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Interagency Expanded Site Investigation

Evaluation of White Phosphorus Contamination and Potential Treatability at Eagle River Flats, Alaska

FY 95 Final Report

Prepared for

U.S. ARMY, ALASKA
DIRECTORATE OF PUBLIC WORKS
William A. Gossweiler, Project Manager

Prepared by

U.S. ARMY COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
David W. Cate and Charles H. Racine, Report Editors

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I. EXECUTIVE SUMMARY

INTRODUCTION

This is the sixth annual report (1990-1995) describing the results of white phosphorus contamination studies in Eagle River Flats (ERF), a 865-ha estuarine salt marsh artillery impact range on Ft. Richardson, Alaska. Waterfowl mortality occurs here as a result of ingestion of white phosphorus (WP) particles from artillery smoke rounds. ERF is the first documented case of WP poisoning on a US Army training area, although since then other artillery range training areas have been found to be contaminated with WP. In 1991 and 1992 efforts were focused on determining the nature and extent of WP contamination in ERF and on the monitoring of waterfowl mortality. In 1993 more detailed studies of the problem were initiated:

- WP toxicology studies;
- Invertebrate and fish studies (with no detection of WP effects); and
- Radiotelemetry of ducks, shorebirds and eagles to monitor movement and mortality.

Pilot field treatability studies began in 1993 and were expanded in 1994 and 1995 to include dredging, barriers, chemical repellents, natural attenuation and pond drainage. In 1992 it was determined that although WP has a reputation for being easily oxidized (natural attenuation), it is very stable as a solid particle underwater and in saturated sediments where waterfowl feed. Investigations of physical system dynamics began in 1992 and continued to the present. Waterfowl censusing by aerial survey began in 1989 and have continued to the present.

II. SITE CONDITIONS

II-1. Physical System Dynamics, WP Fate and Transport, and Remediation

Daniel E. Lawson, Lewis E. Hunter and Susan R. Bigl

The focus of these investigations was on the role of the physical system in the burial or transport of white phosphorus in this tidal flat area. Specifically, these investigations evaluated whether the processes of gully erosion, headward recession, and drainage of contaminated ponds, and of burial of contaminated pond sediments, could produce a natural attenuation of WP contamination. The erosion and potential for off-site transport of WP was examined.

Several important conclusions result from this and previous year's work:

- Physical system processes result in the burial and transport of WP.
- Gully erosion and headwall recession will drain areas of contaminated ponds in about 1–10 years, potentially resulting in in-situ WP degradation and attenuation due to drying. This is a cost-effective alternative to artificial pond draining. Historical analyses, field data and process analyses indicate that Bread Truck Pond will probably begin draining in 1 year, while C/D, Lawson's Pond and a large area of C Pond will begin to drain in 10–15 years or less.
- Pond sedimentation rates are high and could, over time, bury WP-contaminated pond sediments to a depth sufficient to prevent feeding waterfowl exposure.
- Natural sedimentation and burial, perhaps artificially enhanced in some locations by introducing additives to increase flocculation, is a cost-effective alternative to the installation of a barrier, particularly in certain pond areas. Gully erosion and extension may subsequently drain and dry these same areas, furthering the permanency of remediation.
- Ice rafting can move WP by plucking it from the bottoms of contaminated ponds and moving it to other areas.

- WP in sediments is eroded from ponds and drainages by ice and water and subsequently transported by currents into the Eagle River and possibly off-site (Knik Arm), where its fate is unknown. Contaminated sediment is also transported to other locations within ERF.
- Racine Island Pond has neither high gully erosion and headward recession rates, nor high sedimentation rates. This pond also floods at relatively low tidal heights and contains organic-rich sediments. It appears, therefore, that it can only be effectively remediated and readily restored through artificial drainage and temporary berm containment to permit long-term drying and in-situ WP degradation.

Based on the investigations to date, the following recommendations are made:

- Cost-effective remediation can be accomplished to a significant degree by allowing the physical system to remove or isolate WP contamination over time.
- WP contamination of Bread Truck Pond and 50% or more of C Pond, including potentially Lawson's Pond in the long term, should be treated by natural or enhanced drainage and subsequent in-situ WP degradation by drying.
- Sedimentation and burial of WP may be effective in removing it from feeding waterfowl in the short term; in the long term, burial will reduce waterfowl mortality during natural pond drainage in the C, Lawson's and C/D pond areas.
- Racine Island Pond may be effectively remediated by gully extension, artificial pond drainage and pumping, and long-term containment with a temporary berm to permit in-situ WP degradation by extended drying of pond bottom sediments. By simply removing the berm after WP has attenuated naturally, the pond environment will be restored.
- Erosion and recession rates, pond sedimentation, groundwater, pond drainage and drying, and WP degradation and attenuation should be monitored to ensure that remediation is taking place as predicted by physical system analy-

ses and to assess ecosystem impacts of artificial remediation techniques during feasibility studies and remediation.

- WP migration and contamination in Knik Arm should be evaluated, focusing on areas of near-shore zones and mid-Arm bars where there is a potential for WP exposure to receptors.
- The potential for natural attenuation of white phosphorus as the result of mechanical abrasion during transport by gully and tidal currents should be evaluated.

II-2. Climate and Tides

Richard K. Haugen

Weather and tidal activity provide the driving forces for physical and biological processes in the Eagle River Flats area. A meteorological site was installed at the edge of the EOD pad in May 1994. This station has provided a basis for climatic comparisons with Anchorage and other study locations at ERF. Data obtained at the EOD meteorological site included air, ground and surface temperatures, incident and reflected solar radiation, relative humidity, wind speed and direction, and precipitation. A comparison with the 1994 season (May–September) shows that the seasonal average temperature during 1995 was about the same but that precipitation during the 1995 season (250 mm) was over twice that of the 1994 season.

A comparison of 1995 air temperature data for 30 May to 29 October between the EOD site, ERF coastal site and Anchorage showed Anchorage to be warmer than EOD by 2.3°C, and EOD to be warmer than the ERF Coastal Site by the same amount. The 1994 ERF report showed the coastal site to be warmer than the EOD site but it is now apparent that daily *maximum* temperatures were used to represent the coastal site in the 1994 analysis, rather than the daily average temperatures. The –2.3°C difference found with the 1995 data between the EOD pad site and the coastal site should be considered representative.

Data analysis includes discussion of relative humidity, wind speed and air and ground temperature at the EOD site, together with solar radiation. Comparisons between net solar radiation, soil surface temperature and soil moisture measurement are shown graphically. Evapotranspiration rates for the ERF area and for historical time series were calculated. An existing computer program was used to calculate evapotranspiration with different methods, depending on the amount of available input data. Anchorage Summary of the Day records were obtained back to 1952 to calculate historical means and extremes for the summer season for a large number of parameters. Time series of tidal flooding gaps using three flooding heights, precipitation, and estimated evapotranspiration were developed for the growing seasons of 1995–2000. These data should be useful for planning research and remediation activities.

III. RISK ASSESSMENT AND FOOD CHAIN EFFECTS

III-1. Waterbird Utilization of Eagle River Flats and Upper Cook Inlet: April–October 1995

William D. Eldridge and Donna G. Robertson

Aerial surveys were flown over Eagle River Flats from April to November 1995. Thirty-seven surveys were flown with a single-engine, fixed-wing aircraft using standard USDI methodology. 1995 was a wet year in upper Cook Inlet, so ponds were full most of the season. Fall temperatures were mild, which delayed migration through upper Cook Inlet. Numbers and species of waterbirds counted on ERF were similar to other years, dominated by dabbling ducks and Canada geese, particularly in fall. Utilization of standard study areas within ERF by waterbirds was recorded and presented by season.

Other marshes in upper Cook Inlet were surveyed in 1995 to compare to ERF. These included Palmer Hay Flats, Goose Bay, Susitna Flats, Trading and Redoubt Bays and Chikaloon Flats. Twenty-five surveys were conducted from April to May. More than 90% of the waterbirds counted were found on marshes other than ERF during the season. Waterbirds concentrated on broad intertidal mudflats in marshes other than ERF, Goose Bay and Palmer Hay Flats, where this habitat type is poorly represented. Species composition of waterbirds was similar on all areas. Numbers by species and area are presented by season.

III-2. Waterfowl Use and Mortality at Eagle River Flats

Benjamin B. Steele and Leonard R. Reitsma

The objectives for 1995 were to monitor waterfowl mortality at ERF, measure mortality in an uncontaminated reference area, measure mortality in non-contaminated areas of ERF, and evaluate mortality in swans. Mortality at ERF was compared to previous years to monitor decreasing exposure of ducks to white phosphorus from either remediation efforts or natural processes. We measured mortality in uncontaminated reference areas to develop a background level of mortality so that mortality rate at ERF can be used as a measurement endpoint. Mortality was measured by the same methods used since 1992. Counts of carcasses on permanent transects were compared to the number of ducks exposed, calculated from censuses made each morning. Mortality on reference areas was measured by the same method.

The mortality rate at ERF during fall 1995 was lower than in fall 1994. This decline continues a trend that has been seen since 1992, when the mortality rate was approximately ten times higher than in 1995. The fact that the mortality rate decreased in 1995 despite an increase in exposure rate shows that this decline does not result from hazing or other activity on the Flats. Rather, ducks are less exposed to white phosphorus because of natural attenuation, sedimentation on top of contaminated pond bottoms, or high water causing ducks to feed in non-contaminated areas.

The mortality rate in spring was very low but could not be compared statistically to previous years because of a low exposure rate and because no carcasses were found on transects. Only one carcass was found on transects in reference areas in Goose Bay and Susitna Flats. Thus, background mortality may be as much as one tenth that currently occurring at ERF, but more data are needed to accurately measure background mortality. We found only one carcass on transects in uncontaminated areas of ERF (areas B and D). These areas still do not represent a hazard to ducks. Five swan carcasses were found, mostly before swans had been observed in contaminated areas. These deaths raise the possibility that swans ingest white phosphorus in areas thought to be safe for ducks: area D, area B or the pond in area C/D. Swans feed in deeper water than ducks and may be exposed in different areas than ducks are.

The fact that the mortality rate continues to decline before full-scale remediation has begun suggests that the no-action alternative may be sufficient to remediate at least some areas of ERF.

III-3. Analysis of White Phosphorus in Biota at Eagle River Flats, 1995 Field Season

Bill D. Roebuck

Tissues from animals found dead on Eagle River Flats during 1995 were analyzed for white phosphorus to help confirm the cause of death. A total of 31 animals were examined: 30 birds and 1 coyote. The coyote did not contain WP. Of the birds, approximately 20% did not have WP in their tissues. These birds (six in total) are either individuals that died of other causes (some of which may be natural causes, or individuals in whom the WP dissipated prior to their ultimate death.

III-4. Movement, Distribution and Relative Risk of Waterfowl and Bald Eagles Using Eagle River Flats

John L. Cummings, Christi A. Yoder, Richard E. Johnson, Patricia A. Pochop, Kenneth S. Gruver, James E. Davis and Kenneth L. Tope

This project determined the spatial distribution, movements, turnover rate and mortality of waterfowl and bald eagles using Eagle River Flats during fall migration, August 1 to October 17, 1995. Eighty-two ducks and 14 bald eagles were captured on ERF using various techniques. Of the waterfowl, 17 mallards, 16 northern pintails and 21 green-winged teal were fitted with radio transmitters. Of the 14 eagles, 8 were fitted with satellite transmitters, the others with standard transmitters. Waterfowl transmitters were programmed to be on from August to November 1995, and again from April to June 1996. Eagle transmitters are expected to last 24 months. Tracking data indicated that transmitters did not appear to inhibit the movements or activities of either ducks or bald eagles. Daily waterfowl movements indicate that all species moved among areas quite readily. Mallards spent about 60% of their time in areas B and A; pintails spent about 87% of their time in areas A, C/D and D; and teal spent about 63% of their time in areas A and D. After the hazing program was started, waterfowl use patterns changed on ERF. The average number of days spent on ERF by mallards, pintails and teal was 40, 46 and 27 days, respectively. The average daily turnover rate for waterfowl was about 3.8%. The greatest turnover of waterfowl occurred prior to September 5 where 47% mallards, 37% pintails and 43% teal departed ERF. The mortality of instrumented ducks using ERF from August 1 to October 17 was five ducks, or about 9%. Most of the telemetry contacts with eagles, excluding the two nesting birds, indicated that eagles spent an average of 1.4 days on the Flats. Instrumented eagles were only observed in areas A, C and C/D during the spring and A and C/D during the fall. The nesting success of eagles on ERF did not differ significantly from eagles nesting on Susitna or Chickaloon Flats. Eagles on ERF produced an average of 1.3 eggs and fledged an average of 0.33 eaglets. No adult eagle mortality has been documented from instrumented birds, even though eagles scavenge dead ducks (which has included instrumented ducks).

IV. TREATABILITY STUDIES

IV-1. Hazing at Eagle River Flats

Corey Rossi

Hazing of waterfowl from ponds contaminated with white phosphorus was conducted during both the spring and fall migrations. The hazing operations was successful, as ADC observations, DWRC telemetry work and waterfowl surveys by NBS and NEILE all indicated a dramatic decrease in waterfowl numbers in hazed areas compared with those of unhazed areas on ERF.

IV-2. Evaluation of AquaBlok™ on Contaminated Sediment to Reduce Mortality of Foraging Waterfowl

Patricia A. Pochop, John L. Cummings and Christi A. Yoder

The results of a study conducted in 1994 by covering the bottom of a pond indicated that AquaBlok™, a physical barrier to foraging waterfowl, could reduce mortality of waterfowl when applied to a WP-contaminated pond up to 0.5 ha in size. The objective in 1995 was to continue to evaluate the effectiveness of this barrier. Emergent vegetation growing through or on the AquaBlok™ recovered from 45% in 1994 to 76% in 1995. In 1991 (before application), vegetation cover in the pond was only 52%, indicating that there was no adverse impact of the AquaBlok™ on the vegetation. Analysis of AquaBlok™ indicated that WP concentration varied from below the detection limit to 0.02 mg/kg (mean = 0.01 mg/kg) of WP and was probably contamination from the sediment below the barrier. No mortality of waterfowl was observed during a second year of AquaBlok™ exposure to weather and tide events. AquaBlok™ thickness was reduced by 0–5 cm from values in 1994. However, this was largely influenced by heavy traffic (animal and human) and limitations in the sampling method. Tide plots indicated that erosion and movement of AquaBlok™ were lowest on Racine Island, where vegetation was important in stabilizing the barrier.

IV-3. Intrinsic Remediation of WP Particles in Intermittent Ponded Areas of ERF

Marianne E. Walsh, Charles M. Collins and Ronald N. Bailey

Natural attenuation of WP particles appears to be occurring at a highly contaminated site (Site 883) in the intermittent pond of Area C. When 41 samples were taken at this site in the fall of 1995 at the same locations as 41 samples in the fall of 1992, the number of samples with WP concentrations greater than 10 µg/g declined from four to zero, and the number of samples below 0.001 µg/g has increased from 15 to 28. In addition the number of WP particles at this site has decreased; in 1992, when 270 mL of sediment from this site were sieved, over 100 WP particles were isolated. In 1995, 1000 mL of sediment were sieved using the same procedure, and only one WP particle was found. Sediments at this site were desaturated during the summers of 1993 and 1994 when weather conditions and the length of time between flooding tides were favorable for pond shrinkage. During 1995, flooding tides occurred monthly, and sediments at this site were continually under water.

Samples were also obtained from the crater produced from the detonation of a WP UXO in 1992. The crater is also in the intermittent pond of Area C. The rim of the crater, which had a WP concentration of nearly 1000 µg/g when sampled in 1992, had concentrations of 0.0051 and 0.0006 µg/g when sampled in June and September 1995. The bottom of the crater, which is 32 cm below the rim, still has high concentrations of WP. The bottom of the crater was exposed in 1993 and 1994, but for much shorter lengths of time then the rim. WP particles were isolated by sieving 1000 mL of sediment from the crater bottom, and over 100 particles were found, most of which were less than 1 mm in length. WP particles were also isolated from a permanently saturated site on Racine Island. While most of the WP particles isolated were also less than 1 mm in length, several large particles (greater than 2 mm) were also found, with the largest particle measuring 6.6 mm in length. Such large particles were absent from sites in the intermittent ponded areas. We hypothesize that when sediments are exposed and desaturate, the smallest WP particles are the least persistent and disappear relatively quickly since small particles have large surface-to-volume ratios and sublimation occurs from the particle surface. Larger particles are much more persistent but shrink during periods of desaturation.

IV-4. Enhancement of Intrinsic Remediation of WP Particles by Sediment Warming in Intermittent Ponded Areas of Eagle River Flats

Marianne E. Walsh, Charles M. Collins and Ronald N. Bailey

This task was to study the enhancement of reduction of WP particles in intermittent ponded areas by sediment warming. The most important condition for loss of WP particles from ERF sediments is desaturation of the sediments, which occurs in summers with long periods between flooding tides. A secondary factor is sediment temperature. Since the vapor pressure of WP increases exponentially with temperature and oxidation is more likely at higher temperatures, loss of WP particles can be significantly accelerated by warming unsaturated sediments.

A field study was performed to test the effectiveness of passive solar warming techniques on increasing sediment temperature and promoting the loss of planted WP particles. One technique tested was the application of black sand to change the surface albedo. Also tested were two types of synthetic row covers (a spun-bonded polyester and a porous polypropylene) commonly used in agriculture. The row covers transmit short-wave (300–2500 nm) solar radiation and trap long-wave radiation (4000 nm) from the sediment surface, producing a greenhouse effect. Sediment temperatures were monitored at a depth of 5 cm, and all three treatments slightly increased the sediment temperatures relative to the controls. Because of monthly flooding tides during the summer of 1995 and frequent rainfall during July, August and September, sediments were saturated except for a few days prior to the June flooding tides. None of the treatments appeared to significantly inhibit evaporation during this brief period of favorable drying conditions. The amount of time when sediments were unsaturated was so short that most WP particles remained essentially unchanged, except for a few particles under one of the row covers and one particle in the control plot. These results show that row covers are a tool that may be used to raise sediment temperatures, but attention must be focused first on enhancing desaturation of the sediments using methods such as temporary pond drainage.

A laboratory experiment was also performed using a more aggressive method to heat sediments with planted WP particles. The purpose of the experiment was to test the hypothesis that heating the sediments would increase the vapor pressure of the WP sufficiently to initiate oxidation, which in turn would generate heat to sustain continued sublimation and oxidation after the outside heat source was removed. To test this hypothesis, unsaturated sediments were equilibrated at 13°C (typical average temperature for ERF sediments during the first part of June), and then a hot air gun was used to heat the sediments briefly to 40°C. Then the sediments were cooled to 13°C and WP particles were recovered. This treatment failed to rapidly remove WP from the sediments. The average WP mass remaining in the heated sediments was not significantly different from the control, indicating that a longer period of heating would be necessary to accelerate WP loss. However, the energy requirements for prolonged heating in situ would be prohibitive.

Given that intrinsic remediation is occurring in some parts of ERF in areas that naturally desaturate, ways to enhance natural drying should be employed where possible before active methods of raising sediment temperatures.

A third task was to study the reduction in size of WP particles following pond drainage. This was conducted in conjunction with the pond drainage treatability study by C.M. Collins. Along a transect through the intermittently and permanently flooded areas of the Bread Truck Pond, WP particles were planted in May at a depth of 5 cm, and the sediment moisture and temperature were monitored at 5- and 10-cm depths at sites. Because of procurement delays, the pond was not drained and sediments remained saturated throughout the summer.

A fourth task was to study the reduction in size of WP particles in dredge spoils. This was conducted in conjunction with the dredging treatability study by M.R. Walsh. To determine if the moisture levels and temperatures of the spoils reach those conducive for decontamination, monitoring sites were set up at four locations within the basin, and when dredging was completed for the season in September, WP particles of known mass were placed at known locations. The residue from these particles will be recovered next spring.

IV-5. Pond Draining Treatability

Charles M. Collins, Edward F. Chacho, Jr., Michael R. Walsh and Marianne E. Walsh

The overall objective of this treatability study was to assess if pond draining is a viable option for remediating the WP-contaminated Bread Truck Pond in Eagle River Flats. To achieve that objective several tasks were undertaken to determine if pond draining was technically feasible and what environmental conditions occur in the pond-bottom sediments following draining. Task 1 was to determine the environmental conditions in the BT Pond before and after temporarily lowering the pond level by using a pump system. We installed instrumentation at eight sites along a transect through the intermittently and permanently flooded areas of the Bread Truck Pond to measure the sediment moisture and temperature monitored at 5- and 10-cm depths in the pond bottom sediment. We also continuously measured the water surface elevation of the pond. WP particles were planted in May at a depth of 5 cm at each site to monitor any reduction in size. Because of procurement delays for the pumping system, the pond was not drained and sediments remained saturated throughout the summer.

Task 2 was to design, procure, deliver and install in the BT pond a large dewatering pump system to be used to temporarily drain the BT pond. Design specifications of the integrated pump and generator system were initiated in January 1995. We specified an integrated system consisting of a 2000-gal/min electric-powered pump mounted on a float platform. A diesel-powered electrical generator to power the pump was mounted on a separate float platform. Integrated controls allowed automatic control of the generator and automatic startup and stopping of the pump system, controlled by float switches that would cycle the pump as the pond emptied or started to refill. Once funds became available, the requisition process was initiated in March 1995. Procurement problems delayed the award of the sole-source contract for the purchase of the system until July. During the first week of September the contractor completed the pump system and conducted a performance test at the contractor's facility in Montana. After the final tests, the pump system was shipped by truck to Anchorage, arriving on 12 September. Because the delivery of the pump system occurred so late in the season, the pump was not deployed to the Bread Truck pond. Instead we deployed the system in Clunie Inlet to completely test the system and to run the generator for the initial 40-hour break-in period. This allowed us to check fuel procedures and fuel consumption rates and to ensure that all sensors and controls were operational. Initially we had some problems getting the controls to start the pump. It turned out that a control wire connection had come loose during transport and a fuse in the control panel blew after the loose wire shorted out. After we repaired the wire and replaced the fuse, the system was started normally. Water was pumped for approximately seven hours a day for five days until the generator had the required forty hours of running time on it. Following the completion of the test, the system was pulled out, the discharge line disassembled and the components shipped back to Ft. Richardson DPW for winter storage.

Task 3 was to determine the rate of surface water inflow into the C/D area from the adjacent uplands and how that rate of inflow might influence the BT pond. Two instrumented sites were installed in the C/D area in early June to monitor water conditions. One site was located at the eastern edge of the C/D area next to the upland border along the shore of a deep narrow pond running parallel to the upland border. The second site was located at the far western end of the pond system that extends through the C/D area toward the BT pond, perpendicular to the first pond and the upland border. These two sites were instrumented to monitor pond water levels as well as water temperature, salinity and specific conductance. Seven additional sampling sites were located along two transects, one parallel to the upland boundary and one perpendicular to the boundary. At these sampling sites, periodic water salinity and temperature measurement profiles of the water column were made and water quality samples taken. The measurements showed that a prism of fresh water discharged from a series of small springs and seeps along the upland border slowly displaced the brackish water that filled the ponds in this area after a flooding high tide. The formation and extension of the prism of fresh water as it rides over and displaces the brackish water could be seen in the weekly measurements of the water temperature and salinity of the water column at seven measurement sites. From the measurements, rates of inflow of fresh water were estimated. A model of freshwater flow was used to estimate a maximum volume of the freshwater inflow in the two connected ponds after 20 days of approximately 10,615 m^3. This equates to 530 m^3/day of fresh water produced by runoff, seeps and springs along the 445-m total length of upland boundary bordering the pond system. This is equivalent to 0.0061 m^3/s, or only about 1/20 the pumping capacity of the pumping system to be installed in the BT Pond, indicating the system would be more than capable of keeping up with freshwater inflow from the C/D area. Because of the unusually wet summer this year, with above-average rain from July through September, this discharge rate is probably higher than during an average summer.

IV-6. Dredging as a Remediation Strategy for White-Phosphorus-Contaminated Sediments at Eagle River Flats

Michael R. Walsh

This project covers the second deployment of the dredging system and the various factors involved in dredging and remediation of the spoils. This season's work can be divided into three categories: continued investigation of the hydrological properties of the Retention Basin, dredge operations, and initiation of the attenuation study in the Basin.

The hydrological studies of the Basin liner were conducted in mid-June. They consisted of constant-head percolation tests, in-situ density tests and moisture content tests. The percolation tests were run over a period of up to nine days.

While most tests indicated a percolation rate below the acceptable level of 10^{-6} cm/s, one test exceeded that level (<5×10^{-6} cm/s). However, the overall performance of the liner was sufficient for us to judge it acceptable for use again this year. In addition, moisture content and densities were tested near the percolation tests to complete the characterization of the Retention Basin liner. Moisture contents ranged from around 30% to around 70%. Densities generally ran around 0.9 g/cm^3 (55 lb/ft^3).

Some erosion had occurred around the concrete splash pad at the spoils line outlet, so a wooden weir was constructed along one side and flow channels around the remaining sides were blocked with stones. Finally, the geotextile silt fence at the drop inlet structure was subjectively checked with a knife to assure integrity. It was left it in place and covered with a tarp to reduce exposure to UV rays. Later problems with low supernatant salinity levels forced us to forego the use of the silt fence due to clogging problems.

Continued problems with the dredge equipment and the unique environment at the Flats precluded full operation of the dredge until September. At that time, the slurry pump had been reconfigured, the dredge sensors reprogrammed, the electrical work finished, spoils line repaired, the boom box removed, a new grate system installed on the dredgehead, and the lateral winch deadmen anchored. During dredge operations, 160 spoils-line soil samples and 23 supernatant (water) samples were obtained and analyzed, with a total of 26 soil sample WP hits and one water hit. The average concentrations were 6.16 and 4 µg/kg for the soil and water sample hits, respectively. Approximately 1650 m^3 of material was dredged from Clunie Inlet and Area C between and adjacent to Clunie and Canoe Points. Using the results of the analysis of the spoils, about 1420 lethal doses of WP were removed during dredging (based on a 37% mallard, 37% pintail, 26% teal mix). The fine particle size of the suspended solids in the supernatant diminishes the lethality of any WP returned to the Flats.

The attenuation study was initiated and some data obtained from the instrumentation installed in the Retention Basin. Six particles were planted in partially dewatered spoils in four locations, two adjacent to instrumentation stations, on 28 September. The dataloggers were allowed to operate until 7 December. At that time, the temperature was well below zero and the spoils had frozen solid. Only partial drying of the sediments occurred before freeze-up, so definitive data will not be collected and analyzed until next spring.

Due to equipment problems, It was not possible to dredge the entire 0.85-ha area that had been planned. However, by the end of the season, the dredge system was operating reliably and effectively. The ability of the dredge to remove contaminated material from the Flats has been demonstrated, although the cost will be high. The performance of the Basin as a remediation structure should be determinable by next July.

IV-7. Development of a Remotely Controlled Drilling and Sampling System for the Remediation Program at Eagle River Flats

Michael R. Walsh

The goal of this project was to develop, build, test and deploy a remotely operated drilling/coring platform for use in the Flats to assist in the study of remediation efficiencies for these projects. A market survey, including visits to manufacturers, was conducted and the capabilities of various equipment configurations discussed. Additional discussions were held with drilling experts at CRREL in NH and Alaska. From these discussions, a set of specifications was developed and bid requests sent out through the Ft. Richardson contracting office for a small, light-weight mobile drill.

Concurrent with this contracting effort, the U.S. Army Tank Automotive Research Development and Engineering Command in Warren, MI, was tasked to develop, build and test a remote-control system for a vehicle similar to the carriers used with the drilling systems reviewed. A 6 × 6 vehicle was available for this purpose and sent to TARDEC as a test bed. Specifications for a remote camera system were also developed and a system ordered.

Contracting delays resulted in the awarding of the contract on 22 July, with an early September delivery date. This precluded any meaningful work at the Flats for the 1995 season, but through a superb effort by TARDEC, a working, tested system was delivered to the Flats on the 28 September. The drill unit is now in storage at Ft. Richardson, ready for a spring deployment for the 1996 field season.

The drilling of the EOD Pad wells also faced daunting contracting delays, but were drilled and installed the last week in September. Seven wells, each 6 m deep by 10 cm in diameter, were placed at the corners and down the middle of the EOD Pad. As work had ceased before completion of the wells, no attempt was made to instrument the wells with depth sensors. A groundwater sampling plan will need to be developed prior to sampling for chemical analysis.

The final task was to develop a remote-controlled coring machine for use in the Flats. This was to be a follow-on to the drill machine. Due to the delays in the drill project, development of the coring unit is delayed until FY 96. Work has been initiated in conjunction with TARDEC on retrofitting an M501 Hawk missile loader for this task using carry-over funds.

In summary, it was a frustrating field season two of the three tasks came very close to completion but were foiled due to contract delays. The only positive aspect to this situation is that a wet field season and contract delays in other programs resulted in the equipment not being needed as much this season as it will be next season. With the wells in place, a full season's data can be collected during next year's dredge deployment.

V. THE EAGLE RIVER FLATS SPATIAL DATABASE

V-1. The Eagle River Flats Spatial Database

Charles H. Racine, Peggy Robinson and John Mullen

This report describes the construction, use and contents of the Eagle River Flats (ERF) GIS (geographic information system) database. The purpose of the database is to help make and document decisions concerning the designation of WP "hotspots" to be treated, the selection of treatment methods to be used, and the success of the clean-up effort. At present, the database is designed primarily to identify hotspots to be treated, using a waterfowl risk assessment-exposure framework. The database includes both GIS coverages in ARC/INFO and/or ARCVIEW and tabular spreadsheet data residing on computers in the CRREL ERF GIS lab. Sharing of this database with other groups was initiated in an attempt to conduct analyses and make crucial decisions concerning hotspot location and waterfowl risk assessment. The database was originally started in 1993 to show the features of ERF (waterbodies, tidal gullies, vegetation-habitat, boundaries and craters) in relation to sediment and water samples, collected and analyzed for white phosphorus.

Much of the ERF GIS database effort during 1995 centered on the entry of waterfowl census, telemetry and mortality data, collected over the past three to four years, to locate areas where waterfowl use and therefore exposure to WP (if present) is high. In addition, the database for WP samples was updated and rebuilt to make analyses easier. The primary coverages include ERF natural features, white phosphorus sampling data (for 2549 point samples), waterfowl mortality sampling (1254 carcass point locations monitored in 1992, 1993, 1994 and 1995), waterfowl population aerial and ground censuses (1994 and 1995) and radiotelemetry locational data for 127 radio-collared ducks, 14 eagles and 20 shorebirds (1993, 1994 and 1995). About 39 primary coverages compose the master ERF GIS database.

Secondary coverages are also listed and may be important for future decisions at ERF. These include sedimentation-erosion studies, remediation tests, water quality and weather monitoring sites and GPS ground-truth data. To help accomplish the selection of appropriate clean-up method technologies, researchers will need to supply criteria for determining where their technologies would and would not work. The third decision concerning evaluation of clean-up success involves the design of endpoint criteria to be entered into the database.

II-1. PHYSICAL SYSTEM DYNAMICS, WP FATE AND TRANSPORT, AND REMEDIATION

Daniel E. Lawson, Lewis E. Hunter and Susan R. Bigl

U.S. Army Cold Regions Research and Engineering Laboratory

INTRODUCTION

Eagle River Flats (ERF) is a 865-ha tidal flat and salt marsh at the mouth of Eagle River on the Knik Arm, northeast of Anchorage, Alaska (Fig. II-1-1). The tidal flat has been used as an artillery impact range since the early 1940s. Previous work by CRREL has shown that an unusually high mortality of migratory waterfowl, particularly ducks, is attributable to the ingestion of elemental white phosphorus (WP) particles (Racine et al. 1992a,b). White phosphorus particles were introduced by smoke-producing compounds in devices detonated during military training (Racine et al. 1992a, 1993). WP is now present as particles and adsorbed to near-surface sediments at numerous locations in ERF, most notably in pond and marsh bottom sediments where dabbling ducks ingest it during feeding. In addition, WP-bearing sediment can be remobilized and transported to other locations within or external to ERF where it is redeposited (Lawson et al. 1995a) and may pose a threat to unidentified receptors.

ACKNOWLEDGMENTS
Funding and support for this research was provided by the U.S. Army Alaska, Environmental Resources Department, Directorate of Public Works, Fort Richardson, Alaska, through the Alaska Engineers District, Anchorage, Alaska. We thank William Gossweiler, Douglas Johnson, William Smith and Laurie Angell for helpful discussions, logistical support and assistance in the field, and their continuing support of our work, as well as Dr. Charles Racine, Charles Collins and Marianne Walsh for numerous scientific discussions and assistance in the field and laboratory on the Eagle River Flats project. We also thank Troy Arnold, Ron Bailey, Dennis Lambert, Beth Nadeau and Pat Weyrick for their assistance, Jodie Strasser and Audrey Krat for data analysis and plotting and Cora Farnsworth for her contribution in preparing this report.

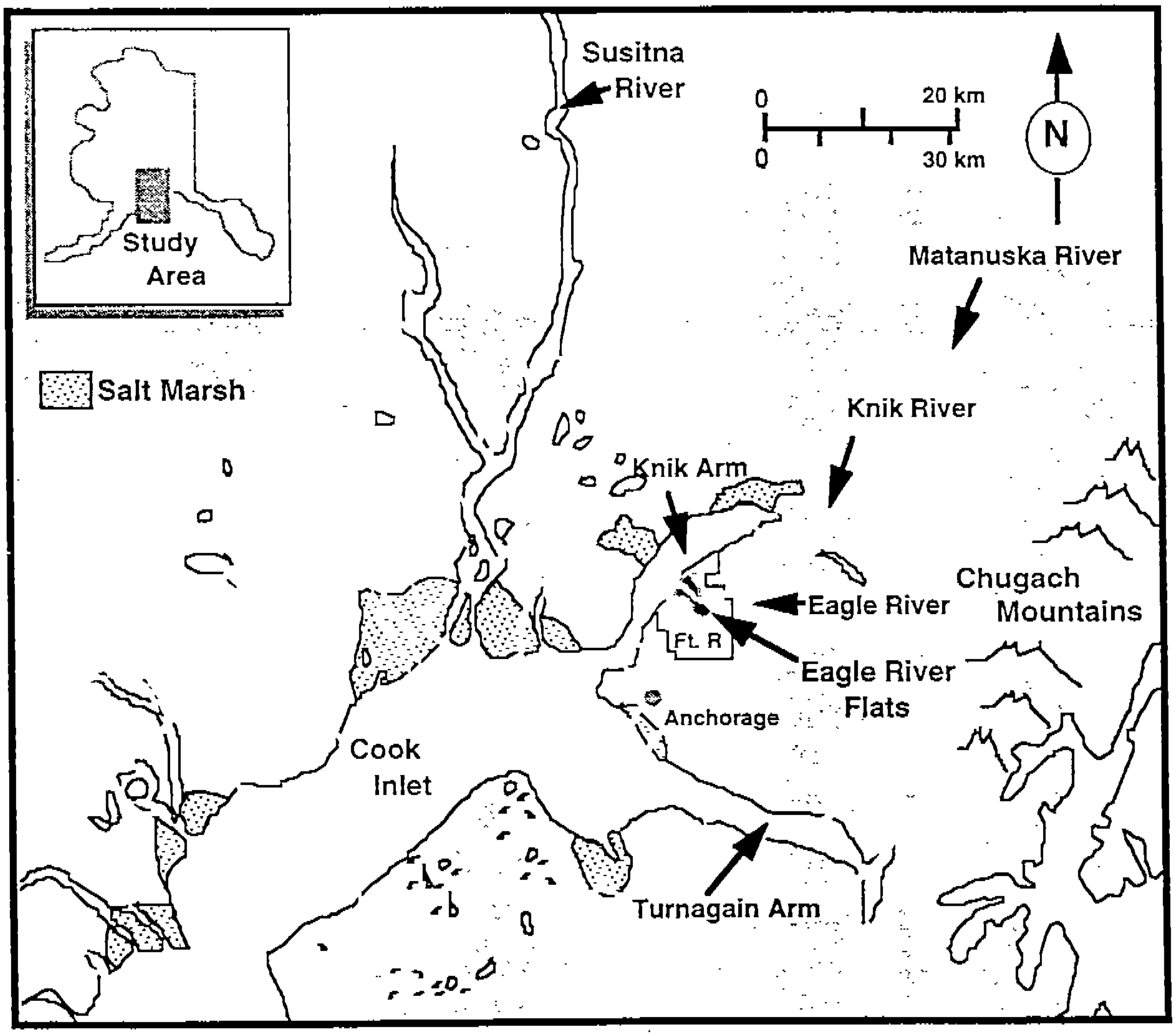


Figure II-1-1. Location of ERF and other salt marshes in upper Cook Inlet.

This report describes the results of 1995 investigations of the physical ecosystem of the Eagle River Flats and its role in the natural attenuation or intrinsic remediation of white phosphorus contamination. These studies included analyses of the tidal and river hydrology and associated factors critical to evaluating proposed remedial technologies for WP contamination. Our studies in 1993 and 1994 (Lawson et al. 1995a, b) suggested that the physical system, and specifically the processes of erosion and recession of gullies draining the contaminated ponds and mudflats, and the sedimentation within ponds, could both result in a natural attenuation and remediation of WP contamination over a significant portion of ERF. Therefore in 1995, we focused our efforts on understanding the rates at which these processes would alter the pond environments and result in removal or blockage of the WP pathway to migrating waterfowl. We also examined WP erosion and transport to further evaluate the potential for off-site migration of WP.

ENVIRONMENTAL CONDITIONS

Eagle River Flats is one of several estuarine tidal flats and salt marshes in the upper Cook Inlet region of south-central Alaska (Fig. II-1-1). Located at the mouth of the Eagle River, ERF is about 2.8 km wide at the coast and narrows inland. This subarctic region has a transitional maritime to continental climate, with moderate annual temperatures (daily mean 1.9°C; minimum mean –2.2°C) and precipitation (330–508 mm; Evans et al. 1972). Inundation results from both the semi-diurnal macrotidal fluctuations of 9–11 m in Knik Arm and the resultant overflow from the Eagle River as it meets the rising tide.

The Eagle River drains a 497-km^2 basin in the Chugach Mountains, 13% of which is covered by glaciers that significantly modify the runoff and sediment yield of the drainage basin (e.g. Lawson 1993). Glaciers modify peak discharges, the timing and volume of hourly, daily and seasonal discharges, the lag between precipitation and the resultant increase in runoff, and long-term trends in annual discharge of the basin (e.g. Gurnell and Clark 1987, Lawson 1993). Because of this glacial influence, maximum and peak discharges usually occur during the primary melt season of July and August. Sediment transport and sediment flux have diurnal, seasonal and annual variations caused primarily by glacial meltwater influx into the river basin (Lawson 1993). Massive quantities of silt- and clay-size particles are transported in suspension by the large rivers draining into Cook Inlet from glacierized basins in the Alaska Range, Chugach Mountains and Kenai Peninsula (e.g. Susitna, Knik and Matanuska River basins, Fig. II-1-1).

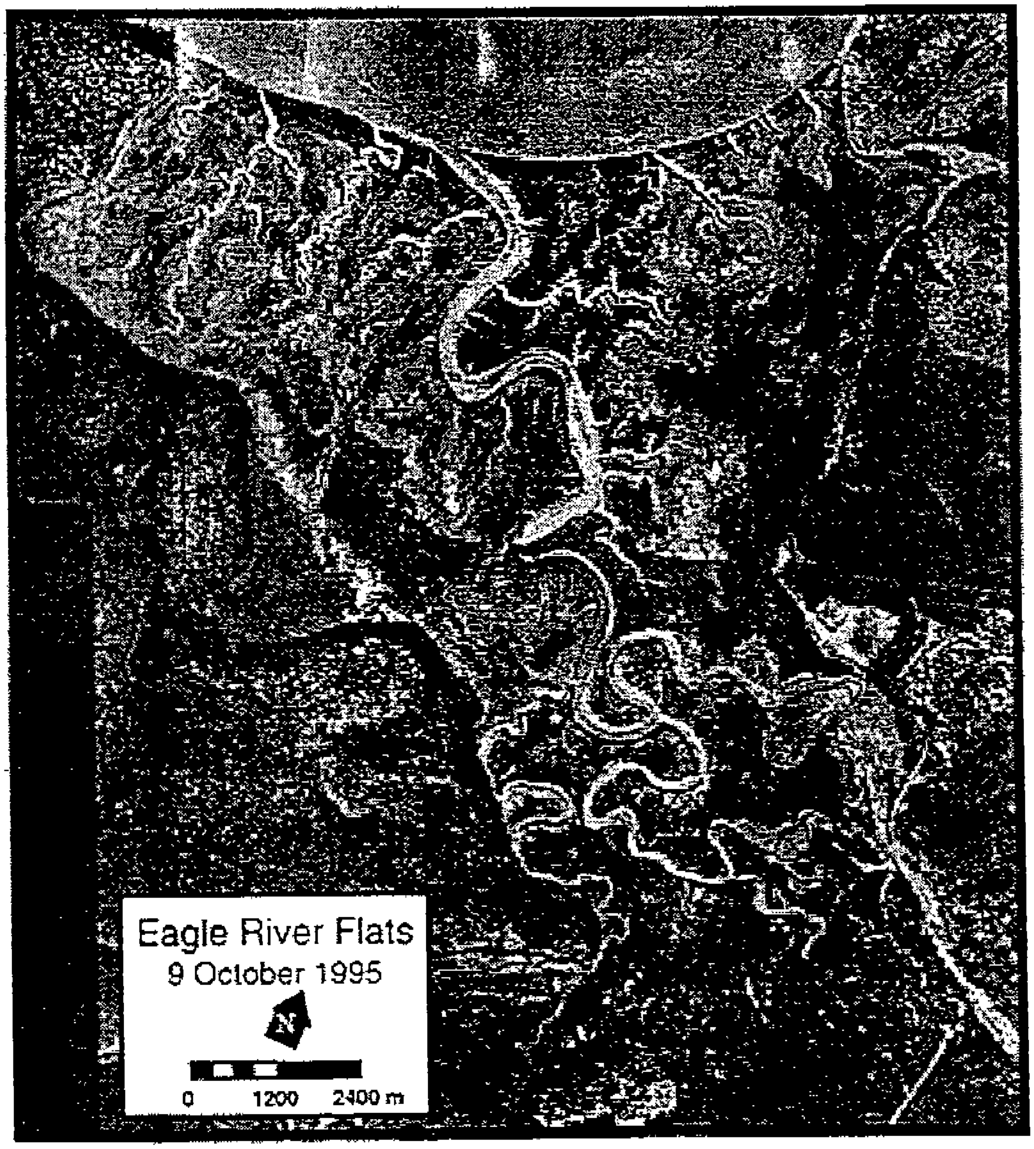


Figure II-1-2. 1995 aerial photograph of ERF showing the dendritic drainage network.

These materials remain suspended for an extended time and are transported into intertidal wetlands during tidal inundation (Lawson et al., in review).

The Eagle River cuts approximately through the middle of ERF, with the primary drainage from ponds and marshes occurring through vegetated channels or drainageways and unvegetated tidal gullies that form a dendritic network (Fig. II-1-2). Where gullies and drainageways do not follow a dendritic course, their location appears to be controlled by relict drainage networks abandoned during evolution of ERF (Fig. II-1-3). The northern and coastal 20% of ERF is

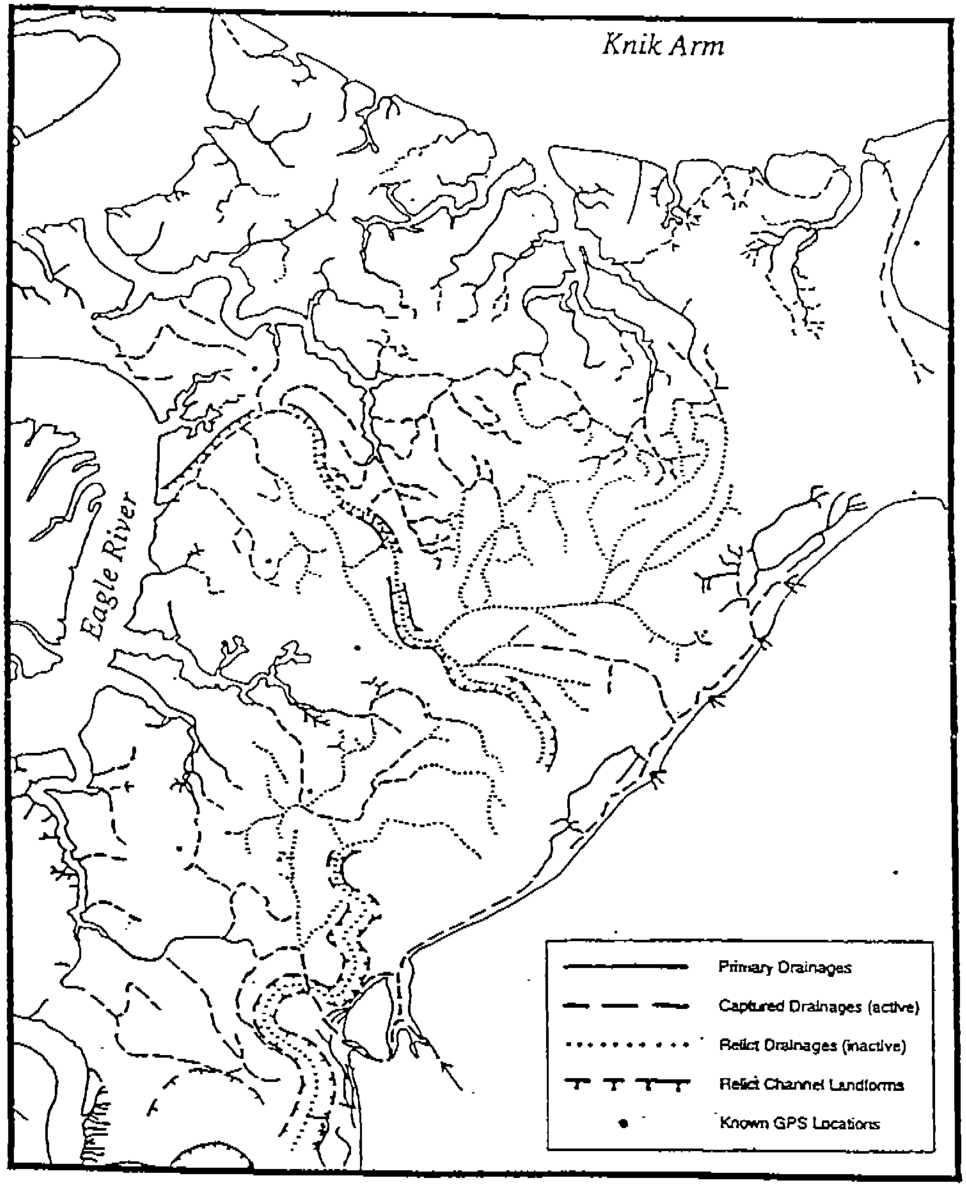


Figure II-1-3. Drainage network in the C and D areas of ERF.

drained through gullies that discharge directly into Knik Arm. The east, west and southern boundaries of ERF are defined by uplands composed of glacial deposits covered by spruce and birch forests.

