds, fish, or plankton. Once suspended, these particles could also be transported by currents to other areas of the ERF. In addition, transport through gullies that drain the tidal flats into Eagle River could make WP particles available for ingestion by fish, invertebrates, and mammals elsewhere in Knik Arm and Cook Inlet (Racine, et al., 1993). The few samples taken at the mouth of the Eagle River have not detected WP.

These materials are available for ingestion and direct contact.

4.5.3 Receptors

Biota at the ERF can be exposed either directly to contaminated sediments and surface water (primary receptors) or exposed through feeding on contaminated organisms (plants, fish, or wildlife; secondary receptors).

4.5.3.1 Primary Receptors

Primary receptors at the ERF include dabbling ducks, shorebirds, fish, aquatic macroinvertebrates, aquatic plants, and numerous terrestrial vertebrates. Although WP is patchily distributed throughout the marsh, the route of exposure for waterfowl is through ingestion of the sediments of feeding ponds, which constitute about 8 percent of the total ERF area (Racine, et al., 1993).

Sediments in the ERF contain food items available to waterfowl, shorebirds, and fish. White phosphorus particles are similar in size to seeds and larvae usable as duck food (Racine, et al., 1993). Waterfowl feeding on pond bottom sediments ingest WP as food items (or possibly as gizzard grit) and insect larvae, which can be numerous in shallow areas if the clam *Macoma balthica* is not present. Seeds and insect larvae are of equal importance as food during fall migration; because they probably die during the winter freeze, larvae are probably less important food during spring migration of waterfowl. Four plant species (*Carex, Scirpus, Potamogeton*, and *Hippurus*) and chironomid larvae were detected in the gizzards of mallards and pintails collected from Cook Inlet salt marshes during July and October in 1978.

It is hypothesized that dabbling ducks mistake phosphorus particles as food items because of size similarities; poisoning results after ingestion. Pond bottom sediments are probably processed by ducks when they submerse their heads in the shallow water and mandibulate the bottom sediments in search of edible solids (Racine, et al., 1993).

The most common invertebrates found in the ERF are chironomid insect larvae. Other invertebrates include other Diptera (Ceratopogonidae, Dolichopodidae, Ephydridae) Coleoptera larvae, aminoid snails, and clams (*Macoma balthica*) (Racine, et al., 1993). These invertebrates, as well as fish, may be exposed directly to WP-contaminated sediments or to WP particles suspended in the water column.

Plants are primary receptors that may take up WP as it slowly dissolves in water (Walsh, in Racine, et al., 1994). Field sampling in the ERF during 1993 indicated that wherever WP was detected in plant tissue, it was also detected in the water column. When detectable in plant tissues, the concentration was a thousand-fold less than that of the sediment concentration. White phosphorus is not considered to be phytotoxic.

4.5.3.2 Secondary Receptors

Secondary receptors include terrestrial and aquatic scavengers and predators (such as eagles, ravens, gulls, terns, kingfishers, bears, coyotes, and beluga whales), as well as herbivores (such as moose and beavers) if WP is accumulated in their food organisms.

Since 1983, waterfowl exposed to WP on the ERF have been found dead at several locations within the ERF. Because WP has been found in the gizzards, fat, and skin of the dead ducks, and many carcasses of dead ducks have been scavenged by other birds and mammals, secondary exposure is a concern. During the spring migration of 1991, field observations were made that documented frequent predation of ducks by bald eagles, herring gulls, and common ravens (Racine, et al., 1993; Nam, et al., 1994). The predators preyed upon both dead and sick ducks. Because WP was found in the tissues of ducks being consumed by predators, it was concluded that the predators are being exposed to WP by consuming WP poisoned ducks. Of greatest concern are bald eagles, because more than 60 bald eagles sometimes use the ERF during the spring migration (Racine, et al., 1993). Bald eagles generally remove dead ducks to the wooded areas surrounding the ERF, where dead eagles or feather piles have been observed (Reitsma and Steel, in Racine, et al., 1994).

During field investigations in early May of 1992, eagles were observed swooping down on duck flocks resting on the shallow ponds and capturing individual birds that did not fly (presumably either dead or incapacitated). The eagles then flew to nearby drier ground or to trees where they consumed the captured ducks, leaving only a pile of feathers and bones. During 1992 studies, there were 78 observations of bald eagles capturing sick or dead ducks; 64 percent carried the ducks to the trees on the east side of the ERF. One of two radio-tagged duck carcasses was carried farther than 1,600 feet into the forest. Predation rates of eagles on sick ducks in May, estimated from field observations, ranged from 0.32 ducks per hour to 4.5 ducks per hour, and declined over the 11-day study period as duck use of the area declined. Field observations documented that 11 of 12 duck carcasses were removed within 24 hours, and the twelfth carcass was removed within the next

24 hours. In August 1992, almost no dead or dying ducks were removed by eagles (Racine, et al., 1993). These seasonal differences in removal rates are probably because of the presence of fewer eagles and reduced visibility of carcasses. During 1993, two eagle feather piles were found along woodland transects and two eagle carcasses were found on the ERF. These findings further suggest that mortality of secondary receptors occurs as a result of WP ingestion.

Ravens use dead ducks as a primary food resource, whereas northern harriers primarily feed on rodents but have been seen feeding on dead ducks. Gulls feed on salmon in Eagle River and on duck carcasses and aquatic organisms in the ponds (Racine, et al., 1993). One arctic tern and three dowitchers collected from ERF during 1993 had enlarged livers (Racine, et al., 1994). In addition, an arctic tern and two dowitchers appeared to have depressed cholinesterase (ChE) activities. Enlarged livers and depressed ChE have been among the signs of toxicity exhibited by WP-poisoned birds. It is unknown whether these birds had experienced either direct or indirect exposure to WP, but circumstantial evidence suggests they had.

Racine, et al. (1993) described the abundance of birds at the ERF as "indicative of a productive food chain that would provide sufficient resources to support the higher trophic levels, both terrestrial and aquatic." Terrestrial organisms that could potentially be exposed secondarily include bears, coyotes, beavers, and other terrestrial vertebrates if food plants or animals are contaminated (Racine, et al., 1993). Aquatic species, such as beluga whales and other marine animals, could be exposed through ingestion of contaminated salmon that migrate into and out of the ERF yearly. Fish-eating birds, such as terns and kingfishers, could be exposed through ingestion of contaminated fish or invertebrates. However, studies thus far have not determined that salmon, other fish, or invertebrate accumulate WP to levels potentially harmful to secondary receptors.

Plants may also be a source of secondary exposure to animals through contaminated seeds, leaves, or other parts (tubers, for example), where WP could be deposited. Dabbling ducks forage for seeds and invertebrates in sediments below shallow ponds. Some seeds of aquatic plants are approximately the same size as WP particles, but contamination of seeds or other plant parts has not been thoroughly evaluated. Seeds in sediments (0.59 mm and 0.15 mm in diameter) were separated from soil by sieving twice in fall and once in spring. Seeds from *Triglochin* sp., *Zanichellia* sp., and *Potamogeton* sp. were found in sediments collected from Area C. Some of the same seeds (particularly *Potamogeton pectinatus*, a submerged aquatic plant with seeds about 2 mm in diameter) have been found in the gizzards of waterfowl collected in Cook Inlet salt marshes (Racine, et al., 1993). Although those seeds may not serve as an exposure medium for foraging waterfowl, they are described here because of the possible incidental ingestion of WP particles when waterfowl are feeding.

Humans may also be a potential secondary receptor through fishing and hunting activities. In Figure 4-7, human exposure would be included as terrestrial predators. Studies conducted thus far do not indicate a significant threat to humans by ingestion of waterfowl or fish. An analysis of 305 gizzards from a 1991 hunter waterfowl bag check by ADFG and USFWS in areas surrounding the ERF did not detect WP (CRREL, 1991). Also, a study by CRREL and Dartmouth Medical School on bioaccumulation in American kestrels demonstrated that bioaccumulation of WP in the food chain was very limited. Upon review of ERF analytical data, Dr. Middaugh, the State of Alaska Epidemiologist, calculated that 3,333 teals would have to be consumed to achieve a lethal human dose of WP (Middaugh, 1991). Although incidental transportation of WP to humans cannot be completely ruled out, the evidence thus far minimizes any significant consequences from such a potential exposure.

4.6 Bioaccumulation and Bioconcentration

4.6.1 Waterfowl

Because WP is highly lipid-soluble and readily accumulates in fat tissues of waterfowl, it is a concern for bioaccumulation through ingestion of tainted waterfowl meat (Racine, et al., 1993; Nam, et al., 1994). Uptake of WP is very rapid in kestrels. Submicrogram quantities of WP were detected in the fat and skin after the first day of WP exposure. This result was consistent with the findings of Fletcher (1974), who observed rapid uptake of WP in cod and salmon during the first 24 hours of exposure. Laboratory WP-treated mallards also had microgram quantities of WP in their fat tissues 4 hours after WP treatment (Racine, et al., 1992b). Based strictly on the lipophilic nature of WP, rapid uptake is expected. However, the reactivity of WP with oxygen is high and makes accumulation of WP unexpected. This may indicate that the reactivity of WP with oxygen is considerably reduced in fatty tissues.

White phosphorus was not dramatically accumulated in kestrel tissues (Racine, et al., 1993; Nam, et al., 1994). In cod, Fletcher (1974) observed that accumulation reached a steady state in 12 to 24 hours, and that phosphorus disappears rapidly when WP exposure is reduced, implying that WP is somehow being metabolized or excreted rapidly in a living biological system. White phosphorus can also be non-enzymatically oxidized. However, in a non-living biological system, such as in frozen muscle and duck tissues, WP levels were found to be relatively stable for weeks (Racine, et al., 1993; Nam, et al., 1994).

Study results for kestrel bioaccumulation indicate that although uptake of WP is rapid, the ability of WP to bioaccumulate up the food chain is very limited (Racine, et al., 1993; Nam, et al., 1994). Only 0.4 to 1.2 percent of the ingested WP was accounted for in the kestrels 24 hours following exposure. This estimate assumed a fat content of kestrels between 4 to 13 percent of body weight. In this study, kestrels were dosed using one of two regimes: consistent daily dose (accumulation group) or rotating daily doses (cyclic group). At the conclusion of the study, tissues were collected and extracted with isooctane and analyzed using gas chromatography. Tissues collected included brain, breast muscle, fat, gizzard, heart, whole intestine, kidney, thigh muscle, femur, liver, testes or ovaries, and skin.

In the accumulation group, distribution of WP in the tissues and organs was not uniform (Racine, et al., 1993; Nam, et al., 1994). In most of the birds, the fat and skin were the only samples having any detectable concentrations of WP. White phosphorus was first detected at 1 day post-treatment (the earliest time point evaluated) and attained a steady-state after the first day of exposure. The fat and skin samples contained similar levels of WP, and correlation was highly significant ($r=0.926$, $p<0.05$). The correlation between days of WP exposure and tissue concentration was not significant (fat: $r=0.571$, $p>0.05$; skin: $r=0.701$, $p>0.05$). The amount of WP ingested and its concentration in fat was also not significantly correlated ($r=0.601$, $p>0.05$).

In the cyclic-dosed group, detectable concentrations of WP were found only in fat and skin and not in other organs or tissues (Racine, et al., 1993; Nam, et al., 1994). White phosphorus concentration in skin and fat were similar and highly correlated to each other. Rapid uptake was observed and WP was present in fat and skin within 1 to 2 days of exposure. When exposure concentrations were reduced tenfold, WP could not be detected in either the fat or the skin. When WP was reintroduced at initial concentrations, levels similar to those of days 1 and 2 were once again detected in the skin and fat.

As discussed in Subsection 3.1.6, the results of this bioaccumulation study should be used with caution (Roebuck, pers. comm., 1994). Methods of exposure (as dissolved or particle forms of WP) and other factors may affect bioaccumulation in birds.

During 1993, bioaccumulation of WP was measured in mallards during toxicity tests and in various species of birds collected from the ERF (Sparling, Grove, and Comerci, in Racine, et al., 1994). Pathological changes in tissues also were associated with the birds' ingestion of WP, as described in Sections IV-2 and VI-4 of that report. These included conspicuous damage to the liver, spleen, heart, and duodenum, as well as depression of ChE activity.

White phosphorus residue concentrations in fat of mallards that died on dosage ranged from 0.117 to 1.776 µg/g tissue (Sparling, in Racine, et al., 1994). There was a significant difference among dosage groups (control, 2.0 mg/kg, 4.0 mg/kg, 5.2 mg/kg, 6.1 mg/kg, 7.1 mg/kg, 8.0 mg/kg, and 9.1 mg/kg), but WP concentrations did not correlate significantly to exposure. Birds that died within 24 hours after dosing had significantly higher WP concentrations in their fat than those that survived for 1 week after dosing. After 1 week, fat residues in survivors were often <1/100 of those in birds that had died. White phosphorus concentrations in livers remained low in comparison to those in skin or fat.

White phosphorus was not detected in the skin or crop contents of arctic terns, mew gulls, yellowlegs, dowitchers, or northern phalarpoes shot on the ERF during 1993 (Sparling, in Racine, et al., 1994). White phosphorus concentrations were detected in tissues of all ducks analyzed after being found dead on the ERF. Skin was the most dependable tissues for analysis. Concentrations ranged up to 2.64 µg/g in pintails, up to 5.71 µg/g in green-winged teals, and up to 20.5 µg/g in mallards. In general, gut contents contained higher concentrations of WP than the skin or other tissues.

The potential for a chemical to bioaccumulate depends on its lipophilicity and its ability to resist degradation. White phosphorus is very lipophilic, but it is prone to degradation in living biological systems. Kestrels exposed to low levels of WP were able to degrade WP either chemically or enzymatically in an efficient enough manner to eliminate most of the ingested WP. However, bioaccumulation of WP is evident in ducks at the ERF and in experimentally poisoned ducks; this may have resulted from ingestion of more WP than could be metabolized by the ducks.

4.6.2 Aquatic Organisms

Although the relative importance of dissolved forms versus particulates in the ERF is unknown, WP bioaccumulates in fish after intake through the gills or by ingestion or dermal contact. It is distributed mainly to the liver, blood, and skeletal muscles and is excreted primarily in urine as inorganic phosphate and an unidentified metabolite (USEPA, 1992c). The bioconcentration factor (BCF) in three fish species ranged from 11.7 to 67.7 in muscle and from 51.5 to 2,000 in liver (Interagency Testing Committee [ITC], 1991).

White phosphorus is also readily incorporated by marine invertebrates and seaweed; in six invertebrate species, BCF values range from 10.5 to 1,267. In seaweed, BCF was 22.2 and 22.8 in two tested species (ITC, 1991).

4.6.3 Mammals

White phosphorus is lipid-soluble and readily incorporated into the fatty tissues of mammals (ITC, 1991).

Studies have not been conducted in the ERF to determine the effects of the contaminated environment on mammals. Although it has been stated that the available evidence indicates mammals that use the ERF are not adversely affected by the contaminants, WP could bioaccumulate in mammals that ingest the particles directly (such as through grazing) or through secondary exposure (Quirk, 1991).

4.7 Summary

Munitions containing WP and other chemicals have been used historically for training purposes at the ERF. Previous studies have identified WP as the main toxic agent acting at the ERF, and most discussion has centered around the toxic action of WP, but other chemicals may be present as well in toxic concentrations.

When WP-containing munitions explode, unoxidized WP particles will settle to the bottom of the water column in the water bodies they contact and become incorporated into the sediments. White phosphorus particles may also be present in an oxidized form as either soluble or insoluble phosphates in the surface water column. White phosphorus present in the sediments or surface water may either be released or transported, or both, through a variety of mechanisms, including tidal flows, river flows, ice flows and runoff of melted ice, wind currents, and disturbances by bottom-feeding waterfowl and other wildlife. White phosphorus has been found often in shallow ponds and only a few times in the gullies. Only limited sampling has been done in Eagle River, and no WP has been detected at its mouth.

Biota at the ERF can be exposed to WP in sediments and surface waters primarily through ingestion, direct contact, and absorption. Potential receptors can include both primary receptors and secondary receptors. Primary receptors can include macroinvertebrates, fish, plants, terrestrial vertebrates, and waterfowl. Secondary receptors include any animals that either prey on or scavenge on primary receptors. (An animal may be both a primary and secondary receptor; a bear, for example, could ingest contaminated water as well as eat contaminated fish). Of greatest concern have been dabbling ducks (primary receptors) that have become moribund or died following exposure in shallow areas of ponds and have been preyed upon or scavenged upon by eagles (secondary receptors). White phosphorus has been detected frequently in ducks from the ERF, and one analysis has shown WP in an eagle. White phosphorus has also been detected in swans, ravens, shorebirds, and herring gull eggs.

Many food items for dabbling ducks are available in the ERF sediments, including seeds and macroinvertebrates. White phosphorus particles present in the sediments generally have a size range similar to that of seeds, larvae, and macroinvertebrates that dabbling ducks feed on. It is hypothesized that the WP particles are either purposefully ingested for gizzard grit or are mistaken for food items.

White phosphorus is also highly lipid-soluble and readily accumulates in fat and skin tissues of waterfowl, making it a concern for bioaccumulation. However, initial studies using kestrels showed that although WP was rapidly accumulated in the tissues, levels decreased when exposure to WP was removed, indicating that WP is somehow being metabolized or excreted rapidly in living biological systems. However, bioaccumulation of WP occurs in ducks at the ERF and in those ducks experimentally poisoned in the laboratory.

