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Cold Regions Research and Engineering Laboratory

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Eagle River Flats Remediation Project Comprehensive Bibliography—1998 to 2003

Michael R. Walsh

August 2003

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Comprehensive Bibliography—1998 to 2003

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Prepared for U.S. ARMY ALASKA
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14. ABSTRACT

White phosphorus (WP) has been implicated in the deaths of thousands of waterfowl annually at Eagle River Flats (ERF), an estuarine salt marsh located on Fort Richardson near Anchorage, Alaska. The source of WP contamination at ERF was the firing of WP-containing munitions into the area by the U.S. military. WP is a well known toxicant and is lethal to a wide range of species. However, WP contamination at ERF is the first documented case of a U.S. Army munitions impact area contaminated with WP particles. This has led to the designation of ERF as a Superfund site by the U.S. Environmental Protection Agency, and the Army must follow the guidelines of remediation set by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Numerous studies have been conducted to better characterize the nature and the extent of WP contamination, and treatability studies for remediation processes are currently being implemented. This comprehensive bibliography provides all publications related to WF contamination remediation project at Eagle River Flats through 2003.

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Bibliography	White phosphorus	Wetlands
Contamination	Remediation	

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ABSTRACT

White phosphorus (WP) has been implicated in the deaths of thousands of waterfowl annually at Eagle River Flats (ERF), an estuarine salt marsh located on Fort Richardson near Anchorage, Alaska. The source of WP contamination at ERF was the firing of WP-containing munitions into the area by the U.S. military. WP is a well known toxicant and is lethal to a wide range of species. However, WP contamination at ERF is the first documented case of a U.S. Army munitions impact area contaminated with WP particles. This has led to the designation of ERF as a Superfund site by the U.S. Environmental Protection Agency, and the Army must follow the guidelines of remediation set by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Numerous studies have been conducted to better characterize the nature and the extent of WP contamination, and treatability studies for remediation processes are currently being implemented. This comprehensive bibliography provides all publications related to WF contamination remediation project at Eagle River Flats through 2003.

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PREFACE

This report was prepared by Michael R. Walsh, Mechanical Engineer, Engineering Resources Branch, Cold Regions Research and Engineering Laboratory, U.S. Army Engineer Research and Development Center. Review of the manuscript was provided by Arthur Gelvin and Dr. Thomas Douglas of the CRREL Fairbanks office. Mark Hardenberg of CRREL was the editor.

Every attempt has been made to bring this bibliography up to date and to include all materials relevant to the project that have been published. If any articles are known that have not been included, contact Michael Walsh at CRREL (mwalsh@crrel.usace.army.mil) and they will be added to the next revision of this bibliography. Any items added to the Eagle River Flats bibliography before its next publication of will be placed on the public CRREL Web site (www.crrel.usace.army.mil/ERF) as we receive them.

Funding for this work was provided by the U.S. Army Environmental Center, Aberdeen Proving Ground, Maryland (Glen Boldt, Remedial Operations Manager), through the Alaska District, Pacific Ocean Division, U.S. Army Corps of Engineers (Joann Walls, Project Monitor), and the Environmental Resources Department, Directorate of Public Works, U.S. Army Alaska (William A. Gossweiler, Army Remedial Project Manager).

The Commander and Executive Director of the Engineer Research and Development Center is COL James R. Rowan, EN. The Director is Dr. James R. Houston.

NOMENCLATURE

ADC	Animal Damage Control
ADEC	Alaska Department of Environmental Conservation
ADFG	Alaska Department of Fish and Game
APHIS	Animal and Plant Health Inspection Service
ARAR	Applicable or relevant and appropriate requirement
BT Pond	Bread Truck Pond (Pond 109)
CER	Comprehensive evaluation report
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COE	U.S. Army Corps of Engineers
CSM	Conceptual site model
DMS	Dartmouth Medical School
DMSV	Digital multispectral video
DOD	Department of Defense
DQO	Data quality objectives
DWRC	Denver Wildlife Research Center (now National Wildlife Research Center)
EOD	Explosive ordnance disposal
ERF	Eagle River Flats (also referred to as the Flats)
ESE	Environmental Science and Engineering, Inc.
FFA	Federal Facilities Agreement
FS	Feasibility study
FSP	Field sampling plan
GIS	Geographic information system
IRA	Interim remedial actions
IRAM	Integrated Risk Assessment Model I
IRP	Installation Restoration Program
LD_{50}	Median lethal dose
LOEL	Lowest observable effects level
MA	Methyl anthranilate
MDL	Method detection limits
MOA	Municipality of Anchorage
NBS	National Biological Survey
NCP	National Contingency Plan
NEILE	New England Institute of Landscape Ecology
NOEL	No observable effect level
NPL	National Priorities List
NWRC	see DWRC
OB/OD	Open burning/open detonation
OUC	Operable Unit C of Fort Richardson
P_4	White phosphorus (WP)
QA	Quality assurance
QAPP	Quality Assurance Program Plan
QC	Quality control
RAO	Remedial action objectives
RCRA	Resource Conservation and Recovery Act
RI	Remedial investigation; Racine Island
ROD	Record of Decision
SPMA	Semi-permeable membranes
SPME	Solid-phase microextraction
TSCA ITC	Toxic Substance Control Act - Interagency Testing Committee
USAEC	U.S. Army Environmental Center
USAEHA	U.S. Army Environmental Hygiene Agency
USARAK	U.S. Army, Alaska
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
UXO	Unexploded ordnance
WCI	Weldin Construction, Inc.
WP	White phosphorus (P_4)

Eagle River Flats Remediation Project
Comprehensive Bibliography—1998 to 2003

MICHAEL R. WALSH

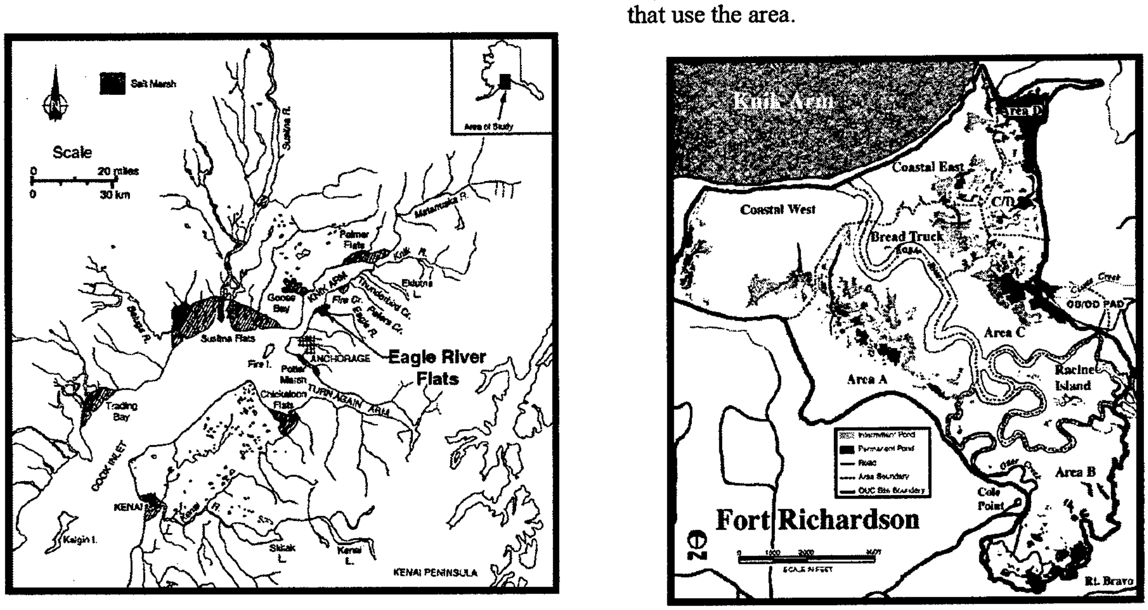
INTRODUCTION

The Eagle River Flats remediation project is a ground-breaking environmental cleanup effort on the U.S. Army's Fort Richardson, near Anchorage, Alaska (Fig. 1). The project's roots extend back to 1982 when various government agencies joined together to investigate high waterfowl mortality observed at the Flats. An interagency task force was formed, comprising the U.S. Army, the U.S. Fish and Wildlife Service, the Alaska Department of Fish and Game, the Alaska Department of Environmental Conservation, and the U.S. Army Toxic and Hazardous Materials Agency, now known as the Army Environmental Agency.

Initial investigations, conducted from 1983 through 1988, failed to pinpoint a specific cause for the mortalities, which continued to occur at the Flats. In 1989, a contractor was hired to investigate the die-offs. Again the results were inconclusive.

In 1990, the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), working with the Environmental Resources Branch, Directorate of Public Works, U.S. Army, Alaska, uncovered the cause of the deaths: white phosphorus (WP) poisoning from the unreacted particulate residue of smoke rounds used during training at the Flats.

With the contaminant finally identified, investigations began into both the site and the agent. A thorough characterization of the Flats was conducted, including biological, meteorological, and physical systems, from 1991 through 1994. A contamination profile was conducted to determine the distribution and concentration of WP in the Flats. Biological and toxicological studies were performed to determine faunal impact of the contaminant. Waterfowl surveys were conducted from the air and on the ground to characterize the use of the Flats and determine the impact and specificity of the contaminant on the birds that use the area.



a. Location of Eagle River Flats.

b. Site map showing general areas.

Figure 1. Eagle River Flats.

During this period, several remediation methods were evaluated. Initial studies concentrated on breaking the uptake pathway by covering the contaminant. Hazing of the waterfowl was used as a short-term solution while these investigations were conducted. Chemical bird repellents were also tried. From 1995 to 1998, more active remediation methods were investigated. Small-scale dredging with a remote-controlled "pocket" dredge was attempted with mixed results. Two highly contaminated ponds that did not lend themselves to other remediation alternatives being considered at the time were permanently drained through explosive ditching. Siphoning of a contaminated pond was attempted to remove the overlying water from the contaminated sediments.

The idea of treating the contaminant in-situ by draining and drying the ponds over the course of several summers was investigated. Initially, intermittently ponded mudflats adjacent to permanent ponds were used as test beds to evaluate natural attenuation rates of untreated areas and areas with passive enhancement treatments. These studies were supplemented with dry land and laboratory experiments. The conclusion derived from these studies was that if the sediments are kept unsaturated, not necessarily dry, and if the soil temperature exceeds 15°C, untreated, drained ponded areas will remediate through natural attenuation of the contaminant over a period of time determined by soil composition, temperature, and length of unsaturation.

In 1997, a large pump system designed to drain ponded areas on the Flats was deployed in Pond 183, Area C, as part of the ERF feasibility study. The first-year results were promising, but much work remained to be done to optimize the method. In 1998, six systems were deployed with very good results. Large areas of ERF were drained and treated through natural attenuation. Methods were developed to evaluate remediation progress, both on a yearly and multi-year basis. Remote monitoring stations were designed and deployed to track parameters such as soil temperature and moisture that directly affect remediation efficiencies.

The success of the pond pumping remediation method led to its choice as the preferred remediation method for white phosphorus contamination in Eagle River Flats, as stated in the Record of Decision (ROD) signed by the U.S. Army, the Environmental Protection Agency, and the Alaska Department of Fish and Game in September 1998. In 1999, active remediation of the Flats officially began with the deployment of six pump units in contaminated ponds throughout the area.

A mortality model was developed by the Denver Wildlife Research Center using Captured Mallards as the indicator species for evaluating the progress towards meeting the remediation goals stated in the ROD. The captured birds are radio-collared and their movements monitored to get an indication of waterfowl use of the Flats. A mortality signal emitted when the bird dies gives the researchers an opportunity to recover the carcass, pinpointing the location where death occurs and allowing later examination of the tissues to determine if WP was the cause of death. Waterfowl surveys are conducted throughout the active season (April through October) to develop an ongoing census of bird use and dynamics for the mortality model.

This bibliography is organized in much the same manner as its predecessor (Nam et al. 1999). There are a few differences that will make it easier to find information. The Contract Reports section is organized first by general publication (the contract report itself) followed by the individual reports by author. The covering reports are listed in order of year (i.e., 1999 is first, 2000 second, and so forth). The Index to Abstracts is ordered first by publication title followed by a section in chronological order by year. In both sections, all abstracts from both bibliographies are listed.

Both bibliographies appear on the Eagle River Flats Web site, available at the time of publication at www.crrel.usace.army.mil/erf. Other information pertinent to the progress of the remediation project can be found at this site. Hard copies of most of the listed publications reside at the Fort Richardson Directorate of Public Works, Environmental Resources Branch, which is the repository for the written records pertaining to the Flats project, or in the library at CRREL in Hanover, N.H.

This bibliography supplements the earlier bibliography (Nam et al. 1999) that documented the publications leading up to the Record of Decision. Over 250 citations are included in that publication, indicating the groundbreaking effort and scope of this unique environmental cleanup effort, the first ever conducted in an active military impact range. Some overlap between the two publications occurs as older publications arise. Some publications dated after 1998 also appear in the 1999 bibliography.

Every effort has been made to bring this bibliography up to date and to include all materials relevant to the project that have been published. If any articles are known that have not been included, contact Michael Walsh at CRREL and they will be added to the next revision of this bibliography. Any items added to the bibliography before the next publication of the Eagle River Flats bibliography will be placed on the public CRREL Web site as we receive them (www.crrel.usace.army.mil/erf).

AERIAL PHOTOGRAPHS OF ERF

Aeromap (1998) 18 August. Color infrared. 1 in. = 600 ft.

Aeromap (1999) 17 August. Color infrared. 1 in. = 600 ft.

Aeromap (1999) 17 August. Color infrared obliques.

Aeromap (1999) 17 August. Digital multi-spectral video. 1.5-m pixels. Scanned and georeferenced.

Aeromap (2000) 8 September. Color infrared. 1 in. = 600 ft.

Aeromap (2000) 8 September. Color infrared obliques.

Aeromap (2001) 9 September. Color infrared. 1 in. = 600 ft.

Aeromap (2001) 9 September. Color infrared. 1 in. = 3000 ft.

Aeromap (2001) 9 September. Digital multi-spectral video. 1.5-m pixels. Scanned and georeferenced.

Aeromap (2002) 27 August. Color infrared. 1 in. = 600 ft.

CERCLA DOCUMENTS

CH2M Hill (1999) Remedial action work plan and final design for Eagle River Flats. Contract Report to U.S. Army Corps of Engineers and U.S. Army Alaska. April.

This remedial action work plan (RAWP) presents the strategy for conducting post-Record of Decision (ROD) activities at the Eagle River Flats (ERF) source area of Operable Unit C (OUC), Fort Richardson, Alaska. Fort Richardson was placed on the U.S. Environmental Protection Agency (EPA) National Priorities List (NPL) in June 1994. The post was then subject to the remedial response requirements of the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA), as amended by the *Superfund Amendments and Reauthorization Act* (SARA) of 1986. Following inclusion of Fort Richardson on the NPL, the U.S. Army Alaska (USARAK), EPA, and the Alaska Department of Environmental Conservation (ADEC) negotiated the Federal Facility Agreement (FFA) for Fort Richardson, which was signed in December 1994.