As with other estuarine salt marshes in Cook Inlet (e.g. Hanson 1951, Vince and Snow 1984, Rosenberg 1986), vegetation occurs in zones that are commonly determined by elevation and related to the landforms of ERF (Fig. II-1-4). This relationship is believed to be a function of flooding frequency, drainage capacity and sedimentation rates. Levees, mudflats, marshes and shallow ponds (to 50 cm depth) are aligned approximately parallel to the Eagle River and coastline (Racine et al. 1992a). Freshwater ponds or shrub bogs lie along the northeast and southwest portions of the upland bordering ERF.

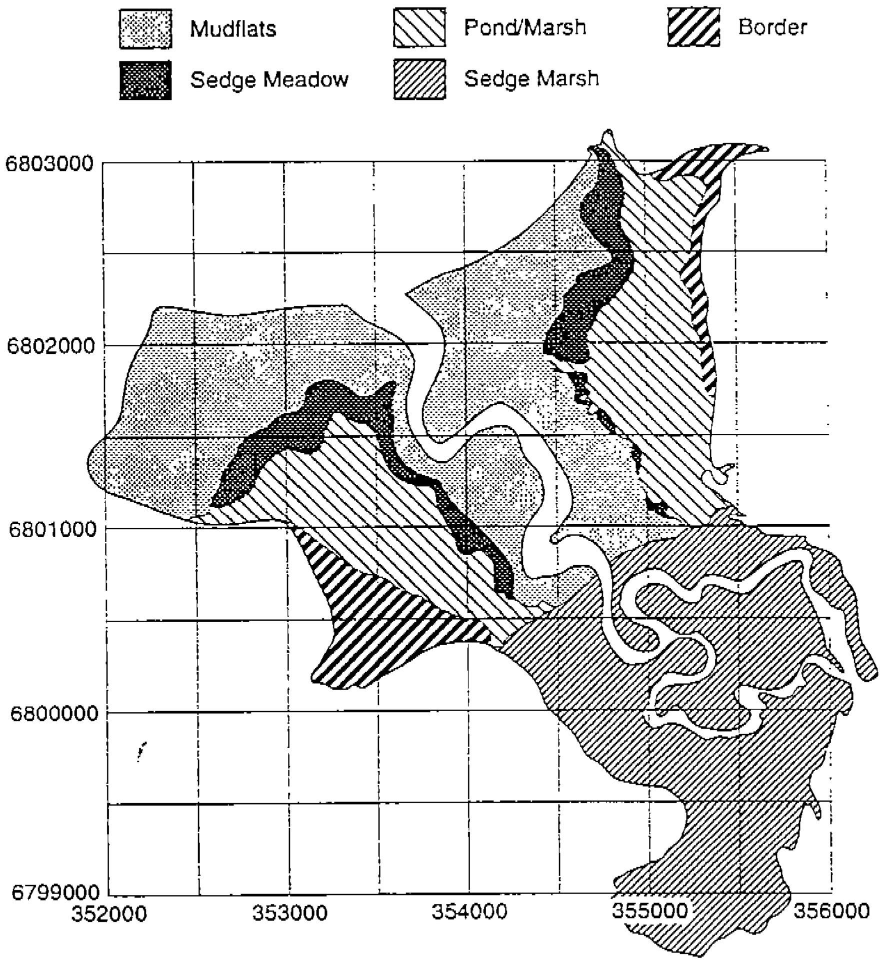


Figure II-1-4. Distribution of primary landform-vegetation units (from Racine et al. 1993).

RESULTS OF PREVIOUS PHYSICAL SYSTEM INVESTIGATIONS

Previous investigations have focused on characterizing the processes and factors affecting the physical environment of ERF (Tables II-1-1– II-1-4) and evaluating the fate and transport of WP, both critical to developing a conceptual model and the remedial technologies required for clean-up. Results of these investigations are summarized here.

Table II-1-1. Factors/controls on physical processes.

Factor
Internal
River
Tides
Glacial sediment/water sources
Substrate material properties
Vegetation
Sediment influx/efflux
Weather/climate
Human activity
Ground water conditions
External
Earthquakes
Tectonic activity
Eustatic sea level rise
Isostatic rebound
Subarctic climate
Glaciers
Surface and ground water systems

Table II-1-2a. Summer erosional processes.

Morphological unit	*Processes*	
Marshes	Currents (rare)	Wind waves (rare)
Ponds	Wind waves Wind currents Ducks and other bottom feeding organisms	Tidal currents Debris impacts (e.g., logs) Bioturbation
Gullies	Currents -tidal -runoff Overland flow -sheet -rill Wind waves	Ground water -piping -sapping Gravitational slope processes -slump -block collapse -sediment gravity flow
Mudflats	Currents -wind -tidal Overland flow -sheet -rill	Debris impacts (e.g., logs) Rain drop impact Bioturbation
Levees	Currents -tidal -river	Debris impacts Wind waves
Coast	Current scour Wind waves	Debris impacts Overland flow

Table II-1-2b. Winter erosional processes.

Morphological unit	*Processes*
Marshes	Ice plucking
Ponds	Freeze-on and ice plucking Ice shove Ice scour
Gullies	Plunge pool undercutting Freeze-thaw cycling Ice segregation and thaw Ice directed current scour
Mudflats	Ice plucking Ice shove (floating/expansion) Ice scour Ice cover confined scour Freeze-thaw cycling
Levees	Ice scour Freeze-thaw cycling Ice shove Ice-directed current scour
Coast	Ice plucking Ice shove (floating/expansion) Ice scour Ice block confined scour Freeze-thaw cycling Current scour Wind waves

Table II-1-3. Transport processes.

Summer processes	*Winter processes*
Currents (river)	Ice floes
Suspended load	Freeze-on
Bed load	Freeze-in
Saltation	Ice shove
Wind Currents (pond/mudflats)	Frazil Ice
Suspended load	Anchor ice
Bed load	Freeze-on
Gravitational slope processes	Freeze-in
Currents (tidal/gully)	
Flood	
Ebb	
Groundwater	
Piping	

Table II-1-4. Depositional processes.

Morphological unit	*Summer processes*	*Winter processes*
Ponds	Suspension sedimentation -settling-out -vegetation trapping	Ice entrapment and in situ melting
Gullies	Suspension sedimentation -settling-out Bedload deposition Sediment gravity flows Slumping	Ice growth entrapment and in situ melting Ice cover confined settling out
Mudflats	Suspension sedimentation -settling-out -vegetation trapping	Ice freeze-on and in situ melting Snow filtering and in situ melting Ice growth entrapment and in situ melting Ice cover confined suspension settling
Marshes	Suspension sedimentation -vegetation trapping	
Levees	Suspension sedimentation -settling-out -vegetation trapping	Ice freeze-on and in situ melting (sediment/organics) Snow filtering and in situ melting Ice growth entrapment and in situ melting Ice cover confined suspension settling out

The processes of erosion, transport and deposition vary seasonally, annually and over decades in response to a number of internal and external factors (Table II-1-1). Their relative importance and magnitude may also vary spatially across ERF in response to these same factors. The role these factors play in determining physical process relationships remains under investigation; previous work on process relationships are described in more detail in Lawson et al. (1995b).

External controls (Table II-1-1) on the physical system are difficult to define because their effects may last several decades or more and exert considerable control on internal factors that influence process relationships. In particular, tectonic and earthquake activity are virtually impossible to predict; however, their impact on the ERF physical system may be enormous. Eagle River Flats was affected by the 1964 Alaskan earthquake (magnitude 8.9 on the Richter Scale), with both sedimentary and tectonic subsidence modifying the site's elevation over time and thus the processes operating therein (e.g. Ovenshine et al. 1976a, Combellick 1990, 1991, 1994, Brown et al. 1977, Savage and Plafker 1991). A tectonic drop of about 0.6–0.7 m was recorded in the Anchorage region (Brown et al. 1977). Sedimentary subsidence caused by sediment liquefaction and solidification during the earthquake probably reduced the pond bottom elevations as it did in the Portage area of Turnagain Arm (Ovenshine et al. 1976a). Following the 1964 earthquake, about 20 cm of post-seismic uplift occurred by 1975 (Brown et al. 1977); Savage and Plafker (1991) have estimated that uplift is continuing at 1.0 mm/yr. Long-term responses of the physical system to these elevational changes are unknown; however, the increase in pond water depth and extent may have increased pond sedimentation rates (e.g. Ovenshine et al. 1976a), while tidal flat hydrology may be responding to the disequilibrium caused by tectonic uplift of this area, or the increase in flooding related to a larger influx of tidal waters because of the overall subsidence of the Flats (Atwater, 1996, personal communication).

Internally, tidal and river water dynamics control the amount of material available for deposition in ERF and affect the locations and rates of erosion. The amount of sediment transported in flood waters is a primary factor in determining the erosion and transport of sediments during ebb (Tables II-1-2 and II-1-3). The transport capacity changes seasonally with variations in glacial input and ambient air temperature. During winter months, sediment and water discharge in the Knik, Matanuska, Susitna and Eagle River catchments decreases. Flooding tides become less diluted and their temperature is depressed, resulting in a net increase in water density and transport capacity. The result is an increased ability for flood waters to erode and transport sediment during the late fall and early winter, although the total volume of material available for transport may be reduced.

Water level changes from tidal inundation show a 20- to 40-minute delay in peak tidal flood height across ERF, in the Eagle River and at the coast relative to that predicted at Anchorage. The flooding height of the delayed tide is also generally 0.5 m or more greater than the Anchorage datum, reflecting at least in part the funneling of water out of Cook Inlet into the narrower Knik Arm. Tidal flooding of the Bread Truck, C, A and Racine Island areas may be enhanced seasonally by the discharge of the glacially fed Eagle River, particularly by snowmelt and precipitation in the river's watershed. In contrast, inundation along the coast is a function of tidal height, which may be influenced by the direction and velocity of the wind, ice cover, and storm-driven surges in Knik Arm, and discharge characteristics of the Knik and Matanuska rivers.

Tidal current measurements indicate that velocities are higher during ebb than during flood, and thus sediment transport and channel erosion are potentially greatest during ebb. Peak velocities in 1994 ranged from about 0.8 to 1.9 m/s and varied from site to site and with the elevation of tidal flooding. The velocity variations reflect differences in gully width, depth, roughness and network configuration.

The Eagle River provides access for tidal waters to inundate the innermost reaches of the Flats. Stage and discharge of the Eagle River are affected by high tides that increase river stage by tidal damming. Damming locally increases depositional rates as flood waters become slack. Sedimentation in the northern two-thirds of ERF is tidally dominated, whereas the southern one-third appears to be river-dominated. Tidally dominated sedimentation ranges from several mm per year on levees, 10–15 mm/yr on mudflats, and up to 20–40 mm/yr in ponds. Sedimentation at the head of ERF appears to be in the form of an alluvial fan (Fig. II-1-5), indicating that deposition here is mainly derived from overbank flooding of the river.

Suspended sediment concentrations measured in 1994 in the Eagle River, tidal gullies draining the ponds and mudflats, and Knik Arm indicate that most of the sediment is derived from Knik Arm tidal waters. The total suspended solids (TSS) in waters of ERF vary with tidal stage, location, source and season. The glacially-fed Eagle River varies seasonally from peak TSS values of 100–700 mg/L between break-up in May and freeze-up in October. Two seasonal highs apparently occur annually, the first during snowmelt runoff and the second during the peak glacial melt season. In contrast, TSS of Knik Arm water ranges from about 1000 to 2800 mg/L from May to October. During a tidal cycle, TSS measurements at gully sites increase steadily through the flooding tide and decrease at a slower rate during the ebb. Seasonally, TSS values in gully and Knik Arm waters increased from spring to fall; the cause of this increase is unknown.

Gullies are actively extending into the mudflats and ponds in the Bread Truck, C, A, D and C/D (Lawson's pond) areas. Headwalls and adjacent lateral walls receded at variable rates ranging from 0.1 to 4.9 m during summer 1992, 0.4 to 6.3 m during winter 1992-93, 0.0 to 9.8 m during summer 1993, 0.0 to 2.3 m in winter 1993-94, and 0.0 to 2.6 m in summer 1994. Large tidal flooding events in 1993 and 1994 caused the highest headwall recessional rates. Two gully headwalls, one on the west side of Bread Truck and the other near the pond complex between Bread Truck and C ponds, are advancing at a rate sufficient to cause increased drainage of those ponds within 15–20 years at mean rates during 1993-94.

Surveyed longitudinal profiles of tidal gully thalwegs revealed non-uniform gradients that reflect their progressive and episodic elongation into the mudflats and ponds, and a lack of equilibrium with present conditions and factors. Gully gradients are relatively steep near their mouths, but are reduced in the lower and mid-reaches of the gully. Channel gradients again steepen in the upper most reaches below a nearly vertical headwall that ranges in height from 1 to 2.5 m. Incipient drainageways from ponds and mudflats into tidal gullies exhibit very low gradients. Several sharp increases in gradient (knick points) occur in each gully, marking channel adjustment as the tidal gully progressively extends into the mudflats and ponds.

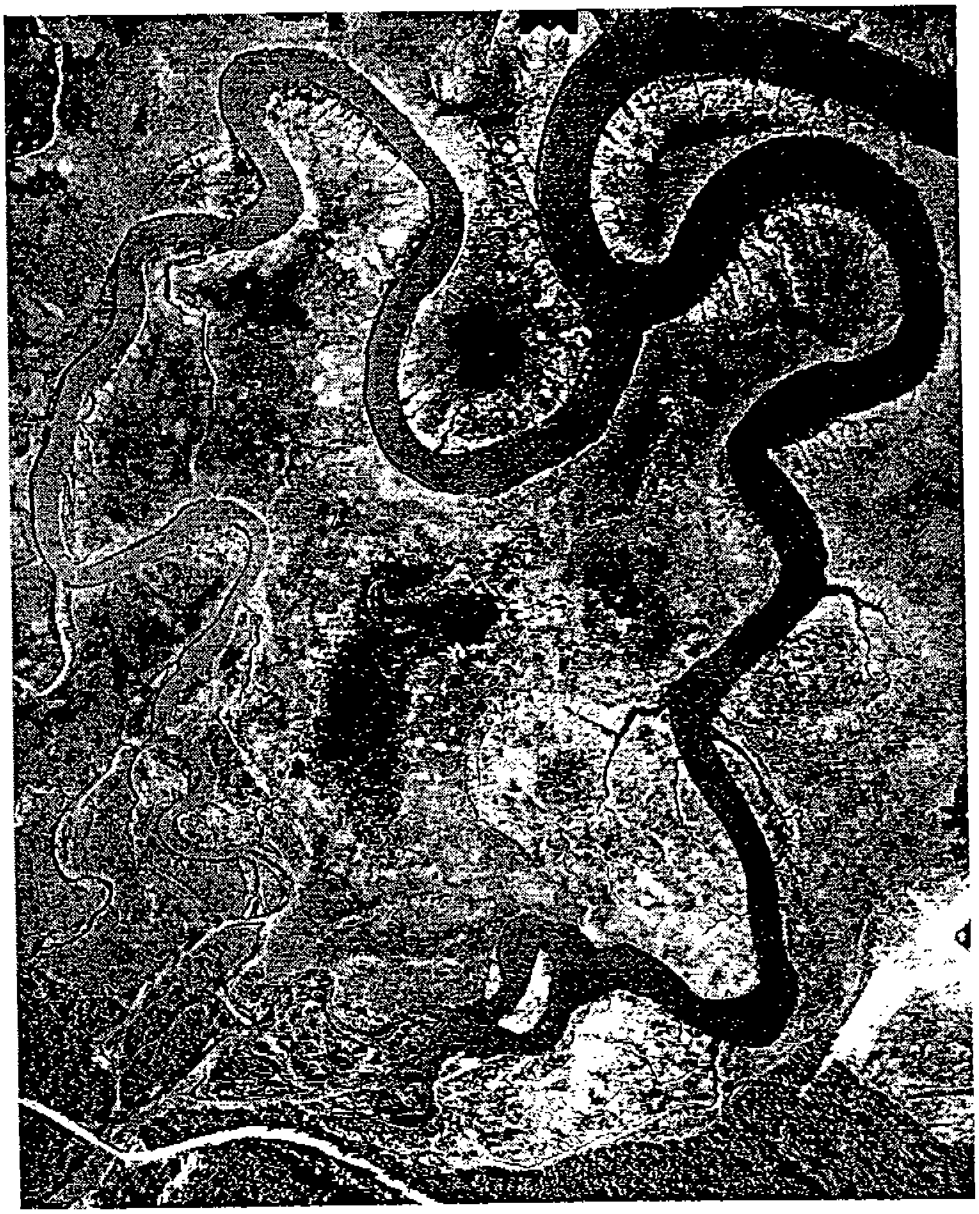


Figure II-1-5. Aerial photograph of Racine Island taken 16 August 1995 showing remnant channel surrounded by overbank deposits.

Aerial photographs from 1950, 1967 and 1993 reveal changes in the distributary channel pattern entering ERF (Fig. II-1-6). Three main channels entered the Flats in 1950, but by 1967 the western most channel was abandoned and the eastern and middle channels diverged just northeast of the Route Bravo bridge. The two primary channels entering the Flats were characterized in 1967 by partial braiding and a divergent pattern characteristic of an alluvial fan (Fig. II-1-6b). Deposits in the fan area are relatively featureless overbank materials deposited by

a. 1950.

Figure II-1-6. Aerial photographs of ERF.

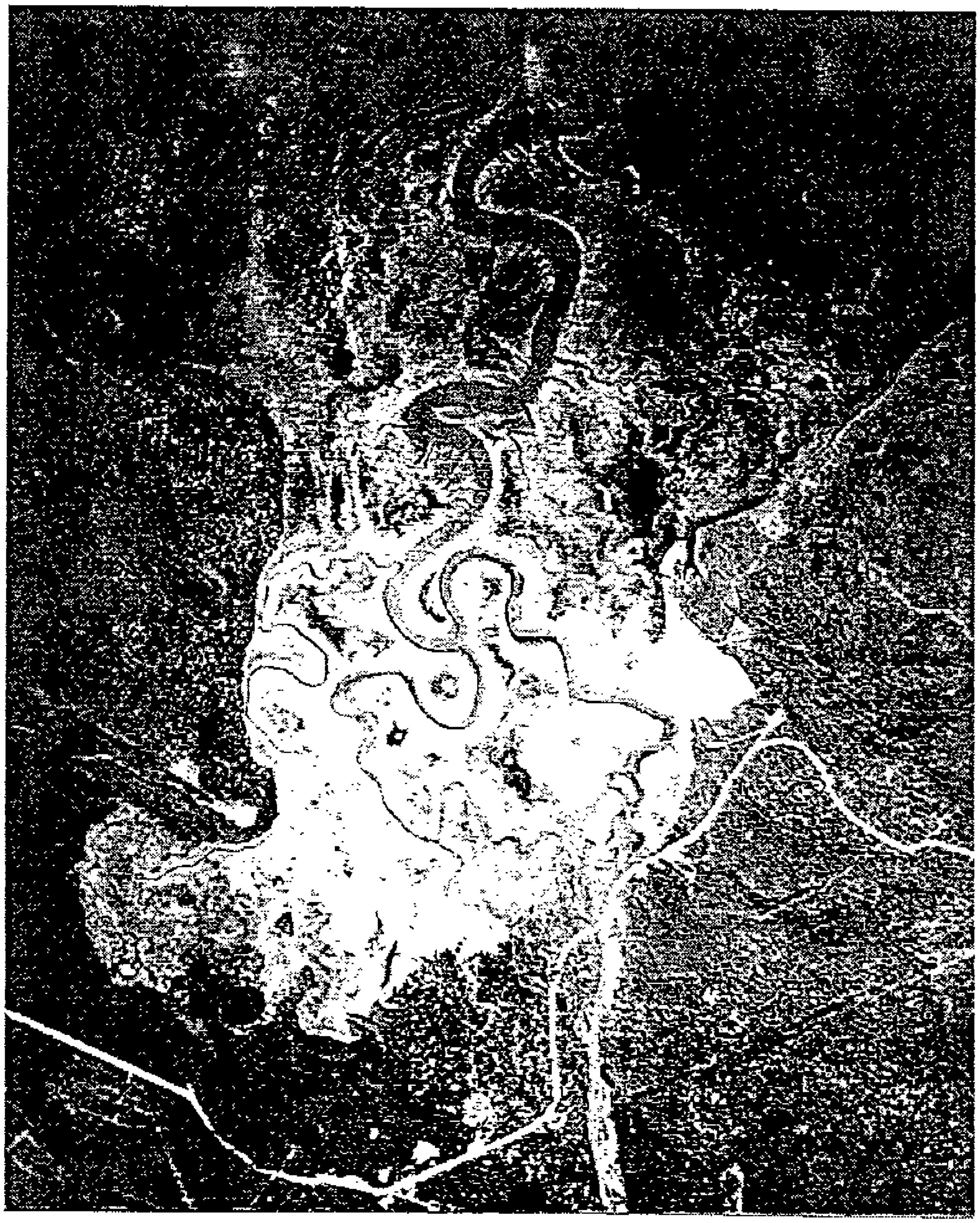
Eagle River flooding. Only the center of the Racine Island area (Fig. II-1-5) is characterized by intertidal ponds and an abandoned gully. The westerly channel was abandoned this September (1995) during flooding of the Eagle River when channel scour and migration shifted the easterly channel further to the north-east.

In contrast, the northern two thirds of ERF have landforms typical of tidal

b.1967.

Figure II-1-6 (cont.). Aerial photographs of ERF.

flats near river mouths (e.g. Ovenshine et al. 1976b) and consist mainly of levees, vegetated marshes and abandoned channels and point bars. Significant changes in the relatively tight meander loops in this lower section of the river have however also taken place over the last 40 years. Channel changes are a natural progression resulting from the erosion and recession of the outer banks of meander bends, deposition of sediments as point bars in the inner parts of each



c.1993.

Figure II-1-6 (cont.). Aerial photographs of ERF.

bend, and a general downstream migration of the channel (e.g. Allen 1982). Meander scars, abandoned meander loops, and point bar deposits are common along the length of the active channel and are evidence of changes further in the past.

Tributary channels with dendritic patterns, referred to as vegetated drainageways, drain water from the mudflats and ponds into the tidal gullies (Fig. II-1-3 and II-1-7). A second set of channels intercepted by the active tributary system

Figure II-1-7. 1992 aerial photograph of northeastern ERF.

unconformably crosses other landforms including ponds (such as C and Bread Truck). Their pattern is irregular and unrelated to the active gully drainage system. These secondary channels are parts of former drainageway and gully systems that are now inactive and therefore relict. Their fragmentary presence indicates significant changes to the drainage system in the past. The cause of such change is unknown, but events such as river avulsion, channel migration, or earthquake-induced subsidence may result in abandonment of drainageways.

Chemical analyses of a limited number of sediment trap and plankton net samples indicate that WP undergoes suspension, transport and redeposition in ERF, as well as transport through tidal gullies into the Eagle River and Knik Arm. Tidal and wind driven currents can scour pond bottoms, resuspending and transporting WP, whether as particles or sorbed to sediment, while plunge pool erosion and scour of vegetated drainageways and gullies can entrain and transport WP in suspension or as bed load. In addition, pond and mudflat sediments can freeze to the base of the ice cover during its growth, and subsequently be rafted during tidal inundation. Bathymetric profiling offshore of ERF shows no evidence of deposition of ERF sediments as a delta at the mouth of the Eagle River. White phosphorus entering Knik Arm is potentially diffused by tidal and river currents, but several potential sites of WP deposition exist and need to be evaluated (Lawson et al. 1995b). These sites include intertidal bars and nearshore deposits.

Previous investigations suggest that natural attenuation and remediation of WP contamination is possible, but further work is needed to assess the length of time over which this may occur and identify specific locations where natural attenuation is the remedial method of choice. The relative importance of erosional and depositional processes vary from area to area in response to tidal and river hydrology; however, changes in the system over seasonal, annual or decadal time periods are possible. Pond sedimentation rates appear to be sufficiently high in some areas to provide a natural method of WP burial, thereby reducing the exposure risk for waterfowl. The drainage system is also actively changing as tidal gullies expand across mudflats into ponds; certain ponds are likely to drain in 20 years or less. Drier conditions will permit in situ degradation and natural remediation of WP contamination. Erosion will however continue to release WP from mudflat and pond sediments over time, while ice and water transport mechanisms will move WP particles into tidal gullies, the Eagle River and Knik Arm. Whether these particles survive mechanical transport and persist in Knik Arm is unknown, but simple laboratory flume tests of WP particle resistance to abrasion could determine if transport destroys them. Again, this process would remediate the contamination naturally.

STUDY SITES AND METHODS

Sedimentation transects

Sedimentation rates are measured along transects across representative landforms of ERF, with eleven landform transects being set out in May 1992 (Lawson and Brockett 1993), one in June 1993, and eleven in 1994 (Fig. II-1-8). Their locations and elevations were surveyed using an electronic theodolite. Grab samples of surface sediment (to 5-cm depth) were taken at each survey point along the transects, and their grain size distribution was analyzed using standard sieving

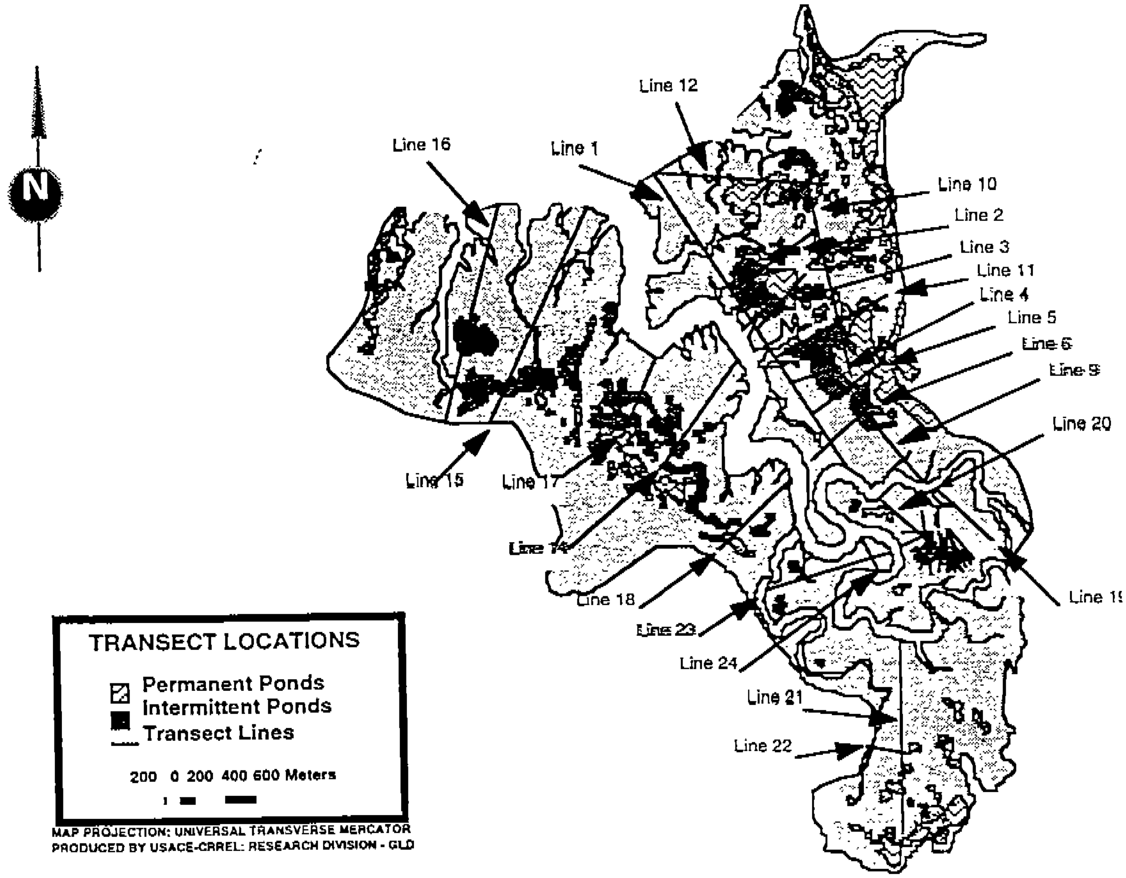


Figure II-1-8. Mudflat sedimentation transect locations.

and hydrometer techniques. These data delineated textural trends in surface materials and the relative importance of tidal or riverine sediment sources to sedimentation and landform development.

New transects were established in May 1995 for detailed measurements of sedimentation rates in six ponds (Fig. II-1-9). Two orthogonal transects were usually established in each pond, with traps located about every 20 m along them.

Sedimentation measurements

Sedimentation rates in permanent ponds and marshes are difficult to measure accurately because a slight disturbance of the water column can resuspend the fine-grained materials covering their bottoms. If they are caught in sediment traps, sedimentation rates will be measured as higher than the actual rate. We therefore used two methods in permanent ponds to measure sedimentation and to evaluate resedimentation resulting from natural resuspension of pond and marsh sediments by wind, waterfowl and other processes.

Sedimentation stakes were used to measure erosion and deposition at transect points where the surface was wet or standing water was temporarily present (Fig. II-1-10). These stakes consist of a rod and a square, rigid plate (about 7 cm^2) that slides freely on the rod as used by Ovenshine et al. (1976 a,b) in Turnagain Arm, Alaska. Erosion depth is defined by the increase in distance between the top of the rod and the top of the plate, as measured periodically to the nearest 0.5 mm. The amount of accretion is the thickness of sediment deposited on the plate surface. The difference between these two readings defines the net sedimentation (or erosion) rate. Monthly rates were measured in July, August and September 1992 following each monthly period of tidal flooding, while seasonal rates were measured in May and September 1993, 1994 and 1995.

Sedimentation on levee and mudflat surfaces was monitored by spraying an area (~30 × 30 cm) on the ground surface with pavement marking paint and locating the corners of this area with wire survey flags (Vince and Snow 1984). Paint was applied at certain sites in June and August 1992, August 1993 and

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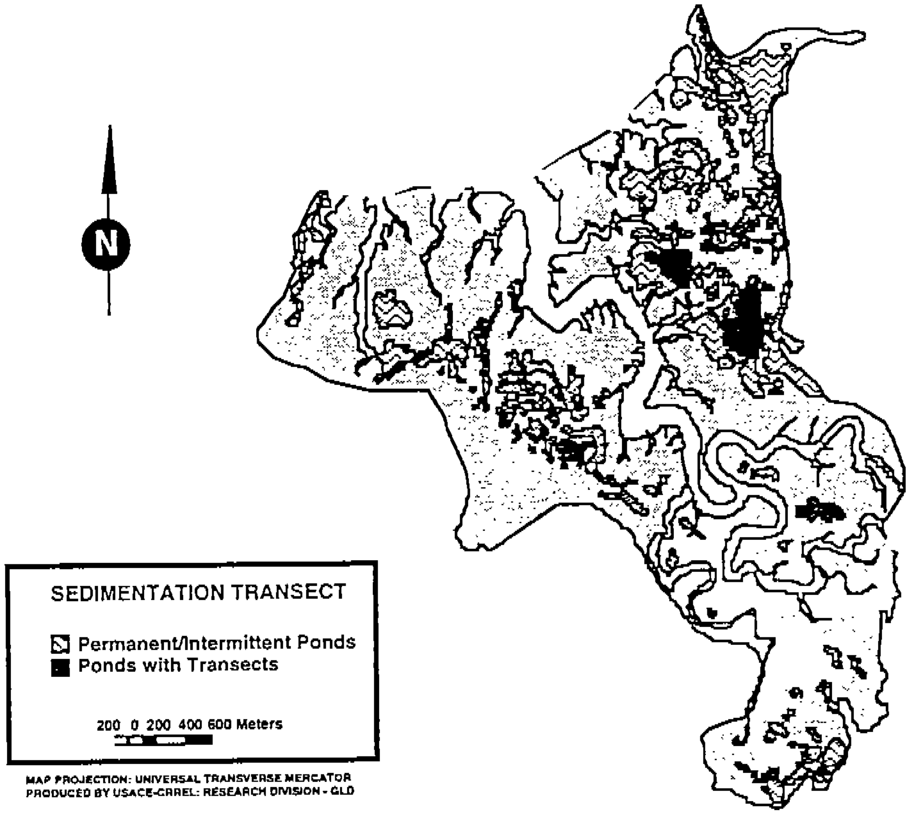
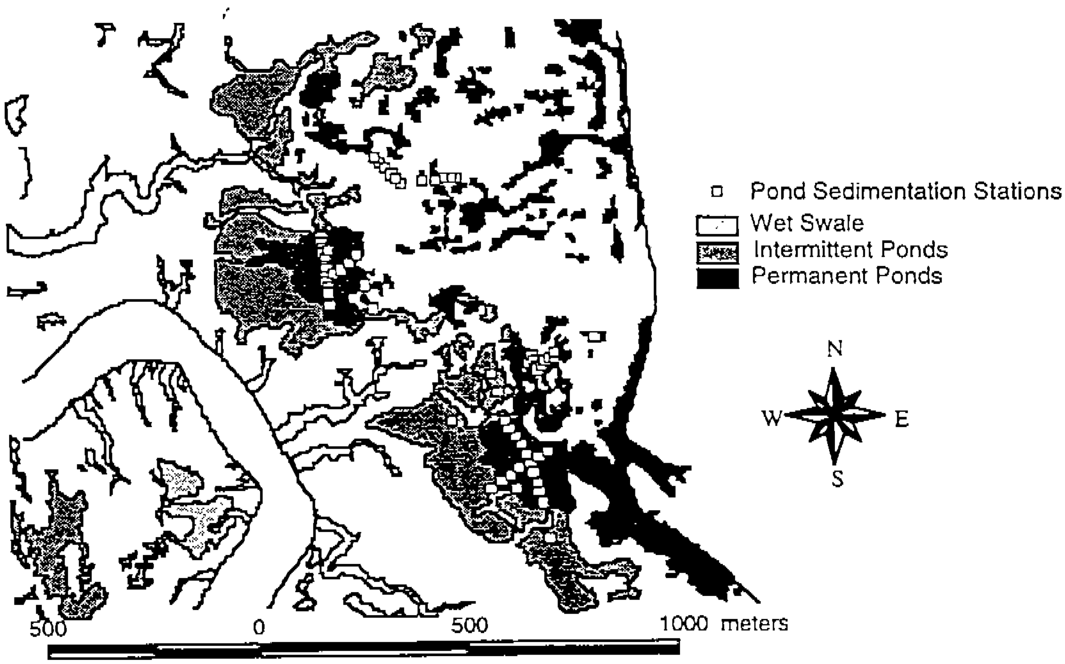
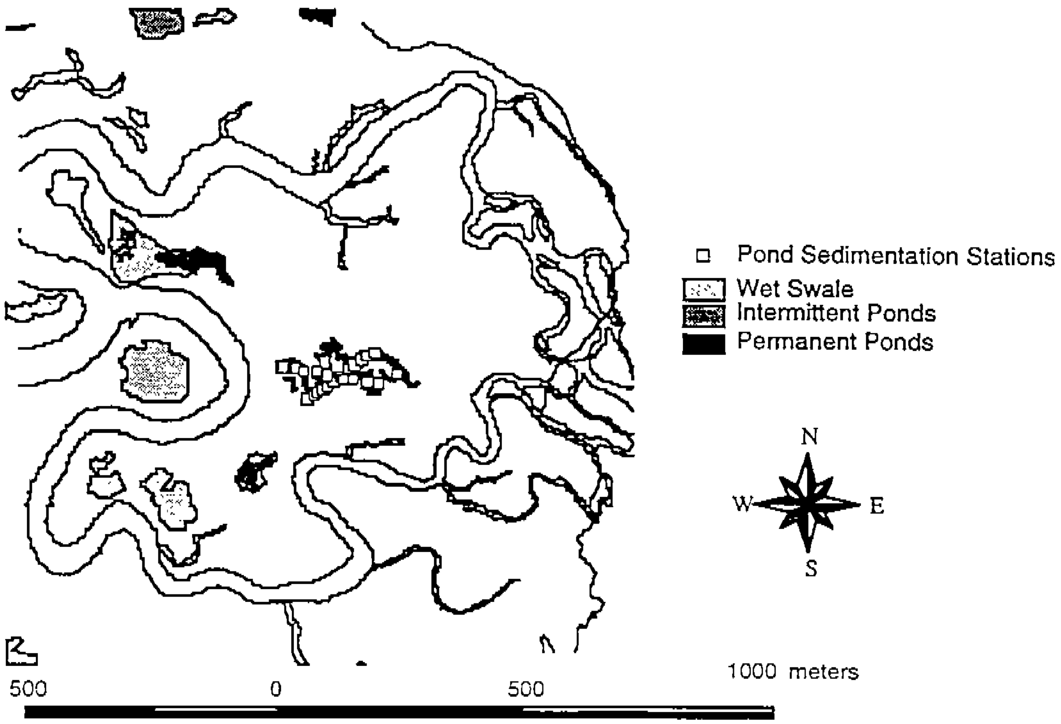


a. Individual 1992-1994 measurement sites and locations of pond transects.

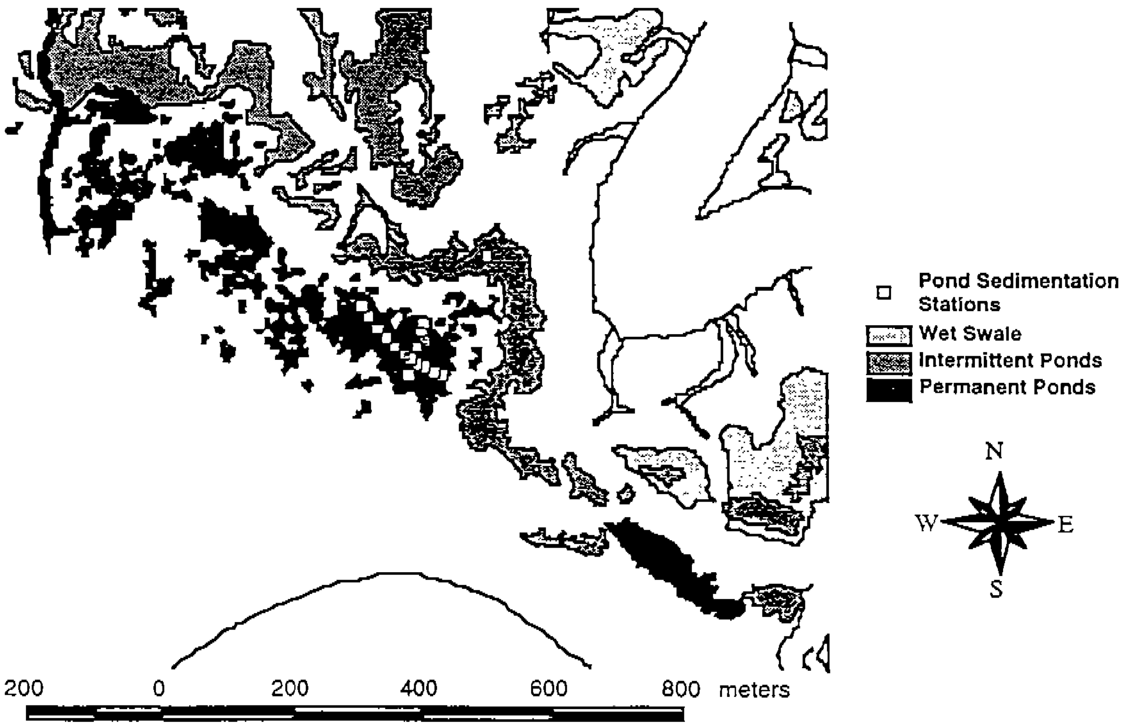


b. Transects in C- and Bread Truck ponds.

Figure II-1-9. Pond sedimentation measurement locations.

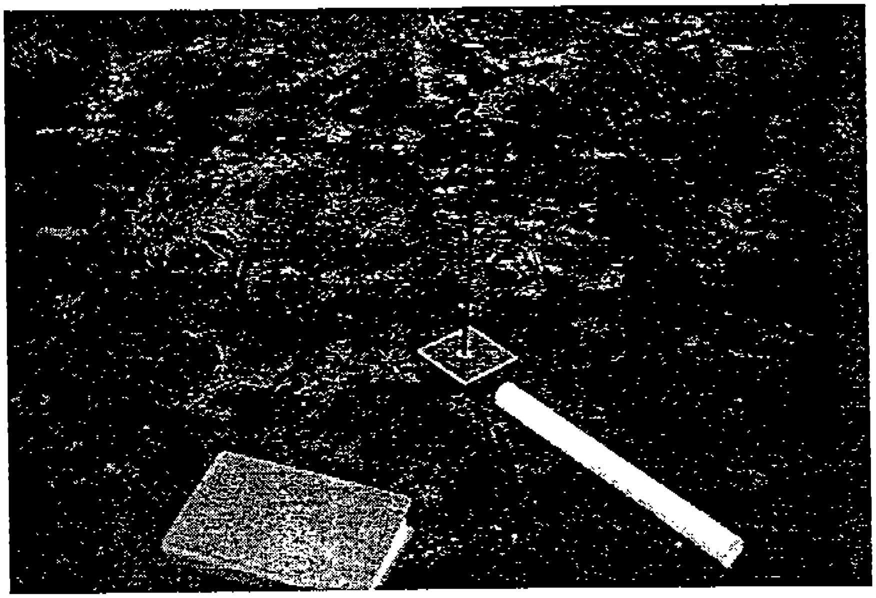


c. Racine Island Pond transects.

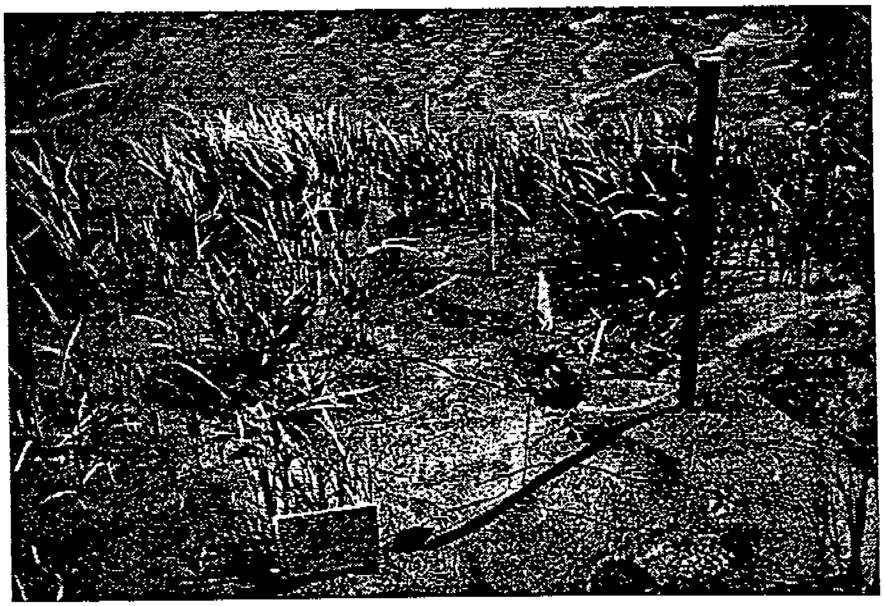


d. A Pond transects.

Figure II-1-9. Pond sedimentation measurement locations.



a. Sedimentation stake with plate.



b. Wire flags mark an area of painted ground.

Figure II-1-10. Sedimentation measurement techniques.

May/June 1994. Net accumulated sediment is measured by cutting and removing a block of sediment with a putty knife or spatula (Fig. II-1-11). The thickness of sediment above the paint layer is then measured to the nearest 0.5 mm. In contrast to sedimentation stakes that are commonly broken or removed by ice

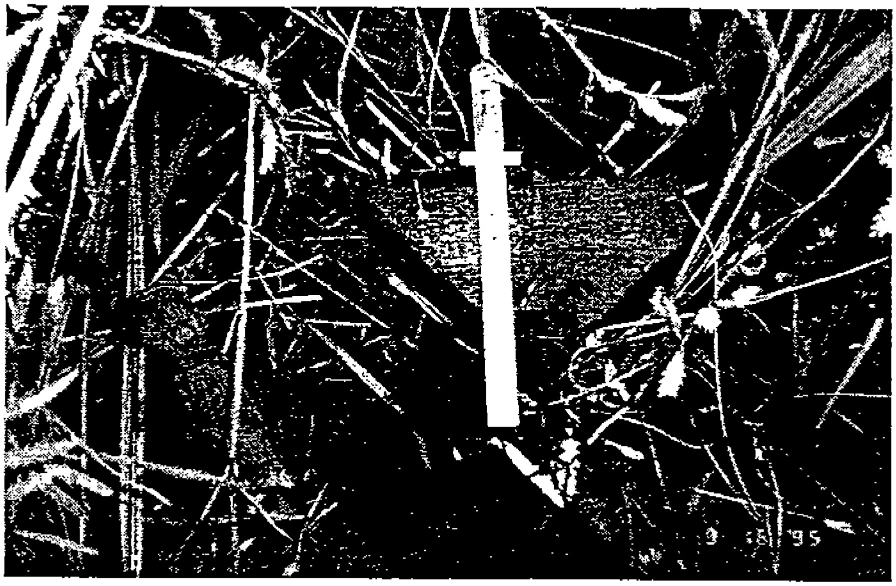


Figure II-1-11. Wedge-shaped sediment block used to measure vertical accretion. Note subhorizontal laminations.

in winter, the wire flags and buried paint horizons enable us to acquire a continuous record of net sedimentation rates. Over an extended period, post-depositional compaction is also accounted for by paint horizon measurements.

Gross sedimentation rate in ponds was measured at 18 sites following tidal inundations in June, August and September 1992, and in May and September 1993, 1994 and 1995 (Fig. II-1-12). Gross (total) deposition from tidal and river inundation as well as resuspended bottom sediments was measured in a sediment trap consisting of either a 4-in.-diameter (10.2-cm-diameter) schedule-40 PVC pipe end cap glued to a short length of 2-in.-diameter (5-cm-diameter) schedule-40 PVC pipe at pond stations, or a 16-cm-diameter end cap at the new pond transect stations established in May 1995. The pipe was inserted into pond sediments until the bottom of the cup was in contact with the bed (Fig. II-1-13). Sediment trapped in the cup includes new sediment brought into the ponds by tidal inundation and river currents, and materials resuspended by wind waves, dabbling ducks or other mechanisms. The quantity of accumulated sediment is measured to the nearest 0.5 mm by inserting a graduated scale into the sediments at three places. After measurement, the sediment in the cup is cleared or saved for analysis of white phosphorus concentration.