Section 5

Preliminary Baseline Risk Assessment

5.1 Purpose and Scope of the Baseline Risk Assessment

A baseline risk assessment is an analysis of the potential, current, and future adverse health and environmental effects caused by releases of, and exposure to, site-related chemicals. To develop a baseline risk assessment, it is assumed that no action is taken at the site to prevent exposure of ecological or human receptors to contamination. Therefore, the baseline risk assessment is an evaluation of the risks that could be present if the site is not remediated. The goal of the risk assessment process is to provide a consistent framework for remedial decisionmaking. Because the information currently available is inadequate for completion of a baseline risk assessment, this risk assessment is considered to be preliminary.

The following are the objectives of the baseline risk assessment:

- Evaluate, under a certain set of assumptions, the potential risks at the site
- Document the magnitude and the known causes of risks at the site
- Determine whether response action is necessary at the site
- Provide a basis for developing risk-based remediation goals (including those for humans, as well as ecological receptors)

This section provides an overview of ecological and human health risk assessment issues, developed with the use of available information.

This baseline risk assessment is not intended to be a stand-alone document; instead it uses the following information, which is presented in Sections 1 through 4:

- Description of the ERF and its surroundings, determination of areas potentially affected by environmental releases to the ERF, and definition of the study area (Section 2)

- Description of the environmental setting and identification of potentially exposed habitats and ecological receptors (Section 2)

- Review of the nature and extent of contamination by medium and contaminant type, as presented in available literature (Section 3)
- Conceptual site model (Section 4)

5.2 Ecological Risk Assessment

5.2.1 Overview

This section presents a preliminary ecological risk assessment of areas potentially affected by chemicals of concern in sediments, water, or biota within the ERF. Available literature was used to identify the potential problems known to exist at the ERF; characterize exposure pathways, receptors, and contamination levels; and describe toxicity and potential effects of chemicals of concern. This information and the results of ongoing studies should be used to characterize risks to ecological receptors, form conclusions, define limitations, and recommend remediation goals or further studies. The risk characterization has not yet been completed because the ongoing studies should provide a significant amount of new information that can be incorporated in the near future.

This risk assessment is based on the following major assumptions and constraints:

- No remedial actions will be taken.
- For the purpose of risk assessment, future chemical concentrations will not change over time.
- Future land uses will be similar to current uses.
- Terrestrial organisms (mammals and birds) may be exposed to contaminated media, primarily through ingestion.
- Dermal or inhalation exposure is not quantitatively addressed because of the lack of toxicological information.

- Exposure to aquatic organisms occurs through all routes and is addressed by direct comparison to waterborne, as well as to other applicable effect levels.

The baseline ecological risk assessment was performed in accordance with the following guidance documents:

- *Risk Assessment Guidance for Superfund: Volume II, Environmental Evaluation Manual* (USEPA, 1989a)
- *Ecological Assessment of Superfund Sites: An Overview* (USEPA, 1991d)
- *Developing a Work Scope for Ecological Assessments* (USEPA, 1992a)
- *Framework for Ecological Risk Assessment* (USEPA, 1992c)

Current guidance recommends use of a phased approach. By using the phased approach, a level of effort is achieved that meets the need of characterizing impacts, but does not exceed that need. The four phases of developing the ecological risk assessment are described below:

- **Phase 1–Site Characterization and Screening.** Phase 1 involves an evaluation of existing data identifying the presence and levels of contaminants at the site; comparing detected levels with available criteria, standards, and effect-level values; and determining whether exposure pathways to ecological receptors exist.
- **Phase 2–Incorporation of Results From Ongoing Studies.** Several ongoing studies are expected to contribute new information in the near future to further characterize the site, assess exposure of receptors, and assess ecological effects of the ERF contaminants.
- **Phase 3–Completion of Additional Studies, as Needed.** If significant information needs remain after the ongoing studies are completed, further field or laboratory studies may be conducted to address uncertainties and data limitations. However, this phase will be managed intensively to reduce the amount of study that is performed before remedial actions begin (Blood, USEPA, pers. comm.).

- **Phase 4–Baseline Risk Assessment.** The baseline risk assessment can be completed once adequate information is available for the exposure assessment, ecological effects assessment, and risk characterization.

With the phased approach, data or observations from one phase determine what, if any, further studies are needed to meet the assessment objectives. Subsequent studies and associated DQOs are then defined. Interim reports, such as this CER, are provided for review by responsible agencies.

This ecological risk assessment presents the findings of the first phase of a preliminary risk assessment; currently available information about an existing site is used to develop a preliminary risk assessment.

5.2.2 Scope, Organization, and Objectives

A Phase 1 ecological risk assessment was conducted to address the ERF and surrounding areas. The scope of the investigation was limited to those areas potentially affected by environmental releases of chemicals of concern through direct release and environmental transport. These areas are defined in Section 4.

Existing literature and reports were reviewed to provide information on the history, data addressing the chemicals of concern, characterization of habitat, and documentation of effects associated with releases to the ERF. The ecological risk assessment is preliminary in that only data available in the reports and literature are used. It is intended to identify the potential for adverse effects to habitats that are potentially affected by releases of WP and other chemicals of concern in the ERF. Based on the preliminary risk assessment and upon evaluation of the results of ongoing studies, recommendations will be made about the need to conduct further studies and to identify additional data needed from them.

This ecological risk assessment draws mainly on information presented in preceding sections. The assessment is organized as follows:

- Problem Formulation–Subsection 5.2.3 provides a description of the ERF, definition of the study area, and statement of ecological issues associated with the ERF. This subsection briefly summarizes information from Sections 1 and 2.

- Areas and Chemicals of Potential Concern–Subsection 5.2.4 summarizes the habitat and the chemicals of concern and determines which contaminants should be considered further in the ecological risk assessment. Supporting information is found in Sections 2 and 3.

- Exposure Assessment–Subsection 5.2.5 summarizes the fate and transport of contaminants, potential receptors, and pathways by which ecological exposures can occur. This information is used to estimate the magnitude of actual or potential ecological exposures and the frequency and duration of these exposures.

- Ecological Effects Assessment–Subsection 5.2.6 summarizes information from available literature on the toxicity of chemicals of ecological concern to environmental receptors, and determines the potential to cause adverse effects in aquatic or terrestrial ecological receptors.

- Risk Characterization–Subsection 5.2.7 integrates information regarding receptors, exposure pathways, and toxicity to estimate the effects on ecological receptors from exposure to potential chemicals of ecological concern.

- Conclusions, Uncertainties, and Limitations–Section 5.2.8 presents basic conclusions of the preliminary ecological risk assessment, uncertainties and limitations in the available data and the approach used, and recommendations for further studies.

Where currently available information is incomplete (for example, exposure assessment and ecological effects assessment), the results from ongoing studies should be added in the near future. The resulting document will be used as the basis for identifying and preparing DQOs and preparing a work plan if further studies are needed to characterize actual or potential adverse effects associated with contaminants at the ERF.

This preliminary ecological risk assessment uses previously reported analytical data for sediment, soil, water, and biota concentrations. Data used are assumed to be valid and usable. In addition, all results presented are assumed to be quantitatively accurate, even though analytical methods have changed and improved over time. There is a need to have adequate quality assurance/quality control (QA/QC) information for all data that are used in the risk assessment to ensure the acceptability of the data. Where such information is not provided in the available reports, it should be reconstructed as soon as feasible to meet the QA/QC needs. Some measures to improve QA/QC of data collection and reporting are being incorporated into the study plans for ongoing studies to be conducted during 1994.

5.2.3 Problem Formulation

The ERF Impact Area is an 865-ha estuarine salt marsh at the mouth of the Knik Arm of Cook Inlet. It includes 75 to 100, small to large, open-water ponds. July and August precipitation can result in heavy rainfall, contributing to high runoff events in local streams, including Eagle River.

The U.S. Army has used the ERF since 1945 as an impact area for artillery shells, mortar rounds, rockets, grenades, illumination flames, and Army/Air Force Door Gunnery Exercises. Thousands of craters resulting from munitions testing are widely distributed throughout the marsh. Despite heavy anthropogenic disturbance, the ERF has continued to support large numbers of waterfowl, shorebirds, gulls, terns, and raptors, as well as several mammalian species. The Eagle River, which bisects the ERF Impact Area, is subject to tides as great as 11 m. In addition to the river, 75 to 100 permanent or semi-permanent ponds account for about 8 percent of the marsh area. Other features of the wetland include regions of barren mudflats, meadows of dense sedges, and stands of bulrush, as described in Subsection 2.3. Waterfowl and shorebirds use the ERF primarily as a migratory stop for several weeks in the spring and fall. However, some species remain on the ERF throughout the summer to nest there.

White phosphorus and potentially other chemicals have been released into the ERF. Evidence of WP has been found in water, waterfowl, and particularly in sediments. White phosphorus and other chemicals present may have entered the food chain of mammals, birds, fish, and other animals. If WP is present in insects, other invertebrates, and fish, it may be transferred through the aquatic and avian food chains. The terrestrial ecosystem may be affected if WP is transferred through invertebrates, fish, birds, and mammals. Effects of WP observed at the ERF include waterfowl deaths, particularly in dabbling ducks feeding in shallow ponds. Bald eagles feed heavily on dead or moribund ducks, especially in spring, and probably have been killed by secondary poisoning.

An important component of the problem formulation that has not been completed is selection of endpoints of concern and specifying the objectives and scope of the ecological assessment. Endpoints should include assessment endpoints (an expression of the environmental value considered to be at risk but that may not be directly measurable) and measurement endpoints (the parameters that can be measured quantitatively and applied to the assessment endpoint). These endpoints, as well as the objectives and scope of the assessment, should be agreed upon by the responsible agencies.

5.2.4 Areas and Chemicals of Potential Concern

Areas of ecological concern currently consist of those areas where artillery-related contaminants may occur in sediments and surface water. On the basis of current information, munitions residues are most abundant in areas where there is high crater density. Areas of highest crater density are found on either side of Eagle River, including Areas A and C and the Bread Truck Pond area. Habitat in these areas is discussed in Section 2.

White phosphorus was identified as the primary chemical of concern at ERF because of duck mortality; however, other munitions-related chemicals are still being considered. Priority testing for WP was recommended under the Toxic Substances Control Act of 1976 (TSCA), Section 4(e), in November 1991, for persistence in surface water and sediments and toxicity to migratory birds and other wildlife. This recommendation was based on concerns of the U.S. Department of the Interior regarding WP in wetland sediments, the adverse effects of persistent WP to birds and wildlife that feed on sediments contaminated with WP, the potential for food-chain effects, and the potential elimination of species (including special-status species) that may feed on carcasses of birds and wildlife that die from WP poisoning (ITC, 1991). Acute and chronic toxicity of WP and other chemicals of potential concern are discussed in Subsection 5.2.6.

5.2.5 Exposure Assessment

The potential release and transport, receptors, and routes of exposure to chemicals of concern are evaluated in the exposure assessment.

5.2.5.1 Environmental Fate and Chemical Transport Mechanisms

Subsection 4.4 describes the fate and transport processes associated with WP that may occur in air, soil, and water in the study area. The chemical and physical characteristics of WP that govern its mobility and fate are presented in Table 4-1.

White phosphorus can occur buried in the sediments to depths of 30 cm or more. Because salt marsh sediments are highly reduced, WP is stable in wet ERF sediments. Particles less than 0.15 mm in diameter can easily become suspended in the water column for up to 2 hours. White phosphorus has been detected in the water column (even in undisturbed controls) and appears to be most easily suspended in the water column along a pond edge and in bulrushes (Racine, et al., 1993). Reasons for these apparent differences are unclear, but may be related to the numbers of particles present and the degree of disturbance. Suspended particles can be transported out of ponds and into distributary channels that connect with Eagle River. High tides can cause Eagle River to back up and flood; deposition of glacial fines (mostly silt with some clay) onto the ERF results (Quirk, 1991).

5.2.5.2 Receptors

Section 2 describes the various habitats and corresponding species in the ERF. The large numbers of species and numbers of individuals counted during spring and fall surveys suggest that the ERF is an important feeding and resting habitat during migration (Racine, et al., 1993). Bird surveys during 1990 to 1993 show as many as 1,460 swans, 2,500 geese, 2,500 ducks, 66 bald eagles, 52 sandhill cranes, 140 common raven, 150 gulls, and several thousand shorebirds using the ERF. The various avian receptors use certain areas of the ERF somewhat differently: swans mainly use Areas A, B, and D; Canada geese are numerous in Areas A and D; and snow geese more frequently use Areas A and B. Use of Areas A, B, C, and D by ducks depends on water levels, ice conditions, and human disturbance. Areas A and D are consistently important to ducks (Racine et al., 1993; W.D. Eldridge, USFWS, pers. comm.). The avian species found dead on the ERF include northern pintail, mallard, green-winged teal, northern shoveler, American widgeon, gadwall, least sandpiper, semi-palmated sandpiper, dowitcher, yellowlegs, swans, bald eagle, mew gull, raven, Canada goose, unknown ducks, shorebirds, and gulls.

Black bear, beaver, muskrat, mink, weasel, wolverine, coyote, red fox, lynx, rodents, and moose use the ERF. Beluga whales occur off the shore of the ERF in Knik Arm and in the river. All these species could be exposed to ERF contaminants if the contaminants bioaccumulate in the food chain (Quirk, 1991). Eagle River has a small natural run of king and red salmon and an increasing run of stocked king salmon, all of which spawn upstream. The ERF provides limited rearing habitat for king salmon and Dolly Varden trout (Quirk, 1991).

A recent report summarizes the risk to potential receptors:

> Because of the extremely toxic nature of P_4 residues in aquatic systems, deposition/washout of any undegraded WP, especially to small water bodies, may create exposure risks to resident finfish, invertebrates, and/or waterfowl, even if resultant WP concentrations are in the low ppb range (Racine, et al., 1993).

The ERF is closed to recreational activities, including hunting. Fish surveys have not been conducted in the lower part of Eagle River, but there are no visible occurrences of toxicity to fish. It is unknown whether some fish species that would be expected to occur in the ERF are present in expected numbers.

5.2.5.3 Exposure Pathways

Potential exposure pathways for ecological receptors are discussed in Subsection 4.6 and are illustrated in Figure 4-7. The actual effects of the release of chemicals through these pathways have not been studied thoroughly. However, available information is summarized in Sections 3 and 4.

5.2.6 Ecological Effects Assessment

5.2.6.1 Acute Toxicity of White Phosphorus

White phosphorus is acutely toxic in minute quantities to wildlife and humans. Acute toxicity of WP in waterfowl, aquatic organisms, and terrestrial vertebrates is discussed below.

Waterfowl. None of the 20 mallards tested at 2.6 or 3.7 mg/kg died during the 3 weeks of observation post-dosage, but one bird developed a liver focus at 2.6 mg/kg and two birds had foci at 3.7 mg/kg (Sparling, Grove, Hill, Gustafson, and Comerci, in Racine, et al., 1994). The acute median lethal dose for adult male and juvenile mallards exposed to WP dissolved in oil was 6.5 mg/kg of body weight. Adult females were substantially less sensitive to WP than other age/sex classes, and the median lethal dose could not be calculated for adult females. Reasons for the lower sensitivity of adult females are not known, but lipid levels in the birds may be a factor. (These were not reported, but lipid levels may be lower in post-breeding females than in the other age/sex classes.) The lowest observed effects level (LOEL) for acute mortality was 4 mg/kg for this study.

Tissue analyses of bird carcasses collected from the ERF found WP in the fat, gizzard contents and other digestive tissues, liver, skin and breast muscle (ITC, 1991; Sparling, Grove, and Comerci, in Racine, et al., 1994). In both laboratory-treated birds and birds collected from the ERF, the highest concentrations of WP were found in the fat and the skin. Other munitions-derived chemicals were also found, but not at levels high enough to cause death.

Before they die, poisoned birds are often taken by either bald eagles or gulls, or both (ITC, 1991; Racine, et al., 1993; Reitsma and Steele, in Racine, et al., 1994). However, few bald eagles or gulls have been found dead on the ERF to date. One bald eagle carcass was found, and subsequent analysis of tissues showed that WP was present. Because no data were available concerning the transfer of WP between trophic levels, it was circumstantially determined that WP was the toxic agent. In addition, two eagle feather piles were found along woodland transects and two eagle carcasses were found on the ERF during 1993. Although the cause of death for all these eagles could not be determined, these findings further suggest that mortality of secondary receptors occurs as a result of WP ingestion.

Investigators have hypothesized that the toxicity of WP may actually be a result of its metabolite or metabolites, rather than the parent compound. This hypothesis is supported by evidence that the wild birds found dead in the ERF had widely varying amounts of WP in their tissues, and WP levels in fish tissues were not correlated to the cause of death (Racine, et al., 1993; Nam, et al., 1994; Racine, et al., 1994).

Aquatic Organisms. Toxicity of WP to aquatic organisms varies within an order of magnitude and it can be toxic to aquatic organisms at concentrations lower than 1 µg/L (Yon, et al., 1983). In one study, lethal concentrations (LC_{50}) for five freshwater fish species ranged from 2.4 to 73 µg/L, with bluegill (*Lepomis macrochirus*) being the most sensitive species (ITC, 1991). However, Zitko, et al. (1970) found Atlantic salmon (*Salmo salar*) were more sensitive than bluegill, with a static 96-hour LC_{50} of 2.3 µg/L (Yon, et al., 1983).

White phosphorus oxides reportedly have a low toxicity in aquatic organisms, but elevated levels increase the eutrophication of the system and result in algal blooms (Yon, et al., 1983).