OUC consists of two source areas: the ERF active firing range and the adjacent former Open Burning/Open Detonation (OB/OD) Pad. The OB/OD pad is subject to hazardous waste regulations under the authority of the *Resource Conservation and Recovery Act* (RCRA). Post-ROD work at the former OB/OD pad consists of preparation of an interim closure plan that will address RCRA closure of the OB/OD pad concurrently with final clearance of the operating ERF firing range. Post-ROD work at ERF consists of the implementation of a remedial design/remedial action (RD/RA). The RD/RA at OUC is being implemented in accordance with the FFA and the OUC ROD developed between the United States Army (Army), the ADEC, and the EPA. The ROD for OUC was signed in September 1998. This document addresses RD/RA at ERF. The Army is currently preparing a separate RCRA Interim Closure Plan for the OB/OD pad for EPA review and approval.

ERF is a 2,160-acre estuarine salt marsh at the mouth of the Eagle River where the river flows into the Knik Arm (Fig. 1).The U.S. Army has used ERF for artillery training since 1949. Although ERF is an active impact area, it remains a productive wetland, serving as an important staging ground for migrating waterfowl during the spring and fall migrations. In the early 1980s, large numbers of waterfowl deaths were observed at ERF. In 1990, the cause of the waterfowl deaths was determined to be white phosphorus (WP) trapped in pond sediments where waterfowl feed. Following a remedial investigation (RI) and feasibility study (FS) at ERF, the remedial project managers (RPMs) selected a remedial action to remove WP in ERF pond sediments to reduce waterfowl deaths.

Although the Fort Richardson FFA lists two separate document submittals for the RAWP and the Final Design, with the approval of the RPMs the two submittals have been combined into one document for review and approval. The Prefinal (95%) Design is incorporated into this draft RAWP in Section 4. The design specifications and drawings and additional documents required by the FFA for other elements of design are included in appendices to this document.

The objective of this work plan is to present a strategy for the implementation, operation, and maintenance of the selected remedy for ERF presented in the OUC ROD. The selected remedy consists of the following remedial action and monitoring requirements, beginning in 1999:

- Treat WP-contaminated sediment by draining ponds with pumps. Pumping will allow the sediments to dry and the WP to sublimate and oxidize.
- Sample pond bottoms for WP at the beginning of the treatment season to confirm or

determine that the pond or area requires remediation, to establish a baseline for WP, and to determine additional areas that may require remediation.

- Sample pond bottoms for WP after treatment to determine effectiveness of the treatment system.
- Perform telemetry monitoring and aerial surveys to determine bird populations, usage, and mortality.
- Conduct aerial photography to monitor habitat changes resulting from remedial actions and to produce updated habitat mapping.
- Use hazing (only as a contingency) if pumping operations and other fieldwork activities have not already deterred waterfowl from using critical areas.
- After RAOs are achieved and pumping is discontinued, apply AquaBlok™ or other cap-and-fill material in ponded areas that did not drain and dry sufficiently to enable the WP to sublimate and oxidize. The cap-and-fill material will be periodically monitored for integrity and effectiveness.
- Incorporate WP sampling, telemetry, aerial survey, habitat, and physical landform data into a geographic information system (GIS) database.
- Maintain institutional controls, including the restrictions governing site access, construction, and road maintenance and the required training for personnel who work at OUC source areas, as long as hazardous substances and unexploded ordnance (UXO) hazards exist at OUC.

The overall goal of this RAWP is to provide a plan and present information needed to guide the successful execution of the RA at ERF. The following are specific objectives of the OUC RAWP:

- Describe techniques and provide guidance for the installation, operation, and maintenance of the selected remedial technology.
- Present the basis for the RD, how it was evaluated and chosen among other designs, the assumptions made during the design, and their justifications.
- Discuss how the RD will meet the remediation goals and regulatory standards identified in the ROD.
- Present a schedule for the implementation, operation, and maintenance of the RD.
- Present a cost estimate for the implementation, operation, and maintenance of the RD, as an update to the cost estimate presented in the ROD.
- Present a health and safety plan (HASP), Quality Assurance Program Plan (QAPP), and operations and maintenance plan (O&M plan) for the RD/RA.

The selected RA addresses only the remediation of WP contamination and does not address the cleanup of UXO at ERF. However, the presence of UXO at ERF presents a safety hazard to workers during RD/RA activities. Required procedures for conducting UXO clearance at ERF areas before remediation and monitoring activities are included in this RAWP and Prefinal Design, and in the Health and Safety Plan presented in Appendix C.

CH2M HILL is preparing the RAWP and design documentation for the COE under Contract DACA85-95-D0015, Delivery Order 22 (DO22). The Army is conducting RD/RA at OUC in accordance with the Fort Richardson FFA and the OUC ROD developed between USARAK, ADEC, and EPA. This RAWP is organized as follows:

Section 1, Introduction. This section presents background information on activities at the site, the objective of the RAWP, and the project organization and personnel responsibilities.

Section 2, ERF Site Description. This section summarizes results from previous site investigations, studies conducted under the RI and FS, and more recent treatability studies.

Section 3, Remediation Goals and Objectives. This section describes how the achievement of the RAOs will be monitored and met during the RA process.

Section 4, Final Remedial Design (RD). This section summarizes the remedial technology design, how it was chosen, and how it will meet the RAOs.

Section 5, Remedial Action (RA). This section presents a plan and schedule for the implementation of the remedial technology and provides direction and technique for installing, operating, and monitoring the systems.

Section 6, Data Management Plan. This section discusses how the data collected as part of the RAWP will be managed.

Section 7, References.

The appendices contain supporting documents:

Appendix A, Design Specifications and Drawings.
Appendix B, System Performance, 1998 Field Season.
Appendix C, Health and Safety Plan.
Appendix D, Standard Operating Procedures (SOPs).
Appendix E, Quality Assurance Program Plan.
Appendix F, Operations and Maintenance Plan.
Appendix G, Spill Prevention and Response Plan.
Appendix H, Baseline Cost Estimate for Remedial Action.
Appendix I, Responses to Comments.

CH2M Hill (1999) 1999 Field work plan for Eagle River Flats, Alaska. Contract Report to U.S. Army Corps of Engineers, Alaska District, and U.S. Army, Alaska. April.

The 1999 field work plan presents guidelines for providing contractor field support to the Cold Regions Research and Engineering Laboratory (CRREL) during remedial activities planned for summer 1999 at the Eagle River Flats (ERF) source area of Operable Unit C (OUC), Fort Richardson, Alaska. Fort Richardson was placed on the U.S. Environmental Protection Agency (EPA) National Priorities List (NPL) in June 1994. The post was then subject to the remedial response requirements of the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA), as amended by the *Superfund Amendments and Reauthorization Act* (SARA) of 1986. Following inclusion of Fort Richardson on the NPL, the U.S. Army Alaska (USARAK), EPA, and the Alaska Department of Environmental Conservation (ADEC) negotiated the Federal Facility Agreement (FFA) for Fort Richardson, which was signed in December 1994.

OUC consists of ERF and the former Open Burning/Open Detonation Pad (OB/OD pad). CERCLA remedial activities are currently under way at the ERF portion of OUC. The selected remedy for ERF presented in the Record of Decision (ROD) consists of treating white phosphorus (WP)-contaminated sediment by draining permanently flooded pond areas with pumps and capping areas that do not desaturate through pumping. Pumping will allow the sediments to desaturate and increase in temperature, which will result in sublimation/oxidation of the WP. The OB/OD pad is being addressed separately under an RCRA closure process. Additional support activities to enhance the pond pumping and draining and several monitoring activities are also included in the remedial action for ERF. The final ROD for OUC was signed in October 1998. CH2M Hill submitted the *Draft Operable Unit C Remedial Action (RA) Work Plan and Prefinal Design for Eagle River Flats* to the U.S. Army Alaska, Directorate of Public Works (DPW), in February 1999.

USA CRREL (2002) 2002 Remediation and monitoring work plan, Operable Unit C—Eagle River Flats. Report to U.S. Army Corps of Engineers and U.S. Army, Alaska. May.

This is the work plan for remediation and monitoring efforts addressing the white phosphorus contamination in Eagle River Flats, a 2,140-acre estuarine salt marsh on Fort Richardson, Alaska. Fort Richardson is on the National Priority List, and Eagle River Flats is designated Operable Unit C (OUC). The main remedy in OUC is pond pumping, using six semi-autonomous pumps to temporarily drain contaminated ponds within several areas of Eagle River Flats. The first part of the work plan describes the remediation efforts for the 2002 field season, the fourth year of a five-year remediation and monitoring effort in Eagle River Flats. The second section describes the monitoring activities to determine the effectiveness of the remediation. These include sediment sampling, monitoring of drying conditions using dataloggers, and the installation of an on-site meteorological station. The third section contains the schedules for the various remediation and monitoring activities. The fourth section contains predicted tidal data for Eagle River Flats. The fifth section is a health and safety plan (HASP).

USA CRREL (2002) 2001 remedial progress report, Operable Unit C (Eagle River Flats), Fort Richardson, Alaska. Report to U.S. Army Corps of Engineers and U.S. Army, Alaska. July.

This report describes the results of remediation and monitoring efforts addressing the white phosphorus contamination in Eagle River Flats, a 2140-acre estuarine salt marsh on Fort Richardson, Alaska. Fort Richardson is on the National Priority List, and Eagle River Flats is designated Operable Unit C (OUC). The main remedy in OUC is pond pumping, using six semi-autonomous pumps to temporarily drain contaminated ponds within several areas of Eagle River Flats. The first part of the report is a progress report summarizing the results of the project to date from the remedial investigation phase through the third year of remediation. The second part of the report describes the 2001 field season, the third year of a five-year remediation and monitoring effort in Eagle River Flats. In the 2001 field season, the pumps kept the ponds drained for extended periods during the summer, allowing the pond bottom sediments to dry and the white phosphorus in the sediment to sublime and oxidize. The combination of warm, dry weather during the first half of the summer and the successful use of the pumps along with small tide gates to prevent flooding tides resulted in a long and effective drying season. Sampling indicated that levels of white phosphorus contamination in the treated ponds continued to decline.

USA CRREL (2003) 2003 remediation and monitoring work plan, Operable Unit C—Eagle River Flats. Report to U.S. Army Corps of Engineers and U.S. Army, Alaska. March.

This is the work plan for remediation and monitoring efforts addressing the white phosphorus contamination in Eagle River Flats, a 2,140-acre estuarine salt marsh on Fort Richardson, Alaska. Fort Richardson is on the National Priority List, and Eagle River Flats is designated Operable Unit C (OUC). The main remedy in OUC is pond pumping, using six semi-autonomous pumps to temporarily drain contaminated ponds within several areas of Eagle River Flats. The first part of the work plan describes the remediation efforts for the 2003 field season, the last year of the five-year remediation and monitoring effort in Eagle River Flats. The second section describes the monitoring activities to determine the effectiveness of the remediation. These include sediment sampling, monitoring of drying conditions using dataloggers, and the installation of an on-site meteorological station. The third section contains the schedules for the various remediation and monitoring activities. The fourth section contains predicted tidal data for Eagle River Flats. The fifth section is a health and safety plan (HASP).

USA COE, Alaska District (2003) Interim remedial action Report: Operable Unit C–Eagle River Flats. Prepared for Eagle River Flats Remediation Project Managers (USARAK, USEPA, and ADEC). May.

This document presents the Interim Remedial Action Report (IRAR) for the U.S. Army at Eagle River Flats (ERF), Operable Unit C (OU-C), Fort Richardson, Alaska. Eagle River Flats is one of two OU-C source areas. The objectives of the remedial action at ERF are designed to ensure the protection of human health and the environment by:

- Reducing the white phosphorus present in ponds that are utilized by waterfowl for feeding.
- Reducing waterfowl mortality due to the ingestion of white phosphorus.

The major components of the remedy are:

- Pumping permanent ponds dry to allow for the sublimation and oxidation of the white phosphorus present in the pond.
- Sampling of ponds under treatment to determine that white phosphorus concentrations are being reduced.
- Conducting waterfowl mortality studies to determine quantity and location of ducks that are dying due to white phosphorus.

This remedy, as outlined in the *Comprehensive Environmental Restoration, Compensation, and Liability Act* (CERCLA) Record of Decision (ROD) (dated September 1998), was chosen to reduce the concentration of white phosphorus and thereby reduce the waterfowl mortality.

The remedial action began during the summer of 1999 and pond pumping is intended to continue through summer 2003. At that time, monitoring activities and waterfowl mortality studies will continue as outlined in the ROD to determine if the remedial objectives have been met. The plan will be reevaluated during the 5-year review.

USA CRREL (2003) 2002 remedial progress report, Operable Unit C (Eagle River Flats), Fort Richardson, Alaska. Report to U.S. Army Corps of Engineers and U.S. Army, Alaska. May.

This report describes the results of remediation and monitoring efforts addressing the white phosphorus contamination in Eagle River Flats, a 2,140-acre estuarine salt marsh on Fort Richardson, Alaska. Fort Richardson is on the National Priority List, and Eagle River Flats is designated Operable Unit C (OUC). The main remedy in OUC is pond pumping, using six semi-autonomous pumps to temporarily drain contaminated ponds within several areas of Eagle River Flats. The first part of the report is a progress report summarizing the results of the project to date from the remedial investigation phase through the third year of remediation. The second part of the report describes the 2002 field season, the fourth year of a five-year remediation and monitoring effort in Eagle River Flats. In the 2002 field season, the pumps kept all but one of the ponds drained for extended periods during the summer, allowing the pond bottom sediments to dry and the white phosphorus in the sediment to sublime and oxidize. Warm, dry weather during July resulted in a long and effective drying season. The remediation of two pond areas was completed this season, and preparations were started for the deployment of the pumping units used in those ponds in the highly contaminated marsh of Area C. Sampling indicated that levels of white phosphorus contamination in the remaining treated ponds continued to decline.

Collins, C.M., M.R. Walsh, M.E. Walsh, J.T. Walls, and M.E. Wong (1999) Remediation of a white phosphorus contaminated salt marsh: Eagle River Flats, Alaska. In *Proceedings, 1999 International In Situ and On-Site Bioremediation Symposium, 19–22 April, San Diego, California.*

Pond pumping treatability studies were conducted at Eagle River Flats in the summers of 1997 and 1998. Pond pumping is a way to temporarily drain the ponds, allowing the sediments to desaturate and the P_4 to sublime. Pond pumping does not permanently alter the environment the way ditching and dredging do. Six automatic remote pumping systems have been designed for ERF: one 1000-gallon-per-minute (gpm) system (powered by a 50-kW diesel generator), four 2000-gpm systems (80 kW), and one 3000-gpm system (125 kW). The pumping systems consist of two units: a 15-cm (6-in.) open-impeller centrifugal pump on floats and a generator set (genset) with fuel tanks, also on floats. A series of float switches automatically turns the pump system on and off as water levels change. Units are sized to allow air transport into remote ponds using UH-60 Blackhawk helicopters. In 1997, one pumping system was operated at ERF, and in 1998 all six systems were deployed.