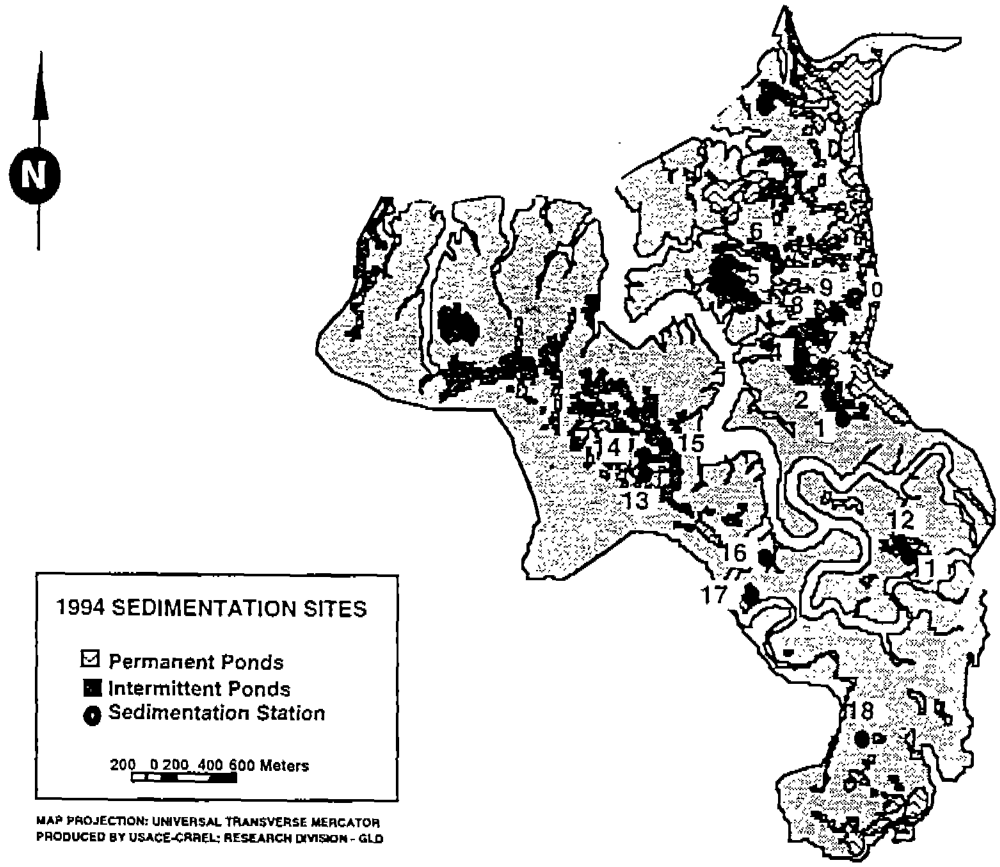


Figure II-1-12. Locations of 1992-1994 pond sedimentation stations.

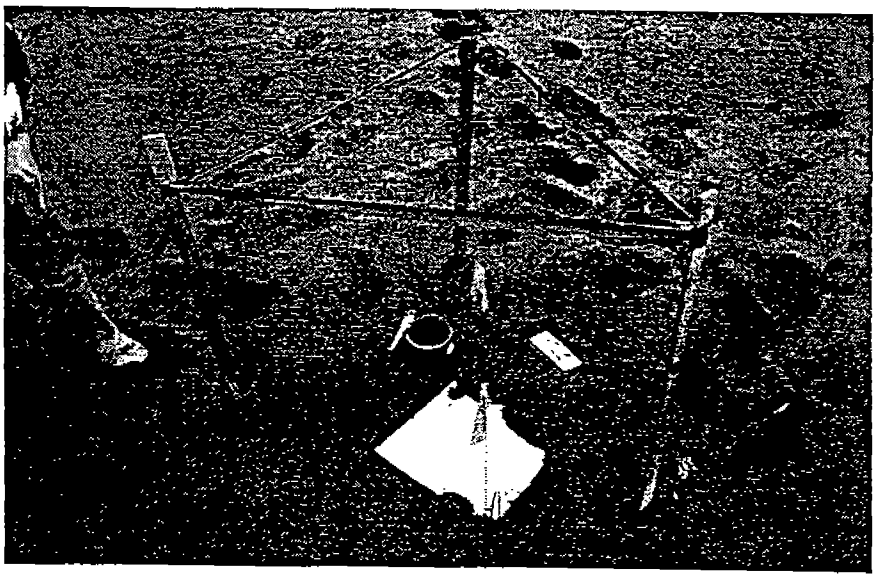


Figure II-1-13. Example of sedimentation station at an intermittent pond location showing layout of cup and plate sampler.

Net sedimentation rate in ponds on stations or transects is measured using a thin, but rigid plastic plate of about 30 cm square that is pushed gently into the pond bottom until the plate surface is flush with the bottom surface. The corners of the plate are secured by aluminum tent pegs (Fig. II-1-13). Sediment in suspension settles onto this plate, but this sediment can also be reworked and resuspended by wind or other mechanisms, thereby delineating a net rate. The thickness of sediment is measured to the nearest 0.5 mm using a graduated scale.

Gully erosion and headwall recession

Tidal gullies draining ponds and mudflats are actively extending inland by erosion at their heads. We established 86 sites between June 1992 and May 1995 to evaluate retreat rates, with periodic relocation of stakes at each site as recession takes place (Fig. II-1-14). At each site, stakes are driven into the ground along a straight line at known distances from one another and from the crest of a gully scarp (Fig. II-1-15). A "hub" stake is set at a known distance from this stake line.

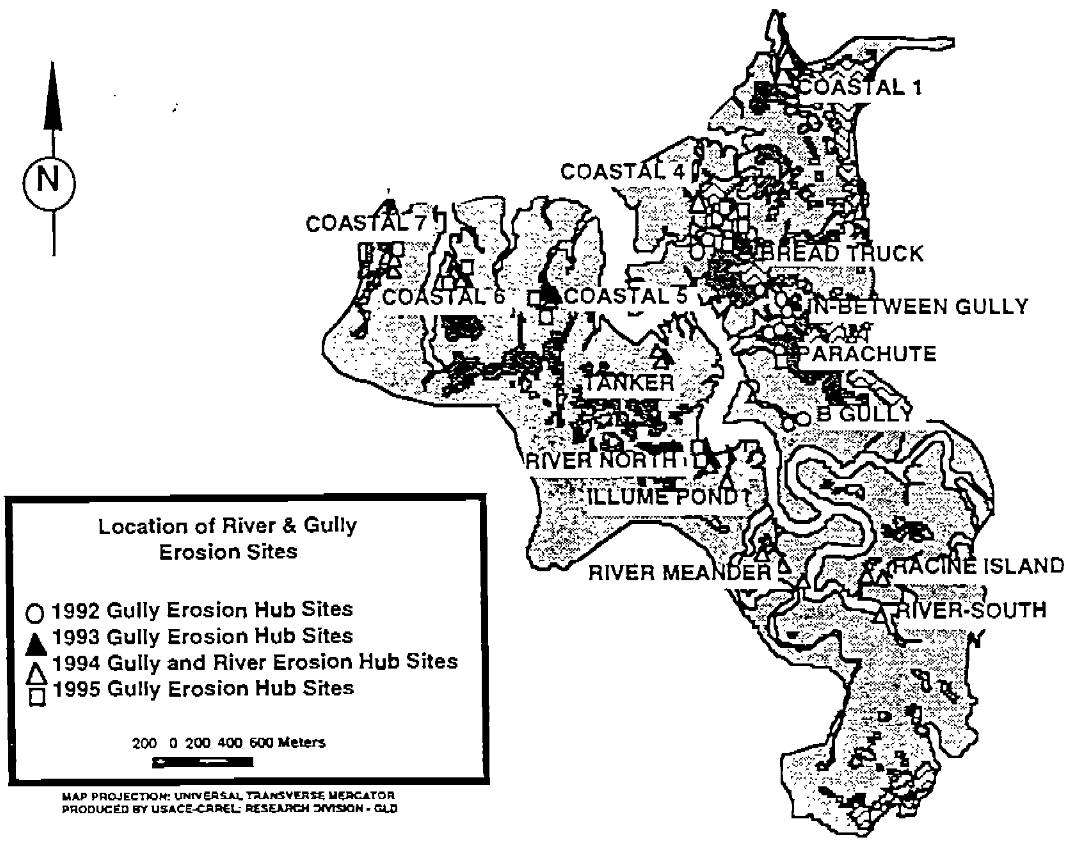


Figure II-1-14. Location of gully headwall and lateral wall erosion sites.

Figure II-1-15. Example of layout of hub and line stakes at River-North erosion site.

The distance between the hub and the crest of the gully scarp was measured across the top of each line stake with a tape measure. The position of the gully scarp crest was identified by lowering a plumb bob on a string from the tape measure, so that the horizontal distance could be read where the string and measuring tape met. Flagged wire stakes were then placed at each point of measurement along the headwall. Repetitive measurements using this technique enables us to monitor changes in scarp geometry with time, as well as the rate of gully recession.

Recession rates were measured in September 1992, 1993, 1994 and 1995, in May, 1993, 1994 and 1995, in November 1994 and late October 1995. The September measurements delineate summer rates, while those of May or June delineate winter rates. The October 1995 and November 1994 data provide constraints on the amount of erosion occurring since the end of summer measurements and the initial period of freeze-up. Repetitive measurements at points without any retreat (as indicated by the continuing presence of wire flags) indicate they are reproducible to ±2–5 cm. Their accuracy, however, is limited by how well the crest of the gully scarp can be defined, the shape of which is highly irregular and therefore accuracy is probably limited to ±10 cm in the worst case.

Recession data are presented as a range of maximum recession rates measured orthogonal to the gully or river at each site. This method differs from previous years where erosion measurements were reported as collected in the field and did not account for apparent distances created by the method (Lawson and Brockett 1993, Lawson et al. 1995a, b). These rates tended to be higher than actual wherever hub to line measurements were made at an acute angle to the scarp, thus recording an oblique distance. Measurements reported herein were taken from the scaled summary plots and are intended to summarize recession ranges, not absolute values for each hub to line stake measurement.

Historical aerial photographic analyses

During 1995, multiple aerial photography sets were acquired to increase our historical coverage of Eagle River Flats (Table II-1-5). Our current aerial photography archive provides a 45-year record of surficial changes at ERF for the interval of 8 August 1950 to 9 October 1995. The images are of variable quality and range from the highly blurred 1967 black and white images to the high resolution natural color photographs of 9 October 1995.

Historical changes were measured by studying aerial photographs taken at approximately a decadal time scale. Individual photography sets were chosen based on their clarity, which provided an ability to detect gully headwall scarps and their temporal setting. Five time frames (1950, 1960, 1972, 1984/86 and 1995) were chosen and the headwalls of B-Gully, Parachute, In-Between, Bread Truck, Mortar and Coastal 5 gullies were mapped to document their recessional histories.

Average rates of headward recession were calculated by transposing the position of the gully headwall scarps in 1950, 1960, 1972 and

Table II-1-5. Historic aerial photography of Eagle River Flats.

Year	*Date*	*Type*
1950	8 August	B/W
1953	27 June	B/W
1957	12 July	B/W
1960	30 August	B/W
1962	17 May	B/W
1967	Unknown	B/W
1972	July	False Color IR
1972	9 August	B/W
1974	7 May	B/W
1977	Unknown	False Color IR
1978	August	False Color IR
1984	12 August	False Color IR
1986	5 October	True Color
1986	12 September	LANDSAT TM
(Digital)		
1988	4 August	B/W
1991	21 June	Color IR
1992	22 May	Color IR
1992	2 August	Color IR)
1993	8 July	B/W Orthophotograph
1994	30 August	Color IR
1995	16 August	Color IR
1995	9 October	True Color

1984/86 onto gully basemaps produced from the 9 October 1995 aerial photographs. The distance of headward recession was measured as the centerline distance within each gully between the known points. The average rates were then determined by dividing the distance of center-line recession by the number of years between each measure.

Water quality parameters

Various water quality data have been collected at multiple sites to assess the surface hydrology and water quality of ERF. The majority of sampling sites were in small plunge pools at the heads of tidal gullies; three were newly located within ponds in 1995. Also in 1995, the sites were concentrated in the most heavily contaminated locations generally east of the Eagle River (Fig. II-1-16). The Mortar site receives tidal waters directly from Knik Arm, whereas Bread Truck, Parachute, B and In-Between are located in drainages which flow into the Eagle

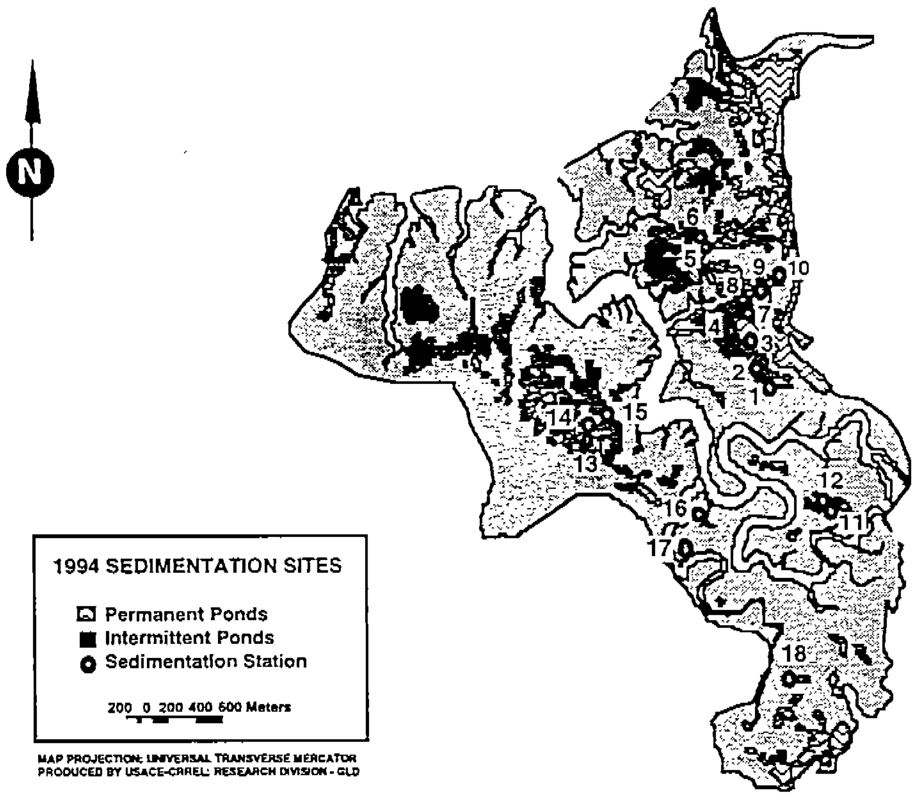


Figure II-1-16. 1995 locations of instrumentation recording water quality parameters and water depths. Locations of weather station and plankton net sampling sites are also shown.

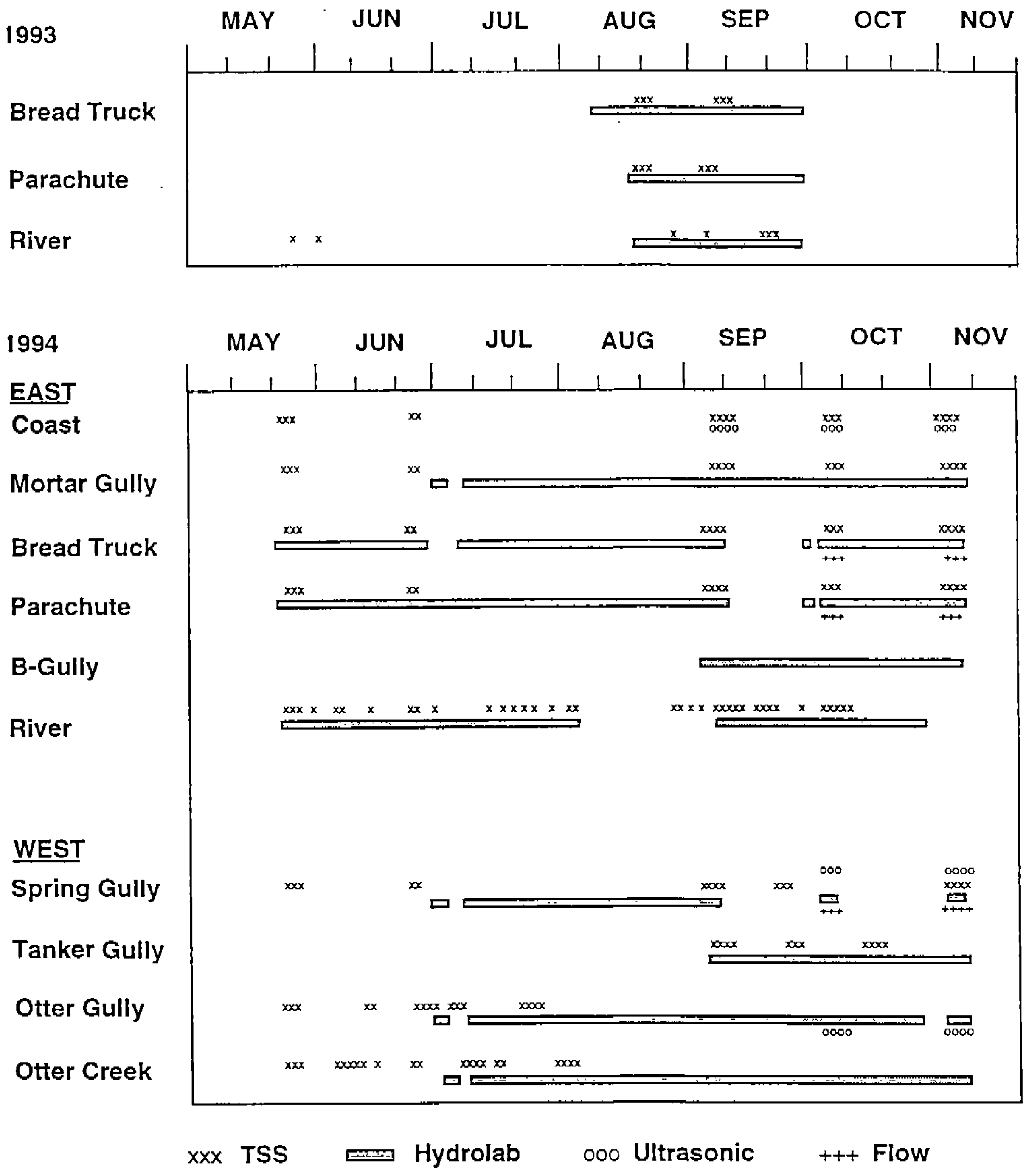
Table II-1-6. Specifications of sensors used in water quality measurements.

Instrument type	*Sensor*	*Accuracy*	*Resolution*
Hydrolab	Temperature	± 0.15°C	0.01°C
(H2O Multiprobe)	pH	± 0.2 units	0.01 units
	Specific oonductance		
	Fresh water	± 0.0015 to 0.1 mS/cm*	0.001 mS/cm
	Salt water	± 0.15 to 1.0 mS/cm*	0.01 mS/cm
	Salinity	± 0.2 ppt	0.1 ppt
	Dissolved oxygen	± 0.2 ppm	0.01 ppm
	Redox	± 20 mV	1 mV
	Depth	± 0.45 m water	0.1 m water
CRREL Thermistor	Temperature	± 0.02°C	0.01°C
Druck (PDCR 950)	Pressure (water depth)	± 0.008 m water	0.001 m water
OBS-3	Turbidity 5 V = 2000 FTU	± 100 mV	1 mV
Marsh-McBirney (model 512)	Water current (velocity)	± 6.10 cm/sec	2.13 cm/S
Cambell Ultrasonic (model UDG01)	Distance (water depth)	± 1 cm	.05 cm
Seagauge Wave/Tide	Pressure (water depth)	± 0.003 m water	0.0015 m water
(model SBE 26-03)	Temperature	± 0.02°C	0.01°C
Seacat CTD	Pressure (water depth)	± 0.75 m water	0.045 m water
(model SBE 16)	Temperature	±0.01°C	0.001°C
	Conductivity	± 0.001 S/m	0.0001 S/m
	Dissolved oxygen	± 0.1 mL/L	0.01 mL/L
	pH	± 0.1 units	
	OBS [5V=2000 FTU]	± 100 mV	3 mV

* Depends on which of three auto-adjusting ranges is employed.

River and therefore have mixed fresh and tidal water sources. Racine Island gully receives most of its water influx from the Eagle River during the summer. The two remaining sites represent the primary source waters: the Eagle River upstream of where it enters ERF, and the Knik Arm on the coast just north of the Eagle River mouth.

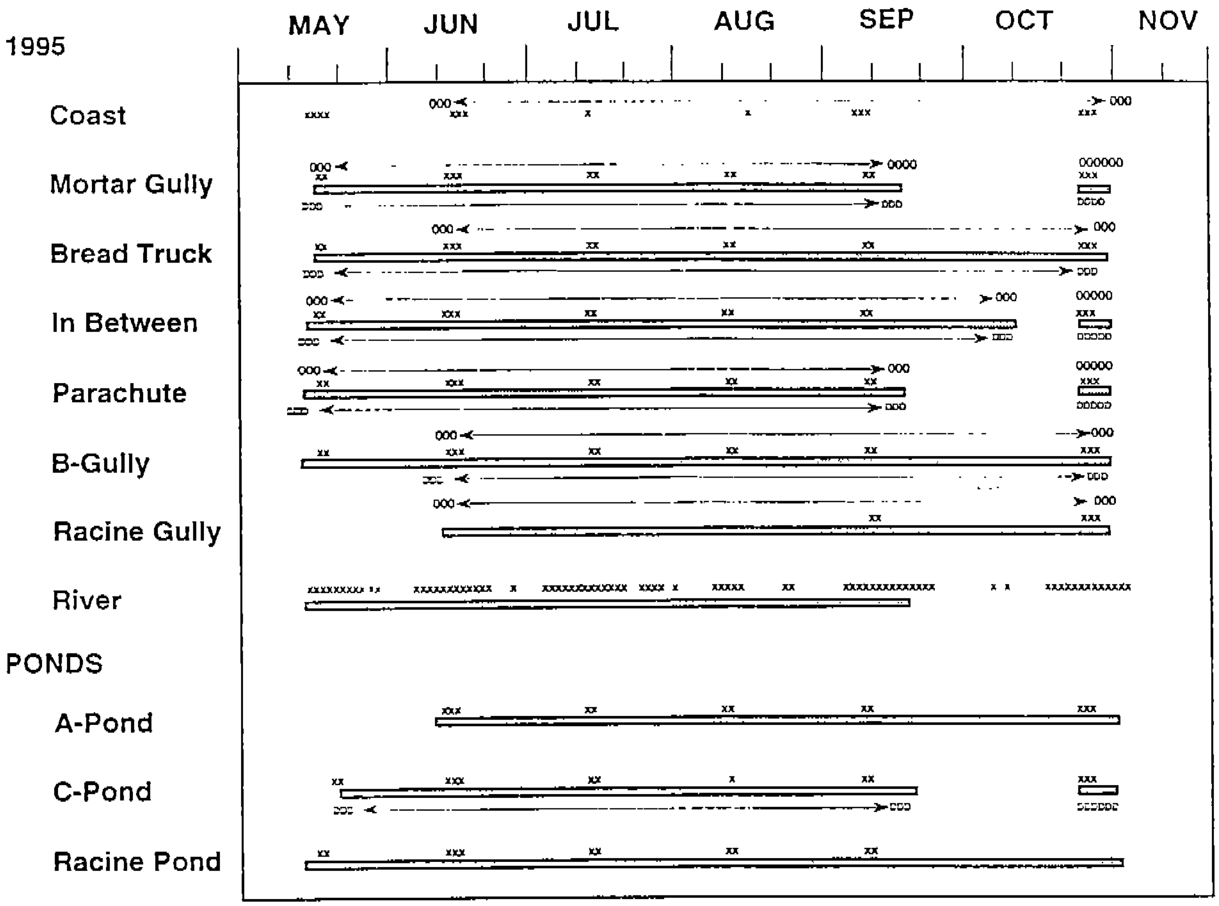
A basic suite of water characterization data was collected at 4-min intervals at each site utilizing the instruments listed in Table II-1-6. These data include temperature (measured by thermistor and/or a Hydrolab H2O multiparameter sensor); salinity, pH, redox and dissolved oxygen (Hydrolab); turbidity (OBS3 optical backscatter sensor); and water surface elevation (Druck pressure transducer). Figure II-1-17 shows the past and present times of data collection since 1993. Water samples were collected with an ISCO suction sampler automatically at various time intervals prior, during and following flood tides. The sampler was pro-



a. 1993 and 1994.

Figure II-1-17. Extent of data collection at hydrostation sites from 1993 to 1995.

grammed to obtain 500-mL water samples at specific intervals through the flood and ebb cycles. These samples were processed for TSS concentration using vacuum techniques and 45-mm glass microfiber filters following procedure 2540D in



a. 1995.

Figure II-1-17. Extent of data collection at hydrostation sites from 1993 to 1995.

Standard Methods for the Examination of Water and Wastewater (APHA, AWWA, WEF 1992). Project modifications to this procedure are described in Lawson et al. (1995b).

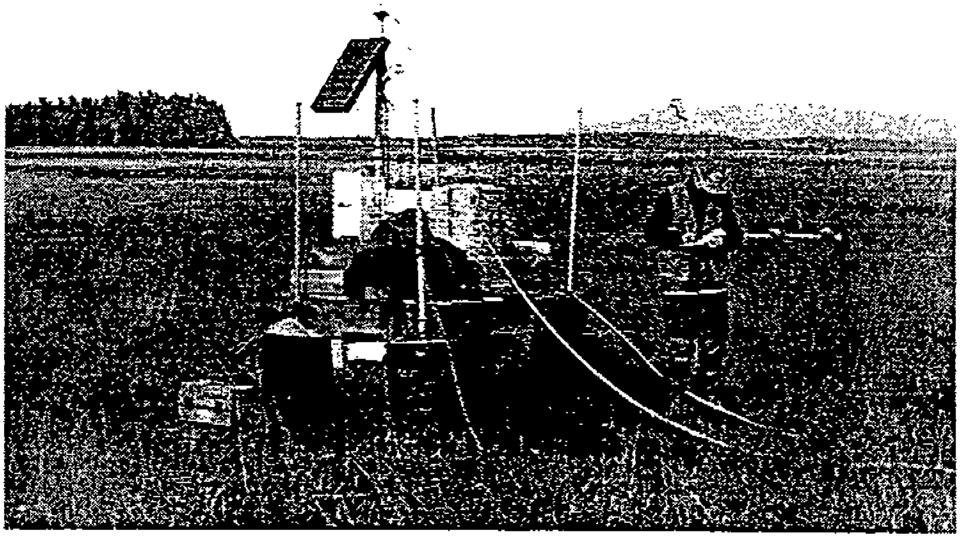
A Marsh–McBirney electromagnetic flow probe was used to measure current velocity during ebb and flood in selected tidal gullies. A unit was also installed in C Pond to measure tidal and wind-generated currents therein. The sensor was mounted about one meter above the bed at the Bread Truck, Parachute, In-Between, Mortar and B gullies (Fig. II-1-16). Ultrasonic sensors were used to measure flooding on the mudflats near the Mortar, Bread Truck, Parachute, In-Between, Racine Gully and Coastal sites.

Water quality parameters were collected at the Knik Arm coastal site using a Seabird SBE 16 Profiler. In addition, a Seabird SBE 26 wave and tide gauge was located here to record water depth and temperature of Knik Arm waters (Table II-1-6). The same location was used in 1993 and 1994 (Fig. II-1-16).

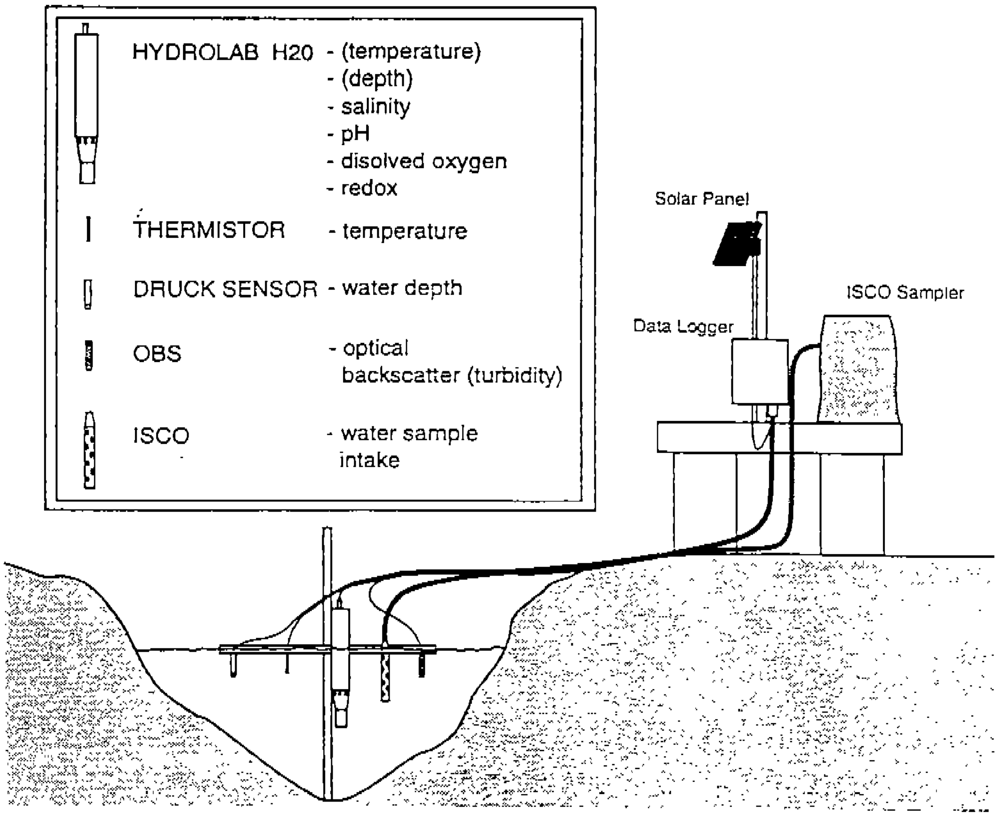
Hydrostation configuration

The instrumentation and samplers for water quality analyses followed an identical configuration at each gully and pond site (referred to as hydrostations). Sensors and the suction sampler intake screen are mounted on a stake driven into the pond or gully bottom under investigation. Mounting hardware was configured identically to permit their precise positioning in the water column. Sensors in gully sites were placed in plunge pools to keep the sensors wet at all times and usually about 15–45 cm above the bed depending on the site's character. Current probes were, however, mounted about 1 m above the bed on separate stakes located downstream of the plunge pool within a reasonably symmetric gully cross section. Ultrasonic sensors are mounted on an arm attached to a metal stake about 10 m from the platform. Each is aimed downward towards the mudflat surface, upon which a plate is pinned to provide a stable, reflective surface.

Instrumentation including the ISCO sampler was located on a floating platform located either on the mudflat next to gully sites or in ponds (Fig. II-1-18). Each platform was constructed of a 4- × 4-ft plywood deck mounted on a 2- × 8-in. wood frame. Large metal eyehooks were screwed into the frame on each corner. Five-foot sections of 0.75-in.-diameter steel pipe were mounted vertically in 20-gal. cans filled with concrete, and the eyehooks mounted on the platform's wood frame lowered over them. Foam filling the inner space of the deck framework provided flotation so that the platform could move vertically up and down the steel pipes during tidal flood and ebb. The platforms allowed us to establish monitoring stations without setting stakes or foundations in the ordnance-bearing mudflat sediments; however, the platforms main task is to keep the datalogger and related devices dry during the highest flood levels. Dataloggers were installed in NEMA plastic enclosure boxes mounted on 2-in. vertical steel pipes. Solar panels of 18-W output are fastened to the pipes above the dataloggers to recharge the 12-V external battery.



a. Platform and instrumentation at Bread Truck Gully.



b. Schematic showing layout of intrumentation in water and collection devices on a flotation platform.

Figure II-1-18. Hydrostation layout at a gully location.

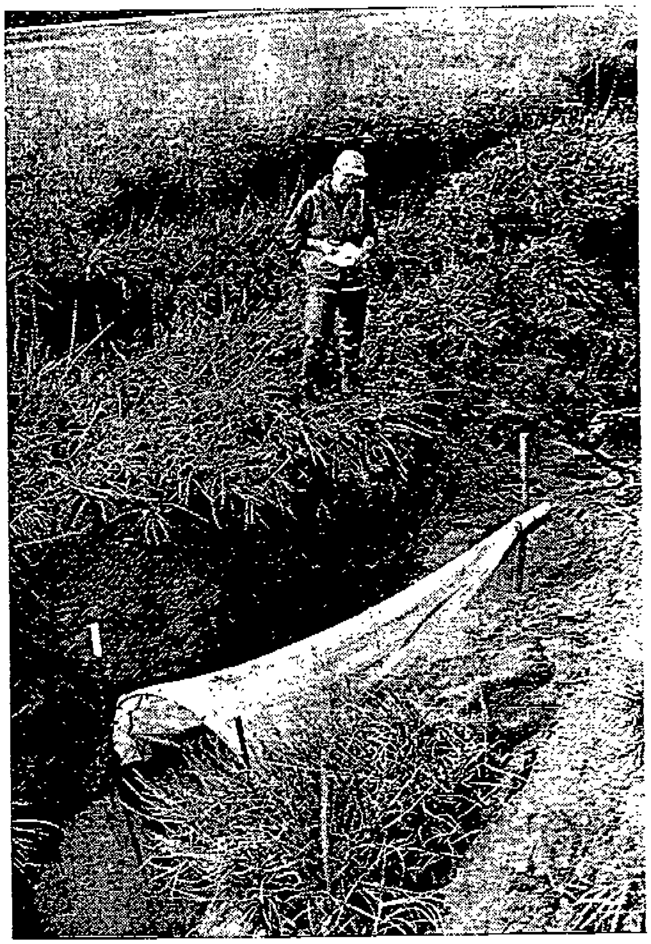


Figure II-1-19. Plankton net used for WP collection in transport at B-Gully.

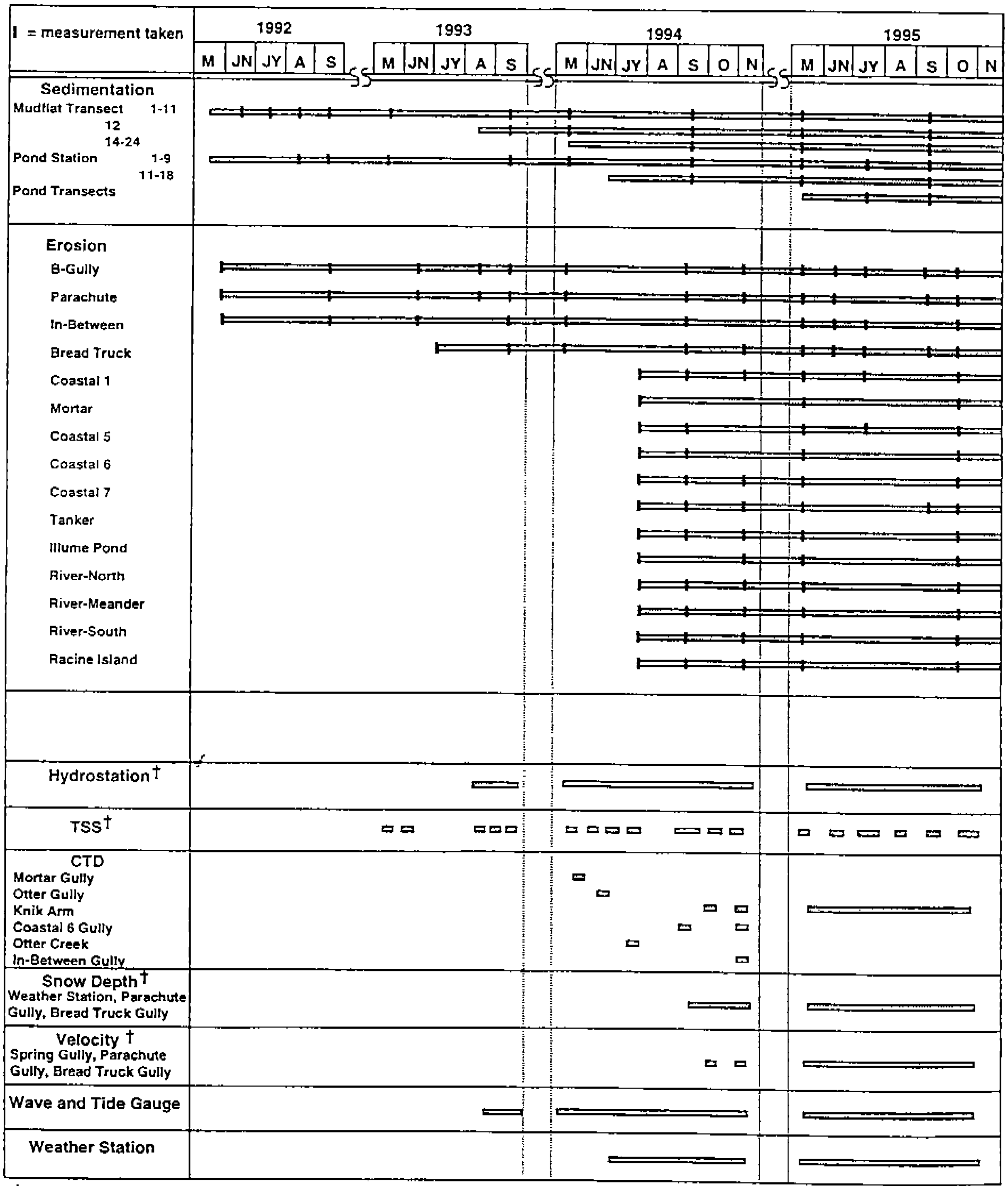
WP transport and resuspension

A plankton net of 3-m length with an opening of 1 m and a mesh size of 80 µm was placed at four gully sites, three of which were previously occupied in 1994 (Fig. II-1-16). The plankton net was tied to stakes driven into the gully bottom and extended down-channel in the direction of ebb (Fig. II-1-19). A cup at the apex of the net collected sediments that were transported into it. Each net was in place during multiple flooding tides each month (Fig. II-1-20). Sediment was collected following each ebb tide during a monitored tidal cycle and analyzed for WP following standard laboratory methods.

Sediments collected in sediment traps from transects in C, A, Racine Island, C/D and Lawson's pond were also analyzed for the presence of white phosphorus. These analyses provide data on resuspension of WP by wind, tidal currents and waterfowl activity.

Data acquisition record

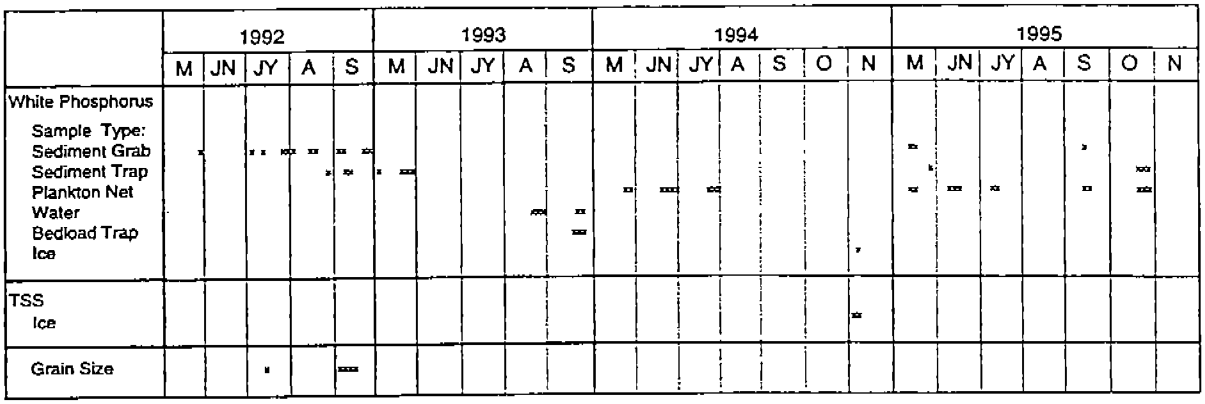
Figure II-1-20 summarizes the periods when various types of field data were acquired. The multiple starting dates for acquisition reflect both the implementation of new methods and expansion to additional sites within ERF. Gaps in the records of water quality sensors, other than during the winter period, resulted from either instrumentation failure or disruption by natural processes.



† see Figure 17

a. Continuous data.

Figure II-1-20. Sampling coverages for various types of field data.



b. Discontinuous data.

Figure II-1-20. Sampling coverages for various types of field data.

INTRINSIC REMEDIATION: POND DRAINAGE BY GULLY EROSION, RECESSION AND EXTENSION

Erosion is one of the most visible mechanisms by which the physical system is currently modifying and reshaping the Flats. Dynamic changes are critical because our initial assessments (Lawson et al. 1995a, b) suggested gully extension could drain contaminated ponds and create conditions conducive to in-situ WP degradation and attenuation within a relatively short time frame. The length of time for drainage to occur will be a function of several factors and may vary spatially across the Flats. The 1964 Alaskan earthquake appears to have had the single greatest effect on ERF, significantly altering the hydrologic system, which in turn has initiated major changes in drainage, gully erosion and extension, and pond and mudflat sedimentation.

External forcing

Drainage system expansion is thought to be a complex response to changes in the base level, tidal inundation and other physical changes caused by the 1964 Alaskan earthquake, and subsequent responses as both external and internal factors have changed since that event (Table II-1-1). Leveling profiles in the Anchorage area indicate that co-seismic subsidence was on the order of 60–70 cm (Brown et al. 1977). This subsidence has been followed by post-seismic uplift that was on the order of 20 cm by 1975. However, tide gauge data indicate that this uplift record has been very erratic in the Anchorage area, and did not reach a reasonably linear response until after 1973 (Savage and Plafker 1991). Savage and Plafker suggest that the oscillatory uplift pattern observed at Anchorage may be caused by creep of rock up the fault plane. Their data also indicate that net uplift, once adjusted for eustatic sea level rise, is nearly negligible (~1.0 + 2.2 mm/yr). It is difficult to compare the results of Brown et al. (1977), with Savage and Plafker (1991); however, it appears as though post-seismic uplift is not as rapid as we had believed in previous reports (Lawson et al. 1995b). The importance of this for ERF is that more water than expected is able to flood the Flats during spring tides, and therefore there is a greater volume of flood waters moving out the drainageways and gullies during ebb tide.

The physical responses to subsidence will occur for an extended time into the future while isostatic recovery continues. Our data indicate significant responses in the physical system since 1964. Sedimentary subsidence of pond bottoms, similar to that of Turnagain Arm (Ovenshine et al. 1976b), probably modified ERF hydrology and affected sedimentation and erosion within them. A lag in response to the earthquake and the various changes since that time can be different at locations across ERF. This lag will be primarily a function of site-specific intrinsic factors (e.g., vegetation cover, peat layers, craters, scattered debris) that control local thresholds for changes in processes or their responses.

Hydrologic changes have led most visibly to increased gully erosion, as is evident by the historical increase in gully entrenchment and their progressive extension into the tidal flats (Lawson et al. 1995a). Knickpoints are locations of abrupt slope change in the longitudinal channel or gully profile that indicate system disequilibrium: the most prominent ones are the near-vertical headwalls that bound plunge pools and mark the upper limit of each gully. In addition, sedimentation in the ponds remains high, as recovery to the subsidence by infilling of the pond bottoms.

Table II-1-7. Summary of gully velocity and discharge data.

Gully	*Tide stage*	*Monthly range in ave. velocity (cm/s)*	*Peak velocity (cm/s)*	*Average TSS (mg/L)*	*Peak TSS (mg/L)*	*Monthly range in ave. water discharge (m^3/s)*	*Monthly range in ave. sediment discharge (kg/s)*
B-Gully	Flood	8.50-15.83	42.39	280-780	2251	0.50-0.94	0.14-0.53
	Ebb	9.04-75.41	207.5			0.54-4.47	0.20-1.81
Parachute	Flood	7.63-26.67	66.96	422-972	2518	0.96-3.36	0.30-1.99
	Ebb	4.56-52.47	96.02			0.57-6.60	0.18-2.79
In-Between	Flood	2.23-15.45	75.16	292-999	2787	0.16-1.11	0.08-1.04
	Ebb	3.46-25.07	97.29			0.25-1.81	0.12-1.62
Bread Truck*	Flood	22.6-29.9	71.1	170-1186	2152	1.24-1.64	0.23-1.95
	Ebb	74.0-81.0	146			4.07-4.46	1.95-3.60
Mortar	Flood	2.75-3.26	15.34	251-856	1973	0.12-0.15	0.03-0.12
	Ebb	7.75-9.93	31.62			0.35-0.45	0.08-0.30

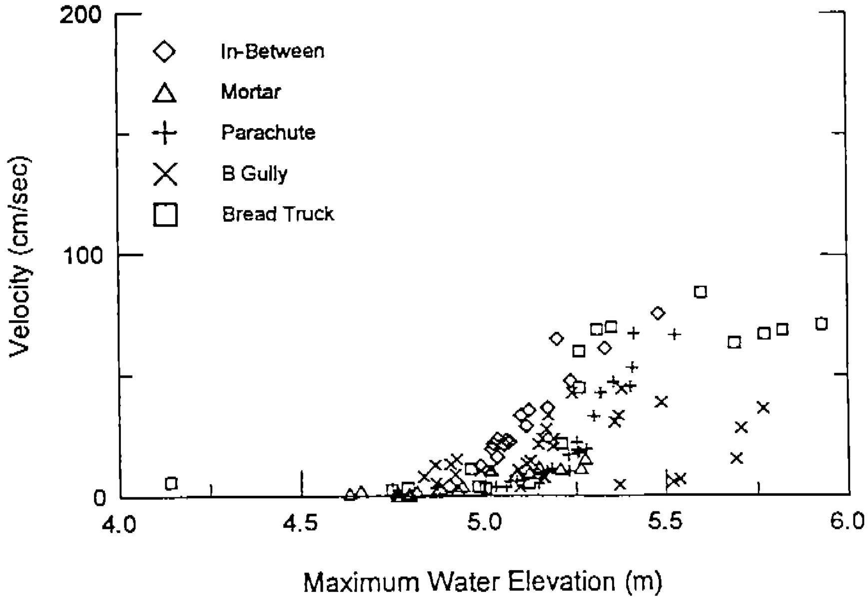
* Based on 1994 measurements

Gully erosion and discharge

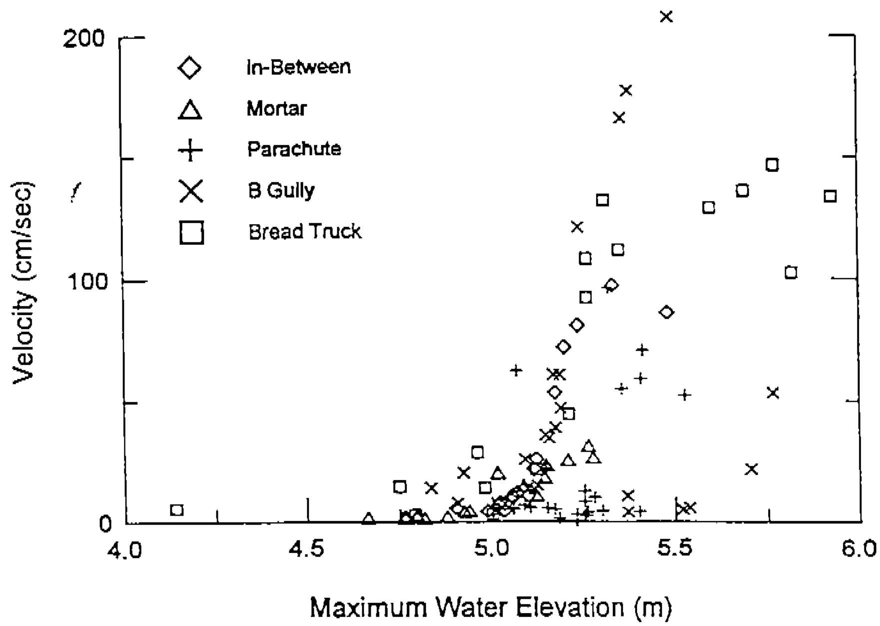
The volume of water that flows through each gully is mainly a function of the height of tidal flooding, as supplemented by river discharge and the additive effects of wind, ice and other factors. The range and magnitude of ebb current velocity is critical to determining both the flux of sediment and water into and out of the ponds and mudflats, and the ability of those currents to scour and resuspend pond, mudflat, and gully sediments.