The LC_{50} for invertebrates can also have a wide range. In one study, the LC_{50} of five invertebrates ranged from 30 µg/L to more than 560 µg/L, with *Daphnia magna* the most sensitive species tested (ITC, 1991).

Localized fish kills can occur if fragments of WP fall into aquatic systems. In Newfoundland, WP accumulated in lobsters, clams, quahogs, mussels, periwinkles, and starfish, as well as in seaweed following exposure to water containing 15 µg/L of WP for 48 hours (CRREL, 1993). Massive fish kills also occurred in Placentia Bay, Canada, in 1969, as a result of "phossy water" discharge from the WP manufacturing plant in Long Harbour. Wastewater containing unoxidized WP particles was released, which widely contaminated marine life in the area. Observed effects included hemolysis. Investigators found that fish and marine invertebrates accumulated high concentrations of WP in their tissues (Nam, et al., 1994; Bouwkamp, in Racine, et al., 1994).

A WP criterion for sediment cannot be derived because of the limited available data and complications caused by differing amounts of WP in the overlying water and the heterogeneous distribution of WP in sediments (Racine and Walsh, in Racine, et al., 1994). In a marine harbor in Newfoundland, Canada, impacts to the invertebrate community were associated with WP sediment concentrations above 70 µg/kg and water concentrations above 3 µg/L. In a freshwater lake where an adverse impact to invertebrates was observed, WP concentrations in sediments were 2 to 3.3 µg/kg and water concentrations ranged from 1.2 to 40.4 µg/L. Therefore, bioassays were conducted using ERF sediments to determine effect levels.

The laboratory sediment toxicity studies did not agree with the results of benthic macroinvertebrate sampling in the field (Bouwkamp, in Racine, et al., 1994). All organisms in both the amphipod (*Hyalella azteca*) and midge larva (*Chironomus riparius*) toxicity tests died in all sediment concentrations used in dilution series that were tested (which ranged from 20 percent to 100 percent ERF sediment). Because the waterborne concentrations of WP in the test chambers were far higher than those observed under field conditions, the toxicity test provided a poor simulation/test of WP toxicity in sediments to invertebrates at the ERF.

Mammals. White phosphorus was widely used in rat poisons and is highly toxic to laboratory animals by the oral route. Oral lethal doses (LD_{50}) range from 3.03 to 3.76 mg/kg in rats, and 4.82 to 4.84 mg/kg in mice. Acute inhalation (LC_{50}) ranges from 660 milligrams per cubic meter (mg/m^3) in mice to 1,400 mg/m^3 in rats (ITC, 1991). An oral dose of 0.0027 mg/kg of body weight per day over 25 weeks resulted in a slight reduction in weight gain in rats (Yon, et al., 1983).

White phosphorus is rapidly absorbed from the digestive tract of mice, rats, and rabbits (complete within 24 hours) (ITC, 1991). Symptoms include anorexia and jaundiced and enlarged liver (Yon, et al., 1983).

Radio-labeled WP is accumulated primarily in the liver, kidney, lung, bone, and skeletal muscles. Elimination is mainly through urinary excretion as inorganic and organic phosphorus; some fecal elimination also occurs. White phosphorus does not appear to be absorbed from the lung or skin of lab animals (ITC, 1991).

5.2.6.2 Chronic Toxicity of White Phosphorus

Waterfowl. Chronic toxicity information on WP is limited; information was not available about its effects on reproduction (USFWS, 1993).

Exposure to WP levels of 1.5 mg/kg per day in ducks causes weight loss, lethargy, anemia, liver congestion, and death within 5 to 10 days. A dose of 12 mg/kg produces signs nearly identical to those observed in the field, and death occurs within 6 hours (USFWS, 1993). There are no appropriate toxicity studies that can be used to derive an LOEL or NOAEL for chronic exposure (Dacre, 1993).

Aquatic Organisms. Chronic WP exposure of fathead minnows to WP (*Pimephales promelas*) resulted in reduced survival at 1.5 µg/L and reduced hatchability at 0.4 µg/L. *Daphnia magna* exposed to 8.7 µg/L showed reduced survival (ITC, 1991).

In chronic 241-day tests with fathead minnows at 0.4 and 0.71 µg/L, eggs did not hatch. Bentley, et al., recommended a water quality criterion of 0.004 µg/L to protect freshwater aquatic life (Yon, et al., 1983).

Mammals. Chronic (4- to 6-month) oral exposures of WP in rats caused growth deficiencies. Lifetime dietary exposure to rats resulted in growth retardation, bone changes, edema of the lungs, and pneumonia (USEPA, 1992).

Dietary studies (22 weeks), in which rats were given daily doses of 0.075 mg/kg per day of WP, showed a severely depressed weight gain, leading to a final weight that was the starting weight. Male rats fed 0.0027 mg/kg per day showed rapid growth from the 15th to the 25th week, with growth 13 percent above the controls at week 25 (ITC, 1991).

Lifetime (up to 512 days) oral rat exposures to a dose of 0.2 mg/kg per day of WP, and greater (dissolved in peanut oil and added to diet), resulted in death. Changes in long bones were observed (thickening of the epiphyseal line; extension of the trabeculae into the shaft). Subcutaneous exposure (0.05 mg/kg per day of WP) demonstrated similar effects in rats and lesser effects in guinea pigs. Livers of treated rats showed mild fatty degeneration, and lungs showed bronchopneumonia, pneumonitis, and bronchitis. These effects were not seen in similarly tested guinea pigs (ITC, 1991).

Two-generation oral reproductive studies with rats showed increased mortality in high-dose parental females; no information is available on developmental effects (USEPA, 1992c), and no effects to reproductive indices were observed. The NOAEL was 0.015 mg/kg per day (ITC, 1991).

White phosphorus solution (weak) does not cause eye or skin irritation, but higher concentrations produce burns and subsequent systemic toxicity, primarily to liver and kidneys (USEPA, 1992c). In 1-month and 90-day oral exposure studies, rabbits and guinea pigs had marked destruction of liver cells, similar to alcohol cirrhosis (USEPA, 1992c). Rabbits given an oral dose of 0.3 mg/kg of body weight per day for 117 days showed reduction in weight gain and retardation of longitudinal bone growth (Yon, et al., 1983).

No evidence of mutagenic effects in *Salmonella* strains or non-carcinogenic effects was observed in lifetime rat studies (USEPA, 1992c).

5.2.6.3 Toxicity of Other Chemicals

Acute poisoning of rats by 2,4-DNT and 2,6-DNT causes ataxia, respiratory depression, and death within 24 hours. Lethal doses for rats range from 270 to 2,000 mg/kg of body weight for 2,4-DNT and 180 to 1,000 mg/kg of body weight for 2,6-DNT (CRREL, 1991).

Exposure of rats and mice to RDX results in gasping, convulsions, and death. Oral LD_{50} values of 80 mg/kg and 120 mg/kg were reported for mice and rats, respectively (CRREL, 1991).

5.2.7 Risk Characterization

The risk characterization integrates the results of the exposure assessment and the ecological effects assessment to estimate the likelihood of impacts to ecological receptors from exposure to chemicals of concern. Adequate information is not currently available to complete the risk characterization; however, several ongoing studies are expected to contribute a significant amount of information concerning exposure and effects for various receptors in the ERF in the near future. The results of those studies will be incorporated in the next phase of the risk assessment.

A commonly used approach for preliminary risk characterizations is to compare maximum observed contaminant concentrations in the various exposure media (for example, surface water, sediment, soil, or food-chain organisms) to criteria or standards (promulgated by federal or state regulations) or to appropriate reference values (such as background values, NOAELs, or LOAELs). This comparison results in a hazard quotient that enables screening of contaminants, media, and exposure pathways where contaminant concentrations exceed criteria or standards (if they have been established), or appropriate reference values (if they can be related to exposure pathways and receptors at the site).

For the ERF, that approach cannot be applied readily because of the absence of criteria and standards and the limited information on reference values. In particular, the distribution and availability of WP particles in pond sediments may be a critical factor that is not yet sufficiently understood to guide the development of remediation goals. The distribution of WP particles is seemingly very patchy, with high frequency occurring in the immediate vicinity of a WP munition detonation, but with widespread transport and persistence throughout permanently or semi-permanently wet portions of the marsh. Foraging birds (such as waterfowl and shorebirds) seem to ingest these particles because of the similarity of their size to the seeds and invertebrates for which the birds are searching. Hence, the occurrence and availability of WP particles to foraging birds may be more important factors in risk characterization than the concentration of WP in water, sediment, or soil. Similarly, the concentration of WP in primary receptors (such as invertebrates, fish, and birds) that could serve as exposure media for secondary receptors (such as predatory, scavenging, or fish-eating species) has not been sufficiently characterized.

Nevertheless, studies have documented a high frequency of mortality among waterfowl (mainly ducks and swans), as well as some mortality or exposure of other ecological receptors (such as shorebirds and bald eagles). The most readily quantifiable risk characterization can be developed from the study of waterfowl conducted during the fall of 1993 and reported by Cummings (in Racine, et al., 1994).

Movement, distribution, turnover rate, and site-specific exposure were determined for duck species most susceptible to WP poisoning at the ERF during fall migration (Cummings, in Racine, et al., 1994). During August and September 1993, 62 ducks of five species were captured in Areas C and C/D and Bread Truck Pond with mist nets and swim-in traps. Radio transmitters were attached to 12 mallards, 11 pintails, 11 green-winged teals, 2 American wigeons, and 3 northern shovelers. Their activities were monitored from August 8 to September 30. The tracking data indicate that during August (before hazing was conducted to discourage bird use) the ducks ranged over the entire ERF. Mallards tended to concentrate in Areas A and B, Racine Island, and the C/D transition area. Pintails used Area C and Bread Truck Pond, whereas teals used the C/D transition area and shallow pools in Areas A and C. After hazing, most ducks concentrated in Area B and the C/D transition area. Preliminary data analyses suggest that there was a low turnover rate of ducks using the ERF during August and September. During the course of the radiotelemetry study, 15 of the 39 instrumented ducks left the ERF (Cummings, in Racine, et al., 1994). The average stay of those ducks on the ERF was about 12 days. Eight of the 34 telemetry ducks were found dead on the ERF. If those birds are representative of the population using the ERF, there seems to be a high mortality rate among the birds that migrate through there.

In addition to the waterfowl that have been rather well documented to have died because of WP ingestion, circumstantial evidence indicates that bald eagles may die as a result of eating poisoned ducks, and that birds such as shorebirds and fish-eating birds also are being affected. However, exposure routes have not been well documented for those species. (It is unclear whether these birds are being exposed secondarily or whether they ingest particles directly.)

A laboratory bioassay indicated that ERF sediments are highly toxic to test invertebrates, but the laboratory results did not seem to agree with field observations. Therefore, the bioassays are being repeated.

5.2.8 Conclusions, Uncertainties, and Limitations

After results of ongoing studies become available, the risk characterization can be completed to provide conclusions and identify uncertainties and limitations related to those conclusions. If significant uncertainties exist, or if new data needs are identified, further studies may be recommended.

At this time, it is possible to conclude that WP ingestion causes mortality of waterfowl and that it probably also causes mortality of other species (such as eagles and shorebirds). Species such as bald eagles and Arctic terns are probably secondary receptors, whereas waterfowl and shorebirds more likely ingest WP particles directly while foraging in ponds or other wetlands in the marsh.

Degree of exposure for other predators and scavengers (especially mammals) is not known, although dead mammals have not been found along survey transects. Likewise, exposure of fish, including those in ponds, as well as in Eagle River, is not well documented. For example, studies have thus far not determined whether some fish species expected to occur in the ERF are found at densities expected for such habitats, and it is unclear whether WP occurs in their tissues. Both fish or aquatic invertebrates could serve as exposure media for birds such as Arctic terns (which have shown signs of exposure although none have been found dead).

5.3 Human Health Risk Assessment

As of early 1994, a complete human health risk assessment had not been undertaken at the ERF. Past reports on the ERF have limited the assessment of human health risks to the following approaches:

- Review of existing toxicity information for the suspected chemicals of concern in explosives and munitions residues (Racine, et al., 1992b)

- Assessment of the possible hazards to hunters of ingesting poisoned birds

The process of developing a baseline risk assessment for human health is discussed below. Also, the toxicity information and risk evaluations for public health presented in past publications on the ERF are summarized.

5.3.1 Overview

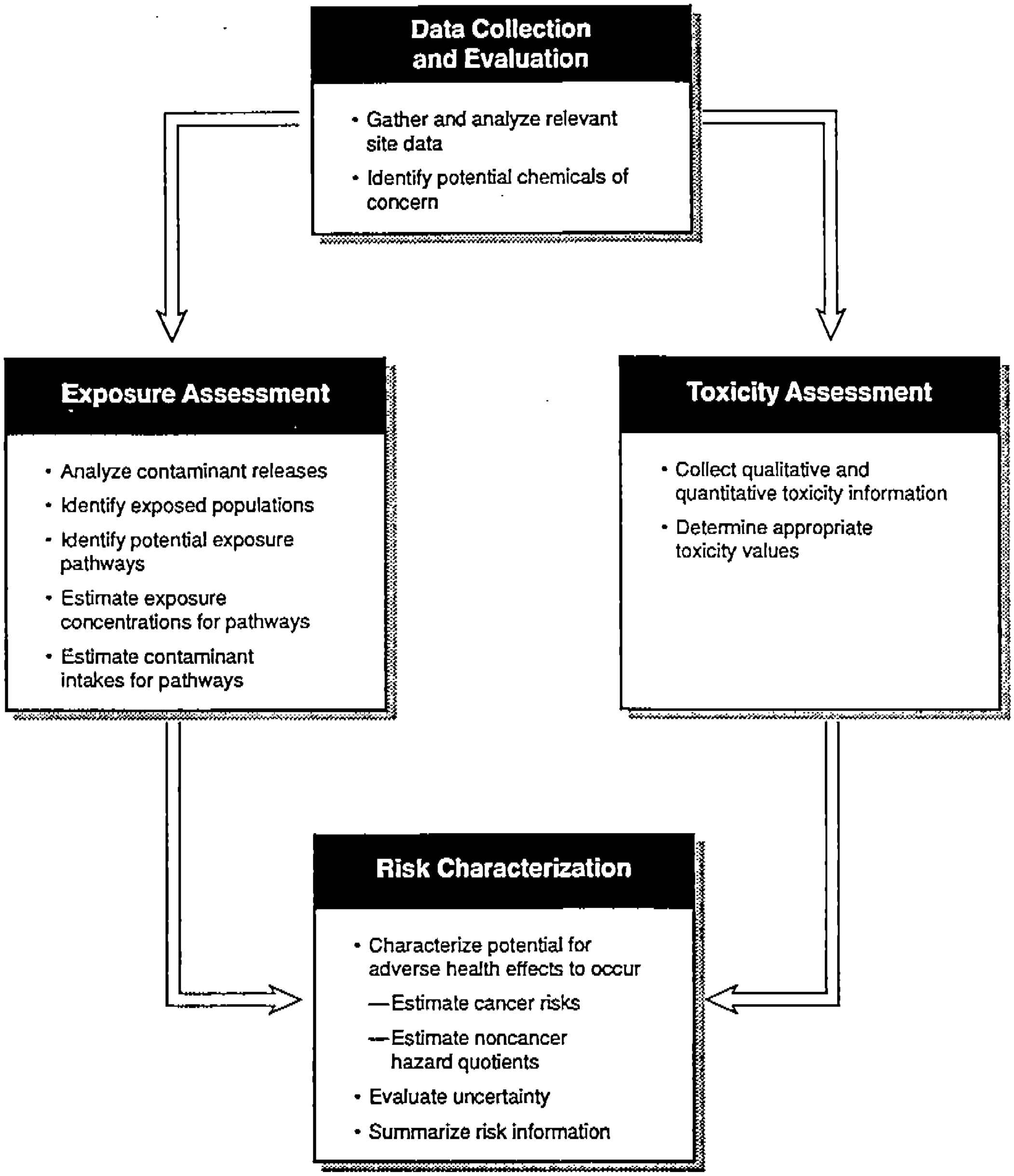
A baseline risk assessment for human health evaluates the potential threats to public health from the site in the absence of any remedial action (USEPA, 1989a) under current and potential future uses. The baseline risk assessment process has four steps (Figure 5-1):

1. Data identification of chemicals of potential concern
2. Exposure assessment
3. Toxicity assessment
4. Risk characterization, including a discussion of uncertainty

Before a baseline risk assessment can be prepared, a CSM is developed that identifies potential sources, pathways, and receptors. The CSM is based on a review of site history, environmental setting, and past findings. It can rapidly identify data gaps that need to be eliminated through additional investigations before the risk assessment can be conducted. The unresolved data deficiencies become part of the uncertainty analysis of the baseline risk assessment.

The first step in formulating a risk assessment is to identify the chemicals of potential concern. This process identifies the chemicals present at the site. Then, to focus subsequent efforts, it identifies chemicals that might be of potential concern to public health.

The exposure assessment identifies potential pathways by which exposures can occur and characterizes the potentially exposed populations and the frequency and duration of these exposures. Both current and potential future exposure scenarios are evaluated. The exposure scenarios should reflect realistic land uses for the habitat.



SOURCE: USEPA, 1989

FIGURE 5-1
HUMAN HEALTH
BASELINE RISK ASSESSMENT

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The toxicity assessment identifies the type of hazards or health effects associated with exposure to the chemicals of potential concern. It also describes the dose-response relationships of those chemicals.

The risk characterization addresses the potential for adverse effects for each exposure setting derived from the exposure assessment. It integrates the information developed during the toxicity and exposure assessments to estimate the potential risks to public health from exposure to site contaminants.