The automatic pump system was highly successful in keeping the treated ponds drained for much of the summer. This resulted in extensive drying of the exposed pond bottom sediments. Following treatment in 1997, P_4 concentrations decreased by over 88% in the pond treated. Laboratory-manufactured P_4 particles were planted in the sediment during the 1997 and 1998 treatment seasons. The planted particles decreased in mass by 50% in 1997, and 60% in 1998 at ponds where pumping was being done. Mallards were selected as the indicator species to measure the effects of any treatability studies or remediation actions on ERF. Overall Mallard mortality, calculated from telemetry and census data, decreased from 983 ducks in 1996 to 360 ducks in 1997, then increased to 532 ducks in 1998. The increase of Mallard mortalities on ERF from 1997 to 1998 can be attributed to remediation efforts that caused more ducks to move from areas being treated to other contaminated areas not yet treated.

Hull, J.P., J.M. Jersak, and H.F. Crowell (1999) "Biofriendly" remediation of impacted wetlands. In *Proceedings, International Conference on Wetlands and Remediation, 16–17 November, Salt Lake City, Utah*, p. 229–236.

In this paper, we explore the potential for concurrent use of two nonremoval, sediment remediation techniques—in situ capping and in situ treatment—for reducing and/or immobilizing contaminants in wetland sediments while minimizing disturbance to wetland habitats and functions.

Organic and metallic contaminants have been discharged to coastal and inland wetland ecosystems across the U.S. Remediation of sediments via removal by dredging is frequently used in deepwater systems (e.g., lakes, harbors, and rivers) and can be performed in wetlands as well. Dredging can result in substantial and irreparable damage to wetland plant and animal communities and alter wetland characteristics.

In situ treatment (including chemical or biological processes) could be used to address sediment contaminants without significantly affecting wetland functions. In situ capping can be used in concert with in situ treatment methods. In particular, a relatively impervious yet reactive clay mineral-based capping technology, AquaBlok™, can be integrated with in situ treatment techniques in impacted wetlands to 1) enhance the effectiveness of in situ treatment techniques and facilitate monitoring of in situ treatment effectiveness through creation of a "closed" sediment system, and 2) provide a comparable "replacement" substrate for indigenous flora and fauna, minimizing impacts to wetland organisms that may occur as a consequence of in situ treatment techniques.

Walsh, M.E., C. M. Collins, and R.M. Bailey (1999) Monitoring of remediation of a salt marsh contaminated with white phosphorus. In *Proceedings, International Conference on Wetlands and Remediation, 16–17 November, Salt Lake City, Utah*, p. 349–356.

Detonation of projectiles containing white phosphorus, a smoke-producing munition, contaminated Eagle River Flats, a salt marsh located on Fort Richardson, Alaska. Ingestion of highly toxic white phosphorus residues by dabbling waterfowl caused significant mortality, leading to the suspension of training with white phosphorus in wetlands and designation of Eagle River Flats as a Superfund site. The anaerobic sediments of shallow salt marsh ponds are ideal for long-term storage of the millimeter-size particles of white phosphorus ejected from detonated mortar and howitzer shells. In unsaturated sediment, white phosphorus particles ultimately sublime and oxidize, leaving nontoxic residues. In 1997, large pumps were installed in permanently ponded areas of Eagle River Flats to temporarily drain contaminated ponds. The complexity of the site required that we use multiple methods to monitor effectiveness of pond draining. In the drained ponds, we measured (a) sediment temperature and moisture conditions using sensors linked to a datalogger to determine if conditions were conducive to sublimation/oxidation, (b) white phosphorus concentrations remaining from past firing of white phosphorus munitions, and (c) residual white phosphorus from particles we planted in the surface sediment. We have used these methods for three years and have confirmed that the chosen remediation method is working.

Walsh, M.E., C.M. Collins, and R.M. Bailey (2000) Monitoring of a salt marsh contaminated with white phosphorus. In *Proceedings of the 219th ACS National Meeting Book of Abstracts, 26–30 March, 2000, San Francisco, California*, Part 1, Section I&EC, No. 63.

Eagle River Flats, a salt marsh on Fort Richardson, Alaska, is contaminated with highly toxic white phosphorus-munition residues. The anaerobic salt marsh sediments are ideal for long-term persistence of the grain-size particles of white phosphorus (P_4) that are ingested by waterfowl. In unsaturated sediment, P_4 sublimes and oxidizes, leaving nontoxic residues. The rate of sublimation is influenced by several factors, including particle size and shape, exposure to the atmosphere, and temperature. The heterogeneity of the sediments required that we use multiple methods to monitor sublimation/oxidation conditions. We measured sediment temperature and moisture conditions using sensors linked to a datalogger, P_4 remaining from past firing of white phosphorus munitions in discrete and composite samples, and residual P_4 from particles placed in the sediment.

Walsh, M.R., C.M. Collins, and D.J. Lambert (1999) Development of a remediation method for white-phosphorus-contaminated wetlands. In *Proceedings, International Conference on Wetlands and Remediation, 16–17 November, Salt Lake City, Utah*, p. 341–348.

The use of the military munition white phosphorus in wetland impact areas has resulted in several documented cases of deposition of residual particles from incomplete combustion. In areas of permanent saturation, such as pond bottoms, these particles are highly persistent. They are also extremely toxic to dabbling waterfowl, which can ingest them through the normal course of sieving bottom sediments during feeding. In Eagle River Flats (ERF), an estuarine salt marsh that serves as a munitions impact area for Fort Richardson, Alaska, particulate white phosphorus has been found to be the cause of large waterfowl die-offs. After several years of investigations into the distribution and persistence of white phosphorus in the Flats, a method of remediation was developed that incorporates a semi-autonomous floating pump system, designed to temporarily drain contaminated ponds and allow the contaminant to attenuate naturally. Preliminary results over three years of treatability studies indicate that this remediation method is highly effective when climatic conditions are favorable to the drying of the exposed contaminated sediment. This remediation method was chosen by the U.S. Army, the Alaska Department of Environmental Conservation, and the U.S. Environmental Protection Agency for the ERF Superfund site cleanup action.

Walsh, M.R., M. E. Walsh, and C.M. Collins (2000) Remediation method for white phosphorus-contaminated wetlands. In *Proceedings of the 219th ACS National Meeting book of abstracts, 26–30 March, 2000, San Francisco, California*, Part 1, Section I&EC, No. 62.

White phosphorus, a man-made contaminant, is both deadly and persistent in saturated environments. In the 1980s, massive waterfowl die-offs were observed at Eagle River Flats, an estuarine salt marsh on Fort Richardson, Alaska. Residual white phosphorus from smoke rounds fired into the Flats by the U.S. Army was discovered to be the cause of mortality. Over the last 10 years, investigations into the nature and extent of the contaminant have led to the examination of several technologies for the remediation of the area. The most promising method encompasses a unique semi-autonomous pumping system for desaturating contaminated sediments. This low-impact technology has proven successful over the past three seasons, with field sampling indicating an 85% per year reduction of the contaminant. The method is also the most economic of the alternatives tested. (Poster)

Collins, C.M., and M.J. Hardenberg, eds. (1999) Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska—FY 1998. USA CRREL Contract Report to U.S. Army Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. July.

This is the ninth annual contract report prepared by researchers from CRREL and other Federal agencies for U.S. Army Engineer District, Alaska, and U.S. Army Alaska–Public Works, describing the results of white phosphorus contamination studies in Eagle River Flats, an 865-ha estuarine salt marsh on Fort Richardson, Alaska. Fort Richardson is on the National Priority List and Eagle River Flats is designated as part of Operable Unit C (OUC) under the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA). Documents produced under CERCLA, such as the ecological risk assessment, remedial investigation report, feasibility study report, the proposed plan, and the Record of Decision, have used the research results first published in this series of annual contract reports.

Of special interest in this year's report is the full-scale treatability study using six remote-controlled pumps to temporarily drain contaminated ponds within several areas of Eagle River Flats. The pumps keep the ponds drained for an extended period during the summer, thus allowing the pond bottom sediments to dry and the white phosphorus to sublime and oxidize. This treatability study expanded on the study conducted last year, when we first used a 2000-gpm pump in Pond 183 in Area C. That study was highly successful, exceeding our most optimistic expectation. This year we deployed five additional pumps and generators to several pond locations. As part of the treatability study, we had to work out the logistics of deploying, refueling, monitoring, and recovering these systems from remote sites within Eagle River Flats. The success of the pumping treatability studies resulted in pond pumping being chosen as the preferred alternative in the Record of Decision for OUC, signed in October 1998.

Despite a very cool and rainy summer, the pond pumping resulted in significant sediment drying and loss of white phosphorus in treated ponds. Composite sampling of the pond bottom sediments before and after treatment showed a reduction of over 50% in the average white phosphorus concentration levels in Pond 183 and lesser levels in other locations. Other studies reported on this year are the waterfowl use and mortality studies, the monitoring of reduction of white phosphorus contamination in the various treatability study areas, monitoring of drained pond habitats and associated vegetation and erosional changes, and the management of all the data collected for Eagle River Flats in the ERF GIS database.

Collins, C.M. (1999) Weather data for Eagle River Flats. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska—FY 1998*. USA CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 99–108.

The meteorological station located on the edge of the EOD pad in Eagle River Flats, originally installed in 1994, was removed, recalibrated, and reinstalled in May 1998. The station ran the entire summer without a problem. It also served as the base station for the relay of data from the remote dataloggers in ERF. Data from those dataloggers were relayed through the base station via radio and mobile phone to a computer server at CRREL in New Hampshire. Both the weather data and the soil moisture and temperature data from four remote sites were made available daily on the CRREL Web site, allowing researchers to monitor conditions in the Flats regularly even when no one was in the field.

The summer of 1998 was one of the wetter summers on record, with especially heavy rainfall events in late May, June, and August. May and June are normally the driest months of the core drying season needed for treatment of contaminated sediments from the pond bottoms. The late flooding tides of May eliminated any effective drying that month, and June was one of the wettest on record, with over twice the normal rainfall. Precipitation in August was also well above normal. Air temperatures were normal for the last week of May and for June but were below normal for July and August. There were only 18 days during the entire summer when the maximum air temperature exceeded 20°C. The radiation record indicates that the skies were cloudy for almost the entire three months from mid-May through August. Rain fell regularly throughout late May and June. During early August, a large rainfall event occurred on the 5th and 6th, totaling 44 mm (1.74 in). There was another large rain event on the 21st with 10.2 mm (0.41 in).

Cummings, J.L., R.E. Johnson. K.S. Grover, P.A. Pochop, D.L. York, J.E. Davis, J.B. Bourassa, and C.H. Racine (1999) Movements, distribution, and relative risk of waterfowl using Eagle River Flats: 1998. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska—FY 1998*. USA CRREL Contract Report to U.S. Army Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 18–29.

We determined spatial distribution, movements, turnover rate, and mortality of Mallards using Eagle River Flats, Fort Richardson, Alaska, during fall migration, 4 August to 22 October 1998. Using a net gun from a Bell 212 helicopter, we randomly captured 109 Mallards between 4 and 13 August on ERF. Each duck was banded and fitted with a 9.1-g backpack transmitter and released at its capture site. Of the 109 Mallards, 60 were fitted with standard transmitters and 49 were fitted with mortality transmitters. Tracking data indicated that transmitters did not appear to inhibit Mallard movements or activities. LOCATE II was used to map telemetry locations.

Mallard movements and distribution indicate that they spent about 75% of their time in Areas A, B, C, and C/D. In addition, the Mallards spent about 65% of their time in areas that are considered contaminated (A, Bread Truck, C, C/D, and Racine Island). The average daily turnover rate for waterfowl was about 1.3%. The greatest turnover of waterfowl occurred from 12–19 August and from 13–16 October, when 24 and 54% of the Mallards, respectively, departed ERF. Mortality of instrumented Mallards that used ERF from 4 August to 22 October was 33. Of those, 29 were attributed to white phosphorus ingestion. The greatest mortality occurred in Area C/D, with 12 of 29 (41%); Area A, with 5 of 29 (17%); and Area C, with 5 of 29 (17%). Overall, these areas accounted for 82% of the Mallard mortality on ERF. No Mallard mortality was noted from capture, handling, or the transmitter. We recovered 13 whole duck bodies from the 29 white phosphorus mortalities. Analysis showed 10 were positive for WP.

A mortality model was developed for ERF to estimate the total individual dabblers using ERF, the peak number of dabblers using ERF, and the total number of duck mortalities on ERF during the fall migration period. In 1996, 5,413 individual dabblers used ERF from 3 August to 16 October, peaking at 2,333 between 13 and 16 September. The overall mortality of dabblers was 655. In 1997, 6,063 individual dabblers used ERF from 2 August to 22 October, peaking at 4398 between 9 and 10 September. The overall mortality of dabblers was 240. In 1998, 3,722 individual dabblers used ERF from 4 August to 22 October, peaking at 1,583 between 27 August and 2 September. The overall mortality of dabblers was 355. These data represent a minimum number of mortalities on ERF during the fall migration. In conclusion, we feel that the baseline data collected in 1996, 1997, and 1998 can be used to measure the effects of future remediation actions.

Eldridge, W.D., and D.G. Robertson (1999) Waterbird utilization of Eagle River Flats: April to October 1998. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska—FY 1998*. USA CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 7–17.

The U.S. Fish and Wildlife Service conducted 36 aerial surveys of waterbirds at Eagle River Flats (ERF) from April–October 1998 as part of the on-going waterbird mortality and monitoring program sponsored by the U.S. Army at Fort Richardson, Alaska. Fixed-wing airplanes obtained complete coverage of ERF during all surveys. Waterbirds were counted by species or species groups and classified in standardized study areas and individual ponds, when possible.

ERF experienced an early spring breakup, a wet summer, and a normal fall, with a final freezeup in late October. Migration phenology was within the normal range, and species composition of waterbirds was similar to previous years. Mean spring and fall use by swans was below the long-term average. Areas A and B were important to swans in the spring, but Areas B and D were most important in fall. Ponds of Areas B, CD, and D were important to ducks in spring and fall, and the tide flats of Coastal East and West also were important to ducks in the fall. Fall use by ducks was 28% below the long-term average. Areas CD and B had the highest densities of ducks on ponded areas in the fall.

There were important changes in fall use of ERF between 1997 and 1998. A 62% reduction in use of Area A occurred in 1998, with a 100% reduction in use of Pond 290, which was drained by pumping this year. Area C also saw decreased use. Area CD experienced a 34% increase in use, and Coastal East and West also experienced more use, primarily from ducks loafing on the tideline. It appears that the goal of moving ducks from Areas A and C to other areas of ERF is succeeding. What is not dear is the white phosphorus contamination levels of some of the areas where increased duck use is occurring.