The velocity of tidal flood and ebb currents at the Mortar, Bread Truck, B, Parachute, and In Between gully sites ranges between 0.75 and 2.07 m/s (Table II-1-7). The peak velocity at each site changes with the height of flooding (Fig. II-1-21), the lower peak and range in velocities occurring during the lower elevation flooding tides. Flow velocities are greatest at B-Gully, with moderate values recorded at Bread Truck, In-Between, Mortar and Parachute gullies.

Peak ebb velocity is greater than peak flood velocity (Table II-1-7, Fig. II-1-21). This asymmetry in flow velocities and therefore discharge determines when erosion and sediment transport will occur and to what magnitude. During tidal flooding, gully water levels rise passively before spreading out onto the mudflats. The suspended sediment load is directly related to the volume of sediment suspended in Knik Arm, except where river water is the primary source of flood.



a. Flood currents



b. Ebb currents

Figure II-1-21. Relationship between peak velocity and maximum water elevation at selected sites.

In contrast, higher velocities during ebb dictate an increase in turbulence and the potential for transporting greater amounts of sediment. Perhaps more importantly, additional energy is available to cause scour and entrain sediment. Thus, drainage and gully erosion are more active during ebb, and it is likely that tidal currents generated on the mudflats or in ponds will also be more erosive.

Discharge (Q) has been estimated for each monitored gully using the peak and mean velocities by:

$$Q = VA$$

where V is velocity and A is the cross-sectional area.

Average discharge values calculated for each gully range from 0.12 to 3.36 m^3/s during flood and 0.25 to 6.60 m^3/s in ebb (Table II-1-7). Peak ebb discharge at each site ranged from 1.16 to 12.30 m^3/s.

Peak and average TSS concentrations collected over the same time intervals as the current velocity and discharge data provide rough estimates of flood and ebb sediment fluxes. Average monthly sediment flux ranged from 0.03 to 1.99 kg/s during flood and 0.08 to 2.79 kg/s during ebb (Table II-1-7).

Ebb sediment flux is greater than the flood sediment flux. This flux is related to the difference in turbulence in the water column during flood and ebb stages; however, the significance is not as clear. These data indicate that over time, there is a net transfer of sediment out of ERF into Knik Arm. Sedimentation rates in ponds and mudflats suggest contradictorily, however, that erosion is localized to drainageways and gully walls and therefore only reflect conditions within them. On the other hand, sedimentation elsewhere may be mainly the system's response to earthquake-induced pond subsidence.

Gully erosion and recession—Modern rates

The amount of recession of scarp crests is highly variable within a particular gully, as well as among all gully sites (Tables II-1-8 and II-1-9). Maximum recession rates ranged from 0.3 to 3.2 m during the May–September 1992 period, 0.1 to 1.3 m during the period September 1992 to June 1993, and 0.1 to 3.3 m during June to September 1993. During the winter of 1993, erosion rates ranged from 0.1 to 5.0 m, 0.1 to 2.0 m in the summer of 1994, 0.1 to 11.7 during the winter of 1994,

Table II-1-8. Seasonal summary of scarp recession

Site name	Summer 92		Winter 92-93		Summer 93		Winter 93-94		Summer 94		Winter 94-95		Summer 95		Total	
	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L
B-Gully	---	0.1-0.3	---	0.2-0.3	---	0.3-0.8	---	0.1-0.6	---	0.1-1.1	---	0.1-0.8	---	0.2-0.8	---	1.0-5.3
Parachute	0.3-3.2	0.2-0.5	0.5-1.3	0.6-0.7	0.1-3.3	<0.1-0.2	0.6-2.7	0.6-0.7	1.7-2.0	0.7-1.2	0.3-1.7	0.1-2.3	0.1-3.4	0.3-0.6	1.1-12.1	1.3-1.8*
In-Between	<0.1-1.0	<0.1-0.5	<0.1-0.8†	<0.1	<0.1-0.8	0.8	0.1-0.3	<0.1	0.1-0.6	~0.8	<0.1-0.2	<0.1-0.5	<0.1-1.2	<0.1	0.2-2.8	0.2-1.2
Tanker									<0.1	0.1-0.8	<0.1	<0.1-0.3	<0.1-0.5	<0.1-0.5	<0.1-0.5	0.3-0.9
Bread Truck							0.3-5.0	0.1-0.3	0.1->1.1	0.1-2.2	1.0-11.7	0.1-0.3	0.3-20.0	0.1-2.0	2.0-33.3	0.6-3.0
Coastal 5									0.3-1.5	<0.1-0.6	0.4-6.4	0.6-1.0	0.3-16.9	0.5-0.7	0.6-25.9	1.0-1.7
Mortar											0.3-1.7	0.5-1.1	0.3-1.3	<0.1-1.2	~1.1-1.6	0.5-2.2
Coastal 6									~0.9	1.0-1.8	~0.3	0.3-.04	0.7-1.2	0.9-1.1	~1.9	1.1-2.7
Coastal 1									1.5-1.7	<0.1-0.3	0.5-0.8	<0.1-0.7	1.1-1.4	<0.1-0.3	0.8-3.1	<0.1-0.7
Coastal 7									1.0-1.2	0.3-1.0	0.4-0.9	~0.6	0.2-0.8	~0.5	1.3-2.4	0.9-1.1
River-North									---	~3.2	---	3.6-4.6	---	1.1-2.5	---	3.3-7.4

H = Headward; L = Lateral
* Maximim total erosion measured from scarp outline of 5/92; local lateral erosion was greater associated with lateral expansion accompanying headward migration of headwall
† Shallow trough (<0.5 m deep) extended ~ 40 m

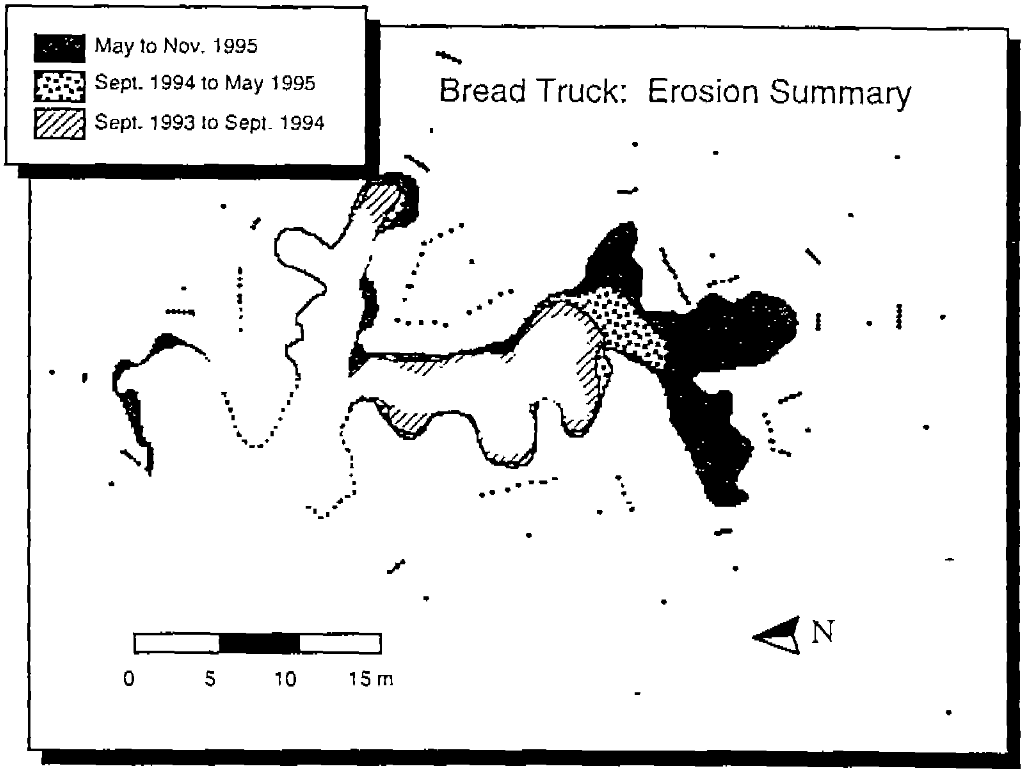
Table II-1-9. Annual summary of scarp recession

Site name	1992-1993		1993-1994		1994-1995		Total to 11/95	
	Headward	Lateral	Headward	Lateral	Headward	Lateral	Headward	Lateral
B-Gully	---	0.1-1.5	---	0.1-1.1	---	0.2-0.8	---	1.0-5.3
Parachute	0.8-4.5	0.3-0.7	0.4-2.8	0.6-1.0	0.3-2.0	0.6-3.2	1.1-12.1	1.3-1.8*
In-Between	<0.1-1.1	<0.1-0.5	0.1-0.8	0.1-1.1	<0.1-1.3	~0.1	0.2-2.8	0.2-1.2
Tanker				<0.1-0.5	0.3-0.7	<0.1-0.5	0.3-0.9	
Bread Truck		0.3-5.0	0.2-2.2	0.8-31.7	0.3-1.3	2.0-33.3	0.6-3.0	
Coastal 5				0.4-7.6	0.9-1.0	0.6-25.9	1.0-1.7	
Mortar				1.1-1.6	0.5-2.2	~1.1-1.6	0.5-2.2	
Coastal 6				0.6-1.0	1.0-1.8	~1.9	1.1-2.7	
Coastal 1				0.8-2.0	<0.1-0.7	0.8-3.1	<0.1-0.7	
Coastal 7				0.8-2.0	~1.0	1.3-2.4	0.9-1.1	
River-North				1.1-7.4	---	3.3-7.4		

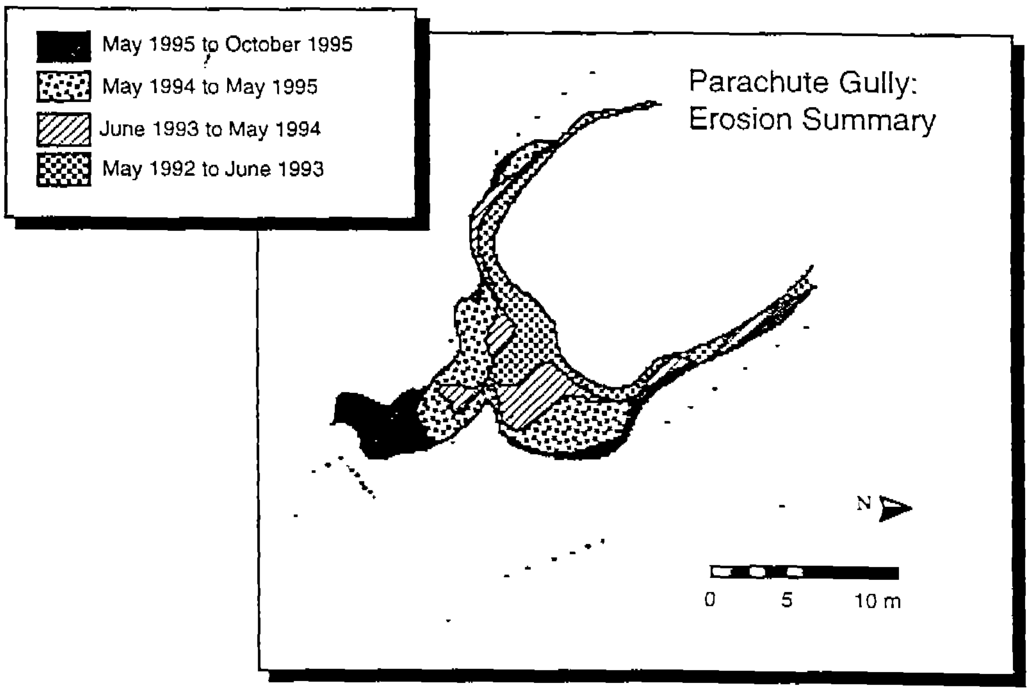
* Maximim total erosion measured from scarp outline of 5/92; local lateral erosion was where greater associated with lateral expansion accompanying headward migration of headwall
† Shallow trough (<0.5 m deep) extended ~ 40 m

and 0.1 to 20.0 m during the summer of 1995. Net headward recession has ranged from 0.1 m to about 33 m between 1992 and 1995, with a maximum of 33 m occurring since the spring of 1994 at Bread Truck Gully (Fig. II-1-22a).

At each site, however, some parts of the scarp crests did not retreat at all, and in fact, extension was measured where tension cracks developed at an early stage of collapse (Fig. II-1-23). Extension was particularly evident in May 1995 following the first tidal flooding cycle (15 to 17 May 1995) after thawing of the ground began. The winter of 1994 saw an unusually low snowfall early in the season, which allowed for deep frost penetration. Intermittent flooding and subsequent pond drainage produced conditions favorable to ice growth in the gullies themselves (Fig. II-1-24). We feel that jacking caused by freezing of interstitial water and growth of needle ice, as well as ice shove caused a reduction in the cohesiveness

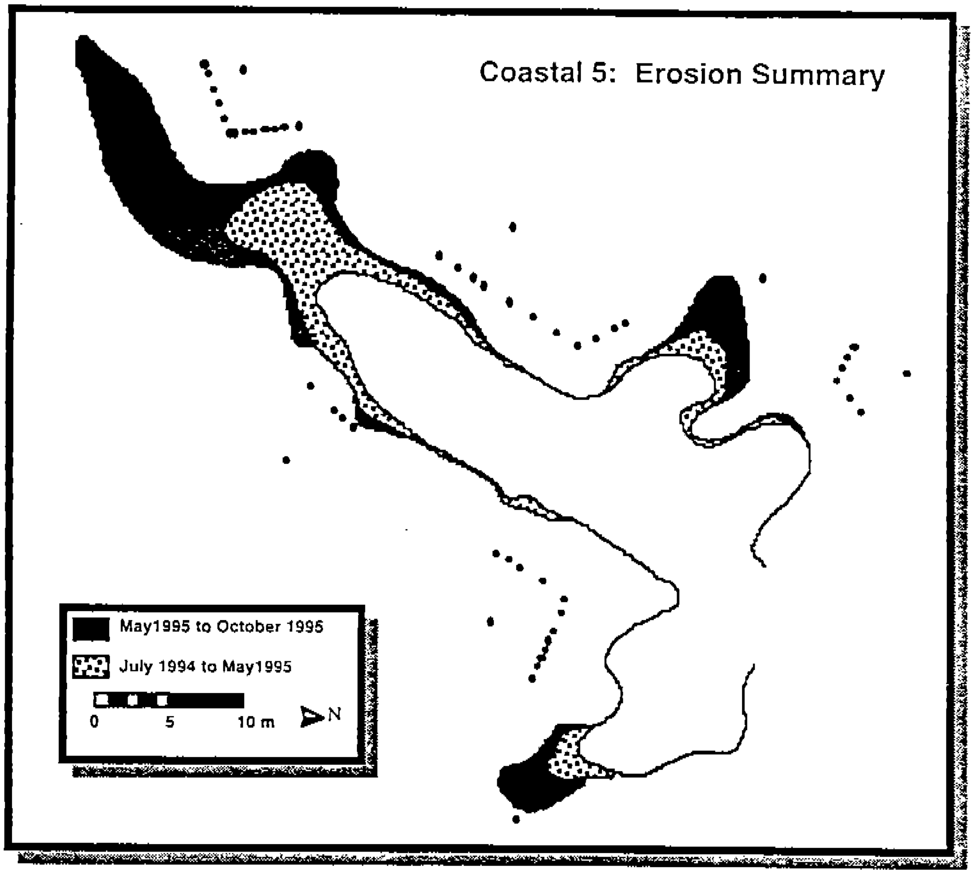


a. Bread Truck Gully.

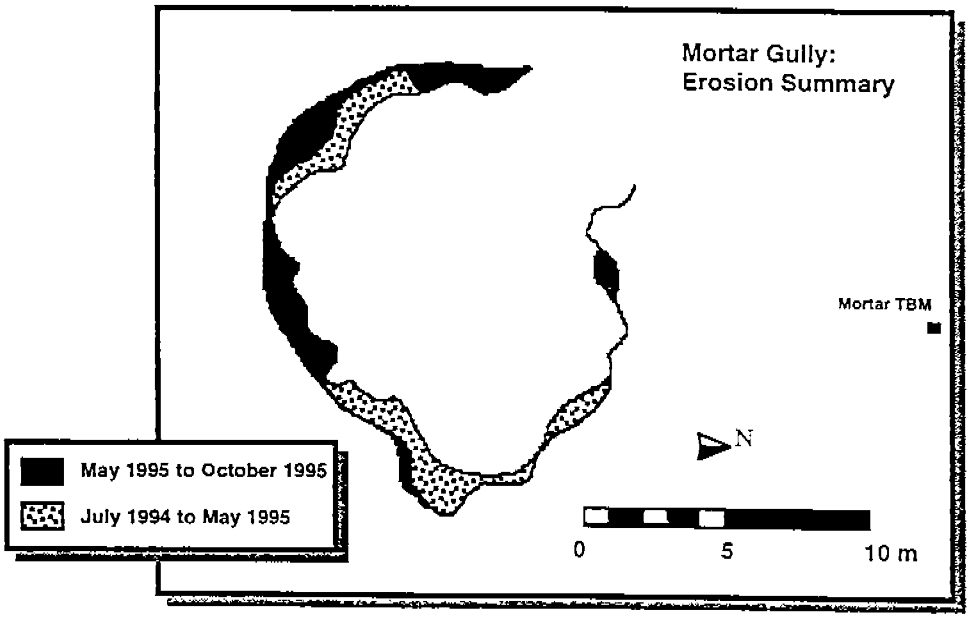


b. Parachute Gully.

Figure II-1-22. Summary of gully scarp recession.

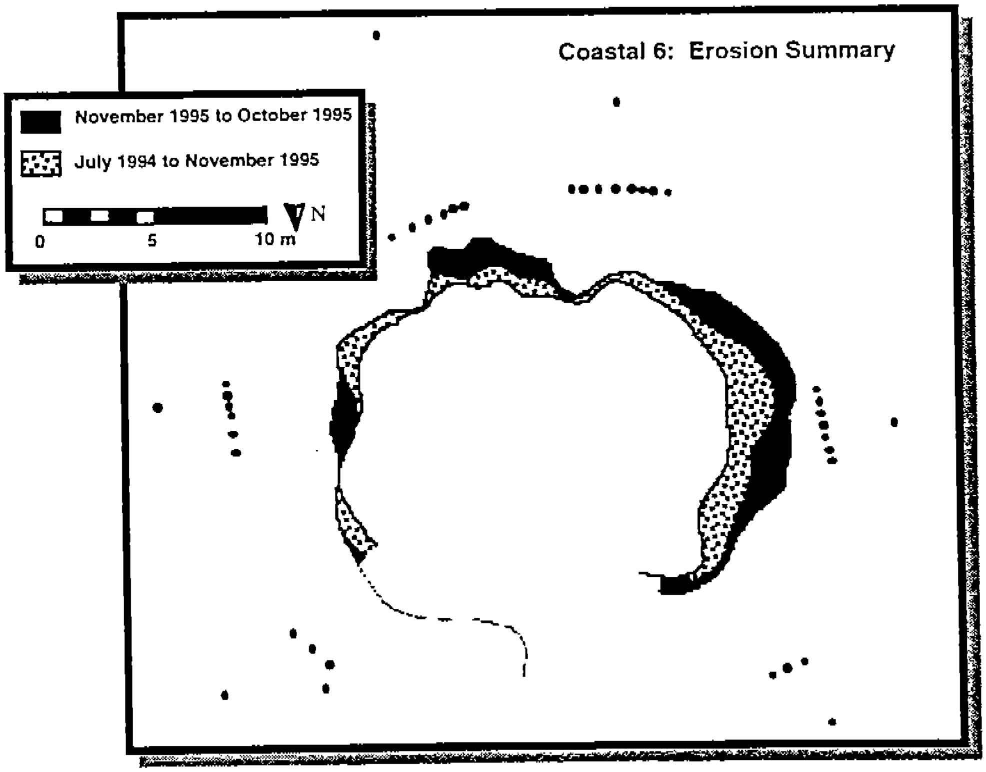


c. Coastal 5 Gully.

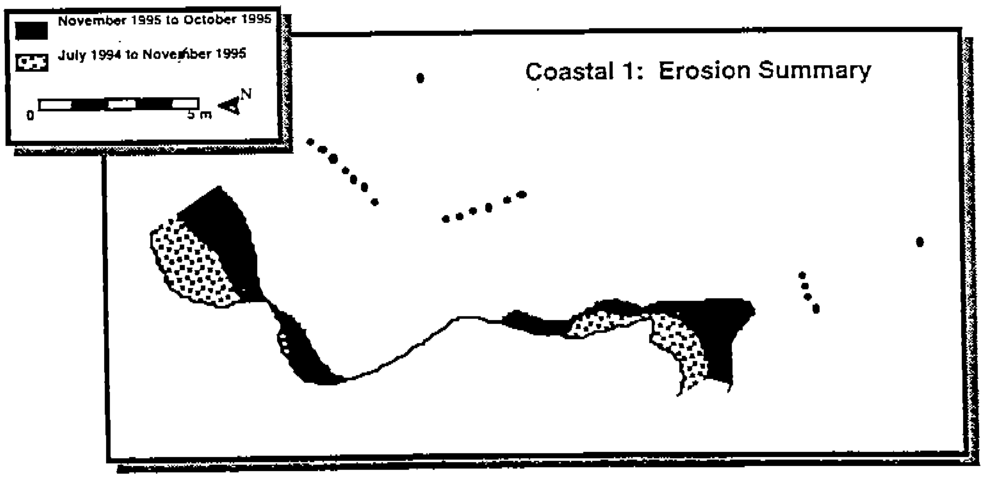


d. Mortar Gully.

Figure II-1-22 (cont.). Summary of gully scarp recession.

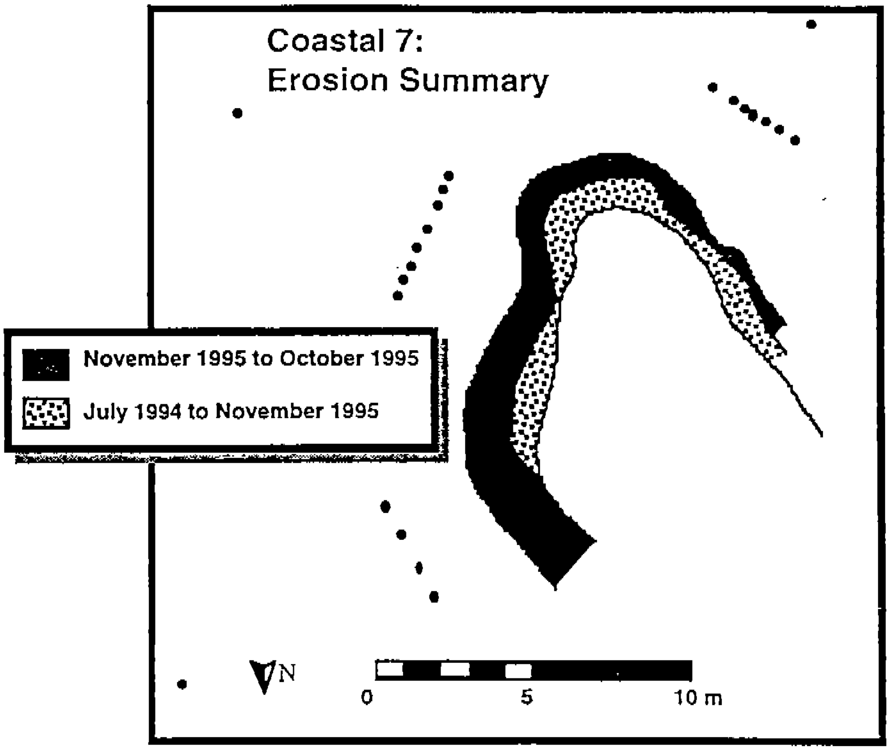


e. Coastal 6 Gully.

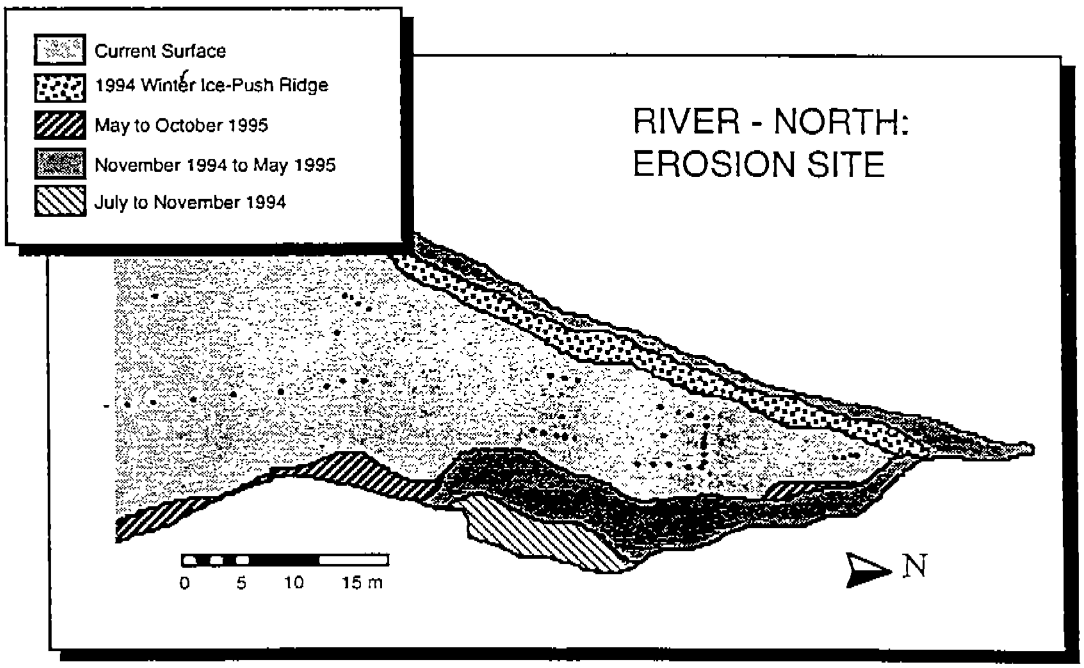


f. Coastal 1 Gully.

Figure II-1-22 (cont.). Summary of gully scarp recession.



g. Coastal 7 Gully.



h. River-North Site.

Figure II-1-22. Summary of gully scarp recession.

a. North view showing extension crack in foreground.

b. Rotational slump blocks visible to right of scarp.

Figure II-1-23. Measurements of bank erosion along Eagle River at the River-North site.

a. Lateral wall view. Ice armor caused by repeated flooding and subsequent freezing in gully.

b. Headwall view showing ice coating formed by freeze-up of waters flowing into gully.

Figure II-1-24. Bank of Bread Truck Gully showing ice growth formation.

Figure II-1-25. Aerial view of Parachute Gully in October 1995 showing accelerated headward recession that has accompanied capture of flow through craters.

of the bank sediments and increased their susceptibility to erosion during the cycle of May tidal flooding.

The spatial variability in recessional rates is evident in the plots showing the sequential recession of scarp crest location through time (Fig. II-1-22). One of the first gullies monitored at ERF is that of Parachute Gully on the west side of Area C (Fig. II-1-14). Since monitoring began in 1992, Parachute gully (Fig. II-1-22b and II-1-25) has undergone up to 12.1 m of headwall recession but only 1.8 m of lateral recession (Tables II-1-8 and II-1-9). Recession has centered around a drainageway that has become incised and enlarged where multiple mortar craters were once situated. In this instance, the craters became hydraulically connected by localized scour during ebb and the direction of gully extension is dictated by their presence. Similar enhanced erosion occurred along drainageways in Area A (Fig. II-1-26a) and B-Gully (Fig. II-1-26b).

Bread Truck and Coastal 5 gullies bracket the mouth of the Eagle River and are the sites with the maximum rates of headward recession (Fig. II-1-14, II-1-22a, II-1-22c). Bread Truck Gully (Fig. II-1-27 and II-1-22a) was first monitored in 1993

a. Area A.

b. B-Gully.

Figure II-1-26. Aerial view of gullies where recession and ebb flow have been modified by surface craters.

Figure II-1-27. Aerial view of Bread Truck Gully in October 1995.

when headward recession ranged from 0.3 to 5.0 m and lateral recession was on the order of 0.2 to 2.2 m (Table II-1-8). In 1995, headward recession accelerated to 11.7 m during the May 1995 flooding tide (representing the winter 94/95 erosion column of Table II-1-8) and an additional 20 m during the 1995 summer season. These rates do not appear to be exceptional or unique; the Coastal 5 gully site experienced 17 m of recession during the summer of 1995 and a total of about 26 m since the hub and line stakes were established in July 1994.

Recession due to lateral erosion is represented by B-gully, a site that has been monitored since 1992. The monitored section lies along the margin of a peninsula between two tributaries to the main gully, about 75 m down-channel of the gully headwall. Gully erosion is characterized by the formation of cuspate embayments that have gradually enlarged since 1992 with a maximum of 5.3 m change (Tables II-1-8 and II-1-9, Fig. II-1-28). This site is significant due to repeated detection of WP in transport within ebb waters (Lawson et al. 1995a), as well as in fauna sampled within the gully (Bouwkamp 1995). The source of this WP may be the erosion and collapse of bank sediments, but at this time, cannot be distinguished from a WP source in C Pond. Data (Tables II-1-8 and II-1-9) indicate that in general, lateral recession is lower (often by an order of magnitude) than headward recession, with the exception of Mortar and Coastal 6 gullies where wide plunge pools be-

Figure II-1-28. Eastward view of eroding cuspate embayments at B-Gully.

low their respective headwalls are expanding laterally through bank collapse and rotational slumping (Fig. II-1-22d, II-1-29).

Figure II-1-22h shows one section of the monitoring network at the River North Site where slope processes are consuming mudflat sediments and introducing material directly into the Eagle River (Fig. II-1-23). Rapid lateral erosion on the order of 3.2 m was recorded at this site between July and November 1994, and up to 7.4 m of recession had occurred by late October 1995. Erosion occurs along large rotational slumps that fail due to river undercutting and removal of sediment supporting the toe of the slope. Prior to failure, large extension cracks develop parallel to the scarp, gradually leading to catastrophic failure. The location of the crack becomes the new scarp of the riverbank (Fig. II-1-23a).

The variability in recession rate is due to the episodic nature of the erosional processes as rapid, short-duration events (Table II-1-2). Recession appears to be caused mostly by currents scouring the lower, unvegetated portion of the gully walls during ebb tide when water velocities are highest. Because the uppermost 20–30 cm of material is consolidated and rootbound (Fig. II-1-30), this soil and root mat are undermined and only fail after an erosional niche of approximately 0.5 m or deeper is cut below it. Within the gullies themselves, current scour during ebb tide removes material from the toe of the slope thereby

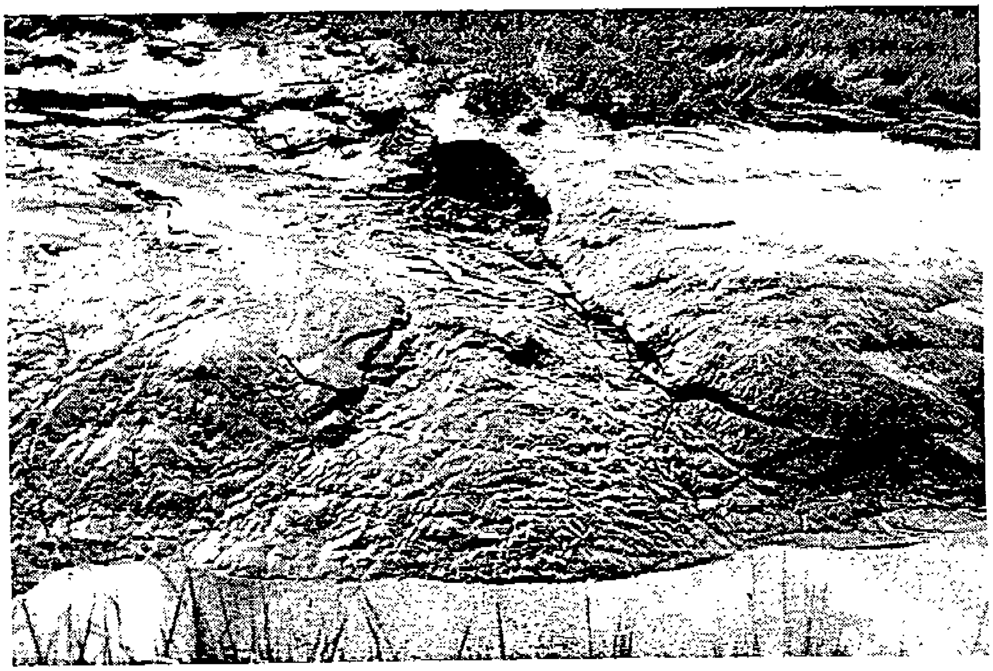


Figure II-1-29. Sediment flow at Bread Truck Gully. Saturated sediment fails when erosion during ebb tide removes material from the slope toe.

Figure II-1-30. Thick laminated peat layer at Coastal 6 forms the threshold to channel downcutting and headward recession.

removing the base of the slope and causing slumping and sediment flow (Fig. II-1-29).

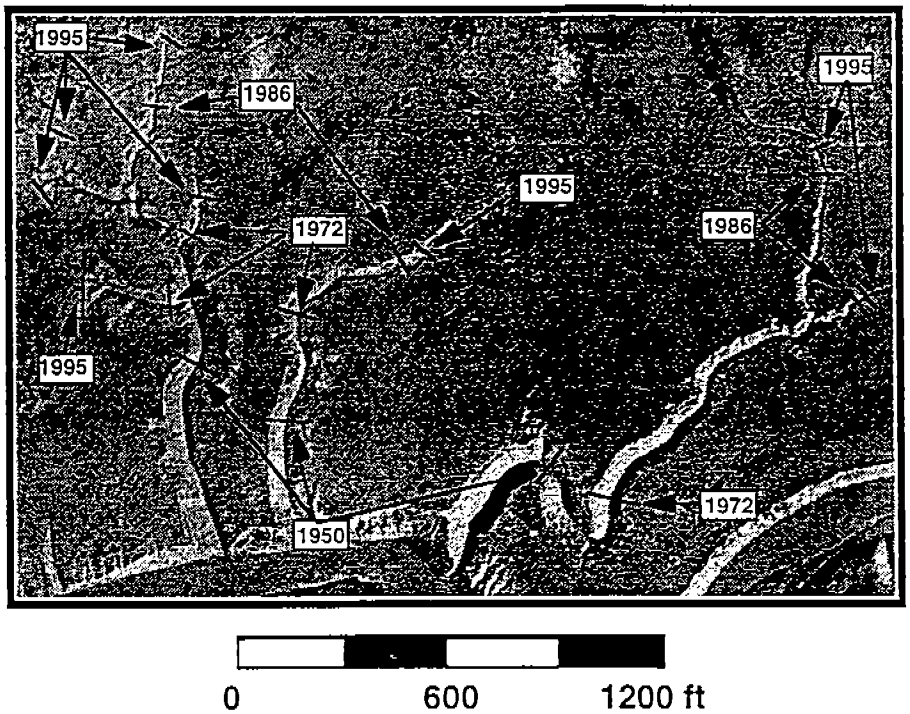
Eroded sediments form deposits in the gullies that are eventually transported into the Eagle River. Along steep scarps the blocks of consolidated sediments bound by roots that fall and roll into the gully bottoms remain intact and block the flow until currents can eventually break them apart as they are forced to roll along the bed. The lateral walls of gullies, which tend to develop low-angle slopes as headwalls recede inland, fail mainly by rotational slump flow, or creeping slowly as a mudflow into the gully channel. On gentler slopes, blocks of root-bound material remain intact as they are transported downslope by slow-moving mudflows that are active in the latter stages of the ebb cycle.

Table II-1-10. Summary of long-term gully erosion rates at selected sites.

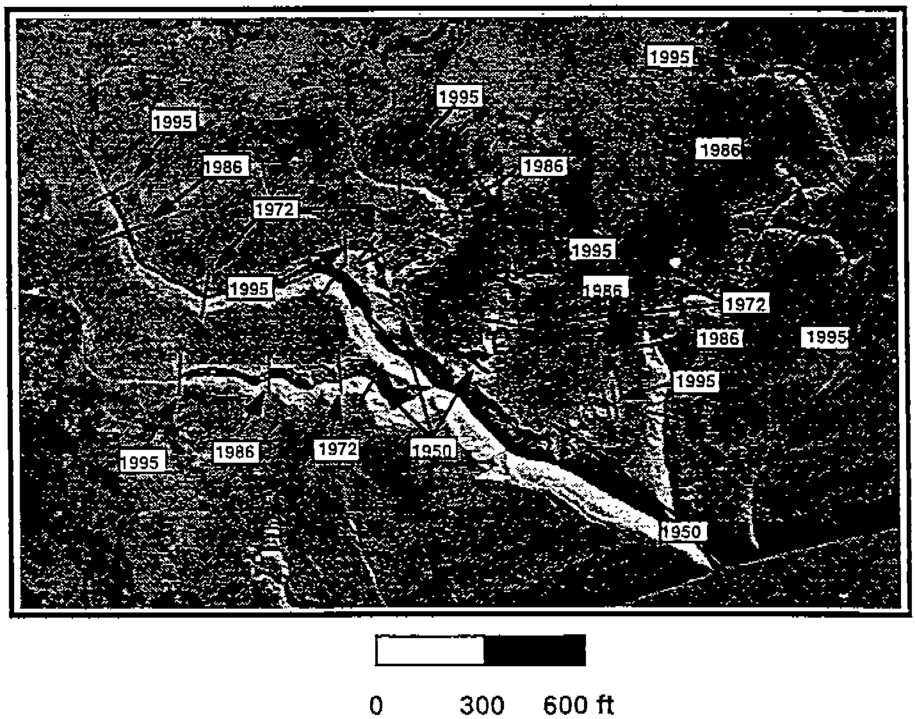
Gully	*Years (19)*	*Duration*	*Distance (m)*	*Rate (m/yr)*
B-Gully	50-60	10	35.4	3.5
	60-72	12	70.8	5.9
	72-86	14	330.4	23.6
	86-95	9	35.4	3.9
	Total	45	472.0	10.5
Parachute	50-60	10	11.8	1.2
	60-72	12	82.6	6.9
	72-86	14	70.8	5.1
	86-95	9	35.4	3.9
	Total	45	200.6	4.5
In-Between	50-60	10	23.6	2.4
	60-72	12	99.1	8.3
	72-86	14	94.4	6.7
	86-95	9	66.1	7.3
	Total	45	283.2	6.3
Mortar	50-60	10	21.4	2.1
	60-72	12	25.2	2.1
	72-86	14	82.0	5.9
	86-95	9	35.3	3.9
	Total	45	164.0	3.6
Bread Truck	50-60	10	34.3	3.4
	60-72	12	34.3	2.9
	72-86	14	251.5	18.0
	86-95	9	194.3	21.6
	Total	45	514.4	11.4
Coastal 5	50-60	10	11.4	1.1
	60-72	12	175.8	14.7
	72-84	12	225.1	18.8
	84-95	11	202.6	18.4
	Total	45	614.9	13.7

Gully erosion and recession—Historic rates

Historic gully recession rates have been reconstructed for B-Gully, Parachute, In-Between, Mortar, Bread Truck and Coastal 5 gullies (Fig. II-1-31, Table II-1-10). Long-term average recession rates over the past 45 years range from 3.6 m/yr at Mortar Gully to 13.7 m/yr at the Coastal 5 Gully. Recession ranged from 1.1 to 3.5 m/yr be-

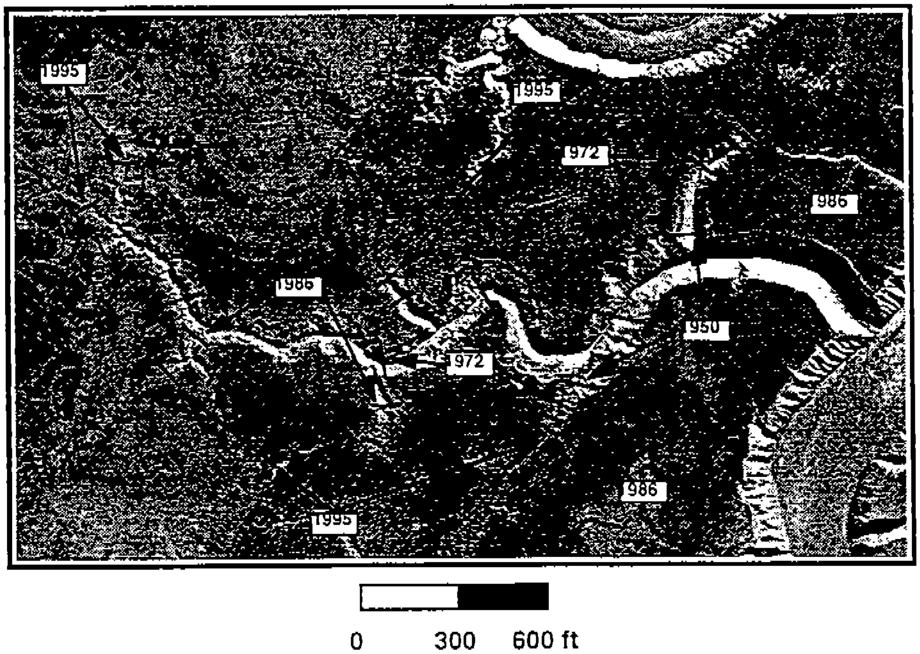


a. B-, Parachute and In-Between gullies.

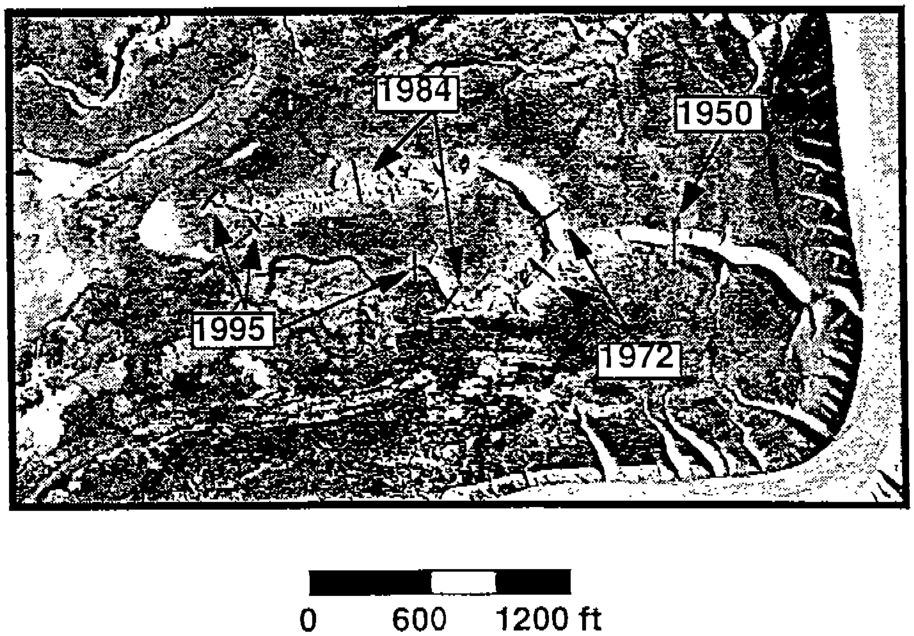


b. Mortar Gully.

Figure II-1-31. Historic gully recession. Refer to Table II-1-10 for corresponding recession rates.



c. Bread Truck Gully.



d. Coastal 5 Gully.

Figure II-1-31 (cont.). Historic gully recession. Refer to Table II-1-10 for corresponding recession rates.

tween 1950 and 1960 and increased to between 2.1 and 14.7 m/yr between 1960 and 1972 following the earthquake in 1964. Recession continued to increase between 1972 and 1986 when rates ranged from 5.1 to 23.6 m/yr. In the decade of 1986 to 1995, recession rates have remained high but have in general slowed slightly, ranging from 3.9 to 21.6 m/yr.

The general pattern appears to reflect a more or less static state prior to the 1964 earthquake. At four of the six locations studied, recession rates reached their peak between 1972 and 1986. The recent high rate of recession at In-Between Gully reflects a rapid, shallow distributary that advanced into the mudflat by about 40 m during the 1992/93 winter (Lawson et al. 1995a), which increases the 9-year average by 4.4 m/yr. Therefore, the last decade of recession at In-Between Gully may be best represented by a rate of 2.9 m/yr (Table II-1-10). The other gullies that have shown a recent acceleration of recession are that of Bread Truck, which has been the site of considerable monitoring (see below), and Coastal 6. Recession at Bread Truck has been accelerating in an unpredictable manner as the gully headwalls have encroached on Bread Truck Pond, and entered into unvegetated mudflats that are intermittently ponded.

Historical analysis of gully extension and drainage

The last 45 years at the Eagle River Flats has seen a progressive change in surface characteristics as the local drainage system has evolved subsequent to the 1964 earthquake. The photographic coverage from 8 August 1950, 27 June 1953 and 30 August 1960 show the surface characteristics of the Flats prior to the earthquake. The overall appearance of the Flats at the time these photographs were taken was one of stability, with the only indication of on-going change being along the incised meanders of the Eagle River where vegetation was absent and some slumping was evident. Small, low-relief channels drained into tidal gullies which were apparently eroding slowly into the mudflats (Table II-1-10).