Finally, an uncertainty analysis identifies sources of uncertainty in the risk assessment process and their impacts on the risk estimates.

A baseline risk assessment for human health under CERCLA is performed in accordance with the following USEPA guidance documents:

- *Risk Assessment Guidance for Superfund: Vol 1- Human Health Evaluation Manual Part A*, Interim Final (December 1989b)
- *Supplemental Risk Assessment Guidance for Superfund*, USEPA Region 10 (August 1991c)
- *Human Health Evaluation Manual, Supplemental Guidance: "Standard Default Exposure Factors"* (March 1991f)

The CERCLA baseline risk assessment is usually part of the remedial investigation (RI). Guidance is also available for project managers to use in linking the human health risk assessment to the feasibility study (FS) and selection of remedial alternatives:

- *Risk Assessment Guidance for Superfund: Volume 1– Human Health Evaluation Manual Part B, Development of Risk-based Preliminary Remediation Goals,* Interim OSWER Directive (December 1991a)
- *Risk Assessment Guidance for Superfund: Volume 1–Human Health Evaluation Manual Part C, Risk Evaluation of Remedial Alternatives,* Interim OSWER Directive (December 1991b)

Additional non-CERCLA guidance in conducting a risk assessment may be available through other federal (such as U.S. Army), state, or local agencies (such as MOA) that may have jurisdiction over the ERF; and that guidance may be considered at the time a risk assessment is conducted for the ERF.

5.3.2 Chemicals of Concern and Land Use

Use of ERF as a firing range, implicates munitions compounds and byproducts as potential contaminants of concern. Site investigations from 1989 through 1993 ERF have narrowed the list of potential contaminants and hazards to human health to the following:

- Munitions residues in sediments, soil, and surface water
- Presence of unexploded ordnance (UXO)

Table 5-1 indicates the maximum concentrations of munitions residues detected in the various media at the ERF.

Munitions residues and, presumably, UXO seem to be localized in the environment to areas of explosion craters and the former EOD pad. Although transport of WP may potentially occur by movement of surface water, sediment, and contaminated waterfowl; environmental sampling in distributaries and Eagle River to date does not show such transport to be a significant element of the CSM.

Fuels, solvents, and other industrial wastes most commonly associated with contaminated military sites were not used to any extent at the ERF. Consequently, chemicals including volatile organics, acid/base/neutral organics (semivolatiles), pesticides, and PCBs have either not been found in environmental samples or were infrequently found at very low levels. Also, metals appear to be at background levels or at most only slightly elevated.

The surface water and, hence, near surface groundwater, is highly saline because of the estuarine nature of the site. Consequently, surface water and groundwater from the site are not currently used as potable water supplies and they would not be expected to be used in the future.

The existence of UXO means that access to the site will continued to be restricted in the future. At this time, the military plans to continue using the site as a firing range. UXO

Table 5-1
Chemicals of Concern for Human Health
Maximum Concentrations of Munition Residues Detected at the ERF

Munitions Residue	Surface Sediment		Surface Water		Surface Soil	
	µg/g	Sample Location	µg/L	Sample Location	µg/g	Sample Location
WP	307/ (wet wt.)	Main Pond, Racine Is.	5-8 Unfiltered undisturbed	Area C, confined crater	NR	-
HMX	ND	-	ND	-	1.4	former EOD pad
RDX	0.076	Area C	ND	-	12	former EOD pad
TNT	115[a]	Area C	ND	-	16	former EOD pad
Tetryl	ND	-	6.5	Area C	NR	-
PETN	34.7	Area C	NR	-	NR	-
2,4-DNT	84	Area C	2.86	Area C	76	former EOD pad
26-DNT	4.47	Area C	2.45	Area C	2.6	former EOD pad
2-AM-46-DNT	0.73	Area C	NR	-	NR	-
4-AM-26-DNT	0.93	Area C	NR	-	NR	-
1,3-DNB	ND	-	1.17	Area C	NR	-
Nitrobenzene	ND	-	3.48	Area C	NR	-

[a] All surface soil and sediments as dry weight except WP reported as wet weight.
[b] The second highest concentration of TNT was 0.467 µg/g.

ND = Not detected.
NR = Not reported.

and the estuarine habitat prevent use of the area as future residential or industrial sites. Human exposures at the site are expected to be restricted to occasional trespassers (such as researchers or EOD personnel) in the future, as they are currently. Offsite human exposure (current and future) may occur when hunters eat contaminated waterfowl that have migrated offsite.

5.3.3 Human Health Toxicity

Toxicity data for munitions known to have been used at the ERF clearly show that some of the component chemicals can have adverse effects in humans. White phosphorus is highly toxic to humans by inhalation, skin contact, or ingestion.

Table 5-2 indicates the current reference doses (RfDs), and Table 5-3 indicates the cancer slope factors and cancer classifications for the chemicals of concern. The values in Tables 5-2 and 5-3 were obtained from USEPA's online Integrated Risk Information System (IRIS) (USEPA, 1994) or USEPA's Health Effects Assessment Summary Tables (1993c).

The two tables also show risk-based concentrations (RBCs) calculated according to USEPA Region 10 guidance (1991c). The RBCs represent a lifetime residential exposure scenario that is highly conservative for the ERF. As previously indicated, a residential use of the site is not expected in the future. However, the RBCs are useful to compare to the maximum site concentrations (Table 5-1) found at the ERF; most of the RBCs are higher than the maximum concentrations detected at the site. A trespasser scenario (occasional worker, for example) would yield much higher RBC values. USEPA's Region 3 recently developed revised soil and water RBCs for both residential and industrial scenarios. These new values have recently been adopted by USEPA Region 10 and will be available for use in future work at the ERF.

The following review of munitions toxicities is limited to readily available documents provided by the Army within the scope of work and does not represent an exhaustive review of the literature. The primary sources of information included toxicity summaries found in a human health baseline risk assessment for Umatilla Depot, Oregon (Dames and Moore, 1992); CRREL summaries at the ERF; and a USEPA drinking water health advisory for munitions (USEPA, 1991c).

Table 5-2
Oral Reference Dose Values and Risk-Based Concentrations for the Chemicals of Concern at the ERF

Chemical	Reference Dose (RfD) (mg/kg/day)	Source	UF	MF	Confidence in RfD[a]	Risk-Based Conc.[b]	
						Water (µg/L)	Soil (µg/g)
1,3-Dinitrobenzene	0.0001	IRIS	3000	1	low	4	30
2,4-DNT	0.002	IRIS	100	1	high	70	500
2,6-DNT	0.001	HEAST	3,000	1	NA	40	300
2-Am-4,6-DNT	NA	NA	NA	NA	NA	NA	NA
4-Am-2,6-DNT	NA	NA	NA	NA	NA	NA	NA
HMX	0.05	IRIS	1,000	1	low	2,000	10,000
Nitrate	1.6	IRIS	1	1	high	60,000	400,000
Nitrobenzene	0.0005	IRIS	10,000	1	low	20	100
PETN	NA	NA	NA	NA	NA	NA	NA
RDX	0.003	IRIS	100	1	high	100	800
Tetryl	NA	NA	NA	NA	NA	NA	NA
TNT	0.0005	IRIS	NA	NA	NA	20	100
White phosphorus	0.00002	IRIS	1,000	1	low	0.7	6

[a] Confidence in RfD as reported in IRIS.

[b] Risk-based concentrations are calculated for a hazard quotient equal to one for a lifetime residential exposure (ingestion) according to EPA Region 10 guidance (1991). This represents a highly conservative exposure scenario that is unlikely to occur at the ERF.

Notes:
UF = Uncertainty factor.
MF = Modifying factor.
IRIS = Integrated Risk Information System, USEPA 1994.
HEAST = Health Effects Assessment Summary Tables—Annual Summary, USEPA, 1993a.
NA = Not available.

Table 5-3
Carcinogenic Slope Factors and Risk-Based Concentrations for the Chemicals of Concern at the ERF

Chemical	Oral Route			Risk-Based Conc.	
	Weight of Evidence[a]	Slope Factor $(mg/kg\text{-}day)^{-1}$	Source	Water (µg/L)	Soil (µg/g)
1,3-Dinitrobenzene	D	NA	IRIS	NA	NA
2,4-DNT	B2	0.68	IRIS	0.1	0.9
2,6-DNT	B2	0.68	IRIS	0.1	0.9
2-Am-4,6-DNT	NA	NA	NA	NA	NA
4-Am-2,6-DNT	NA	NA	NA	NA	NA
HMX	D	NA	IRIS	NA	NA
Nitrate	D	NA	DWHA	NA	NA
Nitrobenzene	D	NA	IRIS	NA	NA
PETN	NA	NA	NA	NA	NA
RDX	C	0.11	IRIS	0.8	6
Tetryl	NA	NA	NA	NA	NA
TNT	C	0.03	IRIS	3	200
White phosphorus	D	NA	IRIS	NA	NA

[a] EPA Weight of Evidence:
Group A–Known human carcinogen.
Group B1–Probable human carcinogen; sufficient evidence in animals, limited evidence in humans.
Group B2–Probable human carcinogen; sufficient evidence in animals, inadequate or no evidence in humans.
Group C–Possible human carcinogen.
Group D–Not classifiable as to human carcinogenicity.
Group E–Evidence of noncarcinogenicity for humans.

[b] Risk-based concentrations are calculated for an excess lifetime cancer risk of 10^{-6} for a residential exposure (ingestion) according to EPA Region 10 guidance (1991). This represents a highly conservative exposure scenario that is unlikely to occur at the ERF.

Notes:
NA = Not avialable.
IRIS = Integrated Risk Information System, USEPA, 1994.
DWHA = Drinking Water Health Advisory, 3/87.

5.3.3.1 *Acute Toxicity of White Phosphorus*

White phosphorus is lethal to humans by oral ingestion at 1 mg/kg of body weight, and doses of 0.2 mg/kg of body weight can cause severe effects (Yon, et al., 1983). Acute toxicity in humans is characterized by three stages over the first few days. The first stage includes symptoms of severe gastrointestinal irritations soon after ingestion. Depending on the dose, death or a latent period lasting a few hours to a few days may follow. Systemic effects observed in the third stage include abdominal pain, vomiting, jaundice, and convulsions, followed by death. Fatty degeneration of the liver is the most common histopathological evidence of WP poisoning (CRREL, 1991).

White phosphorus is an irritant to the respiratory tract, and inhalation of smoke from WP can produce throat irritation at 188 to 500 mg/m^3 (Yon, et al., 1983). The 8-hour time-weighted average (TWA) threshold-limit value (TLV) of the American Conference of Governmental Industrial Hygienists (ACGIH) is 0.1 mg/m^3 for acute poisoning, and the National Institute for Occupational Safety and Health (NIOSH) and Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) is 0.1 mg/m^3 (USEPA, 1992b). Dermal contact can cause severe burns and destroy underlying tissue (Yon, et al., 1983).

White phosphorus was negative in the Ames/*Salmonella* test when evaluated as undiluted, saturated solution in distilled water. Up to 100 microliters (µL) per plate caused no mutations in both presence and absence of S9 fraction of liver (ITC, 1991).

5.3.3.2 *Chronic Toxicity of White Phosphorus*

In humans, toxic effects of WP exposure include death at low doses, nausea, vomiting, garlic-like odor on breath and in excrement, lethargy, convulsions, coma, fatty infiltration of liver and other organs, enlargement of liver with jaundice, kidney failure, and electrocardiographic changes suggestive of an acute heart attack (USEPA, 1992b).

Eye exposure to WP fumes causes conjunctivitis, photophobia, and lacrimation. Inhalation causes shortness of breath and hoarseness, but no permanent tissue damage. Chronic occupational exposure causes phossy jaw (a disease of the jawbone leading to tissue destruction and infection) (USEPA, 1992b).

White phosphorus has a non-carcinogenic oral reference dose of 0.00002 mg/kg per day, and is classified as a Group D carcinogen (not a carcinogen).

5.3.3.3 Toxicity of Other Chemicals

HMX: Data gathered through an occupational health study of 93 workers at an Army ammunition plant indicated that atmospheric exposure to HMX at unknown levels causes no hematologic, hepatic, or renal system abnormalities or autoimmune disease. Patch tests with solid HMX produced skin irritation in occupational workers from an Army ammunition plant (USEPA, 1991a).

The USEPA has classified HMX as Group D, not classifiable as to human carcinogenicity, based on a lack of animal bioassays and epidemiological studies.

RDX: Acute exposure of humans to RDX causes convulsions and unconsciousness. Seizures are followed by a period of stupor, delirium, disorientation, and confusion, then gradual and complete recovery (Burrows, et al., 1989).

Based on animal studies, the USEPA classifies RDX as a Group C or possible human carcinogen.

TNT: Exposure data gathered through occupational health surveys conducted at Army ammunition plants indicated that atmospheric exposure to TNT at levels ranging from 0.02 to 3.0 mg/cm^3 for periods up to 6 months caused increased white blood cell count and a reduction in hematocrit, hemoglobin, and red blood cells.

TNT exposure can cause a yellow discoloration of the skin, nails, and hair; a bluish discoloration of the mucosa; epigastric pain, tenderness, or spasm; enlarged liver; and changes in electrocardiogram and electroencephalogram. An amber to deep color to the urine is also characteristic of exposure.

Initial exposure to TNT in the atmosphere may result in mild irritation of the respiratory passages and skin, and gastrointestinal distress. Absorption of sufficient amounts of TNT through the skin or lungs can produce signs of cyanosis, aplastic anemia, cataract formation, menstrual disorders, neurological manifestations, and nephrotoxicity. Toxic hepatitis and aplastic anemia are reported to be the principal causes of death following acute exposure to TNT (USEPA, 1991a).

Based on animal studies, the USEPA classifies TNT as a Group C or possible human carcinogen.

Tetryl: Occupational exposures to tetryl is associated with digestive disorders, diffuse central nervous system effects, chronic hepatitis, leukocytosis, and anemia (Parmeggiani, 1983). Tetryl has also been reported to adversely affect the menstrual cycle of female munitions workers. Tetryl is a human skin irritant, producing erythema. An allergic dermatitis has also been demonstrated (USEPA, 1990).

Because of lack of human or animal data, the USEPA has classified tetryl as Group D, not classifiable as to human carcinogenicity.

2,4-DNT and 2,6-DNT: Occupational studies suggest that DNT is rapidly taken up by the respiratory, dermal, and possibly, gastrointestinal routes in exposed workers (Oak Ridge National Laboratory [ORNL], 1987). Occupational exposure to 2,4-DNT and/or technical grade DNT (containing approximately 76 percent 2,4-DNT, 19 percent 2,6-DNT, and small amounts of other isomers) is associated with cyanosis, anemia, dizziness, headache, muscular weakness, and nausea. A relationship may exist between DNT exposure and death from ischemic heart disease. One study suggests that workplace exposure to technical grade DNT is associated with reduced sperm count and altered sperm morphology (ORNL, 1987; USPHS, 1989).

Based on findings of carcinogenicity of DNT in rats and supporting mutagenicity data, the USEPA classified the mixed isomer DNT as Group B2, a probable human carcinogen.

1,3-DNB: After occupational exposure to DNB dust (concentration unknown), workers developed cyanosis, anemia, dizziness, and fatigue. Cyanosis and hemolytic jaundice were seen in another worker that was thought to have received dermal exposure to DNB.

The USEPA has classified 1,3-DNB as Group D, not classifiable as to human carcinogenicity.

Nitrobenzene: The most prominent systemic effect of nitrobenzene inhalation and ingestion in humans is methemoglobin formation. Nitrobenzene is reduced by intestinal micro-flora to nitrosobenzene, phenylhydroxylamine, and aniline. One or more of these metabolites may be involved in methemoglobin production. Neurological effects include headache, nausea, vertigo, confusion, unconsciousness, apnea, and coma (USPHS, 1990).

Because of the absence of adequate carcinogenicity data, the USEPA has classified nitrobenzene as Group D, not classifiable as to human carcinogenicity.

5.3.4 Risk Assessment Application to the Eagle River Flats

The only exposure pathway qualitatively evaluated at the ERF was the potential risk to hunters if they ingest contaminated birds. Hunting has been banned on the ERF since 1988, but it may be possible that sick birds fly to nearby hunting areas and are easy targets for hunters. The data indicate that the poisoned waterfowl are incapacitated or die within a relatively short period of time from ingestion of WP. This factor should serve to make them relatively unavailable to the hunting community, or would at least severely restrict the geographical area in which they would be found (Weeks, 1991). As described in Subsection 3.1, bioaccumulation of organic and inorganic chemicals other than WP has not been found to be significant at the ERF.

In June and April of 1991, one dead mallard duck was found in each of Clunie and Gwen lakes on Fort Richardson. Skin WP levels were 0.0051 and 0.034 µg/g. Fat tissues were collected only from the mallard from Gwen Lake. Fat WP concentration was 0.388 µg/g. These ducks were important because they represented the first documented cases of contaminated ducks leaving the ERF. The ducks traveled less than 2 miles, not far enough to reach the nearest public hunting area, more than 4 miles away (Bird, et al., 1991).

In September 1991, researchers collected more than 300 gizzards from ducks harvested by hunters in nearby Cook Inlet marshes. For most birds, a sample of skin or fat also was taken for analysis if WP was detected in the gizzards. There were no detectable levels of WP in the gizzards; therefore, other tissues that had been taken from the birds were not analyzed (Racine, et al., 1992a).