Racine, C.H., and P. Berger (1999) Database for monitoring remediation efforts. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska—FY 1998*. USA CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 121–124.

The Eagle River Flats database currently consists of six libraries containing over 100 GIS coverages, together with about 37 aerial images. The database is useful for evaluating the success of the remediation effort as well as for assessing change in habitat. New additions and revisions of the database made during 1998 are described. These include several methods of white phosphorus sampling, such as composited samples, point samples, and planted particles. Other additions include a pond remediation coverage that tracks ponds where remediation actions are being conducted. Monitoring sites where soil moisture and temperature are measured during the summer are also being added.

Racine, C.H., E.F. Chacho, B. Tracy, and P. Berger (1999) Monitoring physical and biological changes in Eagle River Flats. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska—FY 1998*. USA CRREL Contract Report to U.S. Army Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 110–120.

Methods for monitoring environmental change associated with remediation and natural erosional processes at Eagle River Flats were developed and applied. Both remote sensing and plot monitoring techniques were used to determine habitat change. Aquatic submerged vegetation has been lost from all dewatered (pumped or ditched) ponds. In addition, some emergent species, such as four-leaved mare's tail colonies, have died back in a pond pumped for two2 years. Analysis of spectral data from 1995, 1997, and 1998 suggests loss of vegetation cover over a broad area bordering pumped and ditched ponds (183 and 109). In deeper ponds (146 and 155), pumped during summer 1998, there is evidence of vegetation expansion onto the exposed organic sediments of the pond bottom.

Headward gully erosion rates of 64 m from 1991 to 1995 and 13 m from 1995 to 1998 were measured on a tidal creek using scanned and georeferenced aerial photos. Good agreement was obtained between remote sensing-GIS and field-measured lateral erosion rates from 1995 to 1998 along the same gully section, supporting the use of this method for future erosion monitoring.

Walsh, M.E., C.M. Collins, and R.N. Bailey (1999) Treatment verification: Monitoring the remediation of white phosphorus contaminated sediments of drained ponds. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska—FY 1998*. USA CRREL Contract Report to U.S. Army Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 57–98.

We continued to monitor the effectiveness of pond draining on the remediation of sediments contaminated with white phosphorus by recording sublimation/oxidation conditions and changes in white phosphorus over time. In the drained ponds, we measured 1) sediment temperature and moisture conditions at hourly intervals using sensors linked to a datalogger, 2) white phosphorus concentrations remaining from past training with white phosphorus munitions, and 3) residual white phosphorus from particles we planted in the surface sediment.

In the main pond of Area C (Pond 183), which was drained by pumping, the sediments were not saturated with water for the last half of June and most of July of 1998 despite frequent precipitation. However, sediment temperatures were lower than in previous years. Nonetheless, all measurements of white phosphorus (concentrations in composite and discrete samples, percentage of positive samples, masses of planted particles) show a reduction in the contamination. Owing to heterogeneity of the size of munitions-derived white phosphorus particles and sediment moisture conditions, a precise rate of decline in mass of white phosphorus is impossible to determine. However, based on data we obtained from repeated sampling in an intermittently flooded pond, complete decontamination of the surface sediment can be attained in seven years.

Pond 290 of Area A was also drained by pumping as part of a treatability study to demonstrate the feasibility of pumping in a remote location. This pond was identified as a "hot pond" because of the presence of craters, permanent water, and waterfowl. While previous sampling did not indicate widespread contamination with white phosphorus (of the six samples taken, only one sample was positive: a sample collected by CHPPM, and the concentration was four times lower than the reported method detection limit), the pond was sufficiently similar to other contaminated areas to warrant further sampling. Once it was pumped, we sampled the surface sediments intensively. Confirming the results of previous discrete sampling, we did not find widespread white phosphorus contamination; none of the samples we collected had detectable white phosphorus from past Army training. During the summer, the middle of the pond, nearest the pump, dried significantly, resulting in loss of most of the mass of white phosphorus particles we planted. Owing to constant groundwater recharge, drying was less at the north and south ends of the pond, leaving most of the white phosphorus particles we planted 80 m north and south of the sump.

Ponds 258 and 256 of Area A were drained late in the season. We intensively sampled pond 258, and, again confirming previous discrete sampling, we found low concentrations of white phosphorus in just a few samples (threee out of 44 composite samples).

We continued monitoring in Bread Truck Pond, which is drained by ditching. The gully continues to advance from the north into the pond, and the surface sediment surrounding the gully has eroded several centimeters down to an organic layer. The sediments of the north side of the pond dried, and loss of mass of planted white phosphorus particles was greatest adjacent to the gully. Discrete samples taken from locations that had very high white phosphorus concentrations in 1991 were blank when sampled in August 1998. The surface topography of Bread Truck Pond hampers draining, especially from its south side.

Racine Island Pond 297 is still severely contaminated with white phosphorus particles. Additional remedial actions, such as filling, may be needed for this small pond.

Walsh, M.R., C.M. Collins, and D.J. Lambert (1999) Eagle River Flats pond pumping treatability study: Full-scale deployment of remote pumping systems. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska—FY 1998*. USA CRREL Contract Report to U.S. Army Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 31–56.

The success of the first deployment of a remote pumping system in Pond 183, Area C, of Eagle River Flats indicated that this may be the best remediation method for the white phosphorus contamination in permanent ponds. To determine if this method is feasible under different operating parameters, six pump systems were deployed in 1998. Of these, four were installed at previously prepared sites in May and two were installed in newly prepared sites at the end of June. In May, the pump system deployed earlier in Pond 183 was returned, along with a smaller pump in the adjacent Pond 155 and a large-capacity tandem pump in a dredged area of Pond 146. These three pump systems worked together to pump down Area C after each flooding event. The system in Pond 146 is shore-based, while the system in Pond 155 is remote but easily accessible. An additional pump system was placed in Pond 290 in Area A, a remote site across the Eagle River, to help develop logistical procedures for the deployment of additional remote systems in that area. Four tide gates were installed in Area C to try to extend the period between flooding tides.

In late June, sumps were blown in Ponds 256 and 258, Area A. Pump systems were installed at those sites and all were refueled using Blackhawk helicopters and double-walled fuel tanks. Logic errors in the controls were corrected at this time, and all systems were fully operational at the end of the month.

In August, drainage ditches were blasted using detonation cord, a quick and safe method for enhancing drainage in the ponds. The equipment was shut down in late August and retrograded by the end of the first week of September, prior to the flooding tide. Deployment and retrograde procedures have been developed to minimize the amount of helicopter time required. A total of only 2.5 hr was required to retrograde five pump systems and two fuel tanks in the fall.

Results of the 1998 field season are generally good. Poor weather inhibited drying throughout the normally dry months of May and June. A fuel spill near Pond 146 shut that system down for over two weeks. Only one tide defeated the tide gates all summer, but the area was easily pumped out over the course of a day. The remote fueling operations ran much smoother than anticipated, and three more tanks have been acquired for future operations. Some site work still needs to be done before deployment next spring, with a sump in Pond 146 being the major task. Overall, 8.7 ha of permanent ponds and 10 ha of adjacent mudflats were addressed this year.

Collins, C.M., and M.J. Hardenberg, eds. (2000) Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 1999. USA CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. July.

This is the tenth annual contract report prepared by researchers from CRREL and other Federal agencies for U.S. Army Engineer District, Alaska, and U.S. Army Alaska, Public Works, describing the results of research, monitoring, and remediation efforts addressing the white phosphorus contamination in Eagle

River Flats, a 865-ha estuarine salt marsh on Fort Richardson, Alaska. Fort Richardson is on the National Priority List, and Eagle River Flats is designated Operable Unit C (OUC) under the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA). Documents produced under the CERCLA process, such as the ecological risk assessment, remedial investigation report, feasibility study report, and the proposed plan, have used the research results first published in this series of annual contract reports.

This year marks the first of a planned 5-year remediation effort in Eagle River Flats. Pond pumping, using six remote-controlled pumps to temporarily drain contaminated ponds within several areas of Eagle River Flats was conducted this year. The success of the pumping treatability studies conducted in 1997 and 1998 resulted in pond pumping being chosen as the preferred alternative in the Record of Decision for OUC, signed in October 1998. The pumps keep the ponds drained for an extended period during the summer, thus allowing the pond bottom sediments to dry and the white phosphorus to sublime and oxidize. In addition, temporarily draining the ponds excludes waterfowl from these contaminated water bodies thus reducing potential exposure to white phosphorus.

Despite an expected poor season because of predicted flooding tides every month, the pond pumping resulted in significant sediment drying and loss of white phosphorus in treated ponds. A series of tide gates installed at the heads of tidal gullies that lead into the ponds being treated resulted in the prevention of significant flooding in July, August, and early September for five of the six ponds being treated.

Monitoring of the effectiveness of the remediation showed a greater than 76% reduction in the white phosphorus mass of planted particles in Pond 183 and lesser levels in other locations. Other studies included in this year's report are the waterfowl use and mortality studies, the additional sampling for white phosphorus contamination in ponds in Areas A and in C/D that had either not been sampled before or had only limited sampling, and the collection of environmental and habitat information for Eagle River Flats for inclusion in the GIS database.

Collins, C.M. (2000) Weather data for Eagle River Flats. In *Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 1999.* USA CRREL Contract Report to U.S. Army Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 97–104.

The summer of 1999 had normal to slightly above-normal temperatures for June through September. Precipitation was below normal in June, slightly above normal in July, and considerably above normal in August and the first half of September. May and June are normally the driest months of the core drying season needed for treatment of contaminated pond bottom sediments. The cooler weather and flooding tides of May eliminated any effective drying that month, but June and the first week of July provided near ideal drying conditions. There were 30 days during the summer with maximum temperatures of 20°C or more. This compares to only 18 days during the summer of 1998. After 9 July, the net evaporation rate decreased dramatically because of the increased rainfall, more complete cloud cover, and resulting decreased evaporation. Several large rainfall events occurred in August, with 25 mm (1 in.) falling on 13 August.

Cummings, J.L., P.A. Pochop, R.E. Johnson, K.S. Gruver, D.L. York, J.E. Davis, J.B. Bourassa, B.S. Dorr, and C.H. Racine (2000) Movements, distribution, and relative risk of Mallards using Eagle River Flats: 1999. In *Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 1999.* USA CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 19–32.

We determined spatial distribution, movements, turnover rate, and mortality of Mallards using Eagle River Flats, Fort Richardson, Alaska, during fall migration, 4 August to 14 October 1999. We randomly captured 116 Mallards between 4 and 18 August on ERF using a net gun from a Bell 212 helicopter. Each duck was banded and fitted with a 9.1-g backpack transmitter and released at its capture site. All 116 Mallards were fitted with standard mortality transmitters that emit about 60 pulses per minute when the duck is alive. If the duck dies, the transmitter will emit about 120 pulses per minute. Tracking data indicated that transmitters did not appear to inhibit Mallard movements or activities. LOCATE II was used to map telemetry locations.

Mallard movements and distribution indicate that they spent about 82% of their time in Areas A, B, C, and C/D. In addition, Mallards spent about 61% of their time in areas that are considered contaminated (A, BT, C, C/D, and RI). The average daily turnover rate for waterfowl was about 1.3%. The greatest turnover of waterfowl occurred from 20–31 August and 15–27 September when 29 and 20% of the Mallards, respectively, departed ERF. Mortality of instrumented Mallards that used ERF from 4 August to 14 October was 34. Of those, 24 were attributed to white phosphorus ingestion. The greatest mortality occurred in Area A, 9 of 24 (38%); Area C, 6 of 24 (25%); and Areas C and C/D, each 6 of 24 (25%). Overall, these areas accounted for 88% of the Mallard mortality on ERF. We recovered 11 whole duck bodies from the 24 white phosphorus mortalities. Analysis showed that all 11 were positive for white phosphorus.

A mortality model was developed for ERF to estimate the total individual dabblers using ERF, the peak number of dabblers using ERF, and the total number of duck mortalities on ERF during the fall migration period. In 1999, 1334 individual dabblers used ERF from 4 August to 14 October. Dabblers peaked at 650 between 21 and 24 August and 721 between 21 and 28 September. The overall mortality that occurred on ERF was 198 dabblers. The aerial counts and the model reflected a 55% decrease in the number of dabblers using ERF. In conclusion, the use of radio telemetry to collect data on Mallard distribution and mortality on ERF since 1996 has been an effective and safe method to measure the effects of remediation actions, such as pumping, draining, and AquaBlok®.

Eldridge, W.D., and D.G. Robertson (2000) Waterbird utilization of Eagle River Flats: April to October 1999. In *Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 1999*. USA CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 9–18.

Aerial surveys to monitor waterbird use of Eagle River Flats (ERF) during the spring, summer, and fall of 1999 were flown by the U.S. Fish and Wildlife Service as part of the on-going waterbird mortality and monitoring studies of ERF sponsored by the U.S. Army at Fort Richardson, Anchorage, Alaska. Numbers of waterbirds were counted or estimated and recorded by species or species group at locations on ERF, using standardized study areas.

Nearly 100% of ERF remained snow-covered on 21 April 1999. By 3 May, however, the entire flats were approximately 85% open. The summer of 1999 was generally wet, and water conditions throughout Cook Inlet were good. Pumping continued to keep parts of Areas A, C, and C/D dry, so in general less of the preferred habitat was available to ducks than in previous years. In late September, flood tides again inundated ERF. Skim ice formed periodically in early October, but ERF was 90% open on 13 October, then frozen again, and open again from tides in late October.

Tundra and trumpeter swans utilized ERF in small numbers during 1999. Lesser snow geese made up 79% of the total geese counted in spring, followed by Canada geese. Duck species utilizing ERF in 1999 were similar to other years, dabbling ducks making up 99%. It is clear that in 1999 ERF supported fewer ducks than previous years. In spring the number of ducks peaked on 3 May and the peak was considerably higher than other recent years. Utilization of Area C remains reduced from 1997, but the most noticeable reduction is in the use of Area C/D, which may be attributed to increased pumping in that area in 1999. Use of the permanent ponds of Areas D and B increased, perhaps reflecting the lack of availability of habitat in the treated areas. The numbers of Bald Eagles *(Haliaeetus leucocephalus)* were low, similar to recent years. Lower numbers of eagles in recent years may be ascribed to the decreased mortality of waterbirds on ERF. The numbers of shorebirds were lower than in recent years, and no breeding sandhill cranes were observed.

Racine, C.H. (2000) Pond pumping—ditching and habitat change on Eagle River Flats. In *Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 1999*. USA CRREL Contract Report to U.S. Army Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 105–114.