The Eagle River entered the Flats in 1950 through two well-developed channels that bifurcated about 850 m east of the Route Bravo Bridge (Fig. II-1-32a). North of Racine Island, the channel was straight and confined as it eroded

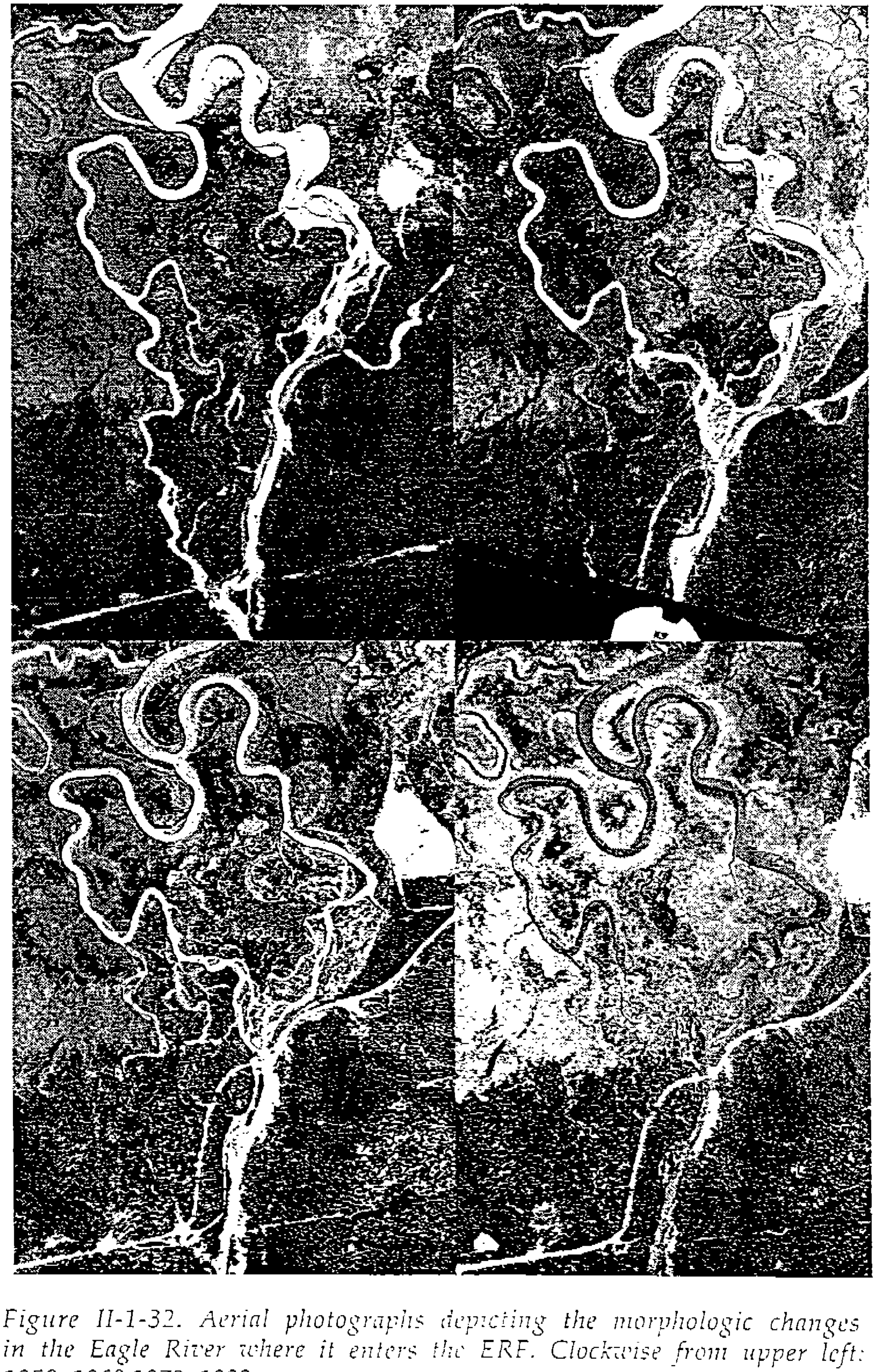


Figure II-1-32. Aerial photographs depicting the morphologic changes in the Eagle River where it enters the ERF. Clockwise from upper left: 1950, 1960,1972, 1993.

into the uplands, while the south channel appears slightly subordinate in discharge volume and exhibited a meandering pattern. Between 1957 and 1960 the south channel had captured all of the flow in the Eagle River and the north channel was inundated only during tidal flooding (Fig. II-1-32b). The southern channel remained the principle discharge until sometime between 1967 and 1972 when flow was reestablished in the north channel (Fig. II-1-32c). Multiple channels then remained active throughout the 1980s and 1990s (Fig. II-1-32d); however, in September 1995 a flood of the Eagle River resulted in the southern channel being abandoned as the northern channel eroded eastward into the upland bluffs.

During the 1950s and early 1960s, the mudflat areas of Racine Island were largely undissected and had a mostly complete cover of vegetation (Interior Sedge Meadow: Racine and Brouillette 1995a). The C, C/D and D areas were mostly vegetated (Halophytic Herb Meadow: Racine and Brouillette 1995), except where dissected by narrow, relict drainageways that extended into freshwater marsh (bulrush) in the areas where the C-, Bread Truck and Pond Beyond ponds now occur (Fig. II-1-2 and II-1-3). Open water can only be observed in the drainageways that feed Mortar, Bread Truck, Parachute and B gullies. In Parachute and B gullies, open water extends down the channels to within about 100–150 m of the Eagle River. At Mortar and Bread Truck, the narrow relict drainages are arranged in a dendritic pattern that penetrates into emergent Sedge Marsh (Racine and Brouillette 1995a). These channels form a tight drainage network along the boundary of what is now Bread Truck and Pond Beyond, where standing water exists currently on the mudflats. Relict drainageways directed water flow through on abandoned meander present in the Bread Truck pond. Small relict pools are also apparent in several of these gullies where present day headwalls and adjacent plunge pools exist, indicating a cyclic nature of stabilization punctuated by rapid erosion.

Open water in the ponds first became visible in 1967 in the areas near Clunie Creek and Clunie Point. There are also several small bodies of water in the C/D and D areas where small sedge bogs are now located. The major gullies of Bread

Truck and Mortar were also actively eroding into the mudflats by 1967 (Fig. II-1-6, II-1-31b, II-1-31c, Table II-1-10). By 1974, areas in C-Pond, the channel in Bread Truck Pond, and large relict drainages in Pond Beyond and C/D Pond exhibited additional open water and by 1984, ponds had dimensions similar to the present. Rapid pond expansion and maximum gully recession rates (Table II-1-10) appear to have been greatest during the late 1970s and early 1980s at a time when isostatic uplift rates were high (~1.5 cm/yr; Brown et al. 1977).

Recent vs. long-term rates of recession

The modern rates of net headward and lateral recession that were measured using the hub and line stake technique are depicted to show the spatial patterns in gully erosion along a transect from the mouth of the Eagle River inland to the head of the Flats (Fig. II-1-33). Nearest the coast, sites Coastal 1 and Coastal 7 have experienced more headward than lateral recession. In the mid-coastal regions, Mortar and Coastal 6 have experienced subequal lateral and headward recession, with a slight lateral erosion dominance as these gullies have been widening by bank collapse and slumping. Slightly inland from the mouth of the river, Bread Truck and Coastal 5 gullies have been experiencing drastic, yet rather symmetric retreat patterns governed by rapid headwall recession. Moving further inland, Tanker and In-Between gully sites have also experienced subequal, yet antecedent headward and lateral erosion and recession. The outer erosion sites (those north of Parachute Gully), appear to be mirrored on either side of the Eagle River to the coast. The mechanisms driving this symmetry are, however, unknown.

Comparison of the recent erosion data (Tables II-1-8 and II-1-9) with historical data (Table II-1-10) indicate dissimilar rates over the short-term, but over the long-term, recent rates are closer to the historical rates. The high rates of headwall recession at Bread Truck (33 m in ~2 yr) and Coastal 5 (26 m in ~1.5 yr) are close to the 11-year average rates of 21.6 and 18.4 m/yr, respectively, as determined from historic photographic analyses (Fig. II-1-31). Similarly, the headward recession of 12.1 m in 3 yr at Parachute Gully (Tables II-1-8 and II-1-9) is almost identical to the 3.9 m/yr average since 1986; the 1.6 m observed at Mortar is close,

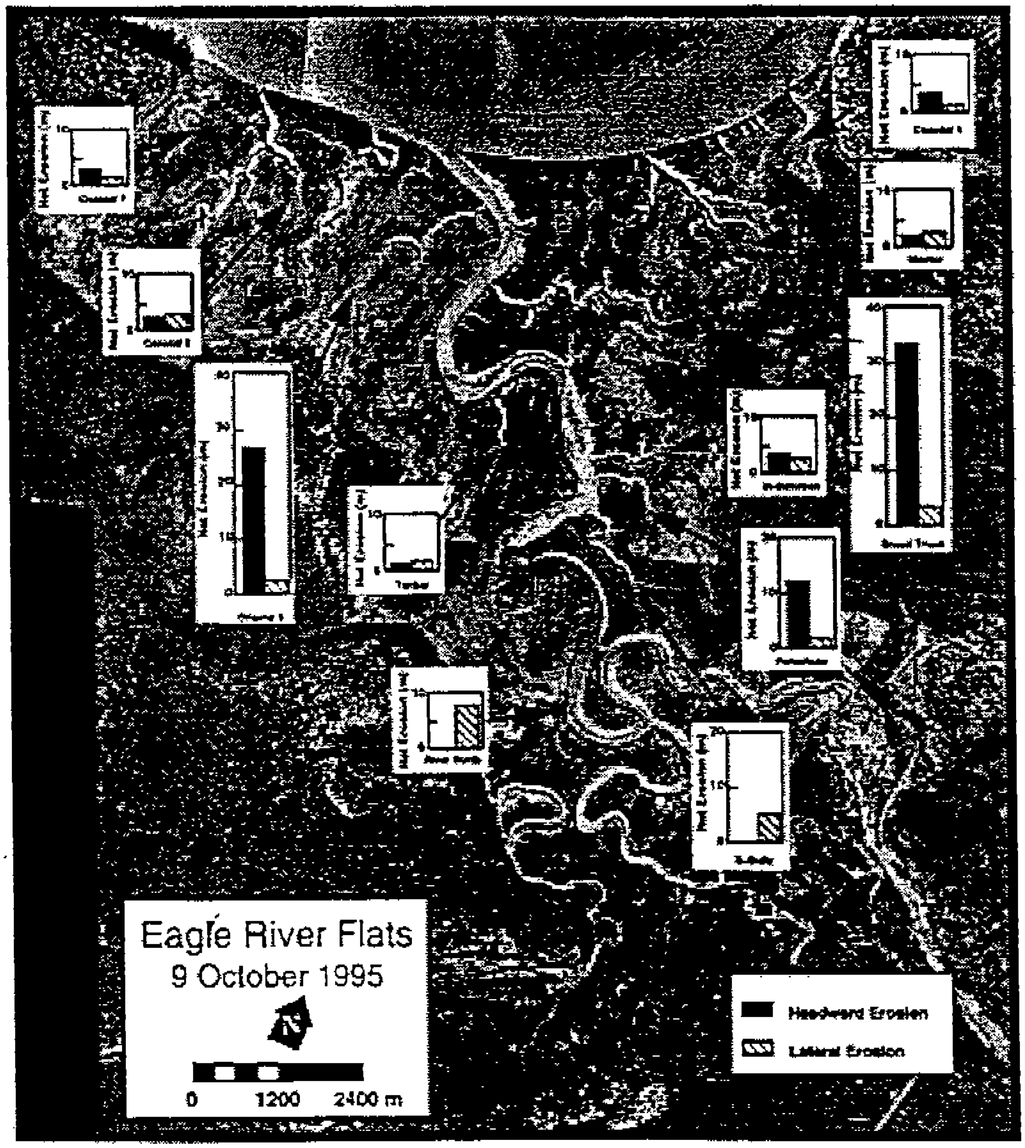
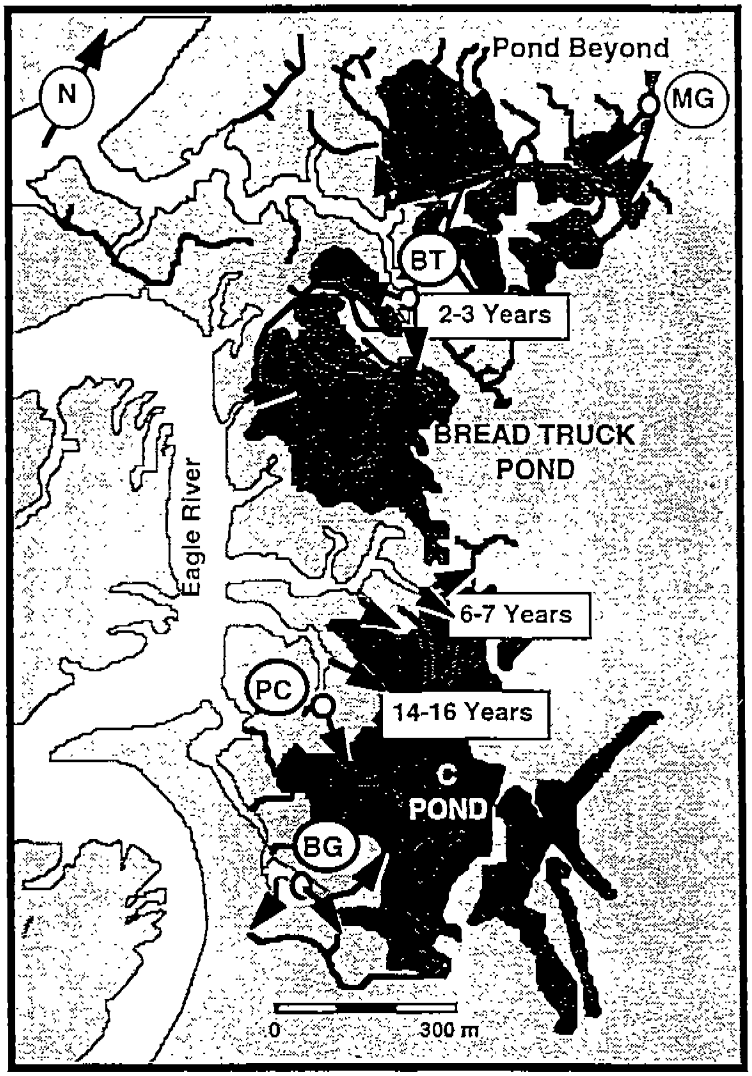


Figure II-1-33. Spatial comparison of headward and lateral recession monitored at selected hub-line stake erosion sites.

but lower than the 11 year average of 3.9 m/yr (Fig. II-1-22d, II-1-31b, Table II-1-9). Since our hub and line stakes at B-Gully record only lateral erosion, the current rates are not comparable to the 11-year average of 3.9 m/yr headward recession.

Feasibility of intrinsic remediation by natural pond drainage

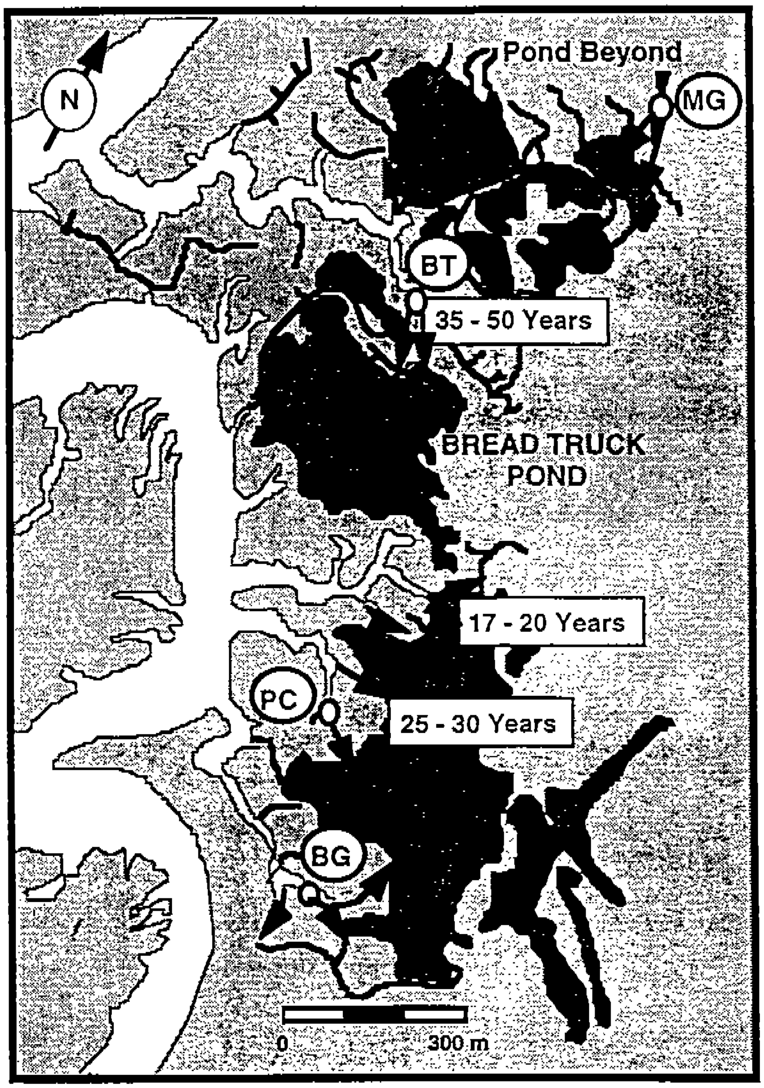
Given that the recent and long-term recession data appear to agree with one another, we revise our 1994 prediction for pond drainages (Lawson et al. 1995). Utilizing these refined recessional data that includes that of the 1995 summer



a. 1995.

Figure II-1-34. Predictions for pond drainage initiation by selected gullies in Areas C, Bread Truck, and C/D.

(Tables II-1-8 and II-1-9) and historical analyses (Table II-1-10), it appears likely that Bread Truck pond will start to drain in 2–3 yr or less. In about 6–7 yr, In-Between gully will drain parts of C and Lawson's pond, and in about 14–16 yr, Parachute gully will drain parts of C Pond (Fig. II-1-34a). Based upon more limited data from 1994, we had previously forecasted that Bread Truck pond would begin to drain in 35–50 years, while the In-Between and Parachute gullies would begin to drain the C Pond area in 17–20 yr and 25–30 yr, respectively (Fig. II-1-



b. 1994.

Figure II-1-34 (cont.). Predictions for pond drainage initiation by selected gullies in Areas C, Bread Truck, and C/D.

34b). The drastic changes in our assessment and predictions reflects the dynamic and variable nature of the erosion processes. By utilizing a greater time span to formulate our assumptions, the predictions for initiating pond drainage are more accurate. Continued monitoring is recommended, however, to document these predicted recession rates and evaluate whether natural processes are a feasible and effective alternative to anthropogenic remediation of the WP contamination.

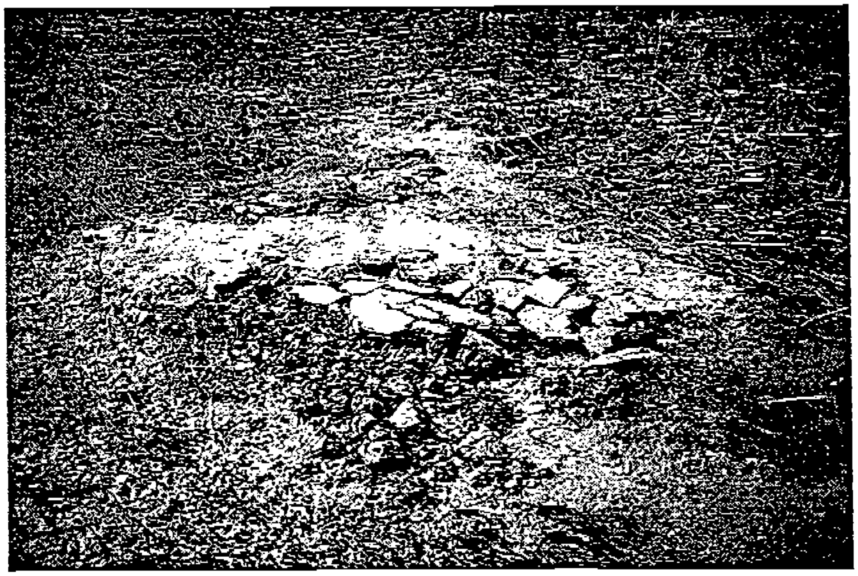
Gullies are routes for pond outflow and therefore potential pathways for WP transport. As the gullies continue headward erosion into WP contaminated areas, fresh sediment will be exposed and introduced into them, potentially increasing the amount of WP in ebb discharge. Gully erosion may also threaten the integrity of other remedial methods. For example, capping measures (i.e., geotextiles and AquaBlock®) may be undercut by erosion, release WP directly, and damage or eliminate the effectiveness of the cap. Similarly, hydrologic and physical changes to the ponds and mudflats may result from dredging and cause rapid extension of the gullies into the dredged areas.

SEDIMENTATION AND NATURAL ATTENUATION OF WP BY BURIAL

Suspension settling through flocculation occurs during slack high tide and through the early stages of the ebb cycle. In ponded areas, it also occurs between tidal flooding when water turbulence is low, allowing fine-grained particles to settle out of the water. Therefore, the longer calm conditions can be maintained, the greater the time over which deposition can occur. The mixing and exchange of flood water with pre-tide pond and marsh water increases the amount of suspended sediment in the ponds and marshes, and provides the primary source for deposition with each flooding tide.

Controls on sedimentation rates at any particular location include elevation, vegetation that traps sediment (e.g. Reed 1995), and the frequency, height and duration of inundations by sediment-laden waters (e.g. Vince and Snow 1984, Reed 1989, 1995, French and Spencer 1993, Reed and Cahoon 1992). The distance from the source also plays a role within some areas, as sediment can be deposited or eroded during flood and ebb, altering its concentration. Large amounts of sediment may be deposited locally from ice rafting of materials plucked from other locations within the Flats (Fig. II-1-35).

a. Sediment layer frozen onto an ice block transported during the November 1994 flooding tides.

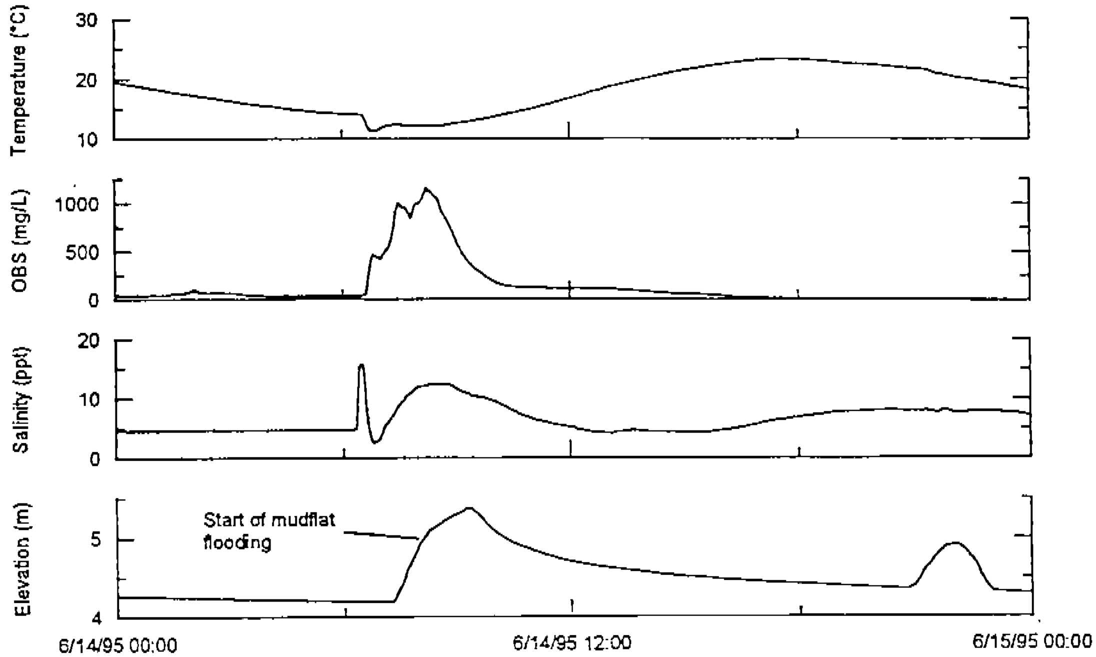


b. Ice-rafted sediment deposited at the head of Mortar Gully.

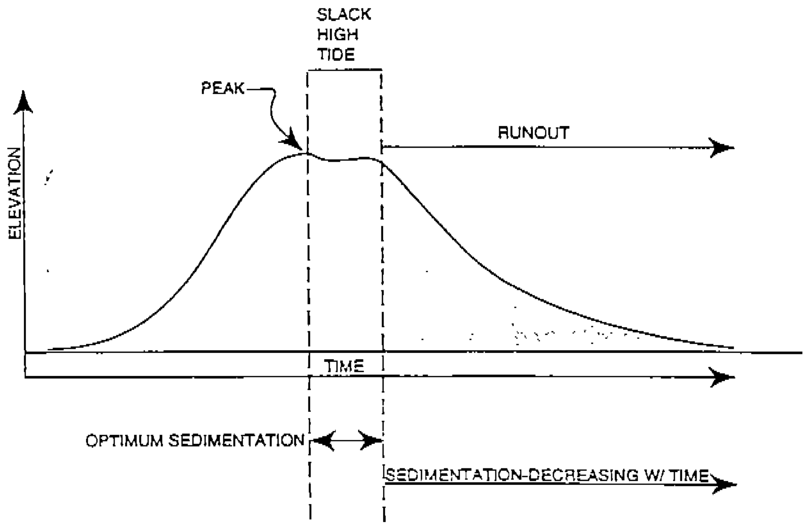
Figure II-1-35. Ice rafting at ERF.

Tidal inundation

Several factors that influence the timing, magnitude and duration of tidal flooding and runoff must be evaluated since flooding drives pond sedimentation and gully erosion, and modulates near-surface soil moisture, thereby affecting the decomposition of WP particles.



a. B-Gully on 14 June 1995.



b. Schematic showing a typical tidal cycle and period of sedimentation during the ebb tide event.

Figure II-1-36. Example of a flooding tide cycle. Note that rate of tidal rise decreases following bankfull stage when water begins to flood adjacent mudflats.

A typical tidal flooding cycle begins with a rise in the water level in the Eagle River and gullies. As the tide reaches its peak, the water floods over the banks of the gullies, displacing the water over a large area, and causing a decrease in the rate of water level rise (Fig. II-1-36). Once the peak is reached, there is a period of

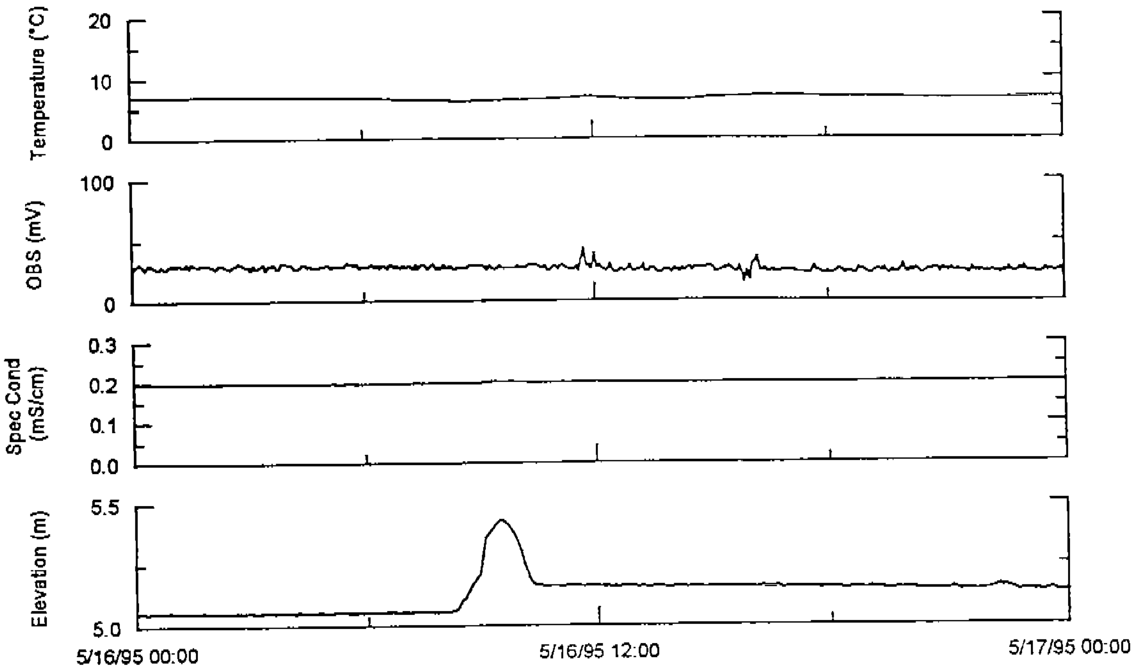


Figure II-1-37. Water quality data from the Eagle River site showing the effect of water damming caused by a flooding tide.

slack high tide when the water is dammed upon the Flats. During ebb the water begins to drain nearest the coast and progressively decreasing water level inland. This effect results in a period of runout that is typically longer than the inundation stage of flooding.

The damming of the river water during the flood tide causes the river to slow, pool, and eventually reverse its direction in the upper Flats (Fig. II-1-37). This damming effect causes the water elevation of the river to rise higher than the elevation of water in the gullies and initiate a reversal in flow direction in the drainage systems, particularly on Racine Island. This damming effect may be accentuated during spring snowmelt or mid- to late-summer runoff peaks caused by glacial melting that increase the amount of water discharged from the Eagle River (e.g. Lawson 1993). Water depths measured at the hydrostations and tidal gauge in Knik Arm show that the peak elevation on the Flats exceeded the predicted tidal height for Anchorage by up to 0.7 m throughout the 1995 summer season (Fig. II-1-38).

Because pond sedimentation results mainly from settling-out of sediment

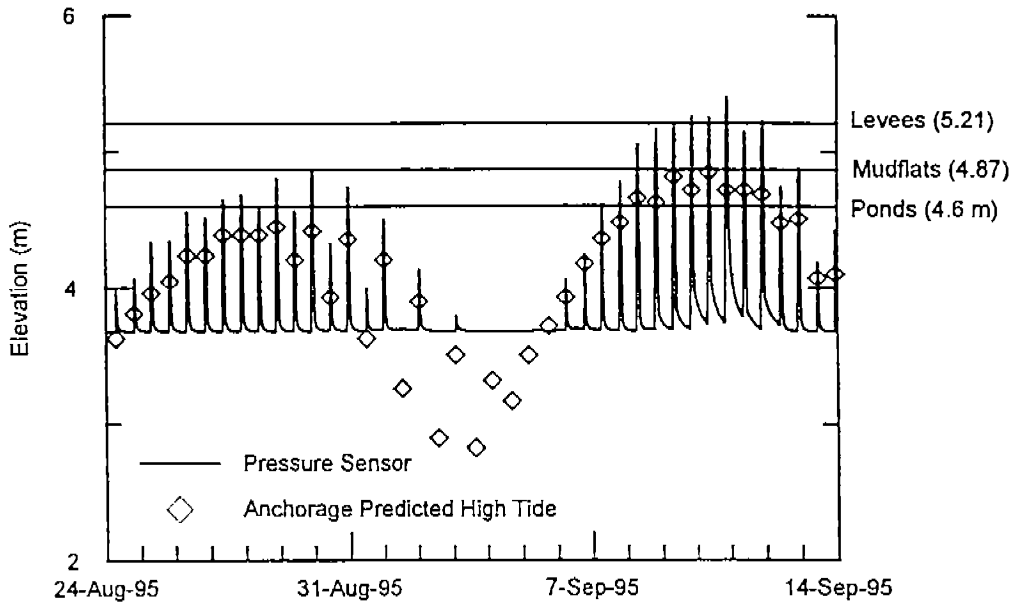


Figure II-1-38. Water elevation record showing elevations required to flood selected landforms and tidal amplification above predicted high tide at Anchorage.

suspended in the water column, sediments are deposited during and immediately following slack high tide (Fig. II-1-36b). The duration, height and mass of water inundating the ponds and mudflats therefore determine the time during which sedimentation will occur. Quiescence is of the essence to suspension setting. Incomplete drainage of pond areas commonly occurs between consecutive tides exceeding 32.4 ft (5.0 m) locally on the Flats. The mixing of flood waters with the pre-tide pond and marsh waters increases the amount of suspended sediment. In those ponds such as Racine Island, which have the highest proportion of fresh river water inundation, suspended sediment concentrations are less than where tidal sources predominate.

The time between the start of water rise and peak high tide was calculated for each gully hydrostation and compared to the peak water elevation at that site. A linear relationship was found between water rise time and peak elevation (Fig. II-1-39). Average elevations for tidal flooding across the Flats were estimated from the surveyed transects (Fig. II-1-8). These data indicate that most ponds will begin to flood at a tidal height of about 4.6 m, mudflats are inundated at 4.9 m and levees are covered at 5.2 m (Fig. II-1-38). Only at Racine Island was there a

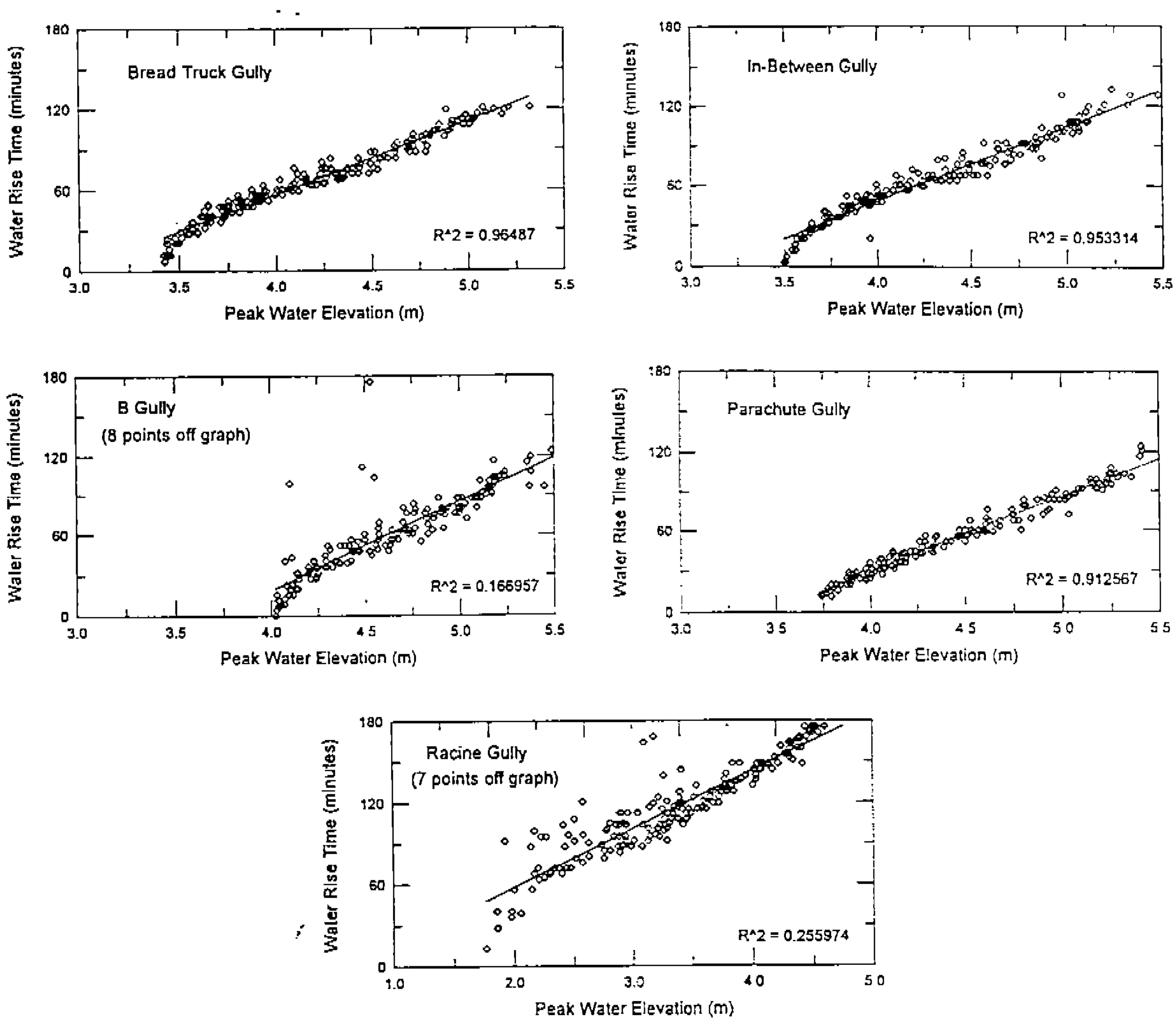


Figure II-1-39. Relationship between water rise time and peak water elevation at several gully sites.

difference; here, survey data indicate a 4.35-m threshold for pond flooding. These former elevations also yielded a linear relationship between the period of flooding (i.e., time when water elevation was greater than 4.6 m) and peak water elevation (Fig. II-1-40). Estimates of how often each landform is flooded in a given time period can be based upon these elevations. The length of time available for sedimentation during tidal inundation is directly related to the peak elevation and each landform's threshold for flooding.

Timing of flooding is a function of the elevation of the levees and mudflats surrounding the gullies, distance of the gully headwall from the coast, and gully length. Water moving down the river can also alter the timing of flooding in-

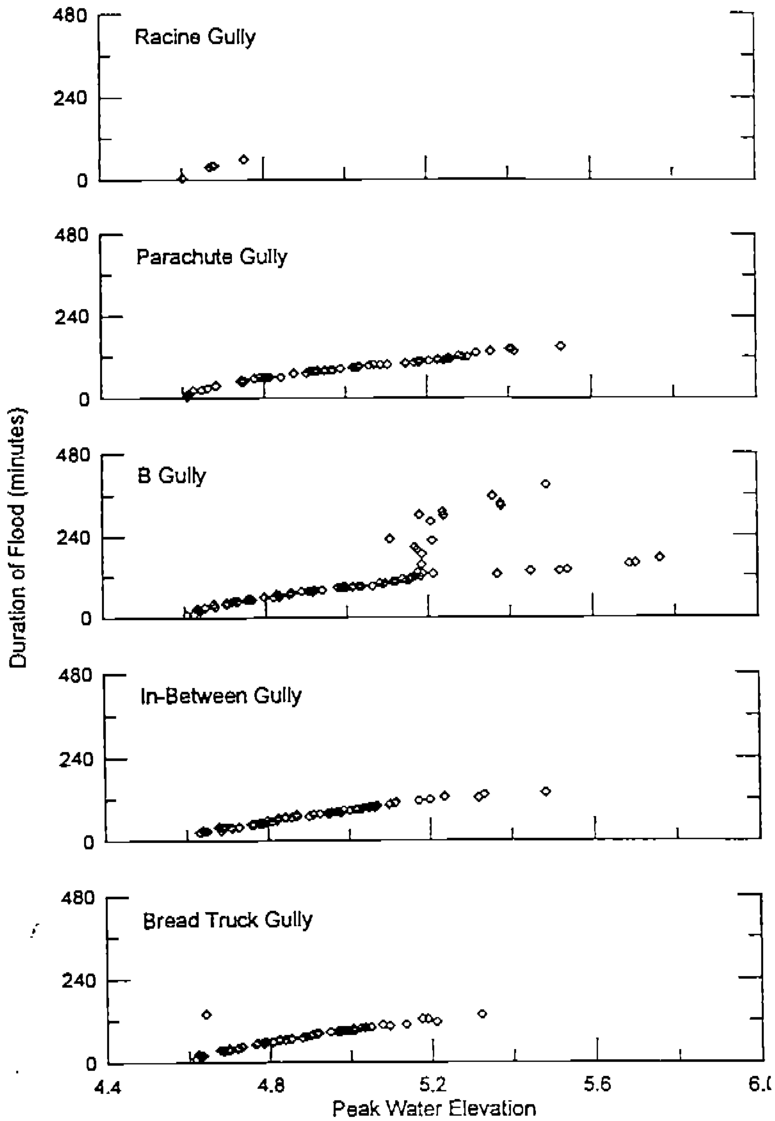


Figure II-1-40. Tidal flooding time as a function of peak flood elevation at selected gullies.

land from the coast, depending upon its volume relative to the volume of tidal waters. Analyses indicate that tidal flooding is best described by a polynomial regression (Lawson et al. 1995a).

Pond drainage is restricted by gully parameters (cross-sectional area, channel roughness, and drainage density) which limit the volume of water that can escape from the pond. This produces a "bottle-neck" effect where water in the pond remains dammed despite turbulent, fast flowing conditions within the gully

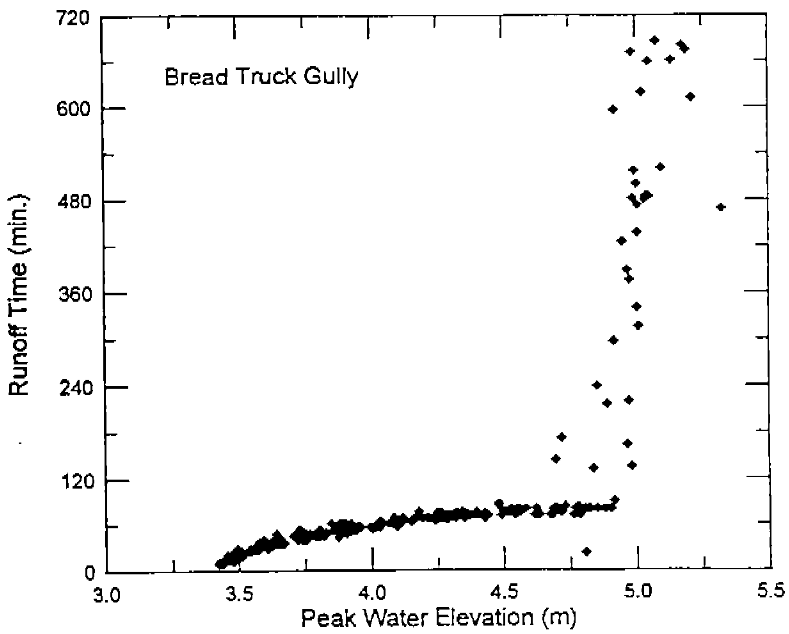


Figure II-1-41. Run-off time versus peak water elevation at Bread Truck Gully. The change in slope reflects the effect of pond drainage where run-off is extended once ponds are flooded.

heads. The response is a non-linear relationship between water elevation and runoff time (Fig. II-1-41) which, in effect, extends the period of time for sedimentation.

Sediment transport and sediment sources

Sediment transported in suspension from Knik Arm is the primary source for ponds and varies seasonally as well as during single tidal cycles (from flood to ebb) (Lawson et al. 1995a). TSS measurements in Knik Arm exceed those at the river throughout the year and show a general increase in sediment concentration through the summer season (Fig. II-1-42). These higher sediment concentrations reflect the high sediment influx from the large glacierized basins of the Susitna, Matanuska and Knik Rivers (Fig. II-1-1). The increase in TSS values during fall and winter probably reflect the colder water temperatures and increased salinity. In the Flats, reduced discharge from the Eagle River minimizes dilution by waters with much lower sediment concentrations, allowing water with greater sediment concentration to enter the ponds and mudflats.

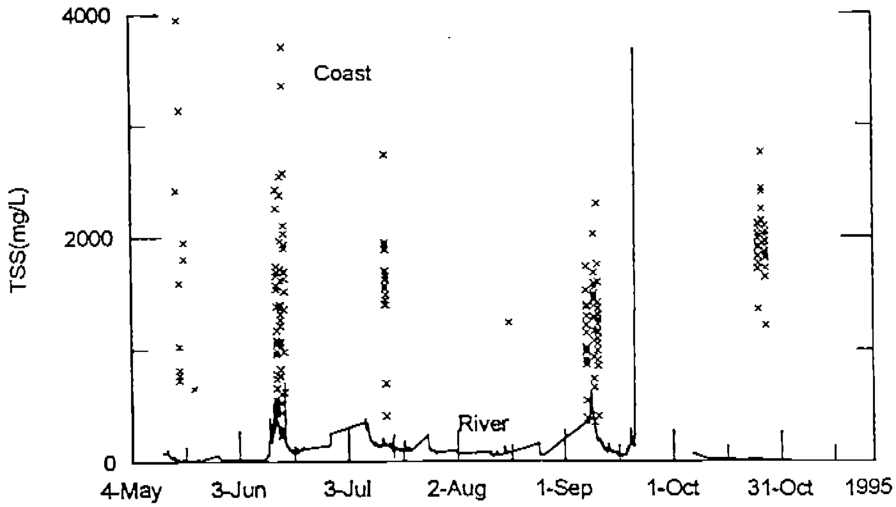


Figure II-1-42. Coastal versus river TSS measurements.

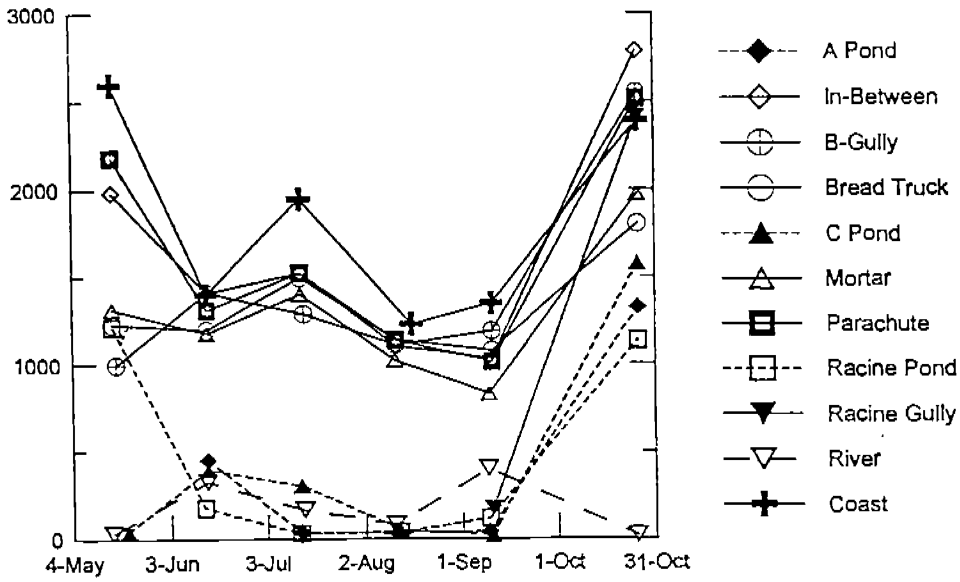


Figure II-1-43. Maximum monthly TSS comparison at all sites.