In 1991, the U.S. Army (Bird, et al., 1991) conducted a risk evaluation of hunters who may eat contaminated ducks. The assessment was based on the analytical results of tissue samples from seven wild teals observed to die on the ERF. This assessment allowed a worst-case estimate of human health risk, and it is considered unlikely that waterfowl that ingest a lethal dose of WP would travel the 4 miles to the nearest hunting area before succumbing to WP toxicity. Analyzed tissues consisted of breast and thigh muscle and skin, the most commonly consumed portions of the duck. Wild ducks from the ERF contain minimal amounts of fat.

The risk assessment assumed a thigh WP concentration equal to that of the skin. The breast muscle, probably more representative of thigh tissue, actually has a much lower WP concentration than does the skin. The breast muscle, thigh, and skin weights used for the assessment were obtained from a single teal, also collected from the ERF. Total WP intake from ingesting contaminated teal was estimated by multiplying the tissue weights by the tissue concentrations and summing these values.

Two exposure situations were considered in the U.S. Army assessment, chronic and acute. For chronic exposure, researchers used the USEPA chronic oral Rfd for ingestion of WP (2×10^{-5} mg/kg per day [USEPA, 1990]). The Rfd is defined as an estimate of a daily exposure level that is not likely to pose a significant risk or adverse effects. For a 70-kg adult, this represents a daily dose of approximately 1.4 µg of WP per day. On a yearly basis, this represents consumption of approximately 17.6 teals per year.

In terms of acute exposure, there is no value comparable to an Rfd with which to compare the WP levels. There are data from humans indicating that the lowest recorded lethal dose of WP as a result of accidental poisoning is approximately 1.4 mg/kg (USEPA, 1990). From the analytical results of the teals found dead or dying on the ERF, a human would have to consume 3,333 teals in a single sitting to obtain the lowest recorded lethal dose of 1.4 mg/kg (Bird, et al., 1991).

The Alaska State Epidemiologist described acute WP exposure risk this way: "While the risk to adverse health effects from potential exposure to elemental phosphorus in waterfowl cannot be said to be zero, based upon evidence from available scientific data and findings of the ongoing investigations, the risk can be said to be so low as to constitute no basis for public health concern" (Middaugh, 1991). He also states that the potential for any adverse health effect to a hunter or person consuming waterfowl obtained by hunters is extremely low because of the following key factors:

- Relatively small numbers of waterfowl are affected, compared to all waterfowl in the area.

- The data indicate that poisoned waterfowl are incapacitated or die in a relatively short time after ingestion of elemental phosphorus.
- Low levels of elemental phosphorus are found in the tissues of dead birds.
- Exposure calculations based on sample data indicate that a human lethal dose would require consumption of 3,333 teals.

5.4 Summary

Determination of endpoints of concern, objectives, and scope for the ecological and human health risk assessments, and the results from ongoing studies are needed before a meaningful summary can be prepared and data gaps identified. For the ecological risk assessment, data such as the following are needed to support the exposure assessment and ecological effects assessment:

- Additional characterization of the nature and extent of all potential chemicals of concern
- Sufficient toxicology data (for example, relationship of WP particle size to toxicity and chronic effects levels) for waterfowl and other wildlife
- Relationship of incidental ingestion versus selective ingestion of WP particles as a mortality factor
- Exposure and effects for invertebrates, fish, and mammals
- Measurement of "damage" to wetlands resulting from various remediation scenarios

Additional summary information is discussed in Section 7.

In addition to the studies noted in Section 7, a method must be established for measuring the effectiveness of remediation. Will the availability of WP particles to species such as fish, swans, and ducks, be measured, or will the dead birds just be counted before and after?

This information, if available from ongoing studies, should be incorporated into the Phase 2 risk assessment or be identified for additional studies, if necessary.

Section 6
Remedial Actions

6.1 Introduction

The investigative work performed to date at the ERF has led to the belief that WP in shallow pond sediments is primarily responsible for observed acute waterfowl mortality. Based on this information, a series of treatability studies has been initiated to explore possible remedial solutions to the environmental impacts identified at the ERF.

Seven ongoing treatability studies at the ERF implement three remedial strategies. Four studies employ an approach intended to reduce waterfowl exposure to WP by using physical barriers or methods that deter feeding in areas known to be contaminated. One study explores in situ reduction of WP in pond sediments, and one study is designed to evaluate the feasibility of pond sediment removal and treatment on the former EOD pad located adjacent to the wetland. The final study evaluates the conditions in the ERF where a no-action remedial alternative would be appropriate.

Multiple remedial strategies are currently being evaluated because the full nature and extent of WP contamination and the true impacts of waterfowl exposure to WP (both chronic and acute) are not fully understood. These initial treatability studies will develop a better understanding of the effectiveness and implementability of each method. As more data are collected concerning WP contamination and its affects on waterfowl, the treatability study results may be used to design and implement a full-scale remedial system.

Because the ERF is part of a facility that is to be designated an NPL site, criteria developed by the USEPA for evaluating remedial actions were considered in reviewing these treatability studies. Nine criteria were developed to encompass a wide range of public, financial, and technical concerns. They are used to evaluate the feasibility of remediation technologies that are under consideration for full-scale implementation. Because the remediation tasks being performed at the ERF in 1994 are treatability studies, it would be inappropriate to evaluate the present remediation efforts by strictly applying these criteria. However, it is useful to review the current treatability studies within the context of the criteria that will ultimately determine which remediation technologies are feasible at the ERF. The criteria are as follows:

1. Overall protection of human health and environment
2. Compliance with federal and state environmental standards
3. Long-term effectiveness and permanence
4. Reduction of toxicity, mobility, and\or volume through treatment
5. Short-term effectiveness
6. Implementability
7. Cost of implementation and operation
8. Acceptance of planned remedial action by state regulatory agencies
9. Acceptance of planned remedial action by the community

This section of the CER describes the individual treatability studies being conducted at the ERF and discusses issues that CH2M HILL has identified as important in evaluating remedial alternatives. The following are major components of this review process:

- Define the objectives of each study

- Briefly summarize the work completed in 1993 and what is planned for 1994

- Identify data needed to evaluate the technical feasibility of each remedial option that have neither been collected nor are part of upcoming planned data collection efforts

- Outline information (in addition to the technical data mentioned above) that will be needed to assess implementation of each remedial option

These four components of this review do not explicitly align with the criteria developed by the USEPA for evaluating remedial action. Rather, they are intended to aid the ERF investigation team in compiling the information needed to determine which remedial options (currently being considered) are most appropriate for the ERF. The last two components of the review process were performed using the nine previously identified criteria as guidance. Because the current projects are treatability studies (preliminary studies designed to screen potential technologies), the nine criteria were loosely applied.

The statement of objective and description of each individual study is a brief summary intended to provide context for understanding the recommended data collection and implementation steps. Detailed descriptions of past work performed on these treatability studies are presented in the interagency, expanded site-investigation report compiled by CRREL (Racine, et al., 1994). The work to be completed for each study during the 1994 field season is documented in a series of work plans submitted to the U.S. Army in April 1994.

6.2 Summary of Current Treatability Studies and Remedial Options

The treatability studies being conducted at the ERF involve a wide variety of activities and technical disciplines. Table 6-1 summarizes characteristics and potential effects of each study important in assessing overall feasibility. These characteristics and effects generally follow the nine criteria previously identified for evaluating treatability studies. The purpose of this table is to provide a convenient means of comparing individual studies as an initial step in screening remedial options.

Two of the treatability studies listed in Table 6-1, hazing and methyl anthranilate (MA), are not being considered as potential permanent remedial options. Both are either being performed or proposed as temporary measures to be applied during the interim period before a final remedial solution is implemented. Despite this difference in application, both hazing and MA were summarized in Table 6-1 in the same fashion as the other options so that all studies can be compared.

A review of Table 6-1 illustrates several aspects of the current remediation program at the ERF, including the following:

- The current program of treatability studies pursues one of four remedial approaches shown in the table. It is currently not possible to identify which of these approaches will ultimately be pursued, because the criteria for evaluating remedial success have not yet been identified.
- Most of the remedial options considered can be initially implemented in a short period of time, but several (such as pond draining) may require continuous operation for multiple years.

Table 6-1
Summary of Remedial Features

	Hazing	Methyl Anthranalate	BentoBalls	Geosynthetic Liners	Pond Draining	Pond Dredging	Natural Attenuation
Remedial Approach							
Reduce exposure frequency and duration by altering behavior	▲	▲					
Reduce exposure frequency and duration by physical barrier			▲	▲			
Reduce WP level by removal						▲	
Reduce WP level by dissipation					▲		▲
Implementation Time Frame (Duration from Present)							
Days or weeks	●	●	●	▲			
Months					▲		
Years					△	△	●
Duration of Effectivenes							
Less than one summer	●	●					
Single summer			▲	▲	▲		
Greater than or equal to 2 years			△	△	△	△	△
Incidental Effects of Remedy							
Limited site disruption	●	●	●	▲			●
Extensive site disruption					●	●	
Adjacent land disruption						●	
Constraints on future use			△	△			
Habitat value reduced			▲	△		△	
Habitat loss					△	△	
Locations Where Remedial Option Is Applicable							
Small isolated ponds		●	●	▲	▲		
Large water bodies (without current)		▲	▲	△	△	▲	
Throughout ERF	●						▲
Cost							
Capital cost	L	M	M	M – H	L	H	L
Operation and maintenance	H	M	L	L	L	H	L
Additional Issues							
Regulatory problems		●				▲	△
UXO exposure (human safety)	H	H	L	M	L	M	L

Legend: ● =Affirmative ▲ =To be evaluated in 1994 △ =Should be evaluated L=Low M=Moderate H=High

Assumptions:
1. Any characteristic requiring additional evaluation that was not specifically discussed in a 1994 proposal was labeled "To be Evaluated."
2. Implementation time frame includes the entire period required to install and maintain the remedial system.
3. Costs were estimated assuming that each option was the only method used over the entire ERF for a period of approximately 20 years. This same procedure was applied to hazing and methyl anthranalate for the purposes of comparison, although they are only considered temporary measures. In general, estimated costs below $10,000 to $20,000 were considered low, estimated costs from $20,000 to $100,000 were considered moderate, and estimated costs above $100,000 were considered high. These estimates are considered to be order of magnitude in accuracy.

- The duration of effectiveness is not well understood for most options. This issue is not directly addressed by the proposed activities in all studies, probably, at least in part, because of the annual cycle on which these studies operate.

- Most remedial options are being evaluated for a particular type of setting within the ERF (such as small isolated ponds), and the full range of applicable locations is not well understood for any option.

- Potential regulatory problems include whether MA will be classified as a pesticide; the 404 permit required for dredging; the impact of dredge spoils on closure of the former EOD pad under RCRA; and the regulatory implications of leaving WP in place as part of a no-action remedial alternative.

In creating the table, several assumptions that directly affect the results were made. The following are the most significant:

- Any characteristic or effect not specifically discussed in a past report or current proposal was labeled "to be evaluated," regardless of how likely it is to be evaluated as followup to current work.

- Costs were assessed as if each remedial method was the only option implemented for a 20-year period.

- The implementation time frame includes the period of time over which the implementation activity is performed (pond draining requires years to implement because the pond must be drained after each flooding tide).

6.3 Review of Individual Studies

6.3.1 Hazing

Objective of Study

The hazing study will reduce waterfowl deaths by frightening birds away from four hot spots identified within the ERF.

Description of Study

A team of up to six specialists will be deployed during the spring (April 18 through May 27) and fall (August 22 through October 21) to frighten birds away from four hot spots within the ERF. At least one specialist will be present on each site during varying daylight hours, providing 7-day-a-week coverage for each of the two periods. The team will employ propane exploders, pyrotechnics, scarecrows, flagging, balloons, and other visual, acoustic and behavioral devices to frighten the birds away from the designated hot spots.

Data Collection

Data will be collected by personnel conducting the hazing as well as a number of other investigators who may be able to monitor the effects and effectiveness of the hazing in reducing bird mortality (primarily waterfowl species). The USDA DWRC and the New England Institute of Landscape Ecology (NEILE) are among those who will be collecting data concerning waterfowl distribution, movement, activities, and behavior during their own studies. The results they will record should reflect changes resulting from the hazing (as observed during 1993).

Implementation

This method is not being considered as a potential permanent remedial action for the ERF. Therefore, the actions recommended for implementation of other remedial options may not be appropriate for this method. Once a permanent remedial strategy has been developed for the ERF and a schedule for implementation has been established, it may be useful to evaluate whether hazing should be continued for the duration of the interim period or another temporary method would be more cost effective.

6.3.2 BentoBalls™

Objective of Study

The BentoBall study will evaluate the effectiveness of BentoBalls as a physical barrier to feeding waterfowl.

Description of Study

Laboratory and field screening studies were performed in 1993 that were designed to assess whether BentoBalls would seal the pond bottom, and whether the layer of BentoBalls would act as a physical barrier between feeding waterfowl and contaminated pond sediments. The results of this work suggest that BentoBalls do form a seal that, if sufficiently thick, does prevent feeding waterfowl from coming into contact with contaminated sediments.

The 1994 study will include inspection of the BentoBalls installed in 1993 to assess how the layer survived the winter and subsequent breakup periods. Sediment and vegetation on top of the layer will be sampled and cataloged. A field test similar in design, but on a slightly larger scale and with more extensive observation of waterfowl behavior, will be implemented. The results of this test will be used to evaluate the effectiveness of this remedial method on a scale that more closely approximates full-scale conditions.

Data Collection

Based on a review of the results for 1992-93 and of the proposed work for 1994, it appears that many of the basic technical questions concerning use of BentoBalls as a physical barrier in ERF ponds are being addressed. Several issues have been identified, however, that either have yet to be addressed or are not discussed. These issues include the following:

- What is the impact of large animals, such as moose, on the effectiveness of the barrier established using BentoBalls? Would the presence of such a barrier present a hazard to these animals?
- Would changing calcium-to-sodium ratios which occur as a function of changing salinity that results from flooding tides affect the sealant properties of the BentoBall layer?

It is known that clay minerals, in particular bentonite, are active participants in ion exchange reactions involving dissolved ions such as calcium and sodium. Water quality records for some ponds indicate significant changes in salinity as a result of flooding tides. It is expected that increased salinity would result in increases in sodium content, which would alter any previously established equilibrium between freshwater and the BentoBalls. Assuming that the BentoBalls display a clay-like texture when hydrated, it is not likely that short-term changes in water quality during a high-tide event would greatly alter the BentoBall seal, because the ion exchange reaction would be diffusion-limited (hence, very slow to penetrate the entire layer). It would be important to understand whether hydrating BentoBalls in sodium-rich water affects their sealing properties, however, and if so, what the calcium-to-sodium ratio is of water in sediments beneath the pond where this method is applied. Interactions between sediment pore fluids and the BentoBalls would be important because the residence time of this water is sufficiently long to affect ion exchange equilibrium and possibly to convert the calcium bentonite to sodium bentonite.

Implementation

Assuming that existing efforts demonstrate the effectiveness of this method, several issues must be addressed in assessing whether use of BentoBalls is an appropriate remedial option for the ERF. These issues include the following:

- What is the cost of installing BentoBalls in the ERF, and what is the cost of maintaining the barrier?

- How long will the barrier need to be kept in place? Will additional applications of BentoBalls be required and, if so, at what frequency?

- Are there locations with WP contamination in the ERF where BentoBalls should not be used? What distinguishes these sites from those where BentoBalls could be applied?

Because the current effort must necessarily focus on the technical feasibility of BentoBalls as a remedial option, it is recommended that these implementation issues be addressed in future efforts to provide Remedial Program Managers (RPMs) with a more complete understanding of BentoBalls as a remedial option.

6.3.3 Methyl Anthranilate

Objective of Study

The MA study will evaluate the degree to which MA beads reduce feeding activity of wild waterfowl and cause them to move away from treated areas.

Description of Study

Laboratory and field studies completed in 1992 and 1993 indicate that waterfowl feeding activity is reduced in areas treated with MA. Much of the effort in the past studies involved optimizing the design of the pellets used to treat ponds. The material used to deliver the MA must be capable of resting in the pond without dissolving prematurely, and must burst under normal bill pressures found during filter feeding. Although some progress has been made, the effective life of a single treatment remains approximately 7 to 10 days. Work planned for 1994 will focus on ways to lengthen this duration of effectiveness, thus requiring only a single treatment for each of the spring and fall migration seasons. Work planned in 1994 will also extend the area treated and will encompass more intensive observation of waterfowl behavior.

Data Collection

Based on a review of the results for 1992-93 and review of the proposed work for 1994, MA will deter feeding activity for short periods of time. Therefore, it appears that the primary technical issue to be addressed is how to lengthen the duration of MA effectiveness. To that end, would it be possible to increase the period of effectiveness by using a delivery system that sits on the pond bottom and releases MA into the water column on a continuous basis? Would such an approach be an effective deterrent, or must the duck swallow a pellet of MA for the chemical to deter feeding? Evaluation of such an option would require a summary of the conditions under which MA is effective in altering feeding activity, which would be useful for the RPMs in evaluating this approach as a remedial option for the ERF.

Implementation

Application of MA in the ERF is intended only as a temporary measure to be used during the interim period before implementing a final remediation program. Therefore, duration of effectiveness is less important for this method than other remedial options. The cost of implementing this method and identifying areas where it may be applied should also be considered.

6.3.4 Geosynthetic Liners

Objective of Study

The main objective of this screening study is to determine which of the liner systems warrant further study at ERF. The criteria used to evaluate liner systems will be prevention of sediment from being resuspended and prevention of sediment within a previously identified size range from being resuspended. A secondary objective is to correlate the presence of WP with either the presence of particles in the prespecified size range or to sediment that is resuspended above the liner.