We monitored the changes in vegetation-habitat in and adjacent to five permanent ponds that were drained by summer pumping or by permanent ditching during 1, 2, 3, or 4 years between 1996 and 1999. While pond aquatic species disappeared almost immediately following dewatering, other emergent species, such as mare's tail, declined more slowly over 2 to 3 years. Sedges such as Ramenskii's sedge and Lyngbyei's sedge appear to be fairly stable and resistant to dewatering. Some sedges, such as Mackenzei's and Lyngbyei's sedge, have expanded onto the moist organic sediments on the bottom of a deeper pond pumped over the past 2 years. There is little evidence that salt-tolerant annuals associated with the mudflat zone are invading the newly exposed permanent pond bottoms. Pumping and ditching of deeper ponds in the bulrush marsh area began more recently and evidence of major change is hard to detect, although multispectral imagery shows a decline in "greenness." There is little evidence of major readjusting of habitat and vegetation attributable to WP remediation.

Racine, C.H. (2000) Tidal creek and drainage ditch erosion at Eagle River Flats in 1999. In *Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 1999*. USA CRREL Contract Report to U.S. Army Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 121–125.

Active tidal creek and gully erosion is a major physical process in Eagle River Flats. The high tides and large volume of water that are drained by these gullies on the ebb tide result in large volumes of fast-moving water that can erode both lateral and headward walls of these gullies. This could result in pond drainage similar to that produced by blasting ditches. The erosion represents a loss of mudflat habitat and could also influence both the remediation success and our ability to restore the wetland habitat once remediation is completed. In addition, erosion can uncover buried munitions. In 1998, we developed a remote sensing technique for monitoring gully erosion and applied it to one gully. This extends some of this work by comparing erosional change from 1998 to 1999.

There has been little new erosion of the headwalls of the three natural gullies draining the treated ponds on the east side of Eagle River Flats during the past year (August 1998 to August 1999). However, two lobes at the headwall of the constructed ditch in the Bread Truck Pond continue to erode at an average of about 8–10 m per year. These will eventually develop into two separate gullies, which may uncover additional ordnance buried by sediments in the Bread Truck Pond as they erode. An effort may be required to stop this "runaway" erosion of the Bread Truck ditch, either by construction of a tide gate or by other means.

Racine, C.H., and C.M. Collins (2000) Updated species list for Eagle River Flats, Alaska. In *Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 1999*. USA CRREL Contract Report to U.S. Army Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 115–120.

We present an updated species list of birds and vascular plants for Eagle River Flats. As monitoring studies and remediation efforts have been carried out over the last several years, additional species have been added to each of the two lists that were originally compiled as part of the extensive site investigation studies carried out in Eagle River Flats during 1990 through 1995 to evaluate white phosphorus distribution, persistence, and ecological risk. As of 1999 there have been 97 species of birds observed in or along the border of Eagle River Flats, indicating the rich diversity of this salt marsh complex and the important ecological role it plays in the Upper Cook Inlet Region. We also include the list of invertebrate species identified in sediment samples collected in Eagle River Flats.

Walsh, M.E., C.M. Collins, and R.N. Bailey (2000) Composite sampling and analysis for white phosphorus in untreated ponds. In *Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 1999*. USA CRREL Contract Report to U.S. Army Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 89–96.

Ponds that were unambiguous sources of waterfowl poisonings are undergoing remediation at ERF. Much of Area C has been drained by pumping, and the Bread Truck Pond and Racine Island ponds have been drained by ditching. These treatments remove severely contaminated ponds as waterfowl-feeding habitat for part of the year. Mortality of telemetry Mallards indicates that localized areas of contamination (hotspots) may still be present in Area C/D and possibly Area A. In 1999, we collected composite samples from Areas A, C/D, and Coastal East, where previous sampling was sparse or non-existent. We found two small areas of contamination: 1) Pond 75, which is on the boundary of Area C/D and Coastal East, and 2) part of Pond 226 in Northern Area A. Contamination was not widespread in either case; neighboring composite samples were blank.

We also sampled two ponds where we suspected contamination based on the pond location or previous sampling. Pond 511 in Area C and Pond 680 on Racine Island were both blank.

Walsh, M.E., C.M. Collins, and R.N. Bailey (2000) Treatment verification: Monitoring the remediation of white phosphorus contaminated sediments of drained ponds. In *Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 1999*. USA CRREL Contract Report to U.S. Army Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 49–88.

The in-situ decontamination of white phosphorus contaminated sediments at ERF by pond pumping continued, and it was monitored with the three part approach developed in 1997. We used dataloggers to record sediment moisture and temperature to see if conditions were favorable for sublimation-oxidation, we measured residual white phosphorus from particles that we planted in the surface sediment, and we resampled areas of known contamination.

The main pond of Area C (Pond 183) has been pumped for three consecutive seasons. This year (1999), the pond was dewatered by pumping in early June and the sediments dried significantly until a series of flooding tides on 14–19 June. Sediments dried rapidly after the flood and were unsaturated for several weeks until persistent rainfall in late July and August. All measures of white phosphorus showed a continuing decline in contamination. Four of the five white phosphorus particles planted decreased from an initial mass of 5.6 ± 0.5 mg to less than or equal to 0.5 mg. One particle showed no change. The composite sample taken from the middle of Area C (C 100 m) has declined from 0.07 μg/g in June 1997 to 0.002 μg/g in September 1999. Discrete samples obtained on a 1.82-m square grid in the previously highly contaminated DWRC Pen 5 showed a decline in both the number of positive samples (from 48 in 1996 to 13 in 1999) and the highest concentration found (420 to 0.036 μg/g). We collected subsurface samples from six locations in Pond 183 that were cored in 1992 and had white phosphorus contamination along the core length. In 1999, white phosphorus was undetectable at five of the six locations. Finally, white phosphorus in Miller's Hole, the crater produced when a white phosphorus-containing UXO was detonated in 1992, is now just barely detectable (0.0008 μg/g) compared to 2400 μg/g in a sample collected on the day of the detonation. Pond pumping is successfully remediating Pond 183.

We sampled Pond 146 adjacent to Canoe Point in an area that showed contamination remaining after dredging. Contamination remains in the surface sediment. We frequently observe ducks using this area, and it may be an important source of poisoning. The sump for this pond was deepened significantly in September 1999 in an effort to enhance drying of this contaminated area during the next 4 years.

Pond 155, to the northeast of Pond 183, is also drained by pumping, but is more difficult to desaturated because of its location within a bulrush marsh. Some minimal drying occurred, but planted particles showed no change in mass. A grid for collecting composite samples was established last fall, but no decline in white phosphorus concentration is evident.

Ponds 258 and 256 were drained for the second consecutive season and both showed drying and a decline in the mass of planted white phosphorus particles of 50 and 48%, respectively. An additional 17 composite samples were taken for Pond 258, but no white phosphorus was detected.

Pond 730 in Area C/D was newly drained by pumping this year, based on the significant mortality of radio-collared ducks there. No white phosphorus was detectable within this pond, but we did locate a hotspot to the north of the pond. This pond was flooded frequently by flow from blasted Bread Truck gully. Some drying and sediment consolidation occurred in this pond and there was loss of white phosphorus from the planted particles at the monitoring stations.

The Bread Truck Pond (Pond 109) dried significantly on the north side, near the blasted ditch. Planted white phosphorus particles declined by 72%, and the white phosphorus concentration in the composite sample near the ditch (BT North 100 m) is only 0.0003 μg/g, declining from 0.012 μg/g in June 1997. The south side of the pond remains wetter owing to frequent flooding and incomplete drainage to the ditch, and decontamination has been minimal. Erosion of the ditch is significant. Advancement of the ditch towards the east exposed a white phosphorus mortar round, which we located by smoke wisping within a gully lobe. Serious consideration should be given to controlling the erosion and flooding from this ditch.

Walsh, M.R., and C.M. Collins (2000) Eagle River Flats pond pumping remediation project: First-year deployment under the record of decision. In *Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 1999*. USA CRREL Contract Report to U.S. Army Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 33–48.

The 1999 field season marks the beginning of the remediation phase for the Eagle River Flats project. This year, tidal predictions indicated a very poor year for remediation at the Flats because of monthly inundation during lunar high tides. However, owing to a slight shift in the riverbed at the south end of the Flats and the increased effectiveness of the tide gates in Area C because of continuing modifications, Areas C and A experienced a treatment season of 102 contiguous days without flooding.

Deployment changes were made over last season. Pond 290 in Area A is no longer being treated, as no significant contamination remained at the end of the 1998 season. A sump was blown in Pond 730, Area C/D, and a 126-L/s pump was placed there. A sump was also blasted in the dredge channel in Pond 146 for the large 189-L/s pump. This allows us to draw Pond 146 down significantly more than in 1998, thus addressing some of the contaminated areas in the vicinity on Canoe Point. Additional ditches were made using Bangalore torpedoes and detonation cord to expedite drainage in treated areas.

This year, we had three 1100-L, double-walled fuel tanks to supplement the two 1900-L tanks used in the field last year. The lack of flooding after the June high tides resulted in a sharp drop in the necessity to refuel the field systems. Logistics still need to be worked out to make the most efficient use of these assets. Three additional 1100-L tanks have been ordered to allow complete field refueling and defueling with a Bell 212 helicopter, thus reducing our reliance on the Blackhawks and significantly reducing costs.

A team from Weldin Construction, Inc., led by Terry Edwards, conducted the field operation and maintenance work this year. The results were excellent. They were able to address and work through a number of potentially crippling problems in the field. As a result, there was no significant unplanned downtime this year. The controls were once again reconfigured and rewired, this time to address stuck float switches. This will also increase the reliability of the systems, as the controls were simplified in the process. A developmental video monitoring system was deployed, with mixed results. Although it was a valuable tool, more work needs to be done before it becomes useful.

Next season looks to be unavoidably bad, with tides in excess of 9.75 m (32 ft) every month. The option of whether or not to deploy was considered, and the decision was made to recommend deployment to ensure continuity of the project, to reduce the effects of inundation of the ponds under treatment (especially Pond 730), and to work out the new communications structure of the meteorological station and the video monitoring system.

Collins, C.M., and D.W. Cate, eds. (2001) Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 2000. USA CRREL Contract Report to U.S. Army Alaska, Directorate of Pubic Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. August.

This is the eleventh annual contract report prepared by researchers from CRREL and other Federal agencies for U.S. Army Engineer District, Alaska, and U.S. Army Alaska, Public Works, describing the results of research, monitoring, and remediation efforts addressing the white phosphorus contamination in Eagle River Flats, an 865-ha estuarine salt marsh on Fort Richardson, Alaska. Fort Richardson is on the National Priority List, and Eagle River Flats is designated Operable Unit C (OUC) under the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA).

This year marks the second of a planned five-year remediation effort in Eagle River Flats. Pond pumping, using six remote-controlled pumps to temporarily drain contaminated ponds within several areas of Eagle River Flats, was conducted again this year. The pumps kept the ponds drained for an extended period during the summer, allowing the pond bottom sediments to dry and the white phosphorus to sublime and oxidize. The logistics continued to be fine-tuned, leading to a more effective and efficient operation this year.

The combination of a warm, dry period during the first half of the summer and the successful use of floodgates to prevent flooding tides resulted in a long and effective drying season. Sampling showed that levels of contamination continued to decline, although localized areas of contamination still exist.

Collins, C.M. (2001) 2000 Weather data for Eagle River Flats. In *Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 2000.* USA CRREL Contract Report to U.S. Army Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 71–78.

May and June are normally the driest months of the core drying season needed for treating contaminated pond bottom sediments. This year the timing of the last spring flooding tide in early May allowed us to deploy equipment and pump the ponds out so that we could take advantage of the warmer weather of late May to start the drying process. June and early July provided nearly ideal drying conditions except for an occasional rainstorm.

The summer of 2000 had normal to slightly above-normal temperatures for May and June. There were 38 days from mid-May to mid-August 2000 with maximum temperatures of 20°C or more. This compares to only 30 days during the summer of 1999 and only 18 days during the summer of 1998. Temperatures were below normal for August and September.

Precipitation was minimal from late May through almost all of June, with a precipitation total from 24 May through 28 June of only 8 mm. Thirteen of the days with maximum temperatures of 20°C or more also occurred in this dry spell, contributing to the excellent sediment drying conditions during this period.

Eldridge, W.D. (2001) Waterbird utilization of Eagle River Flats: April–October 2000. In *Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 2000.* USA CRREL Contract Report to U.S. Army Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 7–18.

Aerial surveys to monitor waterbird use of Eagle River Flats (ERF) during the spring, summer, and fall of 2000 were conducted by the U.S. Fish and Wildlife Service as part of the ongoing waterbird mortality and monitoring studies of ERF sponsored by the U.S. Army at Ft. Richardson, Anchorage, Alaska. Numbers of waterbirds were counted or estimated, recorded by species or species group, and classified by locations on ERF using standardized study areas.

ERF experienced an earlier breakup in 2000 than in 1999, which was a late year. The first half of the summer of 2000 was generally dry, and ERF ponds were low or dry, similar to water conditions throughout Cook Inlet. Extensive pumping was effective in drying large portions of ERF in 2000. After pumping ceased in mid-August, ponds gradually refilled in most areas. Fall high tides did not occur until early October in 2000.

Tundra and trumpeter swans utilized ERF only in small numbers during the spring of 2000 In fall, swan numbers peaked in mid-September at 189 birds, lower than in other recent years except 1999. Peak counts of geese occurred on 27 April, primarily lesser snow geese; fall goose migration was similar to other years except that fewer geese used ERF. Duck species utilizing ERF in 2000 were similar to other years. The mean number of ducks per survey during summer, 127, was lower than the 1988–1997 mean of 190. The mean number of ducks observed in the fall, 435, was considerably lower than the 1988–1997 mean of 836, and is the third year in a row of markedly lower fall numbers. This trend is likely related to the effects of pumping and draining on both the amount of habitat available and the food resources. Numbers of Bald Eagles were low in 2000, similar to recent years. Numbers of shorebirds were lower than in recent years. The mew gull colony, formerly in Area D, now consists of just a few pairs. No breeding Sandhill Cranes were observed on ERF in 2000.

Racine, C.H. (2001) Eagle River Flats database and environmental change monitoring. In *Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 2000.* USA CRREL Contract Report to U.S. Army Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 87–89.

We entered into the database the locations and white phosphorus concentrations for all sediment samples obtained during 2000 so that the database now includes all samples analyzed for white phosphorus from the beginning of the project in 1991 to September 2000. This includes over 3000 point samples and 300 composite samples. During the past year the entire database was transferred to the USARAK GIS, a large database used by the Ft. Richardson DPW environmental branch to manage contamination and cleanup efforts on the U.S. Army facilities in Alaska. During 2000 we developed a CD that contains all of the telemetry data from 1996 to 1999. (In 2000 no telemetry took place.) We also produced maps to show additional erosion of the ditch draining the Bread Truck Pond.

Walsh, M.E., C.M. Collins, and R.N. Bailey (2001) Composite sampling and analysis for white phosphorus in untreated ponds. In *Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 2000.* USA CRREL Contract Report to U.S. Army Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 63–70.