Sediment flux into and out of the ponds and mudflats varies monthly as tidal height, flood duration and runoff time vary (Fig. II-1-43). Total suspended sediment (TSS) concentrations vary among the gullies through a single tidal cycle and reflect distance inland from the coast, as well as spatial variations in runoff, pond storage capacity and the capacity of the gully to drain water from the ponds and mudflats. These differences in sediment flux into and out of the ponds and mudflats result in the spatial variability in deposition. Other factors determining the rate of sedimentation result in more localized rate differences.

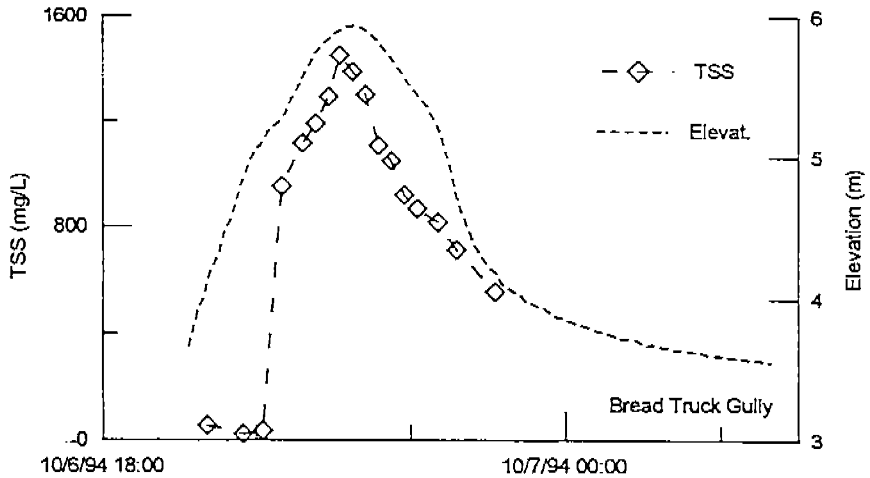


Figure II-1-44. Typical TSS variation through a flooding tide.

A typical pattern in TSS response as measured at the heads of gullies through a flooding cycle is a sharp increase due to the influx of highly turbid flood water from Knik Arm and resuspended gully bed sediment (Fig. II-1-44). TSS values remain high through slack high tide and the start of ebb. An abrupt decrease in TSS occurs during ebb runoff. The duration of ebb runoff is dependent on the ability of the gully or network of gullies to transfer water stored in the ponds and mudflats. The greater the volume of water stored in an area, the longer it will take for gullies to effectively drain the ponds. The decrease in suspended sediment concentration during ebb reflects the loss of material by deposition on mudflats and within ponds, as well as the mixing of the tidal waters with sediment-poor pond and river waters.

Seasonal variability in TSS concentrations occur in the Eagle River, being high through July and August, with sediment peaks occurring in mid-June and early August during the peak periods of snowmelt in the mountains and glacial runoff, respectively (Fig. II-1-42). The relative levels of TSS concentrations in the River are quite low, however, compared with simultaneous values measured in Knik Arm (Fig. II-1-43) and in the gullies during tidal inundations.

Landform transect rates

Sedimentation rates vary with respect to morphology and in a general sense to elevation (Table II-1-11). The overall trend is an increase in rate from levees

Table II-1-11. Gross sedimentation rates. Measurements for seasons through winter 1993-94 are from transect lines 1-12 only, Summer 94 measurements from lines 1-24 (Fig. II-1-4).

	Range (mm)						
Morphological unit	*Sum. 1992*	*Win. 1992-93*	*Sum. 1993*	*Win. 1993-94*	*Sum. 1994*	*Win. 1994-95*	*Sum. 1995*
Levee	1-6	1-12	0-6	0-11	0-15	0-30	0-17
Vegetated mudflat	1-6	1-16	1-14	1-21	1-30	0-31	0-13
Unvegetated mudflat	1-13	7-12	1-8	6-10	1-17	3-21	0-17
Pond - plate	1-4	8-28	6-26	2-17	1-21	1-16	1-37
Pond - cup	2-9	8-26	6-19	1-13	2-20	9-40	1-39
Marsh	ND	ND	ND	ND	1-20	2-10	1-13
Gully	1-77	20-33*	0-19	0-16	1-19	3-50	6-60

* Based on small sample size.

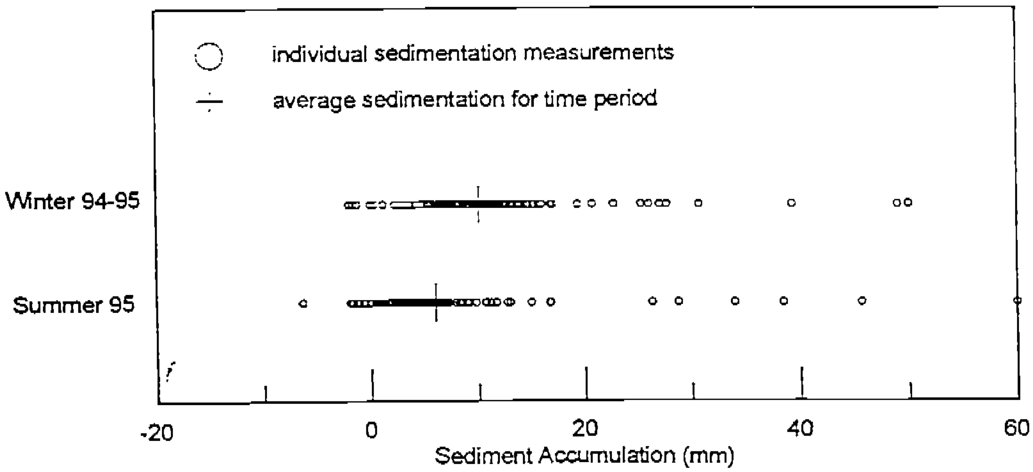


Figure II-1-45. Net seasonal accumulation rates at sites spray-painted in the C and D Areas.

to mudflats, ponds, marshes, and gully bottoms, with the more heavily vegetated areas of mudflats having higher rates of accumulation than those that are not vegetated. Typical annual sedimentation rates range from about 10–30 mm among the various landform types.

Net accumulation rates are generally higher during the "winter" 8-month period from September to May, than during the "summer" 4-month period from May to September. This difference may reflect their respective lengths of measurement, the increases measured in TSS values during the early winter months (Fig. II-1-45), the trapping of sediment by the snow cover, or the number of flooding events. Net accumulation measurements from the paint-layer technique for the period of September 94 through May 95 (winter) and May 95 through September 95 (summer), in Area C and D mudflats and levees vary seasonally. Most winter values fall in the range of 2 to 18 mm (average 10 mm), while the summer values range between –2 and +14 mm (average 6 mm).

The relationship of sedimentation rate to elevation is a response to the number of times the sites are inundated. The number of measured flooding events exceeds that predicted from tidal elevations at Anchorage because of several factors including tidal amplitude caused by the geometry of Knik Arm (e.g. Syvitski et al. 1987, p. 163), river discharge, ice cover and wind. Significantly more tidal flooding occurred at each hydrostation site during both 1994 and 1995, and given this scenario, should far exceed that number again in 1996. During summer, about twice as many floodings occur, but fewer take place in winter, perhaps due to the seasonal reduction in river discharge.

Table II-1-12 depicts on a seasonal basis the number of flooding events that would reach critical elevations to flood different landforms based on predictions using the Anchorage tide gauge. The number of inundations is highest for ponds, being less on mudflats and levees, thereby correlating with the general decrease in sedimentation rates that characterizes this respective sequence of landform types (Fig. II-1-46).

The amount of vegetation cover in the mudflats influences the sediment accumulation rates. Sediment accumulation versus percentage of vegetation cover

Table II-1-12. Comparison of predicted and measured number of flooding events reaching critical heights during summer 1994 and summer 1995. Time periods relate to intervals between sedimentation measurements.

	Number of flooding events				
	*Summer 1994**		*Summer 1995†*		*Summer 1996*
Critical height	*Predicted***	*Measured††*	*Predicted*	*Measured*	*Predicted*
Inundate ponds (4.6m)	16	52	33	38	44
Cover mudflats (4.87m)	8	18	10	22	25
Cover levees (5.21m)	0	4	0	1	2

* Summer 1994 (22 May - 15 Sep)

† Summer 1995 (5 May - 11 Sep)

** Predicted based on Thompson tide table at Anchorage.

†† Measured based on depth transducer at Bread Truck gully.

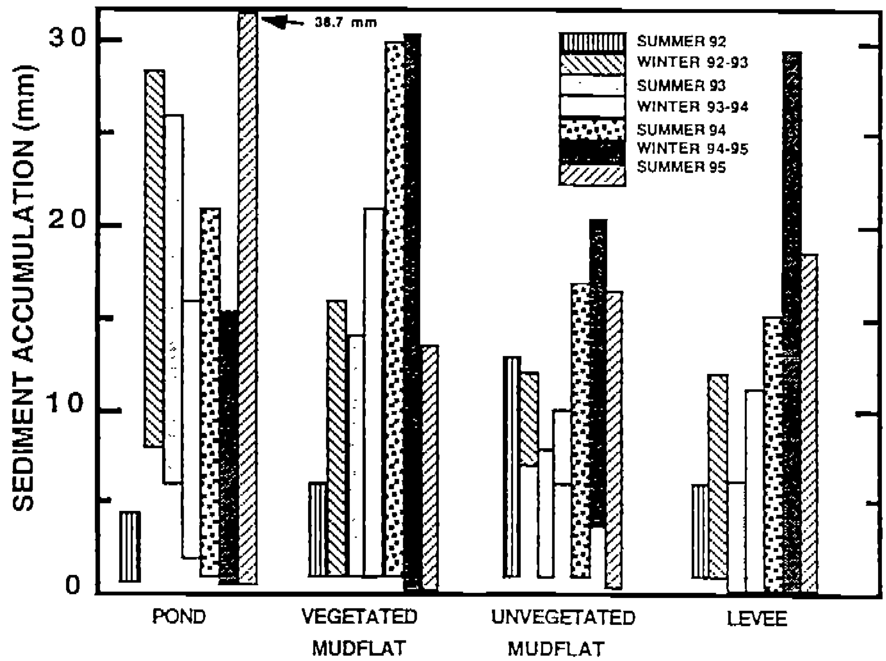


Figure II-1-46. Variations in sedimentation rate as a function of landform type.

at sites first established in 1992 are shown in Figure II-1-47. Gross sedimentation rates had two-year total accumulations of 6–18 mm at sites with less than 60–65% vegetative cover, and 26–32 mm at sites with a vegetation cover of greater than 70%.

Sedimentation rates also vary with distance from source waters. A decrease in sedimentation rate with distance inland is seen along transect 16 (Fig. II-1-48a), which extends southward from Knik Arm in coastal Area A (Fig. II-1-8). Decreased velocities of Knik Arm waters during flooding reduces their ability to transport sediment, causing rapid sedimentation near the coast. The same effect is often seen along

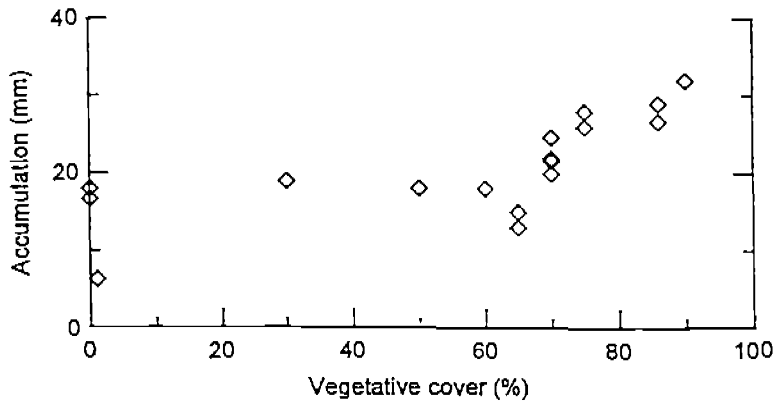
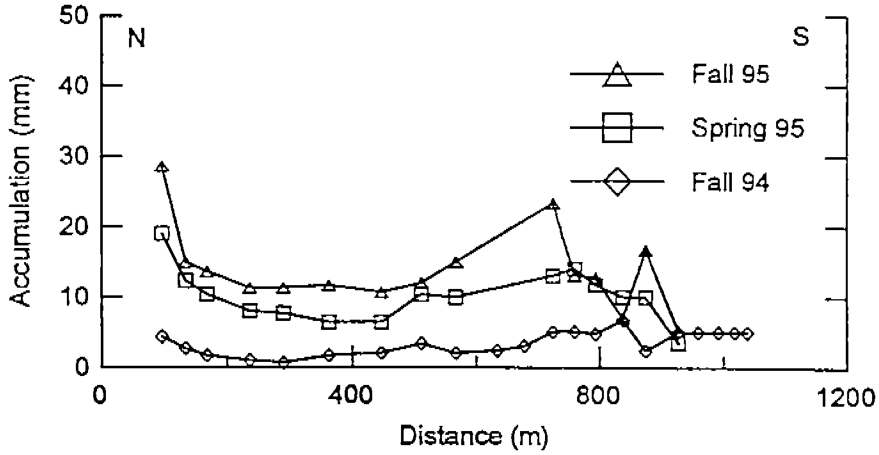
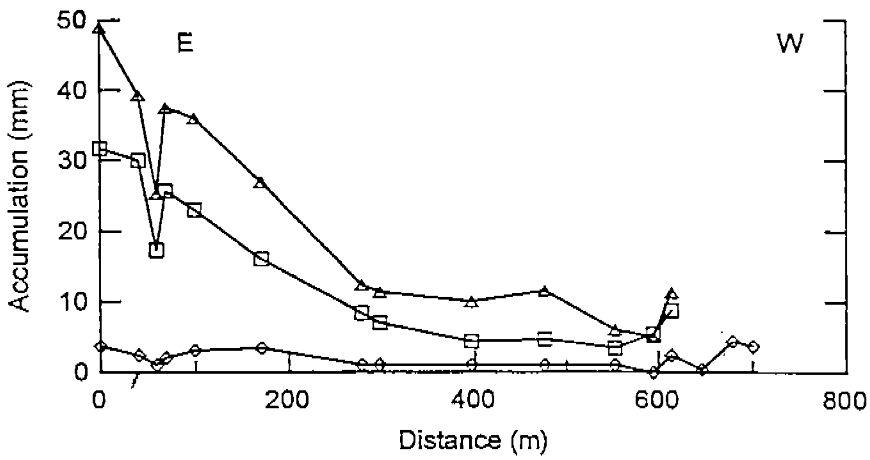


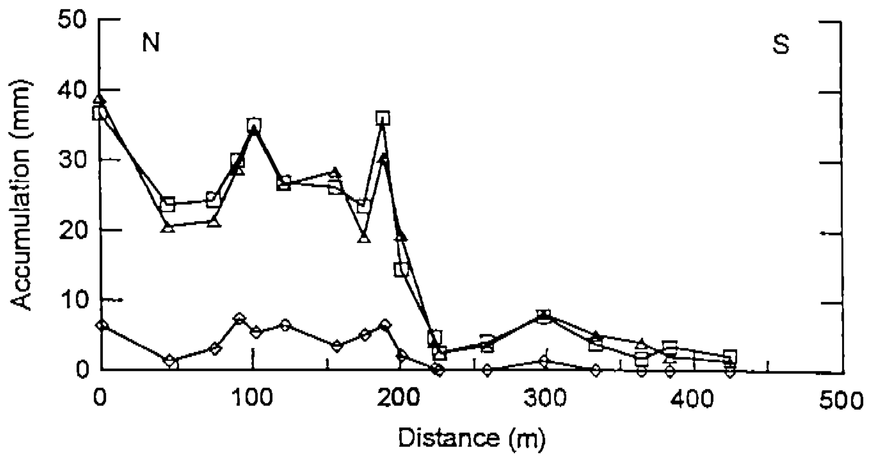
Figure II-1-47. Relation between total sediment accumulation and vegetation cover at sites sprayed with paint in 1992 and measured in the fall of 1994.



a. Transect line 16.



b. Transect line 14.



c. Transect line 19.

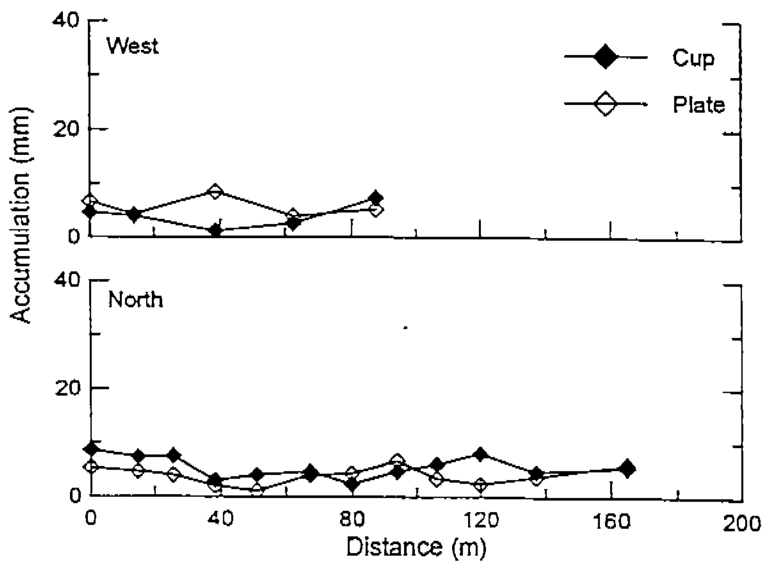
Figure II-1-48. Sediment accumulation along mudflat lines sprayed with paint in early summer 1994 (see Fig. II-1-8).

the scarp of many gullies where flow conditions change rapidly as flood waters overtop gully banks. Sedimentation rates decrease with distance from the Eagle River inland toward the marshes adjacent to the uplands (Fig. II-1-48b). High accumulation rates were also observed at a low elevation oxbow area on Racine Island that floods more frequently (Fig. II-1-48c).

Pond transects and stations

Pond sedimentation transects were newly established in 1995 in Bread Truck, C/D, C, Lawson's, A, and Racine Island ponds (Fig. II-1-9). Measurements on the plates and cups were made in September at each station on these transects; only cup measurements were obtained at C/D pond. The character of the sediment accumulated at the new pond sites during this first summer season is quite liquified. Since it is impossible to differentiate between the mineral and vegetative or organic fraction of accumulated material, the measurement includes both these fractions. At sites where an algal bloom was present in the water column above the measuring devices, the material was either gently removed or moved enough to see the sediment surface and obtain the measurement.

Overall, accumulation amounts were consistent along the transects, ranging from 5 to 20 mm (Fig. II-1-49). There were a few anomalously high readings



a. Bread Truck Pond.

Figure II-1-49. Pond sedimentation measured along pond transects for the period of May to September 1995.

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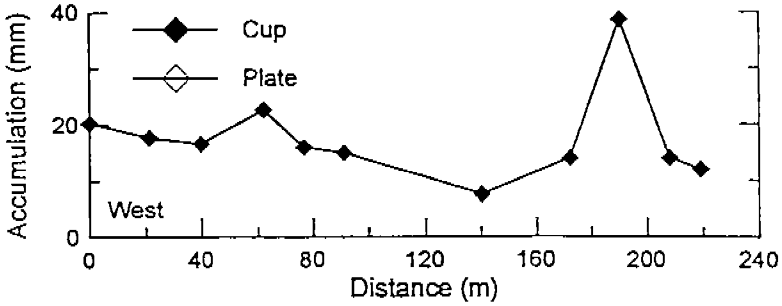
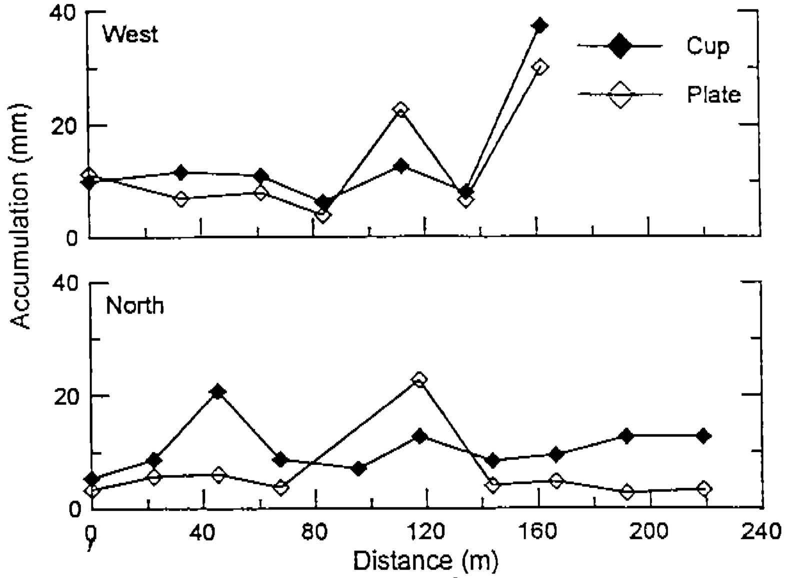
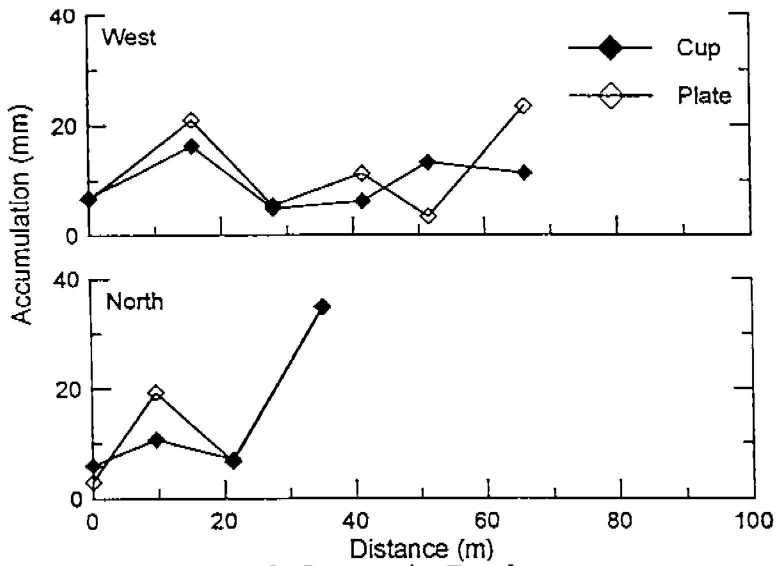


b. C/D Pond.



c. C-Pond.



d. Lawson's Pond.

Figure II-1-49 (cont.). Pond sedimentation measured along pond transects for the period of May to September 1995.

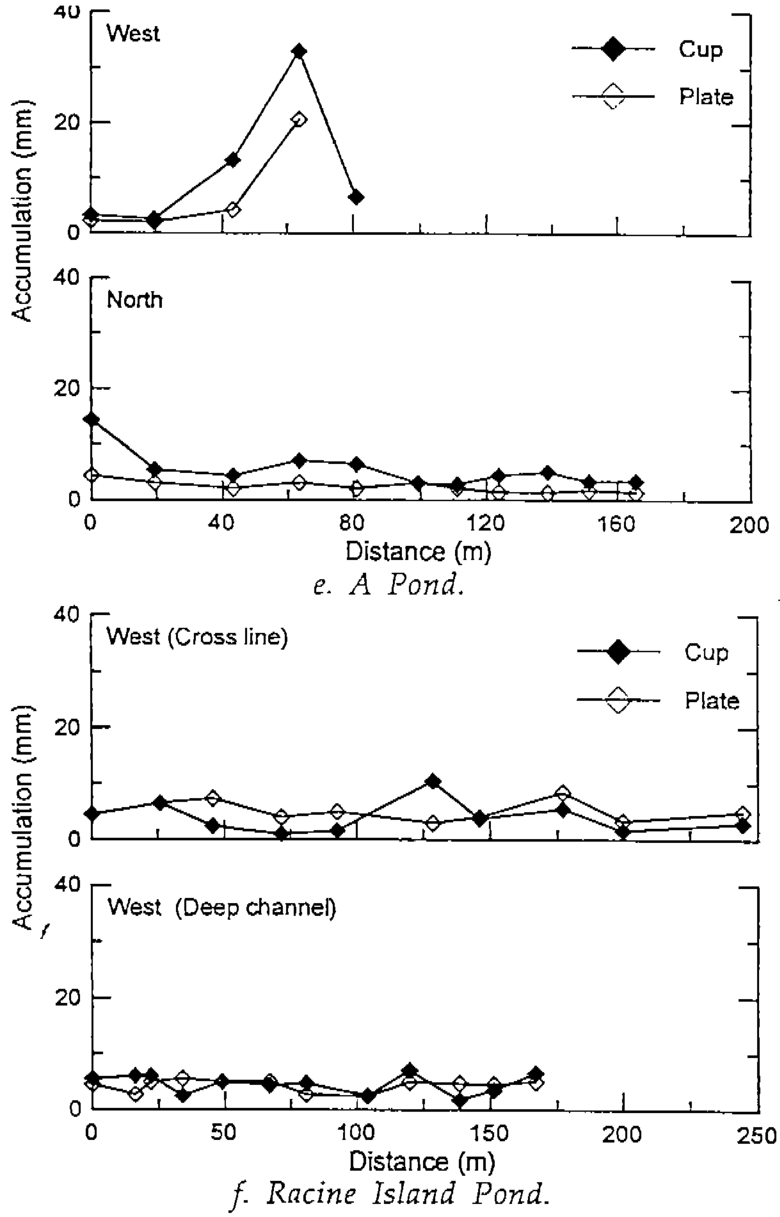


Figure II-1-49 (cont.). Pond sedimentation measured along pond transects for the period of May to September 1995.

among the otherwise consistent readings, which we believe were probably the result of human or wildlife-induced disturbance.

Table II-1-13 summarizes the average and standard deviation of cup and plate measurements at each pond in two ways: with and without data points suspected of resulting from disturbance. The cup measurements, without suspicious data points, indicate Lawson's Pond, C/D Pond and C Pond have higher averages than the other three ponds (Fig. II-1-50). Lawson's Pond and C/D Pond have less open

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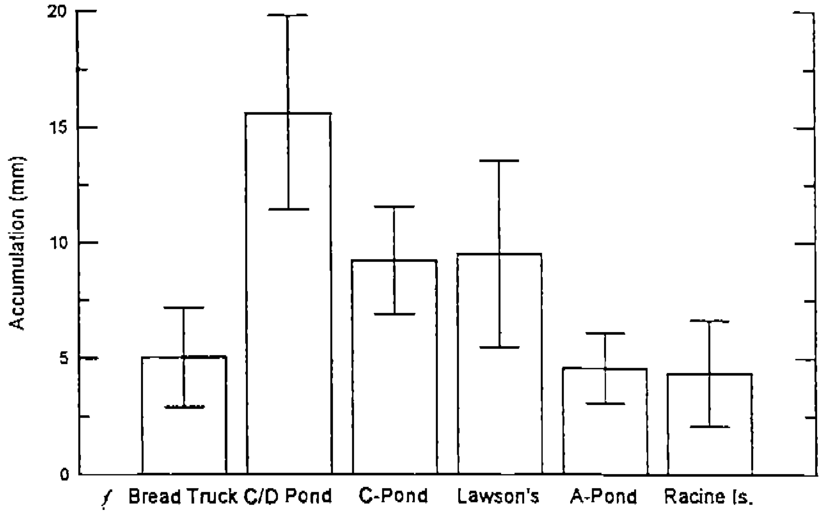
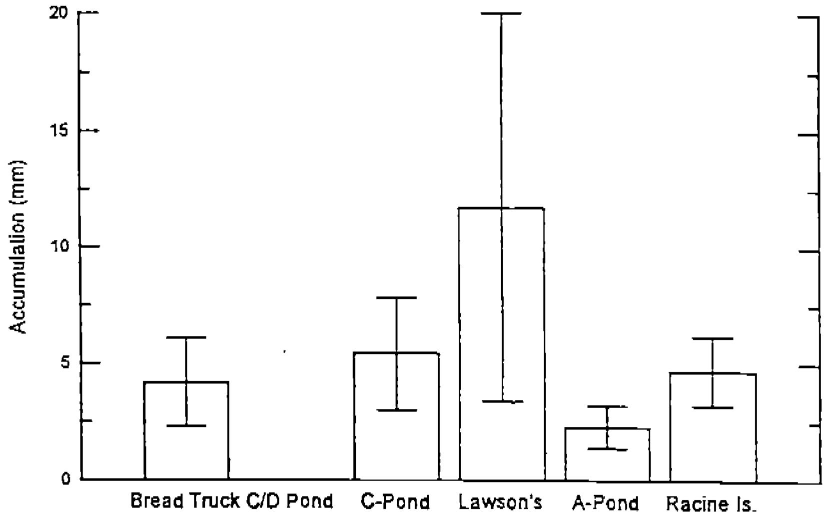
Table II-1-13. May to September 1995 sediment accumulation at pond sedimentation station transects.

	Sediment accumulation (mm)							
	All data				Without disturbance			
	Cup		Plate		Cup		Plate	
Site	Avg	Std	Avg	Std	Avg	Std	Avg	Std
Bread Truck	5.0	2.2	4.2	1.9				
C/D Pond	17.7	8.0			15.6	4.2		
C-Pond	11.9	7.7	8.2	7.8	9.2	2.3	5.4	2.4
Lawson's	12.3	9.3	14.3	10.9	9.5	4.1	11.7	8.3
A-Pond	7.7	7.8	3.7	5.0	4.6	1.5	2.3	0.9
Racine Is.	4.3	2.3	4.7	1.5				



a. Fall 1995 cup measurements.



b. Fall 1995 plate measurements.

Figure II-1-50. Average sediment accumulation, May–Sept. 1995, at pond sedimentation station transects, without data points suspected of disturbance. One standard deviation is shown with error bars.

water and more vegetation to help trap the sediment. The measured values for the plates indicate Lawson's pond has the highest average rate, but with a large variability. The three ponds Bread Truck, Racine Island and C Pond had similar plate accumulation amounts, while A Pond accumulations were less.

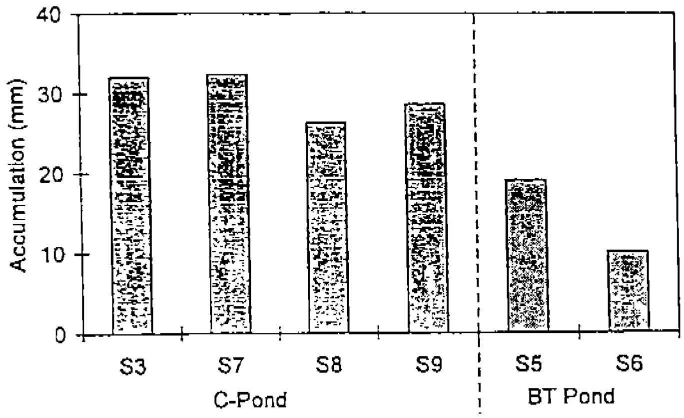


Figure II-1-51. Fall 1995 measurements of accumulation at sedimentation stations established in 1992.

September 1995 measurements on the plates at the sedimentation stations established in 1992 give a representation of longer-term net accumulation over a 3-year time period (Fig. II-1-51). At these sites, the material in about the upper 5 mm is liquified, while the lower portion of the accumulated sediment has undergone dewatering and compaction with a consistency that provides resistance to penetration with a mm rule. Accumulation amounts were somewhat higher in C Pond than in Bread Truck Pond, but in both cases amounts appear to be such that in another 6–9 years, the upper uncontaminated sediment should provide a barrier deep enough to keep dabbling ducks from reaching the lower contaminated material.

WHITE PHOSPHORUS FATE, TRANSPORT AND MIGRATION

White phosphorus, either as individual particles or sorbed to sediment (mineral or organic particles), is eroded and transported from the ponds and mudflats by a variety of processes operating throughout the year (Tables II-1-2 and II-1-3). Processes include primarily wind, river and tidal currents, slope erosion, and during winter, frazil flocs, anchor ice and ice floes formed within the ponds, gullies, Eagle River and Knik Arm. Animals, waterfowl and humans may likewise disturb and mobilize WP in ponds. Ice entrains WP-bearing sediments from the pond bottoms and mudflat surfaces by freezing to them, and these materials are transported with the ice within and out of the Flats during tidal flooding and ebb (Fig. II-1-35). Currents move sediment and WP as bedload and suspended load within drainageways and gullies, the main avenues of movement into Eagle River and Knik Arm. WP transport by ice and water is quantitatively important and ultimately affects its fate.

WP movement therefore occurs episodically from the Flats into the Eagle River and Knik Arm where it is deposited. Intertidal bars and the nearshore zone of Knik Arm are potential areas of deposition where exposure may pose a potential risk to waterfowl or other receptors (Lawson et al. 1995a). The fate of WP within Knik Arm is however not known.

White phosphorus migration was gauged by analyzing material in sediment traps within contaminated permanent ponds, and by analyzing the materials in plankton nets of the bedload and suspended load of gully runoff during ebb (Fig. II-1-20b). Plankton nets in the center of gullies provide the only data available on transport and migration of WP into the Eagle River and Knik Arm. Sediment traps in ponds provide data localized WP movement by resuspension. Sediment trap and surface samples, which were taken in previous years (Lawson et al. 1995a, b), provide data on mudflat scour of WP during runoff. Ice samples were obtained in 1994, but weather conditions in late spring and early fall 1995 did not produce ice conditions suitable to WP analyses. Previous analyses indicate ice is an important mechanism of WP erosion and transport, causing migration from ponds into mudflats and into Knik Arm (Lawson et al. 1995a). Entire "hot spots" can be entrained by a single ice floe.

Plankton nets in four gullies draining contaminated ponds and mudflats were used to trap sediments during the monthly tidal flooding events of May through October (Fig. II-1-20b). Analyses of white phosphorus concentrations revealed that WP was in transport in each gully during all flooding events exceeding approximately 5.1 m in elevation (Fig. II-1-52). This relationship to elevation is consistent with the more limited 1994 results (Lawson et al. 1995b). The quantity detected in these samples were typically less than 0.1 µg/g. The B-gully site

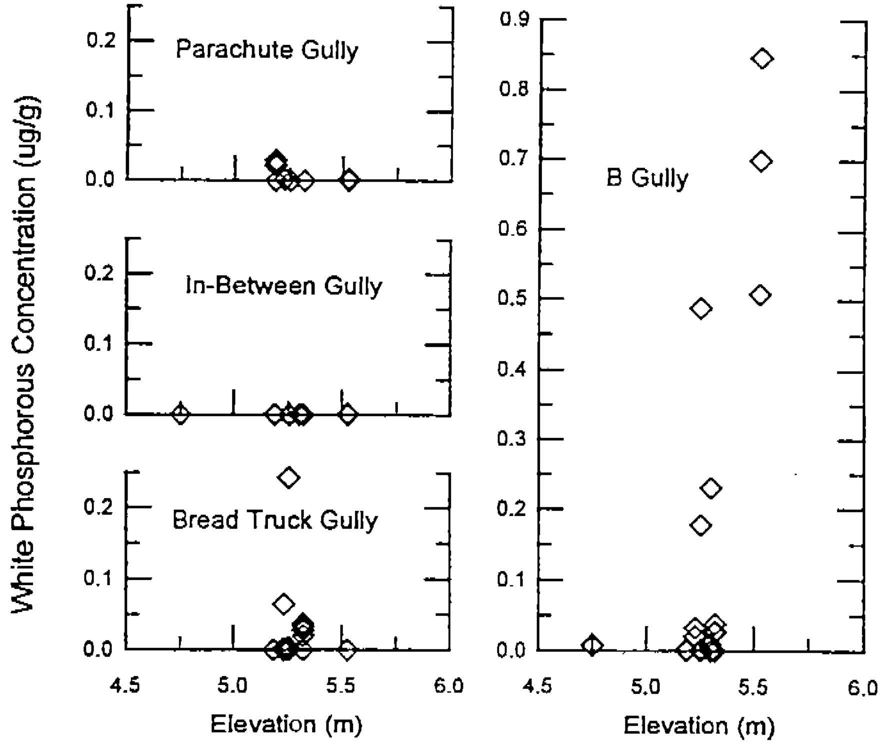


Figure II-1-52. Relationship between WP detected in plankton net samples and peak elevation of flooding event sampled.

was the only exception to this trend, with values ranging from <0.1 to <0.9 μg/g. The reasons for this difference are not clear; however, the upper reaches of B-gully is undergoing lateral and headward erosion into a heavily cratered and highly contaminated part of the mudflats (Fig. II-1-26) (Racine et al. 1993, Racine and Brouillette 1995b). It is therefore possible that the plankton net samples are recording the erosion of these WP-bearing sediments and that the higher concentrations reflect the lack of mixing and dilution which occur during a more extended duration and distance of transport.

Sediments trapped in cups on pond transects revealed some internal movement of WP as the result of resuspension of pond and mudflat materials during both the winter and summer seasons (Fig II-1-9, II-1-12, Table II-1-14). Analytical results were less than 0.1 mg/g, but quantities detected were generally greater in May samples of "winter" activity than in September samples of the summer season. The six WP detections in the May analyses were from a total of 12 trap samples, whereas the September analyses were of a total of 90 samples. These detected values are consistent with those of pond sediment traps which were analyzed previously (Lawson et al. 1995a, b).

Table II-1-14. 1995 Positive WP results from pond sedimentation stations cup samples.

Time	*Area*	*Station no.*	*Conc (µg/g)*
May	B	B Sed Sta.	0.0671
	C-Pond	S-3 Pan N	0.0175
		S-3 Pan S	0.0320
		S-8	0.0225
		S-9	0.0260
	Bread Truck Pond	S-6	0.0268
Sept.	Lawson's Pond	LP-4	0.0008
	Bread Truck Pond	BT-1	0.0003
		BT-6	0.0008
		BT-9	0.0023
	Racine Is. Pond	RI-2	0.0203

The plankton net samples indicate water is actively transporting WP particles from contaminated areas within C, Bread Truck, Lawson's and C/D ponds. These samples were acquired during relatively high tidal flooding events exceeding 5.10 m, as in 1994. Previous samples in 1993 from the Bread Truck and Parachute gullies proved negative for WP, but were collected during tides of less than 5.03 m when the potential for erosion and transport were less.

Resuspension of WP by various processes during winter and summer indicate the need to consider remobilization and potential movement of WP to uncontaminated areas. In this regard, it is similar to the effect ice transport can have: the high level of WP in the B-pond sediment trap, which is in an area considered to be uncontaminated, probably has resulted from ice entrainment and transport of WP from a contaminated pond elsewhere in ERF.

KNIK ARM WP DEPOSITION

Bathymetric analyses of Knik Arm near the mouth of Eagle River in 1994 provided data that are integral to identifying potential locations where WP may be deposited after transport out of ERF proper. A quantitative assessment of WP deposition in Knik Arm could be made if a second bathymetric survey were conducted in conjunction with measurements of WP transport within gully discharges.

The Knik Arm near the mouth of the Eagle River is 9–10 km wide and characterized by large tidal cycles (±9 m). At high tide, Knik Arm fills and spills over into ERF. Currents are relatively weak by comparison to those at low tide. At low tide, this portion of Knik Arm essentially becomes a braided stream system with a main channel located directly off the coast of ERF. Rapid flow in this channel produces highly turbulent conditions with large standing waves. As tidal flooding begins, conditions change rapidly, with transitory areas of severe turbulence and scour, and of back-eddies with minimal turbulence and conditions enhancing sedimentation. There are various areas in Knik Arm, which can change in extent and location, that are sites of sediment deposition. These sediments may originate from within ERF, but also originate in the Arm itself.

Several areas in Knik Arm are therefore potential sites of ERF sediment and WP deposition. These areas include two intertidal bars, a bar at the mouth of the Eagle River, and nearshore zones north and south of the Eagle River (Fig. II-1-53). Each area is periodically exposed and therefore may be areas where receptors may be exposed to WP. Further analyses in Knik Arm are required to evaluate whether WP is being preserved within these deposits, and further, whether the dynamics of Knik Arm can result in potential exposure of WP to waterfowl or other receptors.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The results of the 1995 and previous year's investigations lead to several important conclusions:

- Physical system processes will produce a natural attenuation or in-situ degradation and removal of WP from a significant proportion of the ERF ecosystem (Fig. II-1-54).

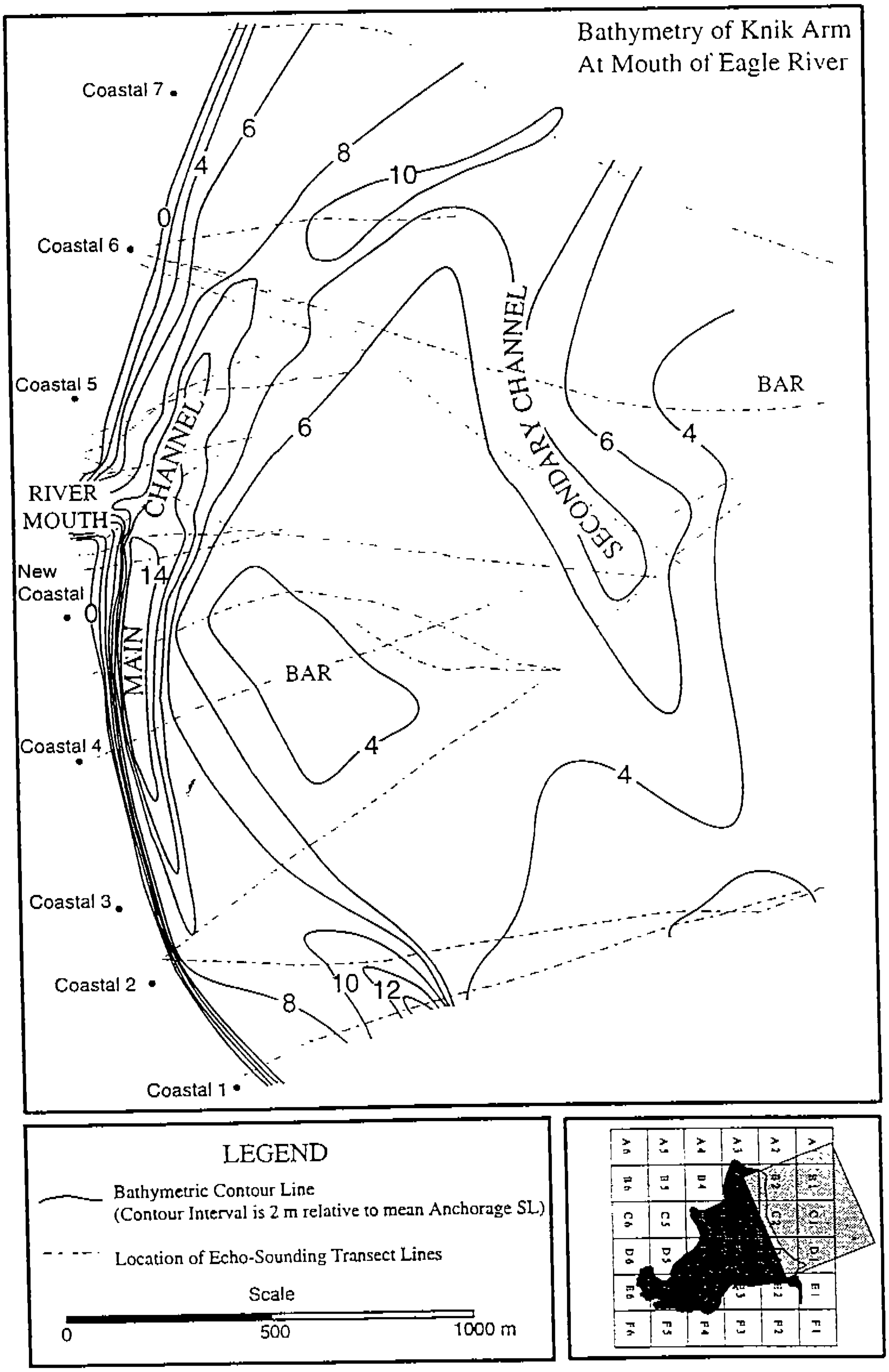


Figure II-1-53. Bathymetry of Knik Arm near mouth of the Eagle River and adjacent to the coast of ERF.

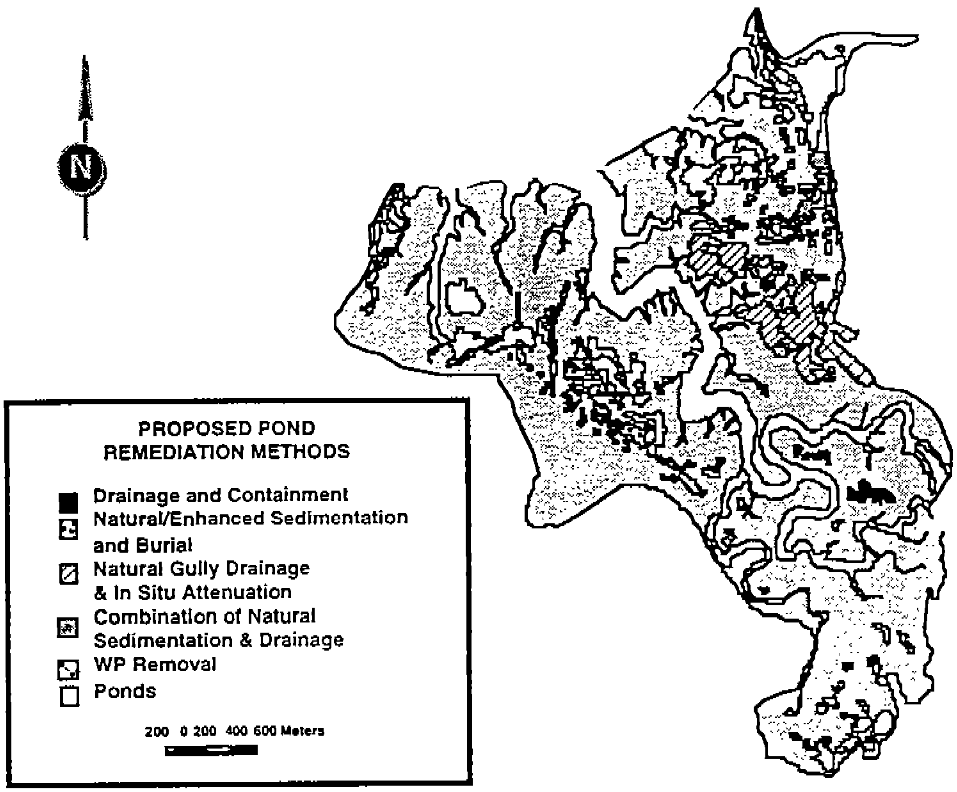


Figure II-1-54. Recommendations for site remediation.