Description of Study

The geosynthetic liner study is ongoing, and is being conducted in a phased manner. Work performed during each field season builds on the results of the previous year. The initial phase was a screening of four types of geotextile liners at one location. The liners were installed in May 1992, and their performance was evaluated using data collected in July 1993. Each geotextile was anchored to the pond bottom by inserting rebar into a cut on the edge of the sample square installed. The weight of the rebar was to provide the force needed to hold the geotextile in place on the pond bottom. Observations of these liners made in June 1993 indicated that most did not remain in place and, therefore, could not be evaluated further.

The activities planned for 1994 include installation of four barrier liner systems to be evaluated by analyzing sediment that settles onto the top of the liner following attempts to mechanically resuspend the sediment. The mechanical resuspension of sediments will be performed before and after installation of the liners so that the effects of the liners may be evaluated directly. Resuspended sediment samples will be analyzed for grain size distribution and WP (using a screening method of analysis). The geotextile component of all liner systems will be cut to allow gas to migrate upward from pond sediments without disturbing the liner placement.

Data Collection

Based on a review of the results for 1992-93 and of the proposed work for 1994, it appears that a number of issues concerning the technical feasibility of using geosynthetic liners in the ERF have been identified and are being evaluated. Several issues have been identified, however, that either have yet to be addressed or are not discussed. These issues include the following:

- How would the liner systems be anchored if installed on a long-term basis?
- What is the effective life of a liner system, and how would it survive winter and spring conditions?
- How long will it take for vegetation to be established on top of the liner system? Will the vegetation be similar to that covered by the liner, or will the re-established vegetation be altered by the presence of the liner?

Implementation

In addition to the data collection issues identified above, three types of information have been identified as being important in evaluating full-scale implementation of this remedial method. The three issues are cost, duration of effectiveness, and areas of applicability. Although the current study focuses on small isolated ponds, it will be necessary to identify the areas within the ERF where geosynthetic liner systems can be applied and whether liners could be effective in other types of settings within the ERF. The length of time a liner system could be expected to last and the maintenance required during the operational life should also be included in the evaluation process. Finally, the initial cost of installation should be augmented by the estimated cost to maintain the liner system as an effective physical barrier so that the full cost of implementing this remedial option can be evaluated.

6.3.5 Pond Draining

Objective of Study

This study will determine whether it is technically feasible to establish soil moisture conditions that are less than saturation by draining one or more ponds.

Description of Study

A study of the shallow outer edge of the pond west of Tower C was completed in 1993. Instruments were installed in the soil in this area to monitor the effects on soil moisture of receding water caused by unusually dry conditions. The results indicated that soil moisture levels could be reduced below saturation where standing water was removed.

A study intended to evaluate the feasibility of establishing dry soil conditions by draining the Bread Truck Pond is planned for 1994. A field survey will be performed to verify preliminary observations that the Bread Truck Pond is isolated from other surface water bodies. A monitoring program will then be initiated to establish baseline water level, pond sediment moisture content, and pond sediment temperature. Shallow piezometers will be installed to monitor subsurface saturated flow, and periodic sediment samples will be collected and analyzed for WP. This sampling and chemical analysis will be coordinated with a study of natural attenuation of WP in pond sediments being conducted in Area C. The pond will be drained and monitored throughout the field season to determine whether soil moisture levels below saturation can be achieved and maintained. The pond will be pumped out following each flooding tidal event.

Data Collection

Given the past work performed on reduction of WP created by dry soil conditions, it can be inferred that WP levels could be reduced if pond draining can be shown to cause soil moisture levels to fall below saturation. Several issues should be addressed, however, before this method could be evaluated as a possible full-scale remedial action appropriate for the ERF. These issues include the following:

- Estimating the rate at which the soil drys and how both drying and subsequent wetting fronts migrate downward when surface conditions change
- Estimating the rate at which WP is removed from the soil when soil moisture levels fall below saturation
- Correlating the rate of WP removal with the rate of soil drying (Does monthly rewetting from flooding tides prevent WP attenuation?)
- Estimating the maximum depth at which this method could be effective in reducing WP levels in pond sediments

It is not possible to determine whether the planned work will collect data needed to evaluate the rate of WP reduction resulting from soil drying. It might be appropriate to coordinate this study with the natural attenuation study by implanting one of the WP particles to be used as part of the natural attenuation study in Bread Truck Pond sediments.

A series of small piezometers are to be installed in Bread Truck Pond to monitor water movement through the subsurface. Although subsurface water movement is not thought to be a viable WP transport pathway (primarily because of low WP solubility in water), upwelling of water could prevent sediment drying. Monitoring of soil moisture and subsurface water levels is intended not only to verify the effectiveness of drying, but also to provide data needed to evaluate whether upward migration of water will occur and affect the potential effectiveness of this effort.

Implementation

This method of in situ WP reduction in pond sediments is being proposed only for smaller ponds that are relatively isolated with no visible surface water inlets or outlets. An inventory of other ponds with similar conditions is needed to assess how this method could be used to remediate the ERF. Should this method be proposed for a larger, less isolated pond, the impacts of draining on the hydrology, sedimentation, and erosion processes active in the ERF would require more extensive evaluation than is currently planned.

The cost of implementing this option must be estimated to assess its applicability to the ERF. The cost of initial draining and whatever monitoring is considered necessary should be estimated, along with the cost to maintain the drainage system. The rate of WP removal must be known with sufficient confidence to estimate the duration of pond draining.

6.3.6 Pond Dredging

Objective of Study

The objective of this study is to confirm the feasibility of operating a small dredge in the ERF, removing dredge spoils to a settling and treatment area, and reducing WP in the spoils to an acceptable level.

Description of Study

The technical feasibility of dredging pond sediments and air drying the spoils to reduce WP levels will be evaluated. A dredge will be operated in a remote fashion to remove the upper 2 to 3 feet of sediment from approximately 1 hectare of Pond C in the ERF. The spoils will be pumped to a holding facility to be constructed on the former EOD pad. The solids will be separated from the water in the holding area and the water will be routed back to the wetlands. Periodic sampling of the spoils entering the holding area and water leaving the holding area will be performed to monitor WP levels.

Dredged solids within the holding area will be sampled periodically to assess the affects of subaerial exposure on WP levels. White phosphorus particles of known dimensions will be placed in the dewatered spoils at various depth intervals, and their dimensions will be monitored over time to evaluate the rate of natural attenuation in unsaturated soils. The technical feasibility of dredging is expected to be evaluated based on the results of work performed in 1994; however, data collection for evaluating natural attenuation of WP in dried soil will not be complete until 1995.

Data Collection

Review of the 1994 proposed work reveals that a number of issues are not addressed in the feasibility study. These issues should be addressed to evaluate whether dredging is appropriate for the ERF. The following issues are not addressed in the 1994 work plan:

- It is expected that terms and conditions of a nationwide permit granted by the COE (404 permit) will be considered in performing the dredging at the ERF. These terms and conditions should be accounted for when planning the fieldwork for 1994.

- Although it is clear that sampling the sediment in the test area following dredging may not be permitted by the U.S. Army for safety reasons, such information would be invaluable in assessing the effect of dredging. Possibly, it would be technically feasible to use the dredge as a remote sampling platform after dredging has been completed.

- No plans are discussed for evaluating the effects of dredging on the pond ecosystem and physical dynamics. Although a very broad issue, the impact of dredging on both should be considered in assessing whether this remedial method is appropriate for the ERF.

- The field screening method of WP analysis proposed for evaluating contaminant distribution in dredge spoils is probably not sufficient to support final disposal of the spoils. The results of natural attenuation planned for the spoils will address the issue of WP persistence in dried soil. Studies are ongoing in 1994 to demonstrate the effectiveness of natural attenuation of WP in site soils. It is expected that some form of verification sampling will be required to support any decision made concerning final disposal of the dredge spoils. Although verification sampling would probably not occur until 1995 or later, it should be included in feasibility study planning process.

- The effects of handling dredge spoils on the former EOD pad should be included in the monitoring program planned for this study. The spoils-holding area design is not described. Therefore, it is not known whether the holding area will be lined to prevent downward migration of water from the spoils. If the holding are is not lined, the potential impact of hydraulic loading on mobilization of contaminants in the former EOD pad should be assessed.

- Although the subject of UXO has been discussed at length in meetings, contingency plans for handling UXO disturbed or removed by dredging should be discussed in the dredging work plan.

Implementation

In evaluating whether dredging should be implemented at the ERF, three additional data collection issues should be addressed: cost, overall effectiveness, and identification of dredging locations.

Aside from the area to be dredged as part of the feasibility study, the areas within the ERF where dredging could be applied should be identified. As part of this process, the characteristics used to define where dredging is appropriate should be listed and discussed.

It is expected that dredging will remove contaminated sediments from the ERF, thus removing the contamination from the location dredged. The absence of information concerning the impacts of dredging on the physical dynamics of the pond make it impossible to assess the duration of effectiveness of this method. Of particular importance is the potential impact of dredging on sedimentation and erosion processes. The impact of dredging on these processes should be considered in evaluating dredging effectiveness.

The initial cost of dredging is expected to be significantly greater than any other remediation alternative currently under study. It is also expected that operation and maintenance costs will be significant. Therefore, it is vital that information be gathered as part of the treatability study that may be used to compile a preliminary cost estimate for full-scale dredging. Some other issues discussed previously (such as the number and characteristics of locations that could be dredged) will need to be assessed before the cost of full-scale dredging can be estimated.

6.3.7 Natural Attenuation

Objective of Study

This study will assess whether WP is non-persistent in some areas of the ERF.

Description of Study

The initial phase of the natural attenuation study will be performed in the laboratory, followed by field data collection and subsequent analysis. Sediments collected from the ERF will be seeded with WP of known size and mass, and the effect of soil temperature and soil moisture on WP persistence will be evaluated under controlled conditions. A similar study will be performed under field conditions at the ERF in the summer of 1994. Particles of WP will be implanted in sediment along a transect in Area C that gradually increases in surface elevation from one end to the other. This increase in elevation results in wetter conditions on one end of the transect and dryer conditions on the other. The particles will be buried for approximately 3-1/2 months. Then they will be exhumed, and the size and mass of WP will be measured. In addition, an area known to be highly contaminated with WP and known to have been subaerialy exposed during the summer of 1993 will be sampled. The analytical results of these samples will be compared to those for samples collected in 1993 to estimate whether WP has diminished.

Data Collection

Review of the proposal for 1994 indicates that data collected as part of this study will enhance the present level of understanding of natural attenuation of WP in ERF sediments. This information will form the basis for estimating the persistence of WP in sediment and determining whether a no-action remedial alternative would be appropriate for the ERF. It is assumed that the results of this study will be combined with the estimated nature and extent of contamination to assess where WP contamination is likely to persist and where it would not. Therefore, natural attenuation in sediment is most effectively evaluated if the full range of contaminated sediment types and conditions found in the ERF are included in this study. Assuming that the two parameters that control WP persistence in sediment are temperature and moisture content, this study represents an appropriate level of effort for an initial evaluation of WP attenuation in the ERF.

Implementation

Three issues to be considered in evaluating potential implementation of any remedial alternative are cost, duration of effectiveness, and locations where the option could be applied. Given that this study would provide the technical basis for proposing a no-action remedial alternative for the ERF, there is no need to estimate the cost of implementation. The duration of effectiveness is essentially the estimated length of time required for natural attenuation to remove all known WP, which is an estimate that should be made using the data collected in the field portion of the study. It would also be important to estimate the reliability of this estimate to aid the RPMs in evaluating the no-action remedial alternative. The third issue, appropriate locations, is the most important of the three. Identification of the areas where natural attenuation is feasible will help to focus attention on remediation alternatives that are applicable to locations where natural attenuation will occur.

Section 7
Data Quality Objectives

7.1 Introduction

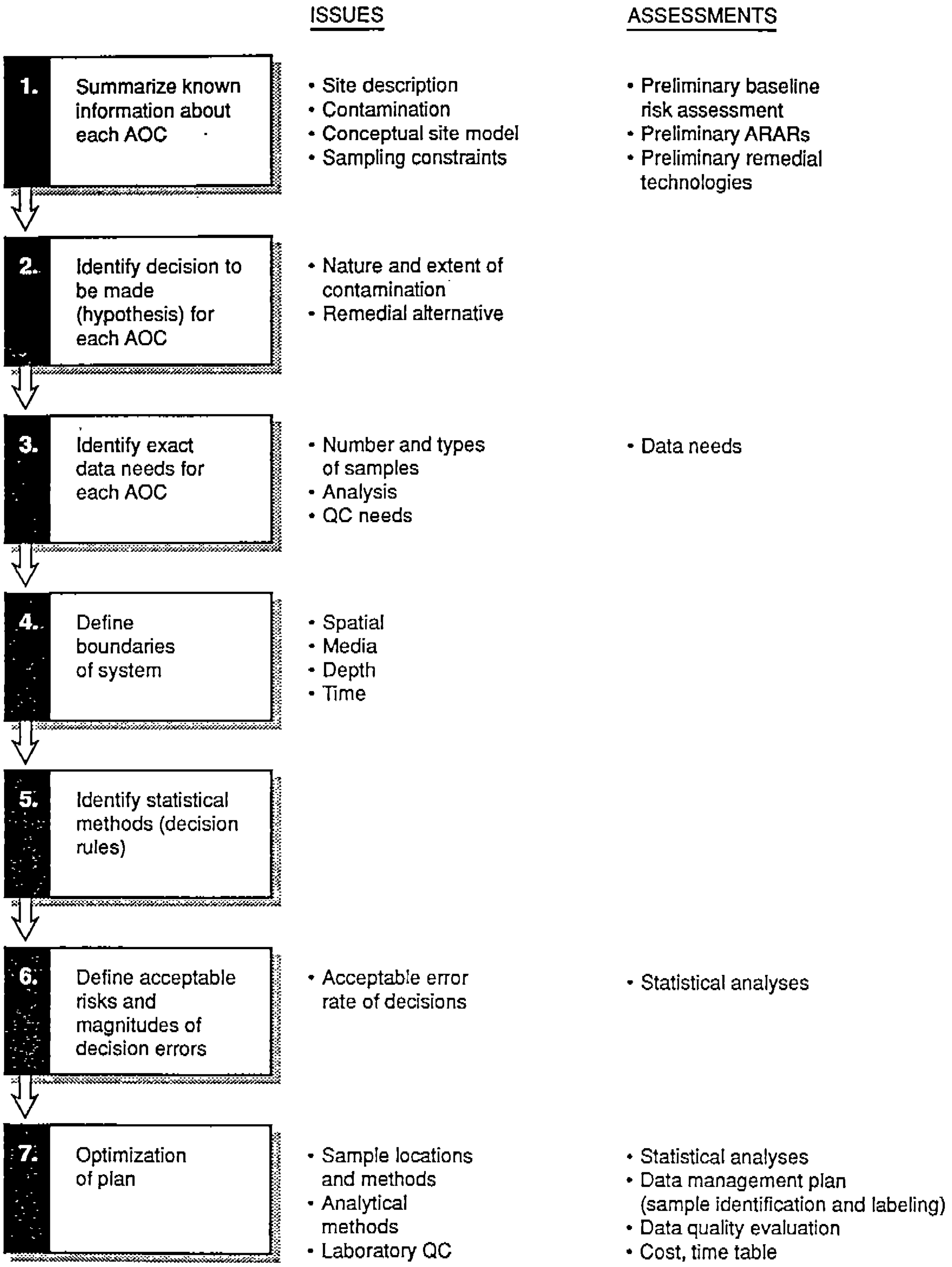
The data quality objectives are used as a tool to facilitate planning for data collection (USEPA, 1993). They describe the objectives of an investigation, the decisions to be made, the data required to make those decisions, the acceptable error rates for the decisions, and the formal rules that will be used to make the decisions. The DQO process requires a careful review of existing data. It is applicable at any time when additional data need to be collected.

Several preliminary activities of data review lead to the DQO process. Existing information should be used to identify and separate areas of contamination (AOCs). Areas of similar processes of potential contamination, similar contaminant transport and exposure, and similar potential remedial decisions can be used as a basis for the AOCs. Areas of contamination are likely the smallest decision unit for investigation and remedial action decisions. Other early activities in the DQO process include the preparation of several preliminary assessments: human health and environmental risk assessments, regulatory requirements, and potential removal or remedial alternatives. The DQO process consists of seven steps, as summarized in Figure 7-1.

The implications of uncertainty and the management approach to dealing with uncertainty are discussed below. The remainder of this section begins the DQO process for the ERF.

7.2 Management of Uncertainty

The environment at the ERF is highly heterogeneous, neither uniform nor predictable. White phosphorus exists as particles, with substantial variation in concentration within the space of a few inches. The technologies for obtaining information there are too expensive (or dangerous for direct sampling in an area of UXO) to provide detailed coverage of large areas. The height of the tide varies from a combination of the tidal cycle as well as recent snowmelt or rainstorms in the ERF watershed. The walls of gullies may move hardly at all or many meters in the space of a season. The number and species of waterfowl at the ERF



	ISSUES	ASSESSMENTS
1. Summarize known information about each AOC	• Site description • Contamination • Conceptual site model • Sampling constraints	• Preliminary baseline risk assessment • Preliminary ARARs • Preliminary remedial technologies
2. Identify decision to be made (hypothesis) for each AOC	• Nature and extent of contamination • Remedial alternative	
3. Identify exact data needs for each AOC	• Number and types of samples • Analysis • QC needs	• Data needs
4. Define boundaries of system	• Spatial • Media • Depth • Time	
5. Identify statistical methods (decision rules)		
6. Define acceptable risks and magnitudes of decision errors	• Acceptable error rate of decisions	• Statistical analyses
7. Optimization of plan	• Sample locations and methods • Analytical methods • Laboratory QC	• Statistical analyses • Data management plan (sample identification and labeling) • Data quality evaluation • Cost, time table

FIGURE 7-1
DATA QUALITY OBJECTIVES PROCESS

depend on the relative desirability of the flats compared to other marshes in the Cook Inlet region. It will not be possible to develop models that can predict effects with high accuracy over space and time. Uncertainty will still be present even after extensive site investigations.