Mortality of telemetry Mallards indicates that localized areas of contamination (hotspots) may still be present in Northern C, Area C/D, and possibly Area A. In 2000, we continued to collect composite samples from Areas A and C/D where previous sampling was sparse or non-existent. We also sampled some small open-water pools within the marsh of Area C and the northern part of Pond 146, which is undrained. All of the new samples in Areas A and C/D were blank. In Area C, one composite sample from the marsh was positive; the white phosphorus concentration was 0.03 μg/g. This concentration is high enough to be of concern.

Walsh, M.E., C.M. Collins, and R.N. Bailey (2001) Treatment verification: Monitoring the remediation of white phosphorus contaminated sediments of drained ponds. In *Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 2000.* USA CRREL Contract Report to U.S. Army Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 37–62.

The in-situ decontamination of white-phosphorus-contaminated sediments at ERF by pond pumping was monitored again with the three part approach we developed in 1997. To see if pond pumping produced conditions favorable for sublimation/oxidation of white phosphorus particles, we used dataloggers to record sediment moisture and temperature, and we measured residual white phosphorus from particles we planted in the surface sediment. Also, we resampled previously identified hot spots to see if the white phosphorus concentrations had declined.

The main pond of Area C (Pond 183) has been pumped for four consecutive seasons. This year (2000), the pond was dewatered by pumping in early May and the sediments dried significantly until a series of flooding tides July 2 to 4. Sediments remained wet through July and August due to frequent precipitation and tidal flooding in August. Despite cool surface sediment temperatures (mean of 14.8°C) during the time that the sediment was unsaturated, we measured a 56% loss of mass of the white phosphorus particles we planted in May 2000 and recovered in August 2000. White phosphorus concentration the middle of Area C (C100 m grid), as determined by composite sampling, has declined from 0.07 µg/g in June 1997 to 0.00055 µg/g in August 2000. A milestone was reached at Miller's Hole, the crater produced when a white phosphorus-containing UXO was detonated on 20 May 1992. In samples of the surface sediment collected from the bottom of the crater in August 2000, white phosphorus was undetectable for the first time since we began sampling the crater when the concentration was over 2000 µg/g. However, Pond 183 is not completely decontaminated. White phosphorus is still detectable in discrete samples collected from the DWRC Pen 5, although only four samples have concentrations greater than 0.001 ug/g (in 1996 all 48 samples were greater than 0.001 µg/g). A few more favorable drying seasons should complete the decontamination of Pond 183.

We installed a datalogger and resampled Pond 146, adjacent to Canoe Point in Area C, in an area that was dredged in 1996 but still had high white phosphorus concentrations in 1999. Particles planted in Pond 146 declined in mass by 27%; composite samples showed a greater loss, with one sample declining from 7.31 µg/g in June 1999 to 0.001 µg/g in August 2000.

Pond 155, to the northeast of Pond 183 in Area C, is located within a bulrush marsh, and the sediments do not dry significantly. This year, planted particles did show a 32% decrease in mass, as compared to last year when no change was found. A grid for collecting composite samples was established in 1998, but no decline in white phosphorus concentration is evident.

Ponds 258 and 256 in Area A were drained for the third consecutive season and both showed drying and a decline in the mass of planted white phosphorus particles of 89 and 92%, respectively.

Pond 730 in Area C/D was drained by pumping for the second year, but minimal drying occurred because of frequent flooding from the Bread Truck ditch. Pond 75 in Coastal East was drained this year because we found white phosphorus in a composite sample collected in 1999. This pond also floods from the Bread Truck ditch and minimal drying occurred.

The former Bread Truck pond experienced 20 flooding tides between June and August, which eroded more of the pond and further enlarged the blasted ditch. After the flooding tides at the beginning of June, both the north and south sides of the pond dried. Planted white phosphorus declined by 79 and 32% for the north and south sides, respectively. White phosphorus is barely detectable in the composite samples collected from the north and south sides of the pond.

Because of the death of telemetry birds in the Aquablok®-treated pond (285) on Racine Island, we were asked to take composite samples of the surface sediment for white phosphorus analysis. We collected five composites, all of which were positive with white phosphorus concentrations ranging from 0.023 to 6.90 µg/g. We also collected eight discrete samples, two of which were blank, and the remaining six ranged from 0.00014 to 6.38 µg/g. This pond needs further remediation.

Walsh, M.R., and C.M. Collins (2001) Eagle River Flats pond pumping remediation project: Second-year deployment under the record of decision. In *Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 2000.* USA CRREL Contract Report to U.S. Army Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 19–36.

The 2000 field season is the second year of the remediation phase of the Eagle River Flats project. This year, tidal predictions indicated a very poor attenuation year at the Flats due to monthly inundation during lunar high tides. However, due to the effectiveness of the tide gates, a successful treatment season occurred in Areas C and A. Work continued at improving logistics, improving equipment reliability, and addressing contaminated areas adjacent to treated areas.

Deployment of the pump units was the same this year as last, with two units in Area A (Ponds 256 and 258), three units in Area C (Ponds 146, 155, and 183), and one unit in the C/D Area (Pond 730). The tide gates prevented flooding during a critical tidal cycle in early June, when we prevented flooding during the 32.3-ft event, 1.2 ft above normal flood stage. This gave us a 52-day contiguous non-flooded period during the critical first months of the season when rainfall is low and attenuation conditions are normally at their best. Significant drying occurred in the A Ponds for the first time, and results from all ponds except Pond 730 indicate this was a very successful season.

Logistics continue to be refined, with an emphasis on optimizing the utilization of helicopters when on site. Deployment of the discharge line and heavy equipment is now accomplished in one day. Sling loading the pipe in and out of the Flats has proven to be quite effective, although there were problems getting the right helicopter for the job. The heavy equipment aerial transfer operations are going quite smoothly, with Weldin, CRREL, and the National Guard all contributing to the effort. In August, all the equipment was transferred to the EOD Pad by 1430 hr, even though we had more equipment in the field than we have ever had for the project. As a result of preventing flooding in June and optimizing flight time with the commercial helicopter, $40,000 was saved on that contract. The money will go towards a badly needed overhaul of the generator sets this fall and to exercise the gensets over the winter.

A team from Weldin Construction, Inc., led by Terry Edwards, conducted the field operation and maintenance work again his year. The results were excellent, and again no significant unplanned downtime occurred. The controls were once again reconfigured and rewired to address stuck float switches. This will also increase the reliability of the systems, as the controls were simplified in the process. A revised video monitoring system was deployed with very good results and was used throughout the season to monitor conditions in both Area A and Area C. The meteorological site was once again operational and accessible over the internet at the Flats Web site.

Next season looks to finally be favorable for remediation at the Flats. Moderate flooding tides in mid-July may be contained by the tide gates, and major flooding tides will not occur until mid-August. A determination, based on sampling work, will have to be made on where the systems will be deployed next season, and additional blasting work will need to be done to address areas found to be contaminated this year. The purchase of lightweight, single-wall fuel transfer tanks capable of being lifted by the A-Star helicopter is anticipated to further reduce helicopter expense.

Williams, C.R., and G.M. Trachier (2001) Eagle River Flats wireless remote imaging system. In *Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 2000*. USA CRREL Contract Report to U.S. Army Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 79–86.

A remote imaging system proved to be useful for monitoring the daily operations of the Pond Pumping Remediation Project at Eagle River Flats. By visually inspecting the daily retrieved images from the remote imaging systems, project managers could monitor the effectiveness of the pumping remediation efforts. Retrieving images from ERF proved to be difficult during the 1999 field season. We analyzed the shortcomings and designed a new robust image retrieval system from the bottom up. The new system, based on wireless technology, was deployed in two ponded areas under treatment.

The retrieved images were successfully used throughout the 2000 field season to monitor the conditions of the pumping remediation efforts. The images that were retrieved and posted to the ERF Web site proved to be invaluable. The images allowed project managers to view the effects of the pumping remediation operations, the drying of soil, the tidal activity, and the flooding events at the Flats. It is apparent that a variety of new applications are possible with the success of the remote imaging system.

Weldin Construction, Inc. (2001) Field summary report: 2001 work season. Contract Report to U.S. Army Corps of Engineers and U.S. Army, Alaska.

Eagle River Flats (ERF) has completed the third year of post-Record of Decision (ROD) remedial activities. As indicated in its initial 1999 Field Summary Report, Weldin Construction, Inc. (WCI) was hired to support CRREL (Cold Regions Research and Engineering Laboratory) for remedial activities at ERF, a source area of Operable Unit C (OUC), Fort Richardson, Alaska. WCI was notified that this area consists of a former open burning/open detonation pad, and that remedial activities were currently underway at the ERF portion of OUC. The selected remedy for ERF presented in the ROD consists of treating white phosphorus (WP)-contaminated sediment by draining permanently flooded pond areas with pumps, which will result in sublimation/oxidation of the WP, and capping areas that do not desaturate and increase in temperature.

Prior to the initial 1999 work season, WCI was provided with a fieldwork plan that presented the technical work requirements needed to successfully support the pond pumping effort and to meet the requirements of ROD. WCI's primary role as field contractor is to support CRREL with its remedial and monitoring activities. Piping, check valves, and supplemental materials such as fence posting were loaded onto helicopters at the OB/OD pad and then unloaded at the ERF mudflats. The unexploded ordnance (UXO) subcontractor first cleared all areas of UXOs where piping was to be placed and where the helicopter was going to land. Most piping was transported by helicopter in bundles of 8 to 10 pieces, and bundles were dropped strategically along the proposed location of the discharge line. The pipe was then laid out and clamped together by hand. The piping was tied down by using fence posting and rope to avoid large amounts of movement during high tides.

For the 2001 season, the systems were stationed at Ponds 183, 730, 246, 155, 146, and 75. Ponds 146, 155, and 183 are in Area C; these areas were easily accessed from the OB/OD pad. Pond 730 is in Area C/D. Most of WCI's activities are performed on foot, with the exception of fueling activities that require the use of helicopters.

WCI provided support to CRREL during the installation and removal of the pumps and generators to and from ERF. The pumps, generators, and fuel tanks were transported to remote locations within ERF by a UH-60 Blackhawk helicopter. The pumps were connected to the discharge lines with flexible hose to ensure mobility during starting, pump down, and stopping, when the pump moves about in the sumps.

All equipment had to be anchored to the ground to decrease excessive movement during high tides and winds and to reduce strain on the flexible hose at startup. CRREL placed the float switches for each generator set at the desired water height on fence posting. Demobilization of the equipment was accomplished through the use of a CH-47D Chinook helicopter.

Collins, C.M., and D.W. Cate, eds. (2002) Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 2001. USA CRREL Contract Report to U.S. Army Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. July.

This is the twelfth annual contract report prepared by researchers from CRREL and other Federal agencies for U.S. Army Engineer District, Alaska, and U.S. Army Alaska, Public Works, describing the results of research, remediation, and monitoring efforts addressing the white phosphorus contamination in Eagle River Flats, an 865-ha estuarine salt marsh on Fort Richardson, Alaska. Fort Richardson is on the National Priority List, and Eagle River Flats is designated Operable Unit C (OUC) under the *Comprehensive Environmental Response, Compensation and Liability Act* (CERCLA).

This year was the third year of a planned five-year remediation effort in Eagle River Flats. Pond pumping, using six remote-controlled pumps to temporarily drain contaminated ponds within several areas of Eagle River Flats, was again conducted this year. The pumps kept the ponds drained for extended periods during the summer, allowing the pond bottom sediments to dry and the white phosphorus in the sediment to sublime and oxidize. The logistics of the pumping operations, especially the installation of the equipment in the spring and the removal of the equipment in the fall, continued to be refined, leading to more effective and efficient operations.

The combination of warm, dry weather during the first half of the summer and the successful use of floodgates to prevent flooding tides resulted in a long and effective drying season. Sampling showed that levels of contamination in the treated ponds continued to decline. Additional areas of localized contamination were identified that will be treated in the future.

The first section of this report is a progress report reviewing the overall project from the initial remedial investigations, through the treatability study phases, to the implementation of the preferred remediation method. It reviews the progress of the remediation through the first three years. It also reviews the ongoing monitoring efforts used to assess the effectiveness of the remediation efforts. And finally it addresses specific issues and procedures raised in the Proposed Plan and the Record of Decision.

Collins, C.M. (2002) 2001 Weather data for Eagle River Flats. In *Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 2001.* USA CRREL Contract Report to U.S. Army Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 121–130.

Average air temperatures in Eagle River Flats were much higher than normal during June (+2°C) and higher than normal during late May (+0.5°C) and August (+1°C). Temperatures were slightly lower than normal for July (–0.5°C) and early September (–1°C). May and June are normally the driest months of the core drying season needed for treatment of contaminated pond bottom sediments. Late May and June provided nearly ideal drying conditions for the pond pumping remediation project. Precipitation was far below normal for the last half of May and June (0.5 and 7.9 mm of precipitation, respectively.) This was 3 and 27% of normal for these time periods. On 3 July, however, things changed as we began a four-week period of almost daily rain. The total rainfall for July in Eagle River Flats was 72.6 mm, some 67% higher than the normal July rainfall for Anchorage. Conversely, August turned out to be drier than normal, with a total rainfall of 27.7 mm, more than 55% below the normal August rainfall for Anchorage.

Collins, C.M., M.R. Walsh, M.E. Walsh, and C.H. Racine (2002) Operable Unit C (Eagle River Flats) remediation progress report through 2001. In *Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 2001.* USA CRREL Contract Report to U.S. Army Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 9–24.

This report gives a brief overview of the Eagle River Flats remediation from the discovery of waterfowl dieoffs in 1982 through the conclusion of the 2001 field season. Treatment alternatives and the final choice of a treatment method that will comply with the ARARs are discussed. The Flats are described, with the pond groups thought to be contributing most to the die-offs covered in more detail. The mortality model, upon which the RA endpoint success is determined, is described, and the results to date illustrated. The pre- and post-ROD remediation efforts at ERF are briefly described up through the 2001 season. A discussion follows on compliance with RAOs. Current remedial activities and unresolved issues are also discussed.

Cummings, J.L., P.A. Pochop, R.E. Johnson, K.S. Gruver, D.L. York, J.E. Davis, J.B. Bourassa, K. Shively, and B.S. Dorr (2002) Movement, distribution, and relative risk of Mallards using Eagle River Flats: 2001. In *Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 2001.* USA CRREL Contract Report to U.S. Army Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 39–52.

We determined the spatial distribution, movements, turnover rate, and mortality of Mallards using Eagle River Flats during fall migration, 2 August to 17 October 2001. One hundred twelve Mallards were randomly captured between 2 and 10 August on ERF using a net gun from a Bell 212 helicopter. Each Mallard was banded and fitted with a 9.1-g backpack transmitter and released at its capture site. All 112 Mallards were fitted with standard/mortality transmitters that emit about 60 pulses per minute when the duck is alive. If the duck dies, the transmitter will emit about 120 pulses per minute. Tracking data indicated that transmitters did not appear to inhibit Mallard movements or activities. LOCATE II was used to map telemetry locations.