- Gully erosion and headwall recession will drain large areas of contaminated ponds within about 1–10 years, potentially resulting in in-situ WP degradation and attenuation due to drying; it is a cost effective alternative to artificial remediation (Fig. II-1-34a). Historical photographic analyses, field data and process analyses indicate that Bread Truck Pond will probably begin draining within 1 year; C/D, Lawson's Pond, and a large area of C Pond will drain in 10–15 years or less.
- Sedimentation rates appear sufficient to bury WP in certain ponds and can reduce the exposure risk to WP contamination for feeding waterfowl.
- Natural sedimentation, perhaps artificially enhanced in some ponds by flocculation or other means, is a cost effective alternative that removes WP from feeding waterfowl through burial. Areas of C/D, Lawson's Pond and A Pond are sites where sedimentation and burial are important in remediation (Fig. II-1-54). It may also be the best method in other isolated and remote ponds where data are currently lacking. Erosion and recession of gullies draining

C/D and Lawson's pond may subsequently drain these areas, furthering the permanency of remediation.

- Ice is an effective erosion and transport medium for WP; entire "hot" spots can be removed by ice plucking.
- WP particles are eroded from within ponds and drainages by ice and water, and transported by currents into the Eagle River and Knik Arm where their fate is unknown. They are also transported to other locations within ERF.
- Racine Island Pond has neither high gully erosion and recession rates, nor high sedimentation rates. It also floods a relatively low tidal elevation (4.35 m). Because the pond bottom sediments are organic-rich, a longer period of time is required for drying to occur. It appears therefore that it can best be effectively remediated and readily restored through artificial drainage and/or pumping of the pond, following construction of a temporary berm to contain the former pond area and permit long-term drying to degrade the WP. By removing the berm after in-situ degradation is complete, the pond environment can be restored.

Recommendations

Based upon our investigations in 1995 and previous years, we recommend the following (Fig. II-1-54):

- Cost-effective remediation can be accomplished across a large area of ERF by allowing the physical system to remove or isolate WP contamination.
- WP contamination of the Bread Truck pond and 50% or more of C Pond, including potentially Lawson's Pond in the long-term, should be treated by natural (or enhanced) drainage and in-situ WP degradation by drying of the former pond bottoms.
- Sedimentation and burial of WP will be effective in certain ponds in removing it from feeding waterfowl over the short term. Over the long term, burial will reduce waterfowl mortality during natural pond drainage, especially in parts of the C, Lawson's and C/D pond areas. It should be considered a

method of natural attenuation, particularly in isolated and small remote ponds.

- Racine Island Pond should be remediated by artificial gully extension, pond drainage and pumping, and long-term containment with a temporary berm to permit long-term, in situ WP degradation by drying. By removing the berm, the pond environment can be naturally restored.
- Erosion and recession rates, pond sedimentation, ground water, pond drainage, and WP degradation and attenuation should continue to be monitored to ensure remediation is taking place as predicted by the physical system analyses.
- WP migration and contamination in Knik Arm should be evaluated, focusing on sampling areas of the nearshore zones and mid-Arm bars where there is a potential for WP exposure to receptors.
- The potential natural attenuation of white phosphorus as the result of mechanical abrasion during transport by gully and tidal currents should be evaluated.

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II-2. CLIMATE AND TIDES

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INTRODUCTION

Weather and tidal activity provide the driving forces for physical and biological processes in the Eagle River Flats area. A meteorological site was installed at the edge of the EOD pad in May 1994. This station has provided a basis for climatic comparisons with Anchorage and other study locations at ERF. The tasks that were addressed for 1995 are to characterize the ERF weather for the season, compare meteorological values with other research sites in the area, to develop average evapotranspiration (ET) rates for ERF from measured meteorological data. Calculated ET rates are then to be compared with measured values of soil moisture and computer-based tidal activity tables. Finally, we attempt to extrapolate summer moisture regimes for ERF for the 1996-2000 period based on calculated historical average and extreme values for ET and gaps between tidal events. The tables developed can provide useful information for planning research and remediation operations.

EOD 1995 METEOROLOGICAL DATA

Data obtained at the EOD meteorological site included air, ground and surface temperatures, incident and reflected solar radiation, relative humidity, wind speed and direction, and precipitation. The instrumental database is at 15-minute intervals; these data were summarized into hourly, then daily records which

Table II-2-1. Anchorage and EOD temperature and precipitation, 1995.

	Precipitation		
	Anchorage		*EOD*
Month	*Precip (mm)*	*Dep from normal (%)*	*Precip (mm)*
May	28.4	152*	19.6*
Jun	20.5	71.0	27.5
Jul	76.7	177.0	83.8
Aug	48.7	79.0	43.0
Sep	75.4	110.0	64.3

	Air temperature		
	Anchorage		*EOD*
Month	*Mean temp (°C)*	*Dep from normal (°C)*	*Mean temp (°C)*
May	9.4	0.8	*
Jun	13.3	0.6	12.0
Jul	15.2	3.0	12.8
Aug	14.5	2.1	12.6
Sep	12.1	3.0	11.8

*May a partial month at EOD

Table II-2-2. Temperature and precipitation comparison for Anchorage, 1994-95.

	Precipitation (mm)		*Temperature (°C)*	
Month	*1995*	*1994*	*1995*	*1994*
May	28.4	12.3	9.4	8.5
June	20.5	25.4	13.3	13.7
July	76.7	14.5	15.2	15
August	48.7	25.6	14.5	15
September	75.4	42.4	12.1	9.4
Total/average	249.7	120.2	12.9	12.32

were used in most comparative studies. The site was activated for the 1995 season on May 27 and will continue to operate through the 1996 season.

Observations during the 1995 season, summarized in Table II-2-1, showed that precipitation was above normal during May and July, and below normal in June and August. September was near normal. July, August and September were two to three degrees (C) warmer than the Anchorage normal. In Table II-2-2, the comparison with the 1994 season (May–September) shows the seasonal average temperature during 1995 was about the same but precipitation during the 1995 season (250 mm) was over twice that of the 1994 season.

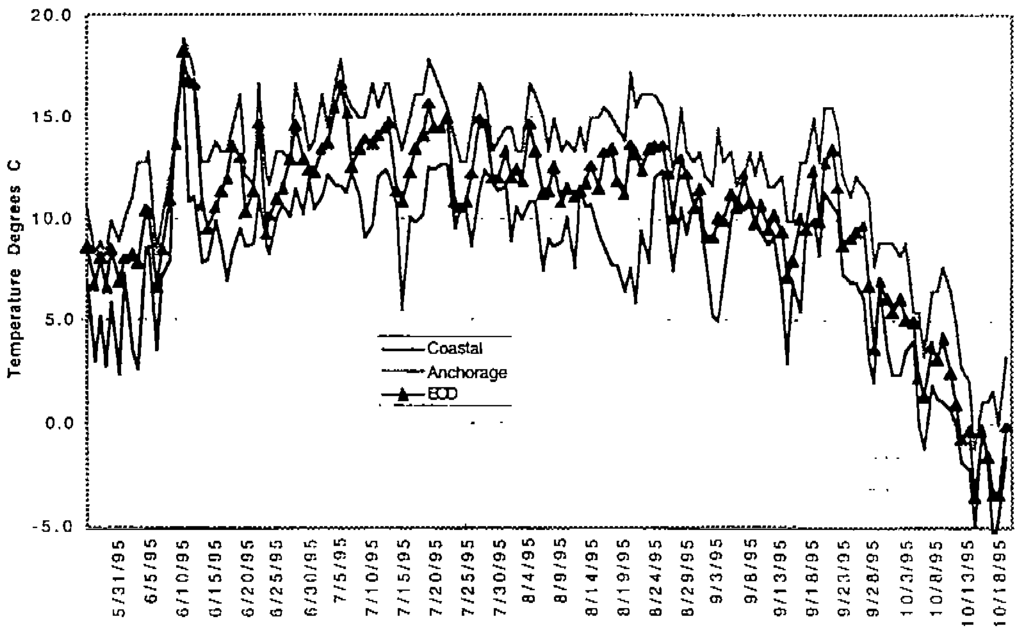

Figure II-2-1. EOD pad, coastal site and Anchorage mean daily temperature.

A comparison of 1995 air temperature data for 30 May to 29 October among the EOD site, ERF coastal site, and Anchorage (Fig. II-2-1) showed Anchorage to be warmer than EOD by 2.3°C, and EOD to be warmer than the ERF coastal site by the same amount, 2.3°C. The 1994 ERF report showed the coastal site to be warmer than the EOD site but it is now apparent that daily *maximum* temperatures were used to represent the coastal site in the 1994 analysis, rather than the daily average temperatures. The –2.3°C difference found in the 1995 data between the EOD pad site and the coastal site should be considered representative. A warm dry period in early June shows the closest agreement among the three sites. In mid-August, a cool period at the coast was not reflected at EOD or ANC. The mean air temperature dropped below freezing around the 10th of October at all the sites, about five days earlier than during the 1994 season.

In Figure II-2-2, a three-week record of air temperatures from a former NIKE site at a 2000-ft summit overlooking ERF is shown. The air temperature regime at this site clearly shows the effects of its higher elevation. It is not only colder by several degrees, but the day-to-day temperature variations do not correspond to

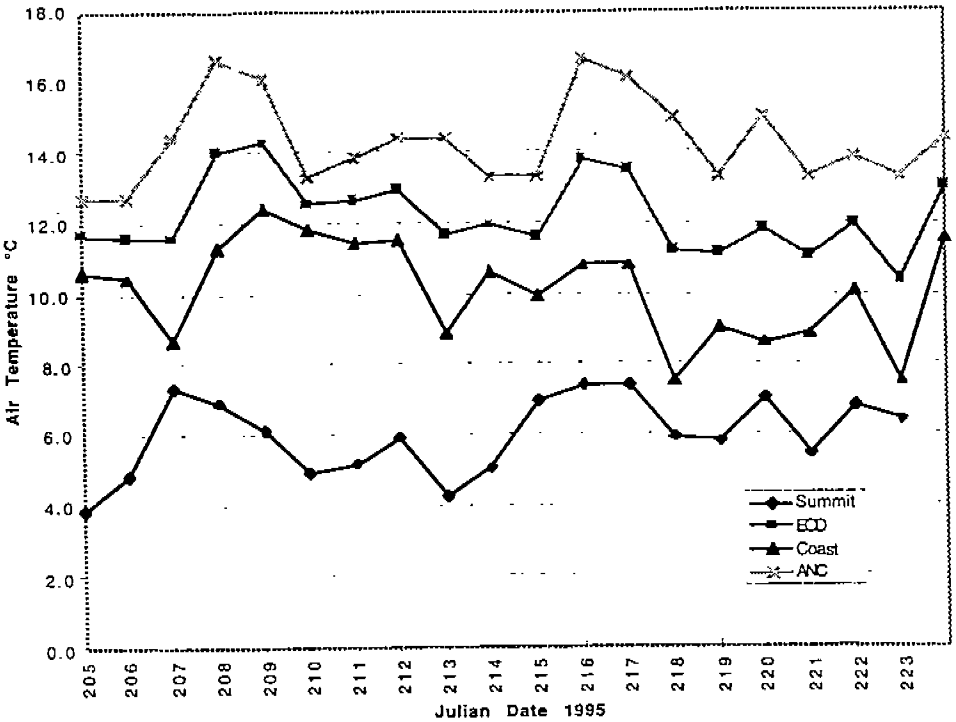

Figure II-2-2. Mean air temperatures at ANC, EOD, Summit and the coastal site.

fluctuations at the other sites and the day-to-day variance is less. This is probably due to the site being within clouds while ERF and ANC is beneath the clouds.

The patterns of daily precipitation at the EOD pad, shown in Figure II-2-3, indicate a more frequent occurrence but of smaller amounts on the average than at ANC. Total amounts on a monthly basis are very similar between the two sites. July 1995 was an exceptionally wet month; if we extrapolate the departure from normal at ANC, it suggests about 200% of normal for that month.

Relative humidity (RH) is a key factor in evapotranspiration and consequently the soil moisture regime. Daily values of RH are shown in Figure II-2-4. Generally the daily maximum values, which were consistently around 90% during the growing season, occurred during the night, and the daily minimum values occurred during the daytime. Figure II-2-4 illustrates the increasing RH for the minimum (daytime) values as air temperatures become cooler toward the end of the season.

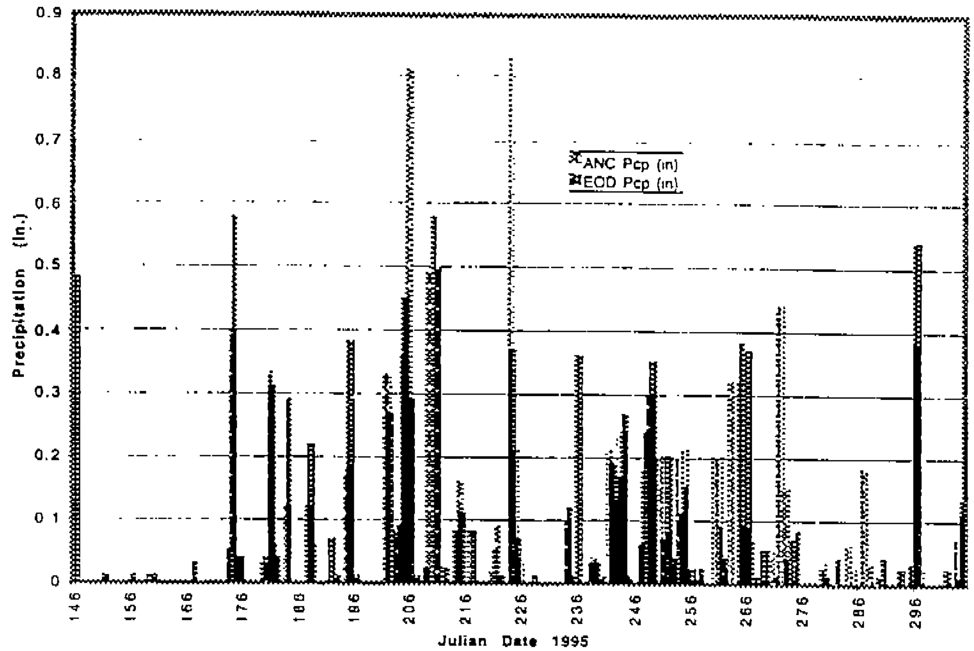

Figure II-2-3. Precipitation at ANC and the EOD pad, 1995.

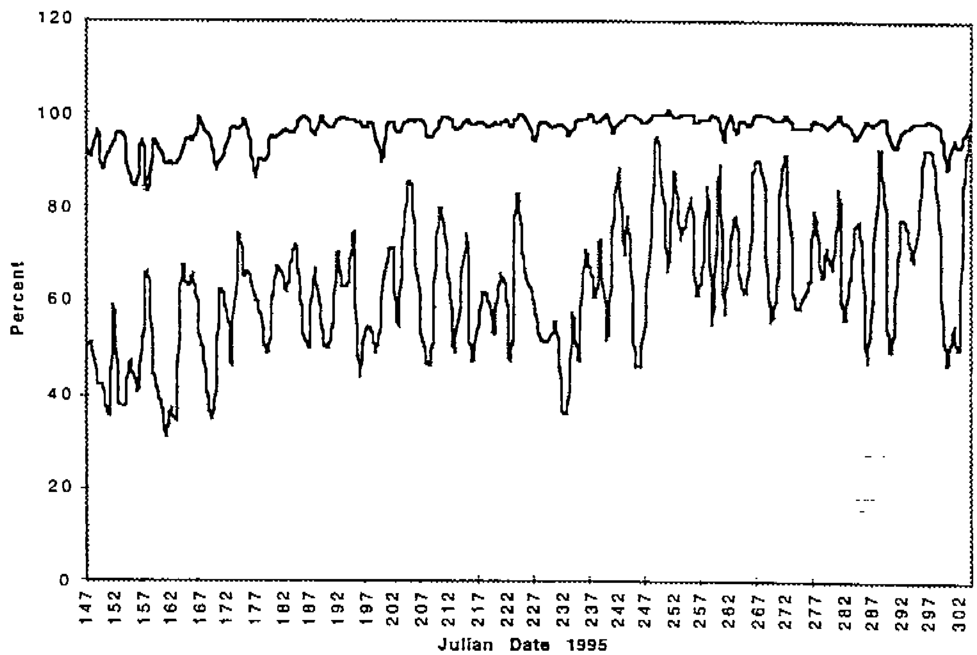

Figure II-2-4. Maximum and minimum daily relative humidity at the EOD pad, 1995.

Incident and reflected solar radiation were measured at the EOD meteorological site to provide a measure of the energy input to ERF physical and biological systems. Net radiation, which is incident minus reflected radiation, is shown on

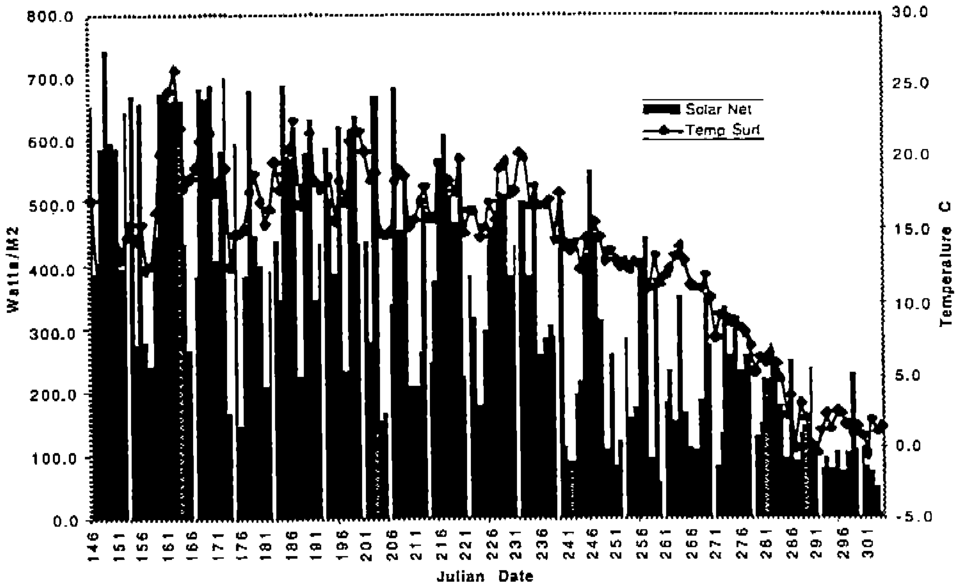

Figure II-2-5. Net solar radiation vs surface temperature.

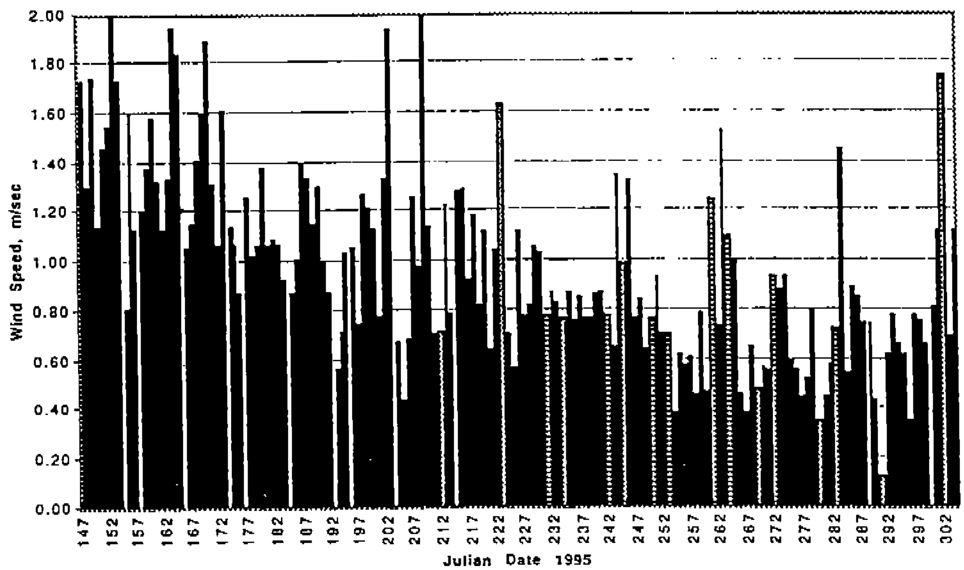

Figure II-2-6. Daily average wind speed at the EOD pad, 1995.

a daily basis in Figure II-2-5. The graph shows maximum daily instantaneous radiation in W/m^2 on a horizontal surface. Ground surface temperature, also measured at the site, is also shown in Figure II-2-5. It is clear that the ground surface temperature regime follows the available solar radiation closely.

Daily average wind speeds ranged between 2 and 3 m/s at the beginning of the growing season to between 1 and 2 m/s at the end of the season (Fig. II-2-6). Peak gusts were not recorded at the EOD site, but peak gust data are available for ANC.

EVAPORATION AND EVAPOTRANSPIRATION

Soil moisture and drying rates for soil saturated by tidal inundation or precipitation are critical to the fate of phosphorus within the soil. This is especially true for the drying rate of dredged material from the flats. The standard evaporation pan is probably the best and simplest method of determining daily evaporation and therefore drying potential for the soil. But pan evaporation measurements are often not available. In this case our task was to develop historical time series of evapotranspiration and a predictive series for planning purposes.

The ASCE Handbook on Evapotranspiration and Irrigation Water Requirements (1990) notes that the term "evapotranspiration" refers to the quantity of water transpired by plants during their growth or retained in plant tissue, plus the moisture evaporated off the surface of the soil and the vegetation. The development of methods of evapotranspiration estimation was driven by the need to predict water requirements for crops, especially in the western part of the United States. The predictive methods all are based on a "reference surface" which is usually grass or alfalfa. None of the methods available are specific to a tidal flats area, but the numbers obtained by the application of ET algorithms provides a relative measure of drying potential for the tidal flat area.

The ERF area is in a summer soil moisture deficit region, i.e., on the average evapotranspiration rates are greater than precipitation rates during the growing season. Patric and Black (1968) show an average growing season deficit of 4.50 in. (103 mm) for Anchorage using the Thornthwaite method of evapotranspiration calculation. But during exceptionally wet summers, such as 1995, precipitation can equal or exceed ET for a month or longer. The ERF soil moisture regime is also affected by tidal flooding which saturates the soil for extended periods.

A computer program developed at Utah State University called REF-ET (Allen 1994) was used to estimate expected evapotranspiration from historic weather records. Evapotranspiration was estimated by the Penman–Monteith method (Monteith 1965, DeGaetano et al. 1994) and the Hargreaves (1985) method. Data availability determined which method was used. For historical time series where few climatic parameters were available, the Hargreaves method was used. This method requires only temperature data; the other need parameters are synthesized. The Penman–Montieth method is probably the most widely used but requires measurements or estimates of solar radiation, wind speed, relative humidity in addition to temperature. The values are available in the ANC record starting in 1984. Precipitation values were taken from Summary of the Day values for Anchorage as were the values needed to estimate the Penman–Monteith evapotranspiration.

Computed evapotranspiration data were compared to a record of pan evaporation observed during June 22–July 30 1995 (E. Chacho, personal communication). The comparative values are shown in Figure II-2-7. The estimated ET val-

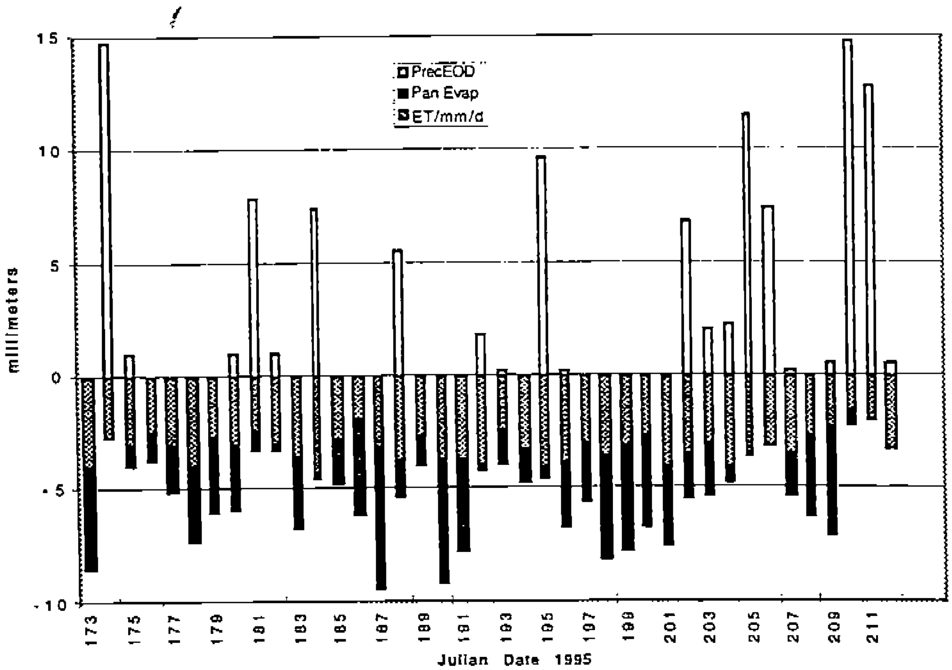

Figure II-2-7. ET, pan evaporation and precipitation for EOD, 1995.

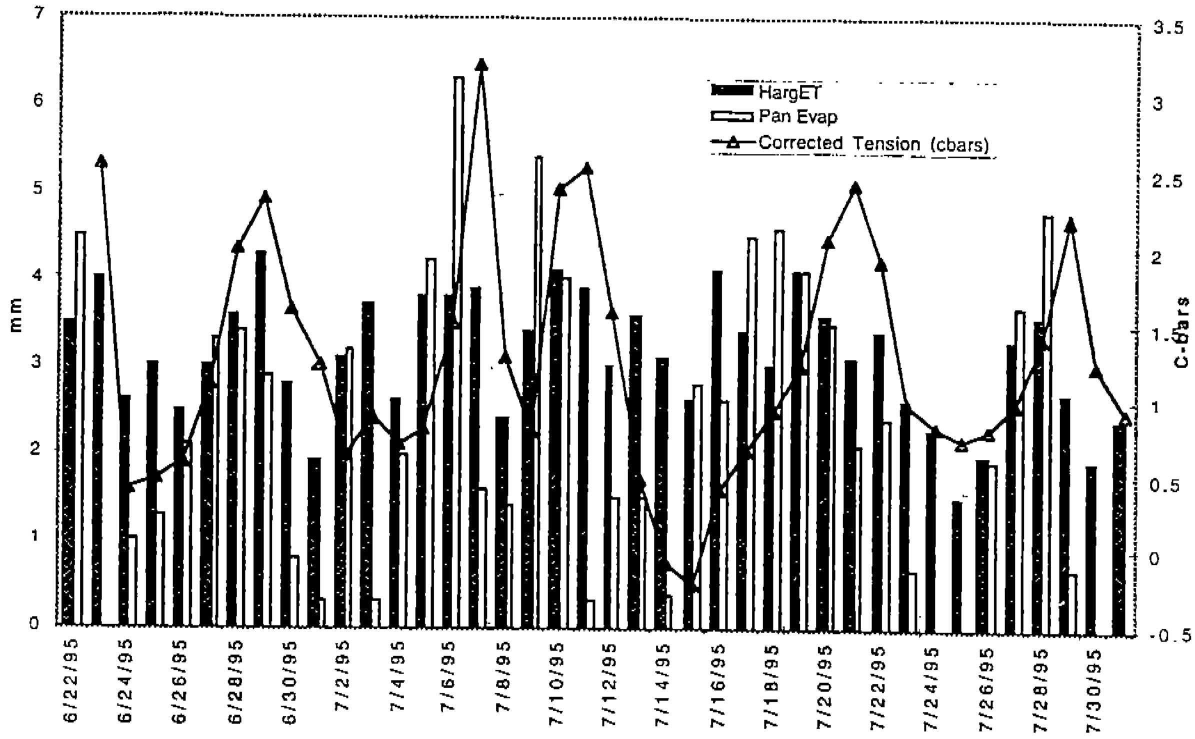

Figure II-2-8. Soil moisture tension, evapotranspiration and pan evaporation.

ues varied with the pan data on a day-to-day basis but were usually similar in magnitude. For this 38-day period of record, the estimated total ET was 121 mm, pan evaporation was 90.1 mm, and precipitation received at the EOD rain gauge was 109 mm. Thus, the ET calculations showed a slight surplus and the pan data a slight deficit for the same period.

ET computed by the Hargreaves method and the pan evaporation data referred to above were compared to soil tensiometer measurements (Marianne Walsh, personal communication) during the concurrent period. Figure II-2-8 shows the variance of soil moisture tension and the corollary ET and pan data. High values of soil tension (measured at –10 cm) tend to follow high ET/pan rates by two days or so. The depressing of the soil tension curve in mid-July is due to a tidal inundation. The relationship between soil moisture measured with the tensiometer and tidal flooding is shown more clearly in Figure II-2-9. Sudden lowering of soil moisture tension clearly happens in response to tidal flooding and to high precipitation amounts (Fig. II-2-9).

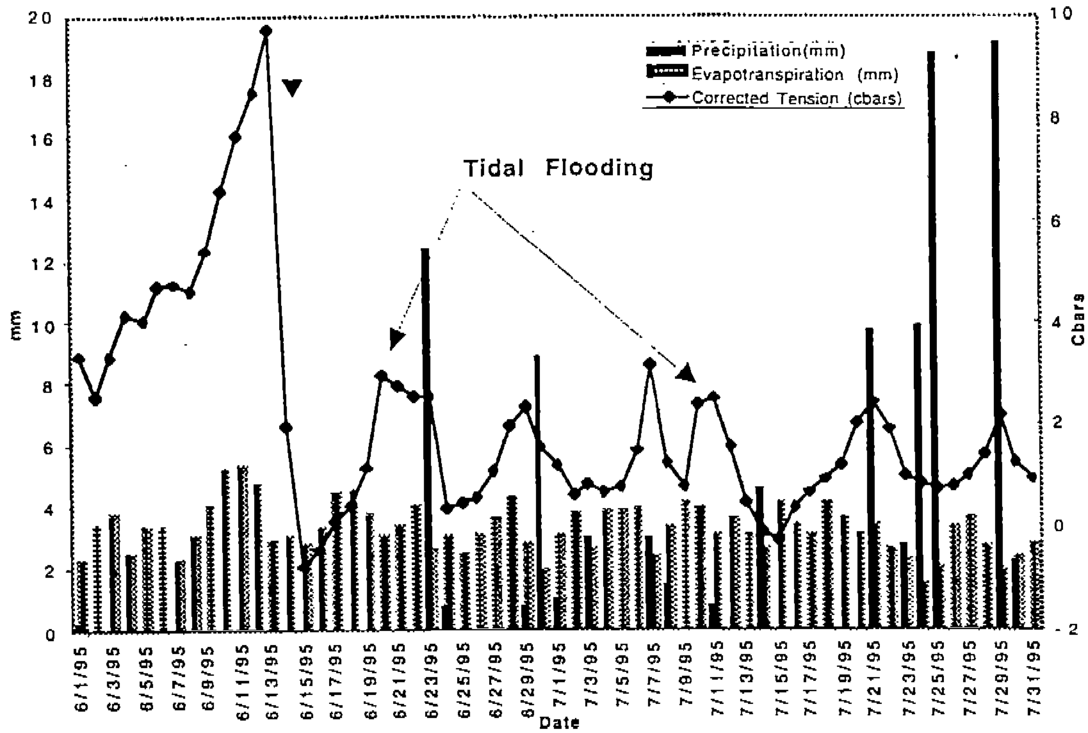

Figure II-2-9. Soil moisture tension, precipitation and calculated evapotranspiration, June–July 1995, Eagle River Flats.

TIDAL FLOODING AT ERF

Tide elevation values to represent tidal levels both for the past (1960–1995) and the future (1996–2000) were computed using algorithms for Anchorage provided to us by the NOAA National Oceanographic Office in Baltimore, MD. Actual tidal levels are also affected by local meteorological and hydrological factors, but these factors are of a small influence (generally less than 25 cm) except during storms in the interior, when the impact on ERF water elevations can be significant.

The tidal elevations over a small range can have a considerably different effect on the topographic features of ERF. The following elevations are considered to have the following effects (Collins and Lawson, personal communication, 1995):

Ponds are filled: 31.1 ft

Mud flats are covered: 32.0 ft

Levees are covered: 33.1 ft.

A period of 21 days between tides is considered to be sufficient to dry the soil sufficiently to destroy white phosphorus if significant precipitation does not occur (M. Walsh, personal communication, 1996). This effect can be observed in the tensiometer data in Figure II-2-9. Periods when tides would not exceed the flood levels for at least this many days were calculated using the tidal algorithms. (It is interesting to note that 1996, 1997 and 2000 will have no tides at all above the 33.1-ft flood level between May and October.)

Using the Hargreaves method, which requires only a temperature input, estimated ET and the average precipitation occurring during periods between high tides of 31.1 ft for the period 1960–1995. Table II-2-3 shows the surplus or deficits occurring during these period for the 45-year period. The years with the largest deficit numbers are obviously best for drying soil. This general approach was used in the next section for the prediction of dry periods 1995–2000.

Table II-2-3. Evapotranspiration and precipitation (in inches) for ANC, 1960-1995, during gaps between high tides of 31 ft or more.

Start of dry period	*End of dry period*	*Ave Hargreaves*	*Ave precip*	*Surplus/deficit*
14-May-1960 09:01	09-Jun-1960 06:27	3.20	0.34	-2.87
12-Jun-1960 08:49	08-Jul-1960 06:10	3.36	0.93	-2.42
12-Jul-1960 22:11	06-Aug-1960 06:00	2.85	2.63	-0.22
10-Aug-1960 21:40	04-Sep-1960 05:52	2.07	2.73	0.65
02-May-1961 07:57	31-May-1961 07:33	2.84	0.40	-2.45
01-Jun-1961 08:15	29-Jun-1961 07:17	3.36	0.98	-2.38
01-Jul-1961 08:51	27-Jul-1961 06:15	3.01	1.58	-1.44
01-Aug-1961 22:53	25-Aug-1961 06:02	1.46	0.53	-0.93
30-Aug-1961 22:18	22-Sep-1961 17:50	3.21	2.30	-0.91
28-Sep-1961 21:43	21-Oct-1961 17:25	1.53	1.34	-0.20
07-May-1962 08:58	01-Jun-1962 05:57	2.40	1.53	-0.87
03-Jun-1962 07:17	16-Aug-1962 07:10	3.07	1.82	-1.25
20-Aug-1962 22:40	13-Sep-1962 06:06	1.93	2.36	0.42
18-Sep-1962 22:10	11-Oct-1962 17:43	0.77	0.84	0.75
26-May-1963 09:01	20-Jun-1963 05:43	3.12	1.28	-1.84
23-Jun-1963 08:01	04-Sep-1963 07:17	2.34	1.59	-0.74
08-Sep-1963 22:25	02-Oct-1963 06:12	4.35	2.92	-1.43
07-Oct-1963 22:00	30-Oct-1963 17:36	2.25	2.22	-0.32

Table II-2-3 (cont.). Evapotranspiration and precipitation (in inches) for ANC, 1960-1995, during gaps between high tides of 31 ft or more.

Start of dry period	*End of dry period*	*Ave Hargreaves*	*Ave precip*	*Surplus/deficit*
15-May-1964 09:15	09-Jun-1964 05:54	3.09	1.05	-2.43
13-Jun-1964 09:04	09-Jul-1964 06:23	3.31	1.44	-1.87
12-Jul-1964 08:54	07-Aug-1964 06:17	3.13	1.38	-1.76
10-Aug-1964 08:39	06-Sep-1964 06:56	2.24	2.07	-0.17
04-May-1965 08:39	31-May-1965 06:58	2.68	0.41	-2.27
02-Jun-1965 08:24	29-Jun-1965 06:37	2.89	0.72	-2.17
01-Jul-1965 08:16	28-Jul-1965 06:27	3.14	1.58	-1.56
31-Jul-1965 21:42	26-Aug-1965 06:20	1.56	2.62	1.52
30-Aug-1965 21:48	24-Sep-1965 06:10	1.40	2.11	0.71
07-May-1966 08:19	16-Aug-1966 06:36	2.94	0.78	-2.16
21-Aug-1966 22:55	14-Sep-1966 06:23	2.14	1.84	-0.30
19-Sep-1966 22:18	12-Oct-1966 18:00	1.00	0.83	-0.16
25-May-1967 07:38	10-Aug-1967 22:24	2.99	2.04	-0.96
10-Aug-1967 22:24	04-Sep-1967 06:43	2.12	3.29	1.17
09-Sep-1967 22:35	03-Oct-1967 06:24	0.71	1.84	1.13
07-Oct-1967 21:23	31-Oct-1967 17:41	0.79	3.10	2.36
15-May-1968 08:37	10-Jun-1968 05:59	2.94	1.51	-1.43
12-Jun-1968 07:36	22-Sep-1968 19:18	2.64	1.54	-1.16
26-Sep-1968 21:33	21-Oct-1968 18:39	0.70	0.50	-0.28
05-May-1969 08:46	01-Jun-1969 07:01	2.68	0.78	-1.90
02-Jun-1969 07:47	30-Jun-1969 06:48	3.50	0.16	-3.34
02-Jul-1969 08:32	29-Jul-1969 06:44	2.98	1.92	-1.55
01-Aug-1969 21:48	27-Aug-1969 06:37	1.79	1.02	-0.77
30-Aug-1969 21:11	25-Sep-1969 06:27	0.56	4.01	3.45
06-May-1970 07:10	20-Jul-1970 07:49	2.87	0.61	-2.26
23-Jul-1970 22:51	17-Aug-1970 06:50	2.49	2.58	0.98
21-Aug-1970 22:14	14-Sep-1970 05:48	1.99	1.77	-0.22
19-Sep-1970 21:37	13-Oct-1970 05:34	0.81	0.73	-0.80
25-May-1971 07:05	08-Aug-1971 07:54	2.60	1.39	-1.26
11-Aug-1971 22:30	05-Sep-1971 06:52	1.36	2.42	1.65
09-Sep-1971 21:58	03-Oct-1971 05:47	3.94	2.02	-1.92
08-Oct-1971 21:30	31-Oct-1971 17:01	1.02	2.62	1.69
16-May-1972 08:54	11-Jun-1972 06:16	2.48	0.70	-1.79
13-Jun-1972 07:54	26-Aug-1972 07:57	2.89	1.15	-1.74
29-Aug-1972 22:10	23-Sep-1972 06:56	1.50	1.73	0.23
27-Sep-1972 21:45	21-Oct-1972 18:03	0.57	0.62	0.44
06-May-1973 09:07	01-Jun-1973 06:32	2.25	0.32	-1.93
04-Jun-1973 08:59	30-Jun-1973 06:19	3.11	0.81	-2.33
03-Jul-1973 08:50	29-Jul-1973 06:14	3.23	0.21	-3.26
02-Aug-1973 21:50	27-Aug-1973 06:06	1.84	3.11	1.27
23-May-1974 07:38	21-Jun-1974 07:26	3.41	0.58	-2.82
23-Jun-1974 09:04	19-Jul-1974 06:28	3.57	0.96	-2.67
24-Jul-1974 23:02	17-Aug-1974 06:17	2.61	1.73	-0.88

Table II-2-3 (cont.). Evapotranspiration and precipitation (in inches) for ANC, 1960-1995, during gaps between high tides of 31 ft or more.

Start of dry period	*End of dry period*	*Ave Hargreaves*	*Ave precip*	*Surplus/deficit*
22-Aug-1974 22:23	15-Sep-1974 06:05	1.61	1.86	0.25
19-Sep-1974 21:07	13-Oct-1974 17:33	0.98	0.85	-0.12
25-May-1975 06:44	11-Jul-1975 08:22	3.25	0.34	-2.92
13-Jul-1975 22:31	07-Aug-1975 06:36	2.63	1.28	-1.35
12-Aug-1975 22:48	05-Sep-1975 06:19	4.17	3.51	-0.66
10-Sep-1975 22:18	03-Oct-1975 17:47	0.90	2.68	1.78
16-May-1976 08:29	11-Jun-1976 05:57	2.70	0.34	-2.36
14-Jun-1976 08:14	25-Aug-1976 06:44	3.15	0.99	-2.16
30-Aug-1976 22:36	23-Sep-1976 06:24	1.55	1.44	-0.12
28-Sep-1976 22:13	21-Oct-1976 17:38	0.53	0.60	0.67
07-May-1977 09:34	31-May-1977 05:25	2.64	0.24	-2.39
05-Jun-1977 09:21	30-Jun-1977 05:54	3.55	0.18	-3.38
04-Jul-1977 09:08	30-Jul-1977 06:35	3.66	1.29	-2.37
02-Aug-1977 08:50	28-Aug-1977 06:25	0.54	3.14	2.66
25-May-1978 08:46	20-Jun-1978 06:12	3.06	1.83	-1.24
24-Jun-1978 22:17	19-Jul-1978 05:56	3.05	1.88	-1.18
24-Jul-1978 22:37	17-Aug-1978 05:46	2.97	1.82	-1.16
22-Aug-1978 22:01	15-Sep-1978 05:36	1.76	1.91	0.16
14-Jul-1979 22:59	08-Aug-1979 06:51	1.93	2.66	0.73
12-Aug-1979 22:29	05-Sep-1979 05:48	0.90	0.64	-0.26
10-Sep-1979 21:57	03-Oct-1979 17:29	0.22	2.13	1.95
17-May-1980 08:45	11-Jun-1980 05:37	2.61	2.00	-0.69
13-Jun-1980 07:03	29-Jul-1980 07:58	2.93	2.33	-0.66
30-Jul-1980 08:43	26-Aug-1980 06:57	2.25	2.51	0.26
30-Aug-1980 22:18	23-Sep-1980 05:52	1.42	1.45	0.28
28-Sep-1980 21:51	21-Oct-1980 17:21	0.50	0.55	0.42
07-May-1981 09:05	01-Jun-1981 05:47	3.13	0.43	-2.79
05-Jun-1981 08:49	01-Jul-1981 06:13	3.25	0.78	-2.47
03-Jul-1981 07:48	01-Aug-1981 07:37	2.79	4.00	1.22
01-Aug-1981 07:37	14-Sep-1981 07:04	1.64	2.57	0.93
18-Sep-1981 22:05	12-Oct-1981 18:29	1.17	3.02	1.85
26-May-1982 09:01	21-Jun-1982 06:24	2.85	1.50	-1.36
24-Jun-1982 08:51	20-Jul-1982 06:10	3.29	0.74	-2.55
23-Jul-1982 08:40	18-Aug-1982 06:04	2.46	3.37	0.97
22-Aug-1982 09:10	16-Sep-1982 18:49	1.60	1.65	0.50
14-May-1983 07:48	12-Jun-1983 07:26	2.95	0.78	-2.17
13-Jun-1983 08:12	11-Jul-1983 07:14	3.48	0.39	-3.94
13-Jul-1983 08:54	08-Aug-1983 06:15	4.11	1.44	-2.67
12-Aug-1983 22:05	06-Sep-1983 06:06	1.38	8.66	7.28
11-Sep-1983 22:10	04-Oct-1983 17:56	1.80	3.47	1.67
17-May-1984 08:08	30-Jul-1984 08:11	3.26	1.04	-2.22
31-Jul-1984 08:58	26-Aug-1984 06:24	2.46	2.65	0.19
31-Aug-1984 22:34	24-Sep-1984 06:08	1.34	1.37	0.24

Table II-2-3 (cont.). Evapotranspiration and precipitation (in inches) for ANC, 1960-1995, during gaps between high tides of 31 ft or more.

Start of dry period	*End of dry period*	*Ave Hargreaves*	*Ave precip*	*Surplus/deficit*
29-Sep-1984 22:00	22-Oct-1984 17:40	0.43	0.55	0.13
08-May-1985 09:11	02-Jun-1985 05:56	2.56	1.16	-1.40
05-Jun-1985 08:10	20-Aug-1985 22:04	2.71	1.10	-1.64
20-Aug-1985 22:04	15-Sep-1985 07:15	2.59	4.36	1.77
19-Sep-1985 22:15	13-Oct-1985 06:10	3.61	3.10	-0.58
26-May-1986 08:23	22-Jun-1986 06:32	3.32	0.12	-3.24
24-Jun-1986 08:14	22-Jul-1986 07:17	3.50	1.39	-2.17
23-Jul-1986 08:06	20-Aug-1986 07:09	2.55	2.27	-0.27
15-May-1987 07:49	13-Jun-1987 07:34	2.69	0.86	-1.82
13-Jun-1987 07:34	12-Jul-1987 07:29	2.74	1.06	-1.68
13-Jul-1987 08:20	09-Aug-1987 06:32	2.92	1.61	-1.40
13-Aug-1987 22:09	07-Sep-1987 06:24	2.02	3.12	1.94
11-Sep-1987 21:29	05-Oct-1987 18:08	1.67	1.27	-0.40
03-Aug-1988 23:15	27-Aug-1988 06:37	2.61	2.12	-0.49
31-Aug-1988 21:54	24-Sep-1988 05:32	1.62	1.27	-0.35
29-Sep-1988 21:20	23-Oct-1988 17:44	0.47	0.51	0.44
08-May-1989 08:35	03-Jun-1989 06:05	2.62	1.56	-1.57
04-Jun-1989 06:50	18-Aug-1989 07:42	2.85	1.68	-1.17
21-Aug-1989 22:09	15-Sep-1989 06:38	1.60	2.89	1.29
19-Sep-1989 21:39	13-Oct-1989 17:58	2.01	1.27	-0.74
27-May-1990 08:40	23-Jun-1990 06:51	3.24	1.43	-1.86
24-Jun-1990 07:41	23-Jul-1990 07:33	3.74	0.14	-3.60
23-Jul-1990 07:33	21-Aug-1990 07:21	2.56	2.37	-0.19
09-Sep-1990 21:50	04-Oct-1990 18:57	1.06	1.11	0.54
17-May-1991 08:52	12-Jun-1991 06:16	3.13	0.04	-3.92
15-Jun-1991 08:45	12-Jul-1991 06:57	3.41	1.72	-1.68
15-Jul-1991 22:07	09-Aug-1991 06:00	2.79	1.18	-1.65
13-Aug-1991 21:31	07-Sep-1991 05:51	0.73	4.55	3.82
05-Jul-1992 23:13	29-Jul-1992 06:15	2.97	0.80	-2.17
03-Aug-1992 22:39	27-Aug-1992 06:02	2.29	2.67	0.38
01-Sep-1992 22:03	25-Sep-1992 05:49	1.32	1.50	0.18
29-Sep-1992 20:50	23-Oct-1992 17:11	0.56	0.54	-0.24
08-May-1993 08:09	21-Jul-1993 08:09	3.42	0.60	-2.83
24-Jul-1993 22:55	17-Aug-1993 06:23	2.10	0.47	-1.63
22-Aug-1993 22:25	15-Sep-1993 06:04	1.00	1.73	0.73
20-Sep-1993 21:57	13-Oct-1993 17:26	2.33	0.96	-1.37
28-May-1994 09:01	23-Jun-1994 06:27	3.47	0.48	-3.00
25-Jun-1994 08:01	11-Aug-1994 21:57	3.19	0.93	-2.27
11-Aug-1994 21:57	06-Sep-1994 07:14	2.43	2.19	-0.24
10-Sep-1994 22:14	04-Oct-1994 18:31	1.27	1.38	0.11
18-May-1995 09:18	12-Jun-1995 05:52	3.08	0.86	-2.22
16-Jun-1995 22:01	11-Jul-1995 05:38	3.38	1.24	-2.14
15-Jul-1995 21:36	10-Aug-1995 06:21	2.36	3.68	1.31
13-Aug-1995 21:05	08-Sep-1995 06:11	1.52		

PREDICTIVE TIDAL FLOODING, EVAPOTRANSPIRATION RATES AND PRECIPITATION 1995-2000

Microsoft Excel spreadsheets were created to show the periods in the years 1995–2000 when the tide will not exceed the flood stage for at least 21 days. Table II-2-4 shows expected precipitation and Penman Monteith ET values for 21-day (or longer) periods without flood tides over 31.1 ft. Table II-2-5 corresponds to a flood tide of 32.0 ft, and Table II-2-6 corresponds to a 33.1-ft tide.