Historically, engineers have faced uncertainty when designing projects in an unpredictable or complex natural environment. For decades, geotechnical engineers have used the observational method for these situations (Peck, 1969; D'Appolonia, 1990). The key elements of the observational method, as applied to site removal or remedial actions, include the following:

- Collect existing information on general site conditions and establish remedial goals and general responses.
- Gather information at the site and refine knowledge of general site conditions and the nature and extent of contaminants.
- Establish the most probable site conditions and reasonable deviations (in other words, other conditions that are consistent with the data).
- Design the action based on the most *probable* conditions and reasonable deviations. (Note the potential for cost reductions compared to a design based on worst-case conditions.)
- To detect deviations, select quantities to observe during the action.
- For each reasonable deviation, prepare a contingency plan for a course of action or design modification.
- Implement the action. Measure the selected parameters during the action, and carry out the contingency plans if deviations are found (Brown, et al., 1990).

This management approach allows the project to move ahead even in the presence of uncertainty, with contingency plans to modify the actions if future discoveries require modifications. Experience has found this to be the most cost-effective approach, and it enhances protection of human health and the environment. Other benefits of the observational method include the following:

- Emphasis on action, rather than expensive studies
- Removal or remediation can be begun more quickly, with safety provisions built in
- Decisionmakers are able to prepare for events and develop contingency plans in advance, rather than merely responding to unforeseen events
- Through monitoring of actual conditions discovered during the action, the implementation of the remedial action becomes more reliable, thus providing better protection of public health and the environment.

The DQO process fits into this management approach by providing the specific linkage between decisions and data needs. The linkage begins with the general decision about whether data are *sufficient* to make a removal or remedial action decision. Decision support for remedial actions is one reason to collect data, and the observational method provides a definition of data sufficiency, as shown in Figure 7-2. Sufficient information exists to proceed beyond the study phase (to a feasibility study, decision document, design, removal or remediation) when the remaining uncertainties can be approached as deviations, which can be monitored for and for which contingency plans can be established. If the uncertainties cannot be considered deviations, more data are needed. CERCLA encourages the use of both removal and interim remedial actions as means of efficient cleanup, and the observational method can support those actions, too.

7.3 Application of DQOs to Eagle River Flats

7.3.1 Step 1: Summary of Existing Information

Existing information about the ERF is summarized in Sections 1 through 4. A preliminary risk assessment and remedial technologies are discussed in Sections 5 and 6, respectively.

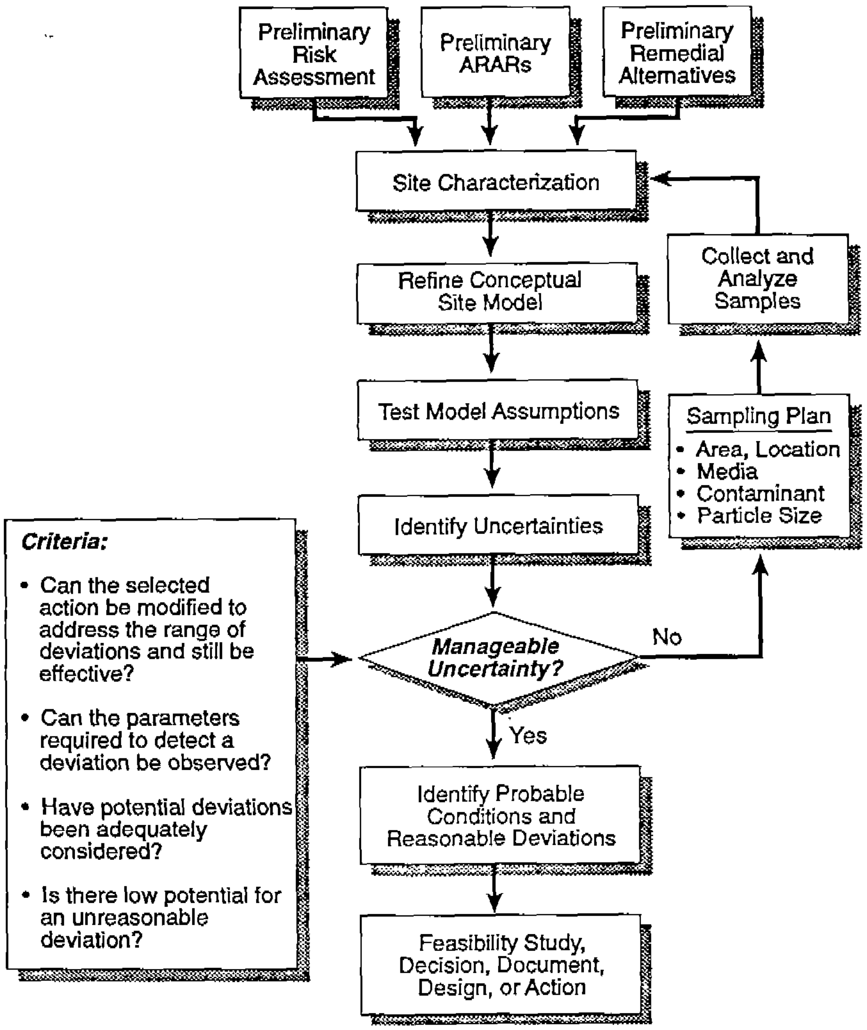


FIGURE 7-2
DETERMINATION OF DATA SUFFICIENCY

Table 7-1 highlights some of the uncertainties that remain in determining the site-specific risks and appropriate remedial alternatives. However, not all uncertainties need to be resolved before making remedial or removal action decisions. Data needs are a function of the decisions, their alternatives, and the required level of confidence for the correct decision. The DQO process correctly places addressing the decisions before addressing data needs.

Table 7-1
Example Uncertainties for Remedial Decisions at the Eagle River Flats

Component	Current Information	Key Uncertainties
Sources	Munitions are the principal source.	Current crater distribution is a surrogate for the level of past WP shells.
Chemical and biological characterization	White phosphorus concentrations in sediment are generally known in major waterfowl areas.	White phosphorus concentrations or particle distribution in other areas of the ERF. Vertical distribution of WP. Also groundwater and air.
Fate and transport	General characteristics of WP fate and transport.	Site-specific characteristics of WP, and the environment (for example, sediment deposition and resuspension rates) leading to estimates of exposure concentrations over space and time.
Exposure	Dabbling ducks are most sensitive populations.	Exposure activities, frequency and duration for environmental species and humans. Future land use.
Toxicity	White phosphorus is acutely toxic to waterfowl.	White phosphorus ecological dose-response relationship, particularly for chronic effects. Particle-size effects.
Risk characterization	White phosphorus is causing the death of substantial number of waterfowl. Humans are apparently not at significant risk (with current land-use restrictions).	Risks from natural attenuation.
Remedial technologies	Unexploded ordnance is widespread. Data from 1993 suggest applicability of dredging, pond draining, and geosynthetic membranes.	Critical parameters that control technologies, range of values at the ERF, and how the technologies perform over the range.

7.3.2 Step 2: Identify Decisions

Three general questions that must be addressed for site remediation are listed below:

1. *Is there a significant risk to human health or the environment?* The data need to cover the broad topics of exposure and toxicity for the chemicals of potential concern. Exposure issues include exposed populations and their activities that lead to exposure, as well as the nature and extent of the contamination (current and future). Toxicity issues include the nature of potential effects, the frequency and duration of exposure, the exposure media, and a dose-response function relating the exposure and effects. The components of Table 7-1 are organized for the risk assessment data needs. This question also requires addressing the degree of certainty required to make the judgment about whether there is a significant risk.

2. *What level of remediation is required?* This is the "how clean is clean enough?" question.

3. *What remedial technology should be employed?* A preliminary set of potential remedial technologies should be chosen in order to focus data collection activities. Data needs are then organized to provide sufficient information to distinguish preferences for different technologies by addressing the criteria to be used for choosing a remedial technology. Nine criteria are used in the CERCLA process: overall protection of human health and the environment; compliance with ARARs; long-term effectiveness and permanence; reduction of toxicity, mobility, and volume through treatment; short-term effectiveness; implementability; cost; state acceptance; and community acceptance.

These questions lead to three key decisions:

- Areas of concern and problem statement, including the chemicals of concern, level of risks, and exceedances of regulatory criteria

- Remedial objectives (protect waterfowl, or remediate flats, as examples), including criteria (such as chemicals, concentrations, particle density)

- Remedial alternatives, including technologies

Depending on resource constraints, additional decisions may need to be made on priorities for remediation. The decisions can change over time, or even be phased, but a set of them will likely lead to different data needs. These decisions and their likely alternatives are discussed more fully below.

7.3.2.1 Area of Concern and Problem Statement Decisions

The site investigations to date have largely focused on identifying the cause and locations of the acute mortality of the waterfowl, leading investigators to focus on major waterfowl areas and on WP. As can be seen in Figure 1-2, the major waterfowl areas cover only a fraction of the total ERF area. Shallow ponds, where dabbling ducks feed, also constitute only a fraction of the total ERF area.

A decision needs to be made about whether these data form a sufficient definition of the areas of concern. The decisions on areas of concern could be part of a phased approach to site remediation. An early phase could focus remediation with existing data while additional phases collect data on other areas and chemicals to determine whether further remediation would be required.

White phosphorus is only one of several chemicals discussed in Section 2 that have been introduced into the ERF through munitions detonation and disposal. The available data for chemicals other than WP suggest that WP is the only chemical of concern, and thus is the focus of the remainder of this chapter. Remediation that focuses on WP may still leave other chemicals that have effects.

The particulate nature of the WP contamination requires careful thinking about appropriate means of measuring contamination and developing remedial action goals. Concentrations are highly dependent on whether particles happen to be included in the small sample actually used for analysis. For remediation (and consideration of the risks to dabbling ducks), it may be more important to measure specific particles than concentration.

Key information for identifying the problem areas and chemicals include the preliminary risk assessment, ARARs assessment, and identification of remedial alternatives. The result is a problem statement of the geographic areas, receptors (human and environmental), exposure routes, ARARs, and chemicals of concern that require remediation. In general, a larger statement of the problem (such as larger areas and more chemicals of concern) will lead to a larger data collection effort.

7.3.2.2 Remedial Objectives Decision

Preliminary remedial goals (PRGs) should be established to aid in evaluating the problem areas and the effectiveness of the remedial alternatives. Broadly, the PRGs are designed to protect the receptors through a reduction in exposure to result in a specified risk level. This design will include assumptions concerning future land use and the resulting exposure conditions of the receptors. For the ERF, the exposure reduction could occur by reducing the sediment and water concentrations (oxidation, for example), or blocking exposure (capping, for example). Assuming no further introduction of contaminants, concentration reduction may be able to reduce exposure so that land use restrictions are not required. Blocking exposure will likely require long-term maintenance and land use restrictions. Preferences for these broad alternatives (and more specific alternatives) will be driven by the choice of PRGs, as will additional data collection efforts. Therefore, the PRGs should be carefully considered.

7.3.2.3 Remedial Alternatives Decision

Remediation alternatives for the ERF are considered within the context of five scenarios:

1. No action
2. Reducing concentrations at a local hot spot
3. Reducing exposure at a local hot spot
4. Reducing concentrations throughout the ERF
5. Reducing exposure throughout the ERF

Actions discussed in Chapter 6 are applicable to one or more of these scenarios. The decisions outlined above will influence additional data needs for reaching a remedial decision. Figure 7-3 shows the relationships between decisions and data needs.

7.3.3 Step 3: Identify Data Needs

Data on the ERF have been collected by many researchers during the past decade, with the bulk of the data collected in the past 4 years. The data have addressed many issues that are important to determining the environmental and human health risk associated with the ERF and the potential effects of remedial actions. Three tables have been created to describe the status of our current information to support answering the key questions identified in Section 7.3.2. Each table identifies significant topics associated with each question, what is currently known about that topic and the basis for that information, what can be anticipated from the written 1994 study proposals, and whether a residual data gap might still be present after the 1994 studies on the issue as it relates to the question. The data gaps are the anticipated important data needs for decisionmaking. Table 7-2 summarizes the data to answer the question on whether there is a significant risk at the ERF. Table 7-3 addresses the specific question of level of remediation, and Table 7-4 examines the knowledge base concerning appropriate remedial technologies. (Given their length, these tables immediately follow the text of this section.)

The length of Table 7-2 suggests the magnitude of the current information available on ERF to address the question of risk. A substantial set of activities is proposed for 1994, but the table also identifies some potentially significant data gaps that may remain after the completion of tasks discussed in the written proposals.

- **White phosphorus particle size distributions.** The focus in analytical sampling has been on concentration measurements. White phosphorus, however, largely exists as particles at the ERF. Because it appears that the dabbling ducks ingest it as part of the sediment, particle size distributions may be a more relevant measure of toxicity and remediation. To support this assessment, size distribution data could be accumulated from a few areas (to determine spatial differences, if any) with additional concentration data using gridded sampling to provide a comparison of the two measurement approaches.

- **Sampling in ponds that have not yet been sampled for WP.** White phosphorus data are very heterogeneous at the ERF, and many shallow ponds have not yet received sampling. This data gap could be filled by combining the data on bird habitat and activities to be obtained in 1994 with data on crater cover and the location of other shallow ponds to identify focus areas for 1995.

- **Importance of the ERF to waterfowl migration.** Although data have been accumulated describing the waterfowl mortality in the ERF, these data have not been placed in the context of the total bird migration through the area. Waterfowl usage of other marshes in the area would provide these data.

- **Fish studies.** One test would compare the number and species of fish in the ponds and gullies with those found in other similar salt marshes. Bioassays would also compare the toxicity of ERF sediment on appropriate test species. These tests parallel those performed for the macroinvertebrates. If significant differences are discovered in the comparison to other marshes, further studies would address the fish in Eagle River.

- **Changes to the ERF habitat as a result of naturally occurring physical processes.** Collection of data on erosion patterns and cycles, for example, may assist in predictions of fate and transport of WP over time.

Other data gaps may be identified as CRREL completes its statistical analysis of the ERF database during 1994.

The principal data gaps, identified in Table 7-3 are the remediation goals. The identification of these goals will bring greater focus to remaining activities at the ERF. Broad choices for the goals include effects measurements (such as reduction in bird mortality), exposure (such as prevent biota exposure), concentration (such as specific sediment WP concentration), particle distributions (such as cutoffs or densities for specific sediment particle sizes), or some combination. Other possible criteria include applicable area (allowing for differences in criteria across the ERF), spatial criteria (for example, an area of measurement that should reach a particular concentration), temporal criteria (allowing for change over a specified time period), measures of reliability (allowing for variability in the achievement of remediation), and a specific protocol for determining whether the remediation goals have been achieved. The goals may also have criteria that are dependent on the choice of remediation technology (for example, action-dependent ARARs).

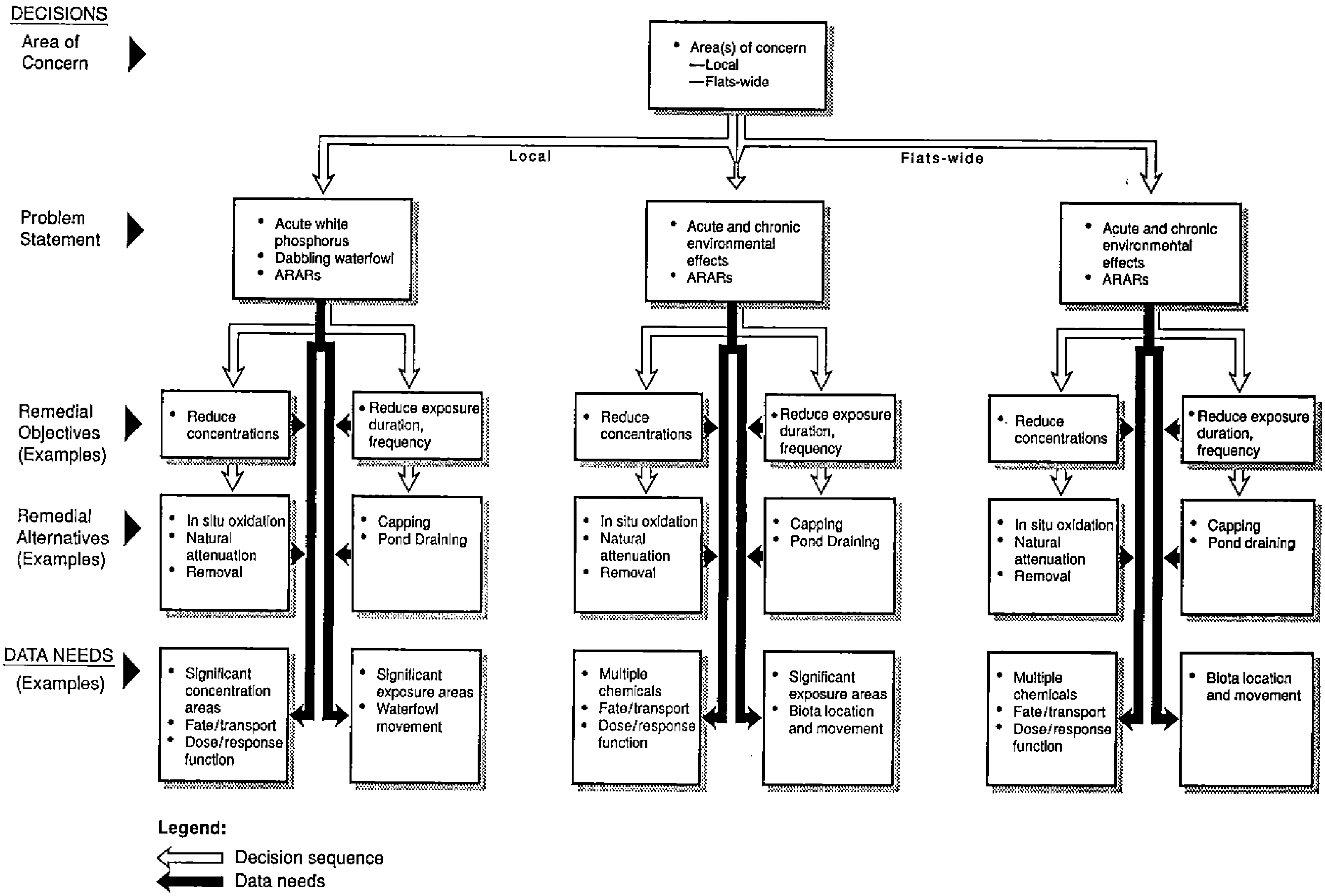
The general data gap identified in Table 7-4 includes information on the parameters that will measure whether and how the remedial technologies perform at the ERF. The parameters include those that will allow assessments of the Superfund nine criteria. They also include the critical parameters that strongly affect the performance of the technology at the chosen area for the pilot studies, as well as other potentially applicable areas at the ERF. The pilot studies should be designed to collect the data to determine whether the technologies should be used elsewhere at the ERF. Important data beyond just the measures of technical feasibility include the following:

- Effects on WP concentrations and habitat
- Achievement of action-specific ARARs and other potential remedial goals
- Cost

Additional data may be needed to provide more details about site conditions in areas that are proposed for a cleanup action, but this study will likely be site-specific and dependent on the nature of the potential action.