Mallard movements and distribution indicate that they spent about 40% of their time in Area C/D and about 24% of their time in Area A. Overall, Mallards spent about 86% of their time in Areas A, B, C, and C/D. The average daily turnover rate for waterfowl was about 3.8%. The greatest turnover of waterfowl occurred 17 to 24 from August and 26 to 27 September, when 42 (38%) of the Mallards departed ERF. Mortality of instrumented Mallards that used ERF from 2 August to 17 October was 17. Of those, 11 were attributed to ingestion of white phosphorus. Mortality occurred in Areas A, 1 of 11 (9%); B, 1 of 11 (9%); C, 3 of 11 (27%); and C/D, 6 of 11 (55%). Seven whole duck bodies from 11 white phosphorus mortalities were recovered. Analysis showed that all seven were positive for white phosphorus.

A mortality model was developed for ERF to estimate the total individual dabblers using ERF, the peak number of dabblers using ERF, and the total number of duck mortalities on ERF during the fall migration period. In 2001, 3628 individual dabblers used ERF from 2 August to 17 October. Dabblers peaked at 1842 dabblers between 22 and 25 September. The overall mortality that occurred on ERF was 87 dabblers. Overall waterfowl mortality in the fall has decreased about 87% from 1996 to 2001. The use of radio telemetry to collect data on Mallard distribution and mortality on ERF since 1996 has been an effective and safe method to measure the effects of remediation actions such as pumping, draining, and AquaBlok®.

Eldridge, W.D. (2002) Waterbird utilization of Eagle River Flats: April–October 2001. In *Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 2001.* USA CRREL Contract Report to U.S. Army Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 25–38.

Aerial surveys to monitor waterbird use of Eagle River Flats (ERF) during the spring, summer, and fall of 2001 were conducted by the U.S. Fish and Wildlife Service. Numbers of waterbirds were counted or estimated during aerial survey flights, recorded by species or species group, and classified by locations on ERF using standardized study areas. Tundra and trumpeter swans used ERF only in small numbers during the spring of 2001; in fall, swan numbers peaked in late September at 258 birds. Peak counts of geese occurred on 21 April, primarily Lesser Snow Geese. Fall goose migration was similar to other years. Duck species using ERF in 2001 were similar to other years. The mean number of ducks per survey during the summer (105) was lower than the 1988–1997 mean of 190. The mean number of ducks observed in the fall, 694, was considerably above the average of 438 in 2000 but lower than the 1988–1997 mean of 836. The effects of pumping and draining on the amount of habitat and food resources available may be influencing duck use of ERF. Numbers of Bald Eagles were low in 2001, similar to recent years. Numbers of shorebirds were lower than in recent years. The mew gull colony formerly in Area D now consists of just a few pairs. At least one pair of sandhill cranes nested in ERF in 2001.

Racine, C.H. (2002) Disturbance and recovery of permanent pond habitat at Eagle River Flats. In *Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 2001.* USA CRREL Contract Report to U.S. Army Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 141–144.

Over the past eight years (1994–2001), efforts to remediate white phosphorus contamination in Eagle River Flats have directly affected 14 permanent ponds covering about 16 ha, or one third of the total permanent pond waterfowl habitat (50 ha) on ERF. Ponds have been temporarily drained by pumping from 80 to 120 days during one to five summers. The impact of draining these ponds includes the loss of aquatic and emergent vegetation as well as consolidation and probable loss of organic matter, fish, and invertebrates in the sediments. Once the white phosphorus has sublimed over a period of several summers, pumps will no longer be deployed and the ponds will be allowed to recover. Monitoring of these ponds should help determine if these ponds return to functioning waterfowl habitat with food and cover equivalent to that before treatment.

Walsh, M.E., C.M. Collins, C.H. Racine, and R.N. Bailey (2002) Composite sampling and analysis for white phosphorus in untreated ponds. In *Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 2001.* USA CRREL Contract Report to U.S. Army Alaska, Directorate of Pubic Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 111–120.

Mortality of waterfowl indicates that localized areas of contamination (hotspots) may still be present in Northern C, Area C/D, Coastal East, and possibly Area A. This year we concentrated our efforts on intensive sampling of the marsh in Northern C east of Pond 155. We collected 60 grid composite samples, of which 14 had detectable white phosphorus (0.0002–0.26 µg/g). We also collected 33 discrete samples from small open water pools in or near our grid composite samples. Of these samples, 16 had detectable white phosphorus (0.0001–19 µg/g). Of note were four large craters in the northeast corner of Area C, all of which were contaminated with white phosphorus and used by waterfowl. Four of the "last alive signals" from the 11 telemetry duck mortalities in 2001 were within this part of Area C. Also, we found four duck carcasses while sampling east of Pond 155. We collected more samples in Area A (Ponds 138 and 190) and Coastal East, but we did not find any white phosphorus. We also collected samples west of the Aquablok® Pond (Pond 285) on Racine Island, but water cover appeared to be mostly intermittent and only in craters. We sampled five craters, one of which had detectable white phosphorus (0.001 µg/g). Evidence suggests that the marsh east of Pond 155 in Area C is the likely source of most of the current waterfowl poisonings.

Walsh, M.E., C.M. Collins, and R.N. Bailey (2002) Treatment verification: Monitoring the remediation of white phosphorus contaminated sediments in treated ponds. In *Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 2001.* USA CRREL Contract Report to U.S. Army Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 79–111.

The success of pond pumping in reducing the concentrations of white phosphorus in Eagle River Flats was monitored in three ways. Moisture and temperature sensors linked to dataloggers indicated when and if conditions were favorable for decontamination by sublimation/oxidation, the mass of residual white phosphorus from planted particles was measured, and previously identified hot spots were resampled.

The main pond of Area C (Pond 183) has been pumped for five consecutive summers. This year (2001) water was pumped from the pond starting 10 May, and sediments were desaturated by 25 May. The sediments remained unsaturated until heavy rains on 4–5 July. Thereafter, sediments intermittently dried between frequent light rains until flooding tides on 22 July resaturated the sediments. During the time that the sediments were unsaturated, the mean sediment temperature at 5 cm depth was 16.5°C, and the maximum hourly average temperature was 29.2°C on 27 June. With these excellent sublimation/oxidation conditions, there was a 95% loss of mass of the white phosphorus particles we planted in May 2001 and recovered in September 2001. Prior to this year the greatest annual loss for planted particles in this pond was 79% in 1998. White phosphorus concentration the middle of Area C (C 100 m grid), as determined by composite sampling, has declined from 0.07 μg/g in June 1997 to <0.0002 μg/g in September 2001. In five replicate core samples taken to 10-cm depth at Miller's Hole, the crater produced when a white-phosphorus-containing UXO was detonated on 20 May 1992, only one core had a detectable concentration of white phosphorus (0.0003 μg/g). (In 1992 the concentration was over 2000 μg/g.) In the DWRC Pen 5, a site we have resampled since 1996 when all 48 discrete samples were well above the detection limit (0.002–421 μg/g), we resampled the last four remaining discrete locations within the pen that had white phosphorus concentration above 0.001 μg/g in 2000; concentrations were 0.0004, 0.0005, 0.0005, and 0.0006 μg/g in September 2001. Based on these measurements, we can say that hazardous amounts of white phosphorus particles are no longer present in the exposed surface sediments in Pond 183. However, a piece of geotextile that was used by DWRC in their pen studies to provide a clean surface for penned ducks was left next to the pen area in one of the most highly contaminated parts of Pond 183. This year, we sampled under the geotextile and found a high concentration of white phosphorus (1.1 μg/g) at 10- to 20-cm depth. An effort should be made early in the summer of 2002 to remove this geotextile and other debris that may be covering small areas of contaminated sediments in Pond 183.

Pond 146, adjacent to Canoe Point in Area C, an area that was dredged in 1996 but still had high white phosphorus concentrations in 1999, has also shown significant decontamination. During the time that the sediments were unsaturated in 2001, the mean sediment temperature at 5 cm depth was 15.9°C, and the maximum hourly average temperature was 26.8°C on 28 June. Particles planted in Pond 146 declined in mass by 30%; composite samples have shown greater loss, with one sample declining from 7.31 μg/g in June 1999 to 0.0005 μg/g in September 2001. Subsurface samples were taken down to 75 cm depth. White phosphorus was detectable at two depths: 0.0005 μg/g at 5–10 cm and 0.0002 μg/g at 51 cm. In 1992 and 1999 white phosphorus was detectable at all depths sampled, with a maximum concentration of 198 μg/g at 15 cm in 1992. This year white phosphorus was undetectable at 15 cm.

Pond 155, to the northeast of Pond 183 in Area C, is located within a bulrush marsh and has been a difficult pond to remediate. This is the first year that the sediments have showed some significant drying. During the time that the sediments were unsaturated, the average temperature was 19.1°C, and the maximum hourly average temperature was 30.5°C on 27 June. This year planted particles showed an 80% decrease in mass, compared to 1999, when no change was found. A grid for collecting composite samples was established in 1998, and this is the first year that a decline in white phosphorus concentration was evident. This year we took 65 discrete samples from within and parallel to the grid, and 75% of the samples were positive. The highest surface sediment concentration was 0.099 μg/g. We took two cores and found white phosphorus down to 25 cm in one core and 51 cm in the other. The highest concentrations were in the top 20 cm. At least two more good drying years are needed to decontaminate this pond.

Pond 730 in Area C/D was drained by pumping for the third year and Pond 75 in Coastal East for the first year. The loss of planted white phosphorus particles was 89 and 20%, respectively.

The former Bread Truck pond experienced 22 flooding tides during three series of flood events in June, July, and August, which eroded more of the pond and further enlarged the blasted ditch. Despite the flooding tides, the pond dried intermittently. Planted white phosphorus declined by 32 and 78% for the north and south sides, respectively. White phosphorus is no longer detectable in the composite samples collected from the north and south sides of the pond.

Pond 226 in Area A was drained for the first time this year. Planted white phosphorus declined by 83%.

In summary, all ponds showed loss from planted white phosphorus particles. The mean loss for all ponds was 64%. Sublimation/oxidation conditions were excellent throughout June 2001 and marginal the rest of the season. All formerly identified hot spots are either clean or have shown significant decontamination.

Walsh, M.R. (2002) Eagle River Flats pond pumping remediation project: Third-year deployment under the record of decision. In *Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 2001.* USA CRREL Contract Report to U.S. Army Alaska, Directorate of Pubic Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 53–78.

The 2001 field season is the third year of the remediation phase of the Eagle River Flats project. This year, tidal predictions indicated a good possibility of a highly successful season, especially if flooding tides in July could be prevented. Although a record rainfall and a high river stage contributed to sheet flooding in July, very favorable drying conditions in late May and through June resulted in significant drying in all treated ponds. Work continued at improving logistics, improving equipment reliability, and addressing contaminated areas adjacent to treated areas.

Deployment of the pump units was adjusted this year, with one unit in a new pond in Area A (Pond 246), three units returning in Area C (Ponds 146, 155, and 183), one unit in the C/D Area (Pond 730), and one unit in a new pond in Coastal East (Pond 75). The tide gates did not play a significant role this season. The longest contiguous period for drying was 71 days, from 12 May to 21 July. Significant drying occurred at Ponds 155 and 730 for the first time, and Ponds 75 and the Pond 246/226 complex also saw dying during their first year of remediation.

Logistics continue to be refined, with an emphasis on optimizing the utilization of helicopters when on site. The heavy equipment aerial transfer operations are going quite smoothly, with Weldin, CRREL, USARAK, and the National Guard all contributing to the effort. The lightweight fuel transfer tanks were used for the first time this season. They worked out well. In September, last minute cancellation of the Guard helicopter led to the use of a USARAK CH-47D Chinook for retrograde operations. This aircraft and its crew worked out quite well, with all the equipment except the towers airlifted out of the Flats in one afternoon. As a result of optimizing flight time with the commercial helicopter and the use of the USARAK CH-47D, $50,000 was saved on helicopter expenditures. We utilized three connexes for the first time this season, two on the EOD Pad and one at 992. These worked out well, especially in the aftermath of the 11 September terrorist attacks, when our access to the EOD Pad was limited. They saved us at least two days, probably more. They are well worth the small investment and will help us in the spring as well.

A team from Weldin Construction, Inc., led by Dave Mitchell and Terry Edwards, helped in the deployment and retrograde operations and conducted the field operation and maintenance work again his year. Maintenance over the winter on all the generator sets resulted in reduced downtime in the field. A revised video monitoring system was deployed with very good results and was used throughout the season to monitor conditions in Areas A, C, BT, and D. Work done at the end of the season indicates that a more efficient, cost-effective transmission method can be employed next season, further increasing image quality and retrieval success. The meteorological site was once again operational and accessible over the Internet at the Flats Web site. The data retrieval rate was 100%.

Next season looks to finally be extremely favorable for remediation at the Flats. No flooding tides are predicted for June or July, and flooding tides in late May will likely be stopped by the tide gates. Mid-August flooding tides may overrun the tide gates, depending on the river stage and climatic conditions. The equipment will be pulled out in late August.

Walsh, M.R., and M.E. Walsh (2002) Remote monitoring of remediation parameters through a Web-based system. In *Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 2001.* USA CRREL Contract Report to U.S. Army Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 135–140.

The ERF Web site is a heavily used tool for the researchers and project managers, providing a daily feel for the conditions and progress of our efforts during and after the remediation season. The site provides a user-friendly interface to the daily and seasonal conditions at the Flats, aiding in our running evaluation of the remediation effort and keeping us in touch with the physical conditions necessary for the attenuation of the contaminant.

This year we monitored four ponds for attenuation conditions (five sensors each), the met site (11 sensors and 18 functions), four treatment ponds (remote imaging up to five times daily each), and the base station on Bravo Bridge (two sensors). This gave us a total of 33 sensor points and four cameras over the course of the season. The pond monitoring sensor and met station data were updated daily, and the Web cameras updated on a three-hour schedule throughout the day (0800–2000 hr).

In addition to the sensor, met, and camera data, other information is available on the ERF Web site. A brief history and a complete bibliography from 1950 through 1999 are on the site. A short write-up on monitoring activities and the ecology of the Flats are there as well. Maps and photographs, although dated and in need of updating, give the viewer a sense of the scope of the project. We have also included a current activities button, updated periodically, and a list of contacts for those interested.

The ERF Web page is one of the most widely accessed Web sites at CRREL, indicative of the interest in the project. It is a good showcase for the Army's effort on this unique remediation project and has been a great public relations tool. We will continue to maintain the site at least through the end of the project.

Williams, C.R. (2002) Eagle River Flats wireless remote imaging system. In *Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 2001*. USA CRREL Contract Report to U.S. Army Alaska, Directorate of Public Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report, p. 131–134.

The wireless remote imaging system (RIS) continued to prove its usefulness during the 2001 season. The images retrieved with RIS enabled project managers and researchers to view the effectiveness of the pumping operations. Images were successfully retrieved and posted to the ERF Web site from four ponded areas: Ponds 5 (Area D), 109 (Bread Truck), 183 (Area C), and 226 (Area A). The wireless system was improved from the systems deployed in 2000 by lowering the power budget of the remote equipment. A programmable microcontroller power management system was designed, built, tested and installed in each remote camera system. Power budgets were reduced from 18 to 6 amp-hours per day for each remote system. Future improvements include replacing the DSN phone lines for transfer of data from the base station with an Ethernet Radio Modem link to post and then directly to the Corps network, allowing wireless FTP transfer of images directly to a host computer at CRREL in Hanover, N.H.

Weldin Construction, Inc. (2002) 2002 Remediation and monitoring work plan: Operable Unit C–Eagle River Flats. Contract report to U.S. Army Corps of Engineers and U.S. Army, Alaska. May.

This is the work plan for remediation and monitoring efforts addressing the white phosphorus contamination in Eagle River Flats, a 2,140-acre estuarine salt marsh on Fort Richardson, Alaska. Fort Richardson is on the National Priority List, and Eagle River Flats is designated Operable Unit C (OU-C). The main remedy in OU-C is pond pumping, using six semi-autonomous pumps to temporarily drain contaminated ponds within several areas of Eagle River Flats. The first part of the work plan describes the remediation efforts for the 2002 field season, the fourth year of a five-year remediation and monitoring effort in Eagle River Flats. The second section describes the monitoring activities to determine the effectiveness of the remediation. These include sediment sampling, monitoring of drying conditions using dataloggers, and the installation of an on-site meteorological station. The third section contains the schedules for the various remediation and monitoring activities. The fourth section contains predicted tidal data Eagle River Flats. The fifth section is a Health and Safety Plan.

Weldin Construction, Inc. (2003) Work plan: Field work to control flooding of the Bread Truck Pond. Contract report to U.S. Army Corps of Engineers and U.S. Army, Alaska.

This work plan describes the need for a control structure in the Bread Truck Pond ditch, created with explosives in 1996 to remove the highly contaminated Pond 109 from waterfowl use. The plan includes a scope of work, a work plan, project organization and responsibility, general operating procedures, and other details pertaining to the execution of the project. A CAD drawing of the structure is included.

Collins, C.M., and D.W. Cate, eds. (in press) Remediating and monitoring white phosphorus contamination at Eagle River Flats (Operable Unit C), Fort Richardson, Alaska—FY 2002. (Collins, C.M., and D.W. Cate, eds.) USA CRREL Contract Report to U.S. Army Alaska, Directorate of Pubic Works, Fort Richardson, Alaska, and U.S. Army Engineer District, Alaska. Final Report.

This is the thirteenth annual contract report prepared by researchers from CRREL and other Federal agencies for U.S. Army Engineer District, Alaska, and U.S. Army Alaska, Public Works, describing the results of research, remediation, and monitoring efforts addressing the white phosphorus contamination in Eagle River Flats, an 865-ha estuarine salt marsh on Fort Richardson, Alaska. Fort Richardson is on the National Priority List, and Eagle River Flats is designated Operable Unit C (OUC) under the *Comprehensive Environmental Response, Compensation and Liability Act* (CERCLA).

This year was the fourth year of a planned five-year remediation effort in Eagle River Flats. Pond pumping, using six remote-controlled pumps to temporarily drain contaminated ponds within several areas of Eagle River Flats, was again conducted this year. The pumps kept the ponds drained for extended periods during the summer in all but one area, allowing the pond bottom sediments to dry and the white phosphorus in the sediment to sublime and oxidize. The logistics of the pumping operations, especially the installation of the equipment in the spring and the removal of the equipment in the fall, continued to be refined, leading to more effective and efficient operations.

The combination of warm, dry weather during July resulted in a long and effective drying season. Sampling showed that levels of contamination in the treated ponds continued to decline. Additional areas of localized contamination were identified that will be treated in the future.

The first section of this report is a progress report reviewing the overall project from the initial remedial investigations, through the treatability study phases, to the implementation of the preferred remediation method. It reviews the progress of the remediation through the first four years. It also reviews the ongoing monitoring efforts used to assess the effectiveness of the remediation efforts. And finally it addresses specific issues and procedures raised in the Proposed Plan and the Record of Decision.

JOURNAL ARTICLES

Clark, L., J. L. Cummings, J. E. Davis, P. A. Pochop (1998) Evaluation of a macro-encapsulated repellent to reduce risk of white phosphorous ingestion by waterfowl foraging in a contaminated marsh. *International Biodeterioration and Biodegradation,* **42**(1998): 135–145.

White phosphorous contamination of a marsh at a U.S. Army artillery training range in Alaska is a causative agent for waterfowl mortality. We developed an encapsulated bird repellent containing the active ingredient methyl anthranilate and evaluated the formulation's efficacy in reducing feeding activity by ducks, reducing mortality of ducks feeding in contaminated sediments, and the repellent's ability to move ducks from contaminated areas. The formulation has a limited life span of about four days. However, in pen trials, feeding activity of Mallards can be reduced by up to 80%. Long-term exposure to treated sediments confers a survival advantage to Mallards tested in pens, and free-ranging Mallards can be moved off of treated sections of marsh. This prototype formulation may have utility in the short-term remediation of contaminated sediments for the protection of waterfowl.

Cummings, J.L., L. Clark, P.A Pochop, and J.E. Davis, Jr. (1998) Laboratory evaluation of a methyl anthranilate bead formulation on Mallard feeding behavior. *Journal of Wildlife Management,* **62**(2): 581–584.

We applied methyl anthranilate bead formulation coded JR930413 to bottom sediment in a simulated pond setting to evaluate its repellency to captive Mallards *(Anas plathyrhynchos).* We applied JR930413 at a rate of 21.7 kg/ha or 7 beads/cm^2 to bottom sediment. Methyl anthranilate bead formulation JR930413 was effective in reducing time Mallards spent in pools ($P < 0.01$). Application of JR930413 to the contaminated waterfowl feeding areas at 21.7 kg/ha could reduce feeding and mortality and warrants further testing in the field.

Pochop, P.A., J.L. Cummings, C.A. Yoder, and W.A. Gossweiler (2000) Physical barrier to reduce WP mortalities of foraging waterfowl. *Journal of Environmental Engineering,* **126**(2): 182–187.

White phosphorus (WP) has been identified as the cause of mortality to certain species of waterfowl at Eagle River Flats, a tidal marsh in Alaska used as an ordnance impact area by the U.S. Army. A blend of calcium bentonite/organo clays, gravel, and binding polymers was tested for effectiveness as a barrier to reduce duck foraging and mortality. Following the application of the barrier to one of two contaminated ponds, we observed greater duck foraging and higher mortality in the untreated pond and no mortality in the treated pond after a year of tidal inundations and ice effects. Emergent vegetation recovered within a year of treatment. WP levels in the barrier were less than the method limit of detection, indicating no migration of WP into the material. Barrier thickness remained relatively stable over a period of 4 years, and vegetation was found to be important in stabilizing the barrier material.

Vann Stephanie, L., D.W. Sparling, and M.A. Ottinger (2000) Effects of white phosphorus on Mallard reproduction. *Environmental Toxicology and Chemistry,* **19**(10): 2525–2531.

Extensive waterfowl mortality involving thousands of ducks, geese, and swans has occurred annually at Eagle River Flats, Alaska, USA, since at least 1982. The primary agent for this mortality has been identified as white phosphorus. Although acute and subacute lethality have been described, sublethal effects are less well known. This study reports on the effects of white phosphorus on reproductive function in the Mallard *(Anas platyrhynchos)* in captivity. Fertility, hatching success, teratogenicity, and egg laying frequency were examined in 70 adult female Mallards who received up to seven daily doses of 0, 0.5, 1.0, and 2.0 mg/kg of white phosphorus. Measurements of fertility and hatchability were reduced by the white phosphorus. Teratogenic effects were observed in embryos from hens dosed at all treatment levels. Egg laying frequency was reduced even at the lowest treatment level; treated hens required a greater number of days to lay a clutch of 12 eggs than control hens. After two doses at 2.0 mg/kg, all females stopped laying completely for a minimum of 10 days, and laying frequency was depressed for at least 45 days. Fertility of 10 adult male Mallards dosed with 1.0 mg/kg of white phosphorus did not differ from 10 controls, but plasma testosterone levels were significantly ($p < 0.05$) reduced in the treated males 1 day after dosing ended. These results provide evidence that productivity of free-ranging Mallards may be impaired if they are exposed to white phosphorus at typical field levels.

Walsh, M.R., M.E. Walsh, and C.M. Collins (2000) Method for attenuation of white phosphorus contamination in wetlands. *Journal of Environmental Engineering*, **126**(11): 1013–1018.

White phosphorus, a manufactured form of elemental phosphorus, is both toxic and persistent in saturated environments. This form of phosphorus (P_4) is used by militaries worldwide as a component for obscurants, tracer rounds, and incendiary munitions. At Eagle River Flats, an estuarine salt marsh located on Fort Richardson, Alaska, white phosphorus has been directly linked through carcass analysis to the deaths of thousands of dabbling waterfowl. Particulate residue from ordnance contaminates the permanently ponded areas of Eagle River Flats, where the waterfowl sieve the soft bottom sediments for food items, picking up P_4 particles in the process. Death follows within hours. Large-scale investigations into the nature, extent, and persistence of the contaminant were initiated in 1989, followed four years later by work on the testing and analysis of remediation methods. In 1997, a method for in situ remediation of the contaminant through low-impact pumping and draining of ponded areas to enhance natural attenuation of white phosphorus was tested. Results indicate that pond pumping is a very effective remediation technique.

NEWSLETTER AND PERIODICAL ARTICLES

Anchorage Daily News (1997) Army to drain pond with three blasts. *Anchorage Daily News,* April 22, p. B3.

Anchorage Daily News (1998) Range cleanup plan due hearing. *Anchorage Daily News,* February 12, p. B2.

Anchorage Daily News (2000) Army to set off explosions as part of phosphorus cleanup. *Anchorage Daily News,* March 17, p. B3.

Campbell, L. (2001) Sounds like an attack, but it's just practice *Anchorage Daily News,* February 25, p. B3.

Chambers, M. (2002) Artillery range bill could stymie suits. Associated Press article in the *Anchorage Daily News,* May 1, p. B2

Darling, M. (1999) Corps cleans up Alaska saltwater marsh. *Engineer Update* **23**(10): p.13.

Darling, M. (2001) CRREL, Army clean up contaminated Alaskan marsh. *Engineer Update,* **25**(5): p 12.

Manning, E. (1998) Pond cleanup planned for Eagle River Flats. *Anchorage Daily News,* February 14, p. A1.

Manning, E. (2000) Army torpedoes bird-killing ponds. *Anchorage Daily News,* May 19, p. B1.

Manning, E. (2002) Army sued over range cleanup. *Anchorage Daily News,* April 18, p. B1.

Prieksat, M. (2001) Operable unit updates: OUC Eagle River Flats. *Environmental Restoration News* **7**(3): p. 3-5.

Ruskin, L. (2002) Military Pushes Bird Bill. *Anchorage Daily News,* May 8, p. B1.

REPORTS

Nam, Sae-Im, M.R. Walsh, C.M. Collins, and L. Thomas (1989) Eagle River Flats remediation project: Comprehensive bibliography—1950 to 1998. USA Cold Regions Research and Engineering Laboratory, CRREL Special Report 99-13.

The purpose of this report is to provide a thorough and complete list of publications on the subject of WP contamination and remediation at Eagle River Flats, Alaska. To date, there are about 250 references in the ERF Bibliography, including CERCLA documents, conference papers, contract reports (encompassing many individual reports), journal articles, aerial photos or photographic series of ERF, newspaper and magazine articles, patents, reports, theses, videotapes, and Web sites. An index is provided at the end of this report for those documents with abstracts included.

Racine, C.H., B.B. Steele, L. Reitsma, and C. Bouwkamp (in press) Biodiversity inventory of Eagle River Flats, Upper Cook Inlet Alaska. US Army Engineer Research and Engineering Center, Cold Regions Research and Engineering Laboratory, Technical Report series.

An inventory of landcover-vegetation, flora, bird, and sediment macroinvertebrate fauna of Eagle River Flats (ERF), an 865-ha salt marsh on Upper Cook Inlet near Anchorage, Alaska, was conducted between 1991 and 1995. This work was carried out as part of an ecological risk assessment for white phosphorus contamination at ERF, used as a U.S. Army artillery training range for the past 40 years.

Landcover-landform classification and mapping was conducted using aerial photos for the entire salt marsh at two scales to show seven physiographic zones at a scale of 1:55,000 and more detailed water body and vegetation types at a scale of 1:27,000. Quantitative sampling of vegetation, avifauna, and macroinvertebrates included a daily population census of waterfowl, 425 1-m^2 plot samples of vegetation, and 82 macroinvertebrate sediment samples obtained in May, July, and August. Comprehensive species inventories as well as relative abundances and habitat relationships are presented here.

The flora of ERF includes over 65 species of vascular plants, including halophytic species characteristic of mud flat salt marsh, aquatic submerged, and emergent marsh species. The avifauna of ERF includes about 68 species of birds, including dabbling ducks, shorebirds, raptors, and granivores. Over 30 species of sediment macroinvertebrates were sampled from the bottoms of ponds and tidal creeks. The dipteran larvae *Chironomus salinarus* is the most common and abundant species, particularly in shallow ponds with high salinites but less common in deeper ponds and tidal creeks.

Although small in area, ERF contains many of the same habitats and species found in other much larger estuarine salt marshes on Upper Cook Inlet but does not contain extensive tidal mudflats along the coastal edge, which likely affects the abundance of both waterbirds and invertebrates species.

VIDEOTAPES

L'Heureux, D.A., and M.R. Walsh (2002) Airlift operations in support of Eagle River Flats, September 2001. USA Cold Regions Research and Engineering Laboratory, CRREL Videotape No. T02005.

WEB SITES

Mason, J., S.I. Nam, G.M. Trachier, and M.R. Walsh (1998) Eagle River Flats Web Site. http://www.crrel.usace.army.mil/erf .

This comprehensive Web site contains information on and links to material related to the Eagle River Flats, Alaska, remedial project. Included are images of the various projects conducted at the Flats, maps, aerial photographs, and the ERF bibliography. The site is used throughout the field season by site investigators to monitor meteorological, hydrological, and tidal conditions at the Flats. A Web camera with image updating of four treatment sites five times daily is accessible through this site.

INDEX TO ABSTRACTS

First Edition (1950–1998)*

* USA Cold Regions Research and Engineering Laboratory, Special Report 99-13.

Second Edition (1998–2003)

CHRONOLOGICAL INDEX TO ABSTRACTS

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