7.3.4 Other Steps in the DQO Process

Completion of the DQO process will require input from the site remedial project managers to define their responses to the decision alternatives raised in Subsection 7.3.2, the remedial or removal goals, and the error rates they are willing to allow in their decisions. These decisions will serve as input to specific sampling that may be created to fill data gaps.



Assumption: Remedial concentration criteria are established. Particle size data would be needed if remediation criterion is on the basis of particle size distributions.

Note: General data need for information evaluating effectiveness of alternatives.

FIGURE 7-3
LINKAGE OF SITE DECISIONS AND DATA NEEDS

Table 7-2
Topics on the Level of Risk

Page 1 of 8

Topic	Current Information	Basis of Information	Proposed 1994 Study	Data Gap	Relative Importance	Plan to Fill Data Gap
Effects						
Ducks	Mortality of at least hundreds occurs consistently each year, especially during spring and fall migration	Field and lab studies, plus chemical analysis	Further quantification of mortality rates in relation to bird numbers (NEILE) Develop methods for assessing sublethal/ reproductive effects. Confirm acute toxicity (PWRC, Dartmouth)	Mortality rate as fraction of ducks using regional area	Medium	Get duck census data for other salt marshes
Swans	Mortality has been observed, especially during migration	Field observations and chemical analysis	Further quantification of mortality rates in relation to bird numbers (NEILE)	Mortality rate as a fraction of swans using regional area	Medium	Get swan census for other salt marshes
Shorebirds	Mortality observed and signs of sublethal exposure in collected birds	Field observations and lab analysis	Further quantification of mortality rates in relation to bird numbers (NEILE)	Mortality rate as a fraction of shorebirds using flats and regional area	Medium	Get census of bird usage in other salt marshes
Macro-invertebrates	Effects observed in lab bioassay with ERF sediments: apparent decrease in number per unit area but not diversity	Lab bioassay and field study comparing ERF with reference area	Repeat field and lab studies (AEHA)	May still be some questions about degree of effect if bioassays/field studies again not conclusive	Medium	Continue testing if needed

Table 7-2
Topics on the Level of Risk

Page 2 of 8

Topic	Current Information	Basis of Information	Proposed 1994 Study	Data Gap	Relative Importance	Plan to Fill Data Gap
Effects						
Fish	No effects documented. Analyses have not detected WP.	No studies of effects. Limited chemical analysis	Chemical analysis (AEHA)	Need testing to determine effects and possible absence of expected species	Medium	Conduct bioassay with relevant media and species
Eagles	Dead eagles have been found	Field study, WP found in one, and kestrel lab study	Further field surveys (NEILE). Experimental study with kestrels consuming contaminated chicks (PWRC)	None identified		
Fish-eating birds	Signs of sublethal exposure in tern shot on ERF	Pathology and cholinesterase assay	Further field study and biomarker development (PWRC) Analysis of fish and invertebrates (AEHA)	May need to collect more terns or their food (fish and odonates) for necropsy or analysis	Medium	Sample, if 1994 results not sufficient
Mammals	None	No reports	Photo stations to be set up to determine scavengers (NEILE)	None identified, unless too few photo stations to determine scavenger exposure	Medium	More photo stations if warranted after 1994 results are in

Table 7-2
Topics on the Level of Risk

Page 3 of 8

Topic	Current Information	Basis of Information	Proposed 1994 Study	Data Gap	Relative Importance	Plan to Fill Data Gap
Chemical Concentrations						
WP in sediment	Frequently detected in shallow ponds (max of 3,071 µg/g wet weight, Racine Island). Heterogeneous. Exists as particles	Analysis of field samples	Sampling in areas for pilot studies (CRREL) Analyze sediment samples for WP (AEHA)	Particle distributions, as they may more closely correlate with exposure. May also be basis for remediation goal	High	Collect concentration and particle distribution and size data in the field
WP in water	Up to a few µg/L WP in one confined area with high sediment concentration, but undisturbed open areas were about 0.01 µg/L	Analysis of field samples	Analyze water samples for WP (AEHA)	None identified		
WP in soils (e.g., former EOD pad)	No data, but WP not expected to persist in surface exposure	Analysis of field samples	Studies on natural attenuation (CRREL)	None identified		
WP in fish and invertebrates	Analysis has not detected WP	Limited chemical analysis	Chemical analyses (AEHA)	Wait for 1994 data		
Other chemicals	Other detected chemicals not found in significant quantities in ERF Former EOD pad has higher concentrations of munitions residues.	Field samples (ESE and AEHA)	No plans	None identified		

Table 7-2
Topics on the Level of Risk

Topic	Current Information	Basis of Information	Proposed 1994 Study	Data Gap	Relative Importance	Plan to Fill Data Gap
Locations						
Habitat	ERF habitat and vegetation have been described.	Field observations	No plans except more detailed in pilot study areas	None identified		
Ponds	Significant WP concentrations in shallow feeding areas: Area C, Bread Truck, Racine Island. Heterogenous distribution. Some detections down to 50-55 cm in limited core sampling Area A had 10% WP detections, but low concentrations (max of 0.053 µg/g wet weight).	Field measurements and observations of dead birds	Bird activity and behavior observations; mortality surveys (NEILE, DWRC)	Many small ponds have not received observations of bird behavior and/or WP analysis	Medium	Determine whether significant additional feeding areas
Mudflats	10% WP detections, with the highest concentration of 0.15 µg/g wet weight	Field observations	No plans			
Gullies	WP may be mobilized from ponds and gully walls	Detection in 1992 but not in 1993	Further studies (CRREL) Distributary sampling (AEHA)	Potential transport to Eagle River and Knik Arm, leading to exposure there	High	Wait for 1994 results
Eagle River	WP not detected at the mouth	Limited sampling	Upriver and downriver samples for WP (AEHA)			

Table 7-2
Topics on the Level of Risk

Page 5 of 8

Topic	Current Information	Basis of Information	Proposed 1994 Study	Data Gap	Relative Importance	Plan to Fill Data Gap
Locations						
Knik Arm	No data		No plans	Wait for results from gullies and Eagle River		
Fate and Transport						
WP form	Particulate, with sizes ranging from 0.15 to 3.5 mm in diameter	Field observations	No plans	Particle density and size distributions across the flats	High	Conduct field studies
WP fate	Sublimation, and oxidation effective in reducing concentrations in unsaturated conditions. Volatilization also effective in agitated water	Field and laboratory measurements	Measure losses of known particles under different moisture and temperature conditions in environmental chambers. Measure loss of known particles in ERF (CRREL)	None identified		
WP surface transport	Resuspension and sedimentation during tidal floods and ebbs. Sedimentation increases with number of flooding events Gully headwalls moving toward ponds, reaching them in perhaps 10-15 years in Area C and Bread Truck	Field measurements Field measurements	Further quantification studies (CRREL) Further studies (CRREL)	None identified		

Table 7-2
Topics on the Level of Risk

Page 6 of 8

Topic	Current Information	Basis of Information	Proposed 1994 Study	Data Gap	Relative Importance	Plan to Fill Data Gap
Fate and Transport						
WP surface transport (continued)	Mixed results on WP in gullies Little information on effects of ice and breakup	Field measurements Some field observations	Further studies (CRREL) Further studies (CRREL)			
Groundwater	Confined lower gravel aquifer at 200 to 400 feet below surface, discharging to Knik and Turnagain Arms	Regional hydrogeology. Little local information	Shallow piezometers in Area C (CRREL)	Await results of 1994 proposals		
Receptors and Exposure						
Primary	Data suggest ducks, swans, shorebirds are exposed while feeding. WP also found in herring gull eggs. Limited data on plants, aquatic invertebrates, fish	Field observations of foraging animals, and WP presence in gut contents. Lab studies	Further studies on fish and macroinvertebrates during spring and fall (AEHA) Lab studies on WP in chicken eggs (Dartmouth)	None identified		

Table 7-2
Topics on the Level of Risk

Page 7 of 8

Topic	Current Information	Basis of Information	Proposed 1994 Study	Data Gap	Relative Importance	Plan to Fill Data Gap
Receptors and Exposure						
Primary–humans	Current land use is a firing range, with no expected change in the future. Incidental exposures to sediment and surface water might occur occasionally. Water not potable	US Army land use. Requirements for personal protection	None planned	Multiparty agreement to future land use	High	
Secondary	Bald eagles and other scavenging species (e.g., ravens and gulls) are known secondary receptors. Shorebirds and terns may be exposed through ingestion of contaminated organisms	Chemical analysis detected WP in bald eagles Shorebirds and terns show signs of exposure but exposure pathway not clear Field collected samples				
Secondary–humans	Possible duck hunting. No onsite use, but possible consumption of exposed ducks killed offsite, but no WP detected in gizzards from 300 duck harvested from nearby marshes	Alaska and U.S. Army risk assessments	Ongoing duck risk mortality studies and offsite migrations (NEILE, DWRC)	None identified		

Table 7-2
Topics on the Level of Risk

Page 8 of 8

Topic	Current Information	Basis of Information	Proposed 1994 Study	Data Gap	Relative Importance	Plan to Fill Data Gap
Toxicology						
Environmental	Median dissolved WP LD_{50} is 6.4 mg/kg for ducks (determined in corn oil)	Laboratory study	Acute toxicity studies (including absorption, and treatment) with particulate WP (PWRC and Dartmouth) Methods being developed for assessing sublethal/reproductive effects (PWRC) Assess sediment NOEL for two invertebrates (AEHA)	None identified		
Human	Lethal at 1 mg/kg, but doses of 0.2 mg/kg can cause severe effects. Respiratory tract irritant. Dermal contact can cause severe burns. Other chronic effects	Literature studies	None planned	None identified		

Abbreviations:
AEHA - U.S. Army Environmental Hygiene Agency
CRREL - U.S. Army Cold Region Research and Engineering Laboratory
Dartmouth - Dartmouth College
DWRC - U.S. Department of Agriculture Denver Wildlife Research Center
NEILE - New England Institute for Landscape Ecology
PWRC - U.S. National Biological Survey Patuxent Wildlife Research Center

Table 7-3
Topics on the Level of Remediation

Topic	Current Information	Basis of Information	Proposed 1994 Study	Data Gap	Relative Importance	Plan to Fill Data Gap
Environmental						
Risk criteria	WP concentrations available from many areas. WP fate and transport in ERF moderately well known. LD_{50} available for ducks. Particle size and distributions may be important.	See Table 7-2	See Table 7-2	Goals not yet established. May lead to other data gaps	May be highly dependent on goals chosen	
Regulatory criteria	No regulatory criteria for WP.	Preliminary ARARs assessment	None	None identified		
Human						
Risk criteria	WP concentrations available for many areas. WP fate and transport moderately well known. Chronic toxicity values not well known.	See Table 7-2	See Table 7-2	Goals not yet established. May lead to other data gaps	May be highly dependent on goals chosen	
Regulatory criteria	No regulatory criteria for WP.	Preliminary ARARs assessment	None	None identified		

Table 7-4
Topics on the Remedial Technologies

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Topic	Current Information	Basis of Information	Proposed 1994 Study	Data Gap	Relative Importance	Plan to Fill Data Gap
BentoBalls™						
Technical feasibility	Small-scale field studies have worked.	Field observations	Assess effectiveness in larger ponds	Delivery system Large-area use Longevity	High	1994 study
Gas migration	No data		To be evaluated	Gas migration potential		1994 study
Physical integrity	Preliminary results indicate resilience to wet/dry cycles.	1993 studies	To be evaluated		High	1994 study
Revegetation	No data		To be evaluated	Revegetation types and rates	High	1994 study
Cost	Preliminary estimates calculated	1993 studies	To be evaluated	Total installation costs O&M costs/area	High	1994 study
Applicability to other areas	No data		To be evaluated			
Geosynthetic Liners						
Technical feasibility	Small-scale tests have found problems with anchoring and gas bubble formation.	Field study	Test 4 liners (CRREL)	None identified		
Anchoring	Problem with the tides and ice movement of small samples	Field observations	Plan to attach edges to vertical barrier to prevent influx of suspended sediment.	Anchoring success during winter. Still need permanent and noninstrusive system	High	1994-95 study

Table 7-4
Topics on the Remedial Technologies

Topic	Current Information	Basis of Information	Proposed 1994 Study	Data Gap	Relative Importance	Plan to Fill Data Gap
Geosynthetic Liners						
Gas migration	Gas is generated in sediments, forming bubbles under liners.	Field observations	Cut small holes (7 to 15 mm) in liners.	None identified		
Physical integrity	No data on effects of animals such as moose.		Drop load on liner.	None identified		
WP concentrations and particles	No data		Assess effect of stirring and loading. WP in sediment on liner			
Revegetation	Other liners revegetated	Field observations	No plans	Revegetation rate and type	Moderate	No plans
Cost	No data		No plans	Technology costs for estimating future actions	High	Cost accounting system
Applicability to other areas						
Pond Draining						
Technical feasibility	Dry 1993 summer dried portion of Bread Truck Pond.	Observation	Survey pond to confirm hydrologic isolation. Drain in June and after each flooding tide (CRREL)	None identified		
Effect on sedimentation and hydrology	No data		Monitor effects before and after (CRREL).			

Table 7-4
Topics on the Remedial Technologies

Topic	Current Information	Basis of Information	Proposed 1994 Study	Data Gap	Relative Importance	Plan to Fill Data Gap
Pond Draining						
Soil moisture and temperature at different depths	No data		Measure during the summer	None identified		
WP concentrations	No data		Measure pond sediment and drainage discharge during summer.	None identified		
Capital and operating costs	No data			Technology costs for estimating future actions	High	Cost accounting system
Applicability to other areas	No data			Determine other significant areas that may be hydrologically isolated.	Depends on the success of the 1994 pilot	
Dredging and Drying of Spoils						
Technical feasibility	No cases of remote dredging in area of UXO documented, but technology has been used elsewhere.		Pilot study in Area C (CRREL)			
Effect on sedimentation and hydrology	No data		Monitor effects before and after (CRREL)			
Spoils transfer	None available		Plan to transfer spoils at least several hundred feet through pipe.			

Table 7-4
Topics on the Remedial Technologies

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Topic	Current Information	Basis of Information	Proposed 1994 Study	Data Gap	Relative Importance	Plan to Fill Data Gap
Dredging and Drying of Spoils						
Spoils handling	Sediment should dry.	1993 study on former EOD pad, although 1993 was an unusually dry summer.	Spoils will be held in bermed area. Sediment fence will be used to separate solids from water. Water will be pumped back to wetland, or allowed to flow via gravity.	Specifications were unavailable for review.	High	
WP concentrations	WP likely to decrease over time if sediment is dried.	1993 study on former EOD pad, and laboratory studies.	None	WP concentrations over time	High	Measure WP systematically over time.
Spoils disposal	No significant volume of sediment has been removed from ERF.		No plans for spoils beyond storage on former EOD pad.	Requirements for final disposal. Effect of spoils on RCRA closure of former EOD pad.	High	Triparty agreement
Capital and operating costs	No data for these conditions.		No plans	Technology costs for estimating future actions	High	Cost accounting system
Natural Attenuation						
Natural Attenuation	Air drying can reduce WP. See Table 7-2 for other issues associated with "no action" assessment.	Small-scale study in 1993.	See proposals discussed in Table 7-2	None identified		

Abbreviations: CRREL - U.S. Army Cold Regions Research and Engineering Laboratory

Section 8
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