These files show the expected average daily precipitation and expected evapotranspiration totals (in units of mm/day) for all periods between 1996 and 2000 when the Eagle River Flats could be dredged for white phosphorous removal. The tables show the following data:

- The beginning of each 21-or-more-day period with no tides ≥ 9.45 m;
- The end of each 21-or-more-day period with no tides ≥ 9.45 m;
- The length of each such period, in days;
- The average daily precipitation (period of record May 1, 1984 to July 31, 1995), as well as the design high (avg. of three wettest years) and the design low (average of three driest years); and
- The average expected daily evapotranspiration (period of record May 1, 1984 to July 31, 1995) as well as the design high and design low ETs.

There are at least two caveats to be kept in mind when applying these numbers to the conditions at Eagle River Flats. First, the meteorological data were taken at the Anchorage Airport, which is at a somewhat higher elevation than the flats (106 m at the airport vs a few meters above sea level). Second, the Penman–Monteith equation is an idealized and generalized equation which models conditions in perfectly flat and completely grass-covered areas. Nevertheless, these numbers should be a useful index for determining when wet soils might dry most quickly.

Table II-2-4. Projected Penman–Monteith evapotranspiration and precipitation values, based on data from ANC, for 21-day (or longer) periods without tides over 31.1 ft.

		Pmon			*Precip*			
*Start DT**	*End DT*	*Avg*	*Hi*	*Lo*	*Avg*	*Hi*	*Lo*	*Gap*
18-May-1995 09:18	12-Jun-1995 05:52	3.39	4.03	2.75	0.73	1.23	0.14	24.86
16-Jun-1995 22:01	11-Jul-1995 05:38	3.36	3.97	2.95	0.95	1.60	0.32	24.32
15-Jul-1995 21:36	10-Aug-1995 06:21	2.83	3.23	2.35	1.75	3.19	0.87	25.36
13-Aug-1995 21:05	08-Sep-1995 06:11	2.10	2.50	1.68	2.46	3.63	1.54	25.38
06-May-1996 08:44	02-Jun-1996 07:02	3.07	3.71	2.46	0.75	1.31	0.25	26.93
04-Jun-1996 08:31	01-Jul-1996 06:45	3.48	4.12	2.93	0.80	1.24	0.22	26.93
05-Jul-1996 22:45	30-Jul-1996 06:33	3.11	3.63	2.64	1.29	2.49	0.43	24.33
03-Aug-1996 22:14	27-Aug-1996 05:31	2.39	2.74	1.94	2.32	2.83	1.64	23.30
01-Sep-1996 21:41	25-Sep-1996 18:02	1.61	1.79	1.30	2.14	3.70	1.30	23.85
09-May-1997 08:27	20-Jul-1997 06:53	3.31	3.86	2.81	0.81	1.02	0.60	71.93
24-Jul-1997 22:35	18-Aug-1997 06:38	2.63	3.04	2.12	2.38	4.26	1.02	24.34
23-Aug-1997 22:54	15-Sep-1997 05:32	1.83	2.19	1.47	2.43	3.75	1.69	22.28
20-Sep-1997 21:37	14-Oct-1997 17:51	1.18	1.42	0.97	1.36	2.59	0.75	23.84
28-May-1998 08:32	23-Jun-1998 06:05	3.48	4.08	2.86	0.70	1.36	0.13	25.90
25-Jun-1998 07:33	09-Aug-1998 07:46	3.06	3.55	2.57	1.33	2.01	0.74	45.01
12-Aug-1998 22:24	06-Sep-1998 06:44	2.15	2.55	1.71	2.42	3.65	1.47	24.35
11-Sep-1998 22:43	04-Oct-1998 18:14	1.36	1.67	1.15	1.65	3.05	1.01	22.81
19-May-1999 09:38	12-Jun-1999 05:27	3.41	4.05	2.76	0.74	1.25	0.14	23.83
16-Jun-1999 08:35	12-Jul-1999 05:58	3.36	3.99	2.94	0.96	1.55	0.35	25.89
15-Jul-1999 08:23	11-Aug-1999 06:39	2.82	3.21	2.37	1.82	3.14	0.87	26.93
13-Aug-1999 08:08	10-Sep-1999 07:10	2.07	2.43	1.70	2.55	3.86	1.66	27.96
29-Sep-1999 21:45	23-Oct-1999 18:12	0.93	1.10	0.79	1.07	1.93	0.53	23.85
07-May-2000 09:01	02-Jun-2000 06:32	3.09	3.76	2.48	0.76	1.30	0.26	25.90
05-Jun-2000 08:47	01-Jul-2000 06:09	3.48	4.11	2.91	0.79	1.29	0.19	25.89
05-Jul-2000 09:29	30-Jul-2000 05:57	3.11	3.63	2.64	1.29	2.49	0.43	24.85
03-Aug-2000 21:53	28-Aug-2000 05:50	2.38	2.75	1.92	2.28	2.78	1.58	24.33
01-Sep-2000 21:19	26-Sep-2000 18:30	1.59	1.76	1.30	2.18	3.87	1.28	24.88

*The headings indicate:

1. The beginning of each 21-or-more-day period with no flood tides (Start DT).
2. The end of each 21-or-more-day period with no flood tides (End DT).
3. The length of each such period, in days (Gap)
4. The average expected daily evapotranspiration (period of record May 1, 1984 to July 31, 1995) as well as the design high and design low ETS determined by the Pennman-Montieth method (from Allen 1994) (Ave Pmon, Hi Pmon, Lo Pmon).
5. The average daily precipitation (period of record May 1, 1984 to July 31, 1995), as well as the design high (avg of three wettest years) and the design low (average of three driest years) (Ave Precip, Hi Precip, Lo Precip).

Table II-2-5. Projected Penman-Monteith evapotranspiration and precipitation values, based on data from ANC, for 21-day (or longer) periods without tides over 32 ft.

		Pmon			*Precip*			
*Start DT**	*End DT*	*Avg*	*Hi*	*Lo*	*Avg*	*Hi*	*Lo*	*Gap*
17-May-1995 08:29	13-Jun-1995 06:40	3.38	4.04	2.74	0.74	1.20	0.13	26.92
15-Jun-1995 08:17	13-Jul-1995 07:18	3.36	3.98	2.93	0.95	1.55	0.33	27.96
14-Jul-1995 08:06	11-Aug-1995 07:07	2.84	3.23	2.39	1.78	3.09	0.84	27.96
12-Aug-1995 07:52	10-Sep-1995 07:37	2.08	2.43	1.71	2.53	3.75	1.66	28.99
10-Sep-1995 07:37	24-Oct-1995 19:04	1.13	1.28	1.01	1.39	2.53	0.77	44.48
03-Jul-1996 08:21	30-Jul-1996 06:33	3.11	3.60	2.64	1.31	2.56	0.53	26.93
03-Aug-1996 22:14	28-Aug-1996 06:21	2.38	2.75	1.92	2.28	2.78	1.58	24.34
01-Sep-1996 21:41	26-Sep-1996 06:10	1.59	1.76	1.30	2.18	3.87	1.28	24.35
29-Sep-1996 20:30	25-Oct-1996 18:18	0.91	1.04	0.77	1.02	1.82	0.52	25.91
07-May-1997 07:11	18-Aug-1997 06:38	3.11	3.62	2.62	1.17	1.59	0.81	102.98
22-Aug-1997 22:06	16-Sep-1997 06:22	1.84	2.17	1.48	2.41	3.79	1.69	24.34
20-Sep-1997 21:37	14-Oct-1997 17:51	1.18	1.42	0.97	1.36	2.59	0.75	23.84
27-May-1998 07:48	07-Sep-1998 07:29	2.92	3.38	2.46	1.45	1.95	0.95	102.99
10-Sep-1998 21:57	05-Oct-1998 06:25	1.36	1.66	1.14	1.72	3.13	1.00	24.35
18-May-1999 08:50	13-Jun-1999 06:14	3.39	4.06	2.74	0.75	1.19	0.13	25.89
15-Jun-1999 07:47	26-Sep-1999 19:53	2.55	2.92	2.17	1.74	2.34	1.11	103.50
28-Sep-1999 21:05	24-Oct-1999 18:46	0.93	1.07	0.80	1.09	2.04	0.54	25.90
06-May-2000 08:19	03-Jun-2000 07:15	3.09	3.72	2.49	0.73	1.29	0.25	27.96
04-Jun-2000 08:00	02-Jul-2000 06:58	3.48	4.10	2.96	0.78	1.21	0.21	27.96
04-Jul-2000 08:38	31-Jul-2000 06:49	3.09	3.58	2.63	1.27	2.40	0.53	26.92
02-Aug-2000 08:26	29-Aug-2000 06:39	2.37	2.71	1.90	2.29	2.84	1.49	26.93
01-Sep-2000 08:56	28-Sep-2000 07:13	1.56	1.73	1.30	2.13	3.85	1.25	26.93

*The headings indicate:

1. The beginning of each 21-or-more-day period with no flood tides (Start DT).
2. The end of each 21-or-more-day period with no flood tides (End DT).
3. The length of each such period, in days (Gap)
4. The average expected daily evapotranspiration (period of record May 1, 1984 to July 31, 1995) as well as the design high and design low ETS determined by the Pennman-Montieth method (from Allen 1994) (Ave Pmon, Hi Pmon, Lo Pmon).
5. The average daily precipitation (period of record May 1, 1984 to July 31, 1995), as well as the design high (avg of three wettest years) and the design low (average of three driest years) (Ave Precip, Hi Precip, Lo Precip).

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Table II-2-6. Projected Penman–Monteith evapotranspiration and precipitation values, based on data from ANC, for 21-day (or longer) periods without tides over 33.1 ft.

		Pmon			*Precip*			
*Start DT**	*End DT*	*Avg*	*Hi*	*Lo*	*Avg*	*Hi*	*Lo*	*Gap*
01-May-1995 00:00	31-Oct-1995 23:59	2.37	2.69	2.02	1.32	1.81	0.93	184.00
01-May-1996 00:00	31-Oct-1996 23:59	2.37	2.69	2.02	1.32	1.81	0.93	184.00
20-Aug-1997 08:11	17-Sep-1997 07:09	1.84	2.18	1.48	2.40	3.89	1.62	27.96
19-Sep-1997 20:55	15-Oct-1997 18:31	1.18	1.39	0.97	1.34	2.55	0.75	25.90
01-May-1998 00:00	31-Oct-1998 23:59	2.37	2.69	2.02	1.32	1.81	0.93	184.00
17-May-1999 08:04	25-Oct-1999 19:22	2.41	2.74	2.05	1.43	1.97	0.99	161.47
01-May-2000 00:00	31-Oct-2000 23:59	2.37	2.69	2.02	1.32	1.81	0.93	184.00

*The headings indicate:

1. The beginning of each 21-or-more-day period with no flood tides (Start DT).
2. The end of each 21-or-more-day period with no flood tides (End DT).
3. The length of each such period, in days (Gap)
4. The average expected daily evapotranspiration (period of record May 1, 1984 to July 31, 1995) as well as the design high and design low ETS determined by the Pennman-Montieth method (from Allen 1994) (Ave Pmon, Hi Pmon, Lo Pmon).
5. The average daily precipitation (period of record May 1, 1984 to July 31, 1995), as well as the design high (avg of three wettest years) and the design low (average of three driest years) (Ave Precip, Hi Precip, Lo Precip).

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III-1. WATERBIRD UTILIZATION OF EAGLE RIVER FLATS AND UPPER COOK INLET: APRIL-OCTOBER 1995

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and

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INTRODUCTION

Aerial surveys to monitor waterbird use of Eagle River Flats (ERF) during spring, summer and fall of 1995 were conducted by the U.S. Fish and Wildlife Service as part of the ongoing mortality studies on ERF sponsored by the U.S. Army. The purpose, history and status of this investigation have been presented elsewhere (CRREL 1995).

In addition to the aerial surveys of ERF, which have been conducted annually since 1988, upper Cook Inlet (UCI) marshes were also surveyed for waterbirds in 1995. The purpose of the UCI surveys was to compare waterbird numbers on ERF to other marshes in the region.

STUDY AREA

Eagle River Flats is a salt marsh complex comprising approximately 870 ha located on the southern side of Knik arm in UCI, approximately 10 km east of Anchorage (Fig. III-1-1). A detailed description of this area is presented in CRREL

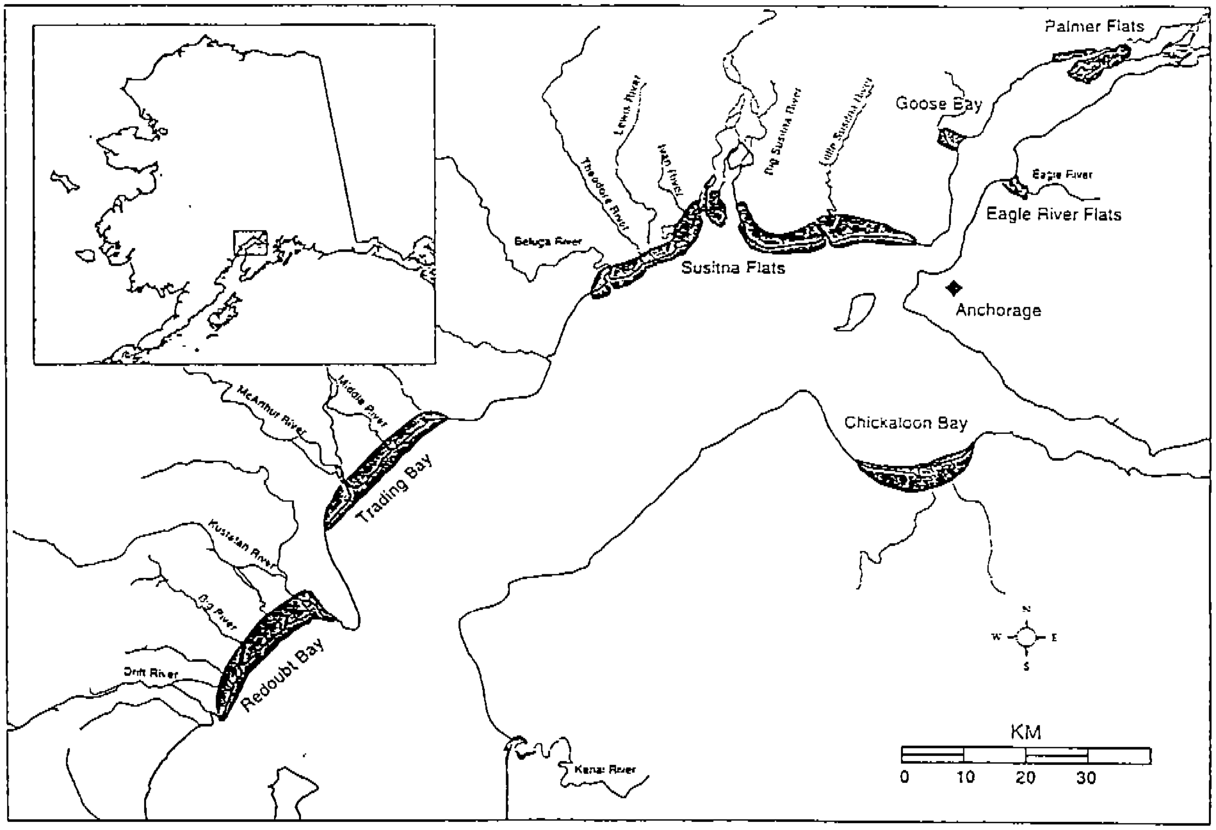

Figure III-1-1. Location of coastal wetlands, including ERF, in upper Cook Inlet surveyed in 1995

(1995). Upper Cook Inlet marshes surveyed in addition to ERF in 1995 include Palmer Hay Flats, Goose Bay, Susitna Flats, Trading Bay, Redoubt Bay and Chickaloon Bay. Sellers (1979) and Vince and Snow (1984) describe habitat characteristics of various UCI marshes. The location and approximate area surveyed for each marsh are indicated in Figure III-1-1.

METHODS

Eagle River Flats

Aerial surveys of ERF were flown from April to early November, 1995. Surveys were conducted twice per week during spring and fall and once per week

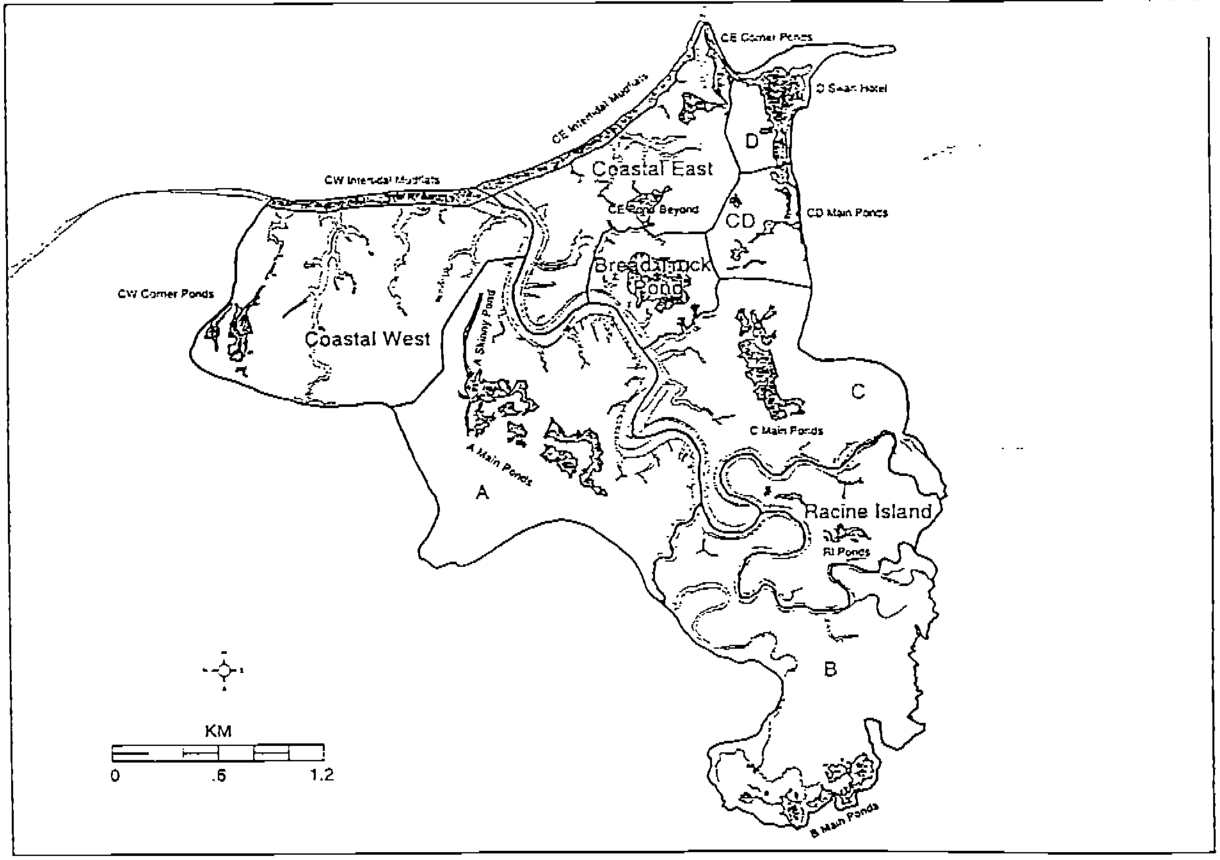

Figure III-1-2. Standardized study zones (outlined) and selected ponds and intertidal mudflats (shaded) surveyed for waterfowl.

during summer. Surveys were flown using fixed-wing aircraft at an airspeed of 100–120 km/hr and at an altitude of 50–75 m. Total coverage of ERF was obtained by overlapping transects. Numbers of waterbirds were counted or estimated and recorded by species or species groups with a cassette tape recorder. Waterfowl numbers were classified by location on ERF using study areas recently standardized for other researchers (Fig. III-1-2). In addition, separate counts were recorded for selected ponds to better delineate bird use. Areas (ha) of study areas and ponds were obtained from digitized base maps and used to convert bird numbers to densities.

Upper Cook Inlet

Aerial surveys of UCI were conducted from mid-April to mid-October 1995. Surveys were flown approximately once per week, but weather conditions did not permit complete coverage of the area for each survey. Chickaloon Bay was only surveyed during fall. The survey area was divided into 17 inland segments and 13 intertidal segments. Surveys were flown using the same aircraft, speed and altitude as described for ERF. Inland areas were surveyed using a standard, s-turn route which incorporated the most important duck habitat. This route required occasional adjustment due to water, snow and ice conditions. Intertidal areas were flown along the water line on the return from each inland survey because feeding ducks tended to congregate there. Ducks and swans were the primary focus of this survey, however, all waterbirds were recorded by segment with a cassette recorder.

RESULTS AND DISCUSSION

Moisture conditions

Snow and ice covered 95% of ERF in mid-April 1995, similar to 1994. Some ice remained on ponds in Areas B and D through the first week of May 1995. The remainder of UCI had more open habitat. Similar to 1994, exposed upland habitat and a few ponds were available to geese before they arrived in mid-April on the Susitna Flats. The portion of Trading Bay northeast of the MacArthur River provided open habitat in mid-April. The mouth of the Kustatan River in Redoubt Bay provided open habitat at this time.

Early summer was relatively dry and some ponds began to dry on ERF and UCI. However, rains beginning in mid-June combined with flooding tides caused ERF and UCI marshes to remain wet through August. Fall flood tides and persistent rains through September caused the wettest conditions in years throughout UCI and ERF marshes.

Mid-October temperatures caused ERF to partially freeze by 16 October. However, some ponds opened periodically during the last two weeks of October and early November, providing waterfowl habitat. UCI marshes also experienced varying degrees of freezing throughout the last two weeks of October. The

Susitna Flats varied from 95% frozen to 95% open within a few days during the third week of October. Trading and Redoubt Bay marshes tended to freeze earlier and more solidly than Susitna Flats. The amount of icing on intertidal mudflats, which is critical to the utilization of this habitat by waterbirds, was minimal into November. This allowed waterbirds to remain in UCI in high numbers 2–3 weeks longer than normal.

Abundance and distribution of waterbirds on ERF

Thirty-seven surveys of ERF were conducted in 1995. Numbers of birds by species or species group are listed by survey date in Table III-1-1 for ERF. Utilization of ERF study areas by major waterfowl groups is presented in Table III-1-2. A discussion of utilization of ERF by major species or species groups is presented below.

Swans

Utilization of ERF by tundra (*Columbus columbianus*) and trumpeter swans (*C. buccinator*) was minimal during spring 1995 (Table III-1-1, Fig. III-1-3) similar to 1994. A peak count of 54 was made on 28 April; however, 69 were counted from the ground earlier the same day (Burson, pers. comm). Most swans departed the area during the first week of May, but small numbers were observed in late May. The majority (65%) of swan use occurred in Area D during spring (Fig. III-1-4) .

Swan use on ERF during fall was similar to other years. Swan numbers began building during the last two weeks of September, peaked in late September and early October, then declined during the first week of October. A peak count from the air of 268 occurred on 26 September, but over 400 were counted from the ground on 28 September (Burson, pers. comm.). There were no extreme climatic conditions in Alaska or Cook Inlet that caused high concentrations of swans in ERF during 1995. Swans used Areas B and D equally in 1995 (Table III-1-2), with little use recorded elsewhere similar to other recent years. Mean swan densities were highest on ponds in Area D in spring and ponds in in Area B in fall (Fig. III-

Table III-1-1. Numbers of birds, by species or species group, observed during aerial surveys of ERF in 1995.

	4/16	4/28	5/01	5/03	5/08	5/12	5/17	5/22	5/25	6/02	6/16	6/22	6/28	7/09	7/18	7/26	8/04	8/09
Swans	5	54	51	10	0	0	2	6	2	0	0	0	0	0	0	0	0	0
Geese																		
Greater white-fronted	8	0	24	24	0	0	0	0	0	8	0	0	0	0	0	0	11	7
Lesser snow	370	2,778	250	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Canada	150	900	247	97	23	6	0	2	0	7	8	38	0	0	23	0	200	66
Subtotal geese	528	3,678	521	121	23	6	0	2	0	15	8	38	0	0	23	0	211	73
Ducks																		
Green-winged teal	0	0	163	135	91	61	4	36	0	8	7	45	2	0	0	16	66	368
Mallard	0	174	33	68	8	24	18	34	22	42	36	9	8	21	11	22	142	67
Northern pintail	0	70	231	109	48	48	2	15	10	14	7	24	2	0	8	5	30	60
Blue-winged teal	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Northern shoveler	0	0	36	43	22	29	0	34	4	5	13	0	0	0	0	0	0	0
American wigeon	0	4	153	192	72	70	37	40	44	30	186	355	289	0	8	30	35	171
Scaup	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
Goldeneye	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
Merganser	0	4	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Unidentified duck	0	0	0	0	0	5	0	0	0	0	18	0	0	33	12	12	236	230
Subtotal ducks	0	252	618	547	241	240	63	159	80	102	267	433	301	54	39	85	509	896
Other birds																		
Red-necked grebe	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bald eagle	0	2	4	1	0	0	0	0	2	0	1	0	0	0	0	0	0	0
Sandhill crane	0	0	54	5	4	10	2	4	41	20	10	2	12	0	16	9	25	7
Shorebird	0	0	0	34	70	52	131	244	229	15	30	434	260	0	134	599	23	96
Small gull	0	0	170	7	0	0	0	0	0	0	0	0	0	0	5	0	0	0
Large gull	50	0	0	104	53	90	16	77	182	140	78	0	0	43	29	0	5	0
Arctic tern	0	0	0	3	14	31	6	68	52	15	17	0	0	6	3	0	0	0
Common raven	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0

	8/17	8/28	8/31	9/04	9/10	9/13	9/17	9/19	9/21	9/26	10/02	10/05	10/10
Swans	0	0	0	8	10	18	45	36	57	268	198	150	2
Geese													
Greater white-fronted	22	35	15	15	11	0	0	0	0	0	0	0	0
Lesser snow	0	0	0	0	0	0	0	0	0	0	0	0	0
Canada	18	170	100	283	222	50	250	80	0	495	355	150	282
Subtotal geese	40	205	115	298	233	50	250	80	0	495	355	150	282
Ducks													
Green-winged teal	573	210	279	309	95	186	572	0	318	109	521	211	258
Mallard	137	187	162	158	136	73	320	0	112	70	378	299	193
Northern pintail	525	147	305	334	35	178	119	0	25	0	292	3	22
Blue-winged teal	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern shoveler	0	0	0	15	0	0	0	0	25	0	0	0	0
American wigeon	60	100	105	399	152	186	114	0	40	15	0	20	0
Scaup	0	0	0	0	1	4	0	0	0	0	0	0	0
Goldeneye	0	0	0	0	0	0	0	0	0	0	0	0	0
Merganser	0	0	0	0	0	0	0	0	0	0	0	0	0
Unidentified duck	181	187	451	363	130	125	550	410	274	789	465	95	74
Subtotal ducks	1,476	831	1,302	1,578	549	752	1,675	410	794	983	1,656	628	547
Other birds													
Red-necked grebe	0	0	0	0	0	0	0	0	0	0	0	0	0
Bald eagle	0	0	1	3	0	0	2	0	0	1	2	2	0
Sandhill crane	5	6	5	18	19	0	25	0	20	0	0	0	0
Shorebird	62	25	2	130	0	35	0	0	47	0	5	25	0
Small gull	0	0	0	0	0	0	0	0	0	0	0	0	0
Large gull	2	10	7	0	1	0	0	0	0	0	0	0	0
Arctic tern	0	0	0	0	0	0	0	0	0	0	0	0	0
Common raven	0	0	2	1	0	0	0	0	0	0	0	0	0

Table III-1-2. Mean numbers of waterfowl groups on ERF study areas by season. The number of complete surveys, used to classify observations by area, for spring, summer and fall were 9, 6 and 16, respectively.

	Coastal West	*A*	*B*	*Racine Island*	*C*	*CD*	*Truck Pond*	*Bread Coastal East*	*D*
				Spring					
Swans	0.0	1.9	0.7	0.0	2.0	0.4	0.0	0.0	9.4
Geese	9.0	27.4	0.9	0.4	42.4	0.0	11.1	38.3	5.4
Lesser snow	0.0	7.8	0.0	0.0	16.7	0.0	11.1	33.3	0.0
Canada	8.8	18.8	0.9	0.4	20.0	0.0	0.0	0.4	0.9
Ducks	19.9	63.7	40.0	1.8	42.4	19.7	11.3	5.2	44.6
				Summer					
Swans	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Geese	40.2	1.3	5.5	0.0	3.8	0.0	0.0	0.0	1.7
Lesser snow	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Canada	40.2	1.3	5.5	0.0	3.8	0.0	0.0	0.0	0.0
Ducks	12.7	63.5	29.7	0.0	71.5	52.7	18.5	17.5	42.3
				Fall					
Swans	0.0	0.0	25.3	0.0	0.0	0.1	0.0	5.5	25.7
Geese	61.4	26.1	20.9	0.4	7.5	0.0	0.0	72.9	0.7
Lesser snow	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Canada	55.6	25.3	19.1	0.4	3.9	0.0	0.0	12.9	0.0
Ducks	157.1	226.9	125.9	1.3	80.4	127.0	50.9	153.6	231.9

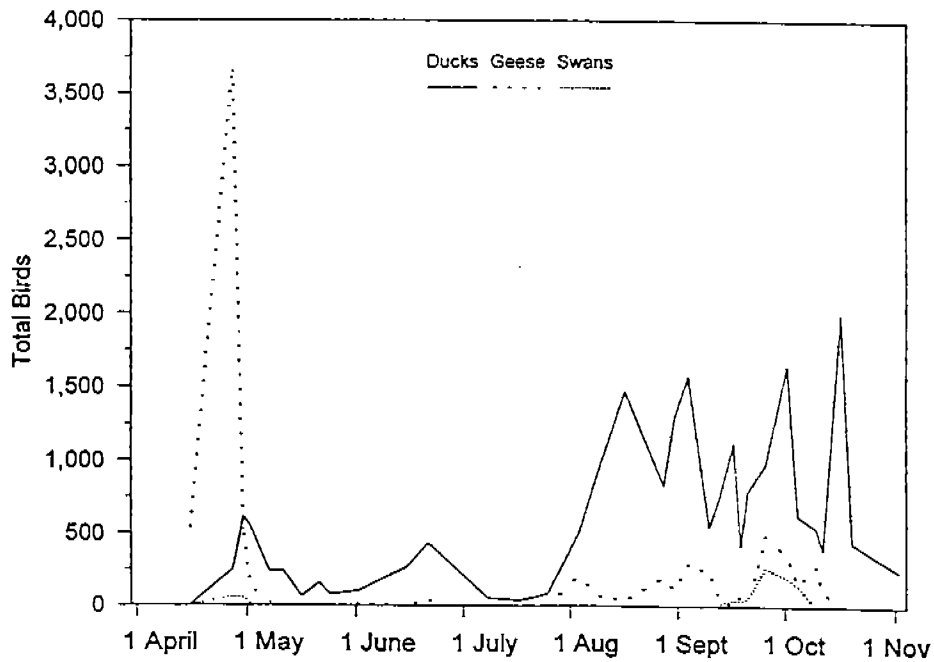

Figure III-1-3. Numbers of ducks, geese and swans counted on ERF in 1995.

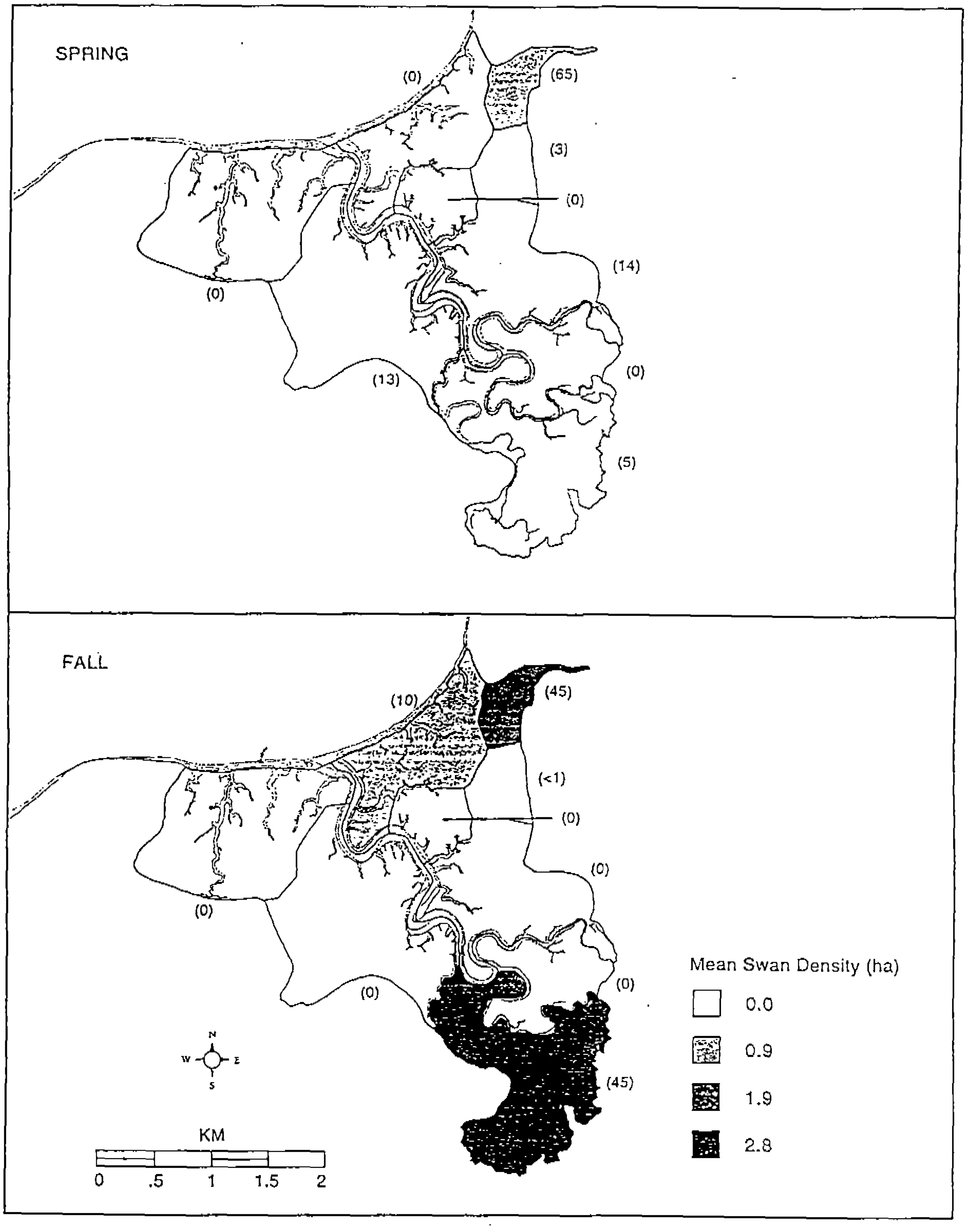

Figure III-1-4. Mean densities of swans on ERF study areas in spring and fall 1995. Numbers in parentheses are the percentage of total swans observed in each area. The area (ha) of permanent and intermittant ponds in each area were used to calculate densities.

1-4 and III-1-5). Hazing and human activity designed to keep swans away from more highly contaminated areas, such as Areas A and C, appeared effective.

Table III-1-3. Minimum mean population estimates (± 95% confidence intervals) for ducks and swans on ERF by season for years with less disturbance (1988-1991), more disturbance (1992-1995), and for all years.

	Spring	*Summer*	*Fall*
Ducks			
1988-1991	295 ± 120	156 ± 60	975 ± 135
1992-1995	453 ± 160	160 ± 30	809 ± 90
1988-1995	394 ± 115	156 ± 28	869 ± 80
	n* = 67	n = 49	n = 113
Swans			
1988-1991	63 ± 70	0	260 ± 100
1992-1995	27 ± 13	0	172 ± 32
1988-1995	39 ± 26	0	213 ± 55
	n = 38		n = 63

*n = total number of aerial surveys flown by season, 1988-1995.

To determine the mean spring and fall population of swans on ERF, data were combined from 1988 to 1991 when less human activity and no hazing occurred on ERF, and from 1992 to 1995 when more disturbance occurred, and for all years (Table III-1-3). Swans were consistently less abundant in spring than fall. Combining data in this manner averages years with extreme populations, such as for the fall of 1990, when nearly 1800 swans were counted.

Geese

Peak aerial counts of geese in spring occurred during the last week of April and were similar to other years when snow geese (*Chen caerulescens*) were present (Table III-1-1, Fig. III-1-3). Snow geese comprised 69% of the total geese counted, followed by Canada geese (*Branta canadensis*) (30%). Canada geese utilized more inland areas in spring 1995 (70% of all observations) (Table III-1-2, Fig. III-1-6) than previous years. Two subspecies of white-fronted geese (*Anser albifrons*), Pacific (*A. a. frontalis*) and Tule (*A. a. gambelli*), were found in low numbers similar to other years. Mean numbers of all species of geese were highest in Area C (Table III-1-2), but mean densities were highest in Coastal East (Fig. III-1-6).

Canada geese used ERF in small numbers during summer. Fall goose migration phenology was similar to other years, peaking in late September and early October (Fig. III-1-3). Two subspecies of Canada geese, lesser (*B. c. parvipes*)

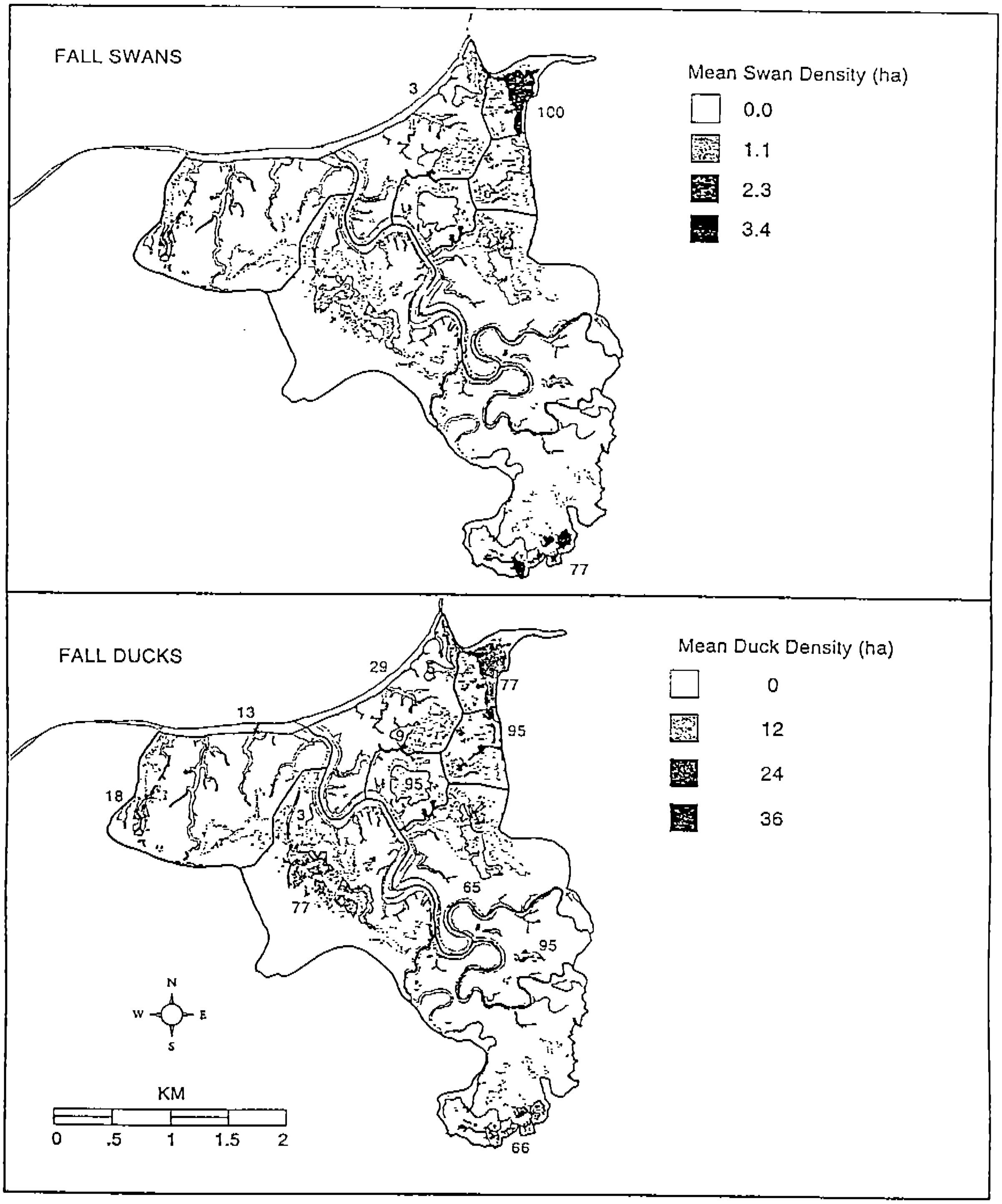

Figure III-1-5. Mean densities of swans and ducks on selected ponds and intertidal mudflats within ERF study areas, 1995 (see Fig. III-1-2). The numbers by selected ponds and mudflats are the percentage of observations within each study area that occurred within those sites

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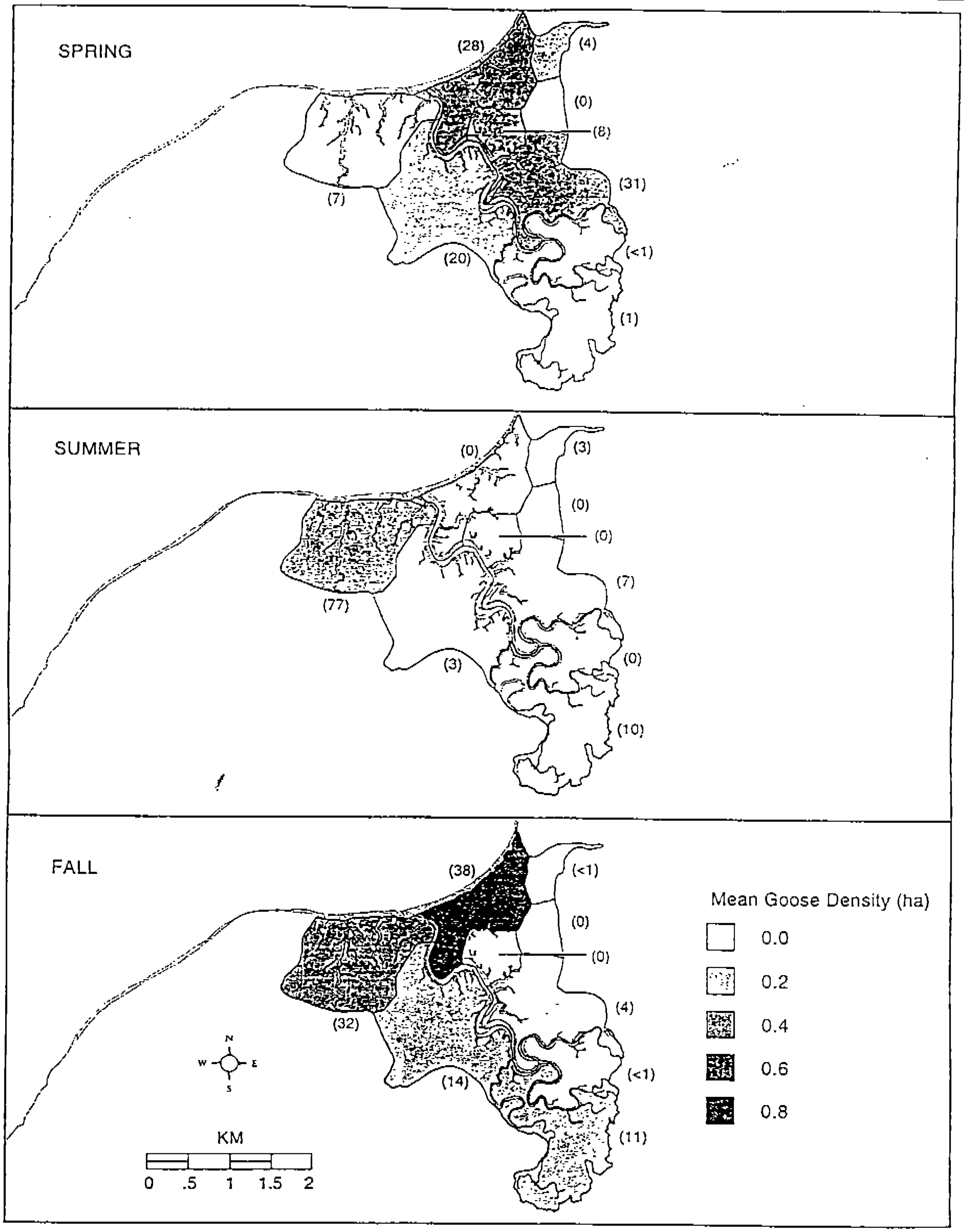

Figure III-1-6. Mean densities of geese on ERF study areas in spring, summer and fall 1995. The numbers in parentheses are the percentage of total geese observed in each area.

and Taverner's (*B. c. taverneri*) were the most common, comprising 96% of the fall count. Canada geese were most commonly observed in coastal areas in fall, and Coastal East had the highest density (Fig. III-1-6). Tule white-fronted geese comprised 4% of the fall count. Snow geese rarely migrate through Cook Inlet in fall and were not observed on ERF. In general numbers of geese utilizing ERF in 1995 were lower than the late 1980s and early 1990s, probably due to increased hazing and other disturbance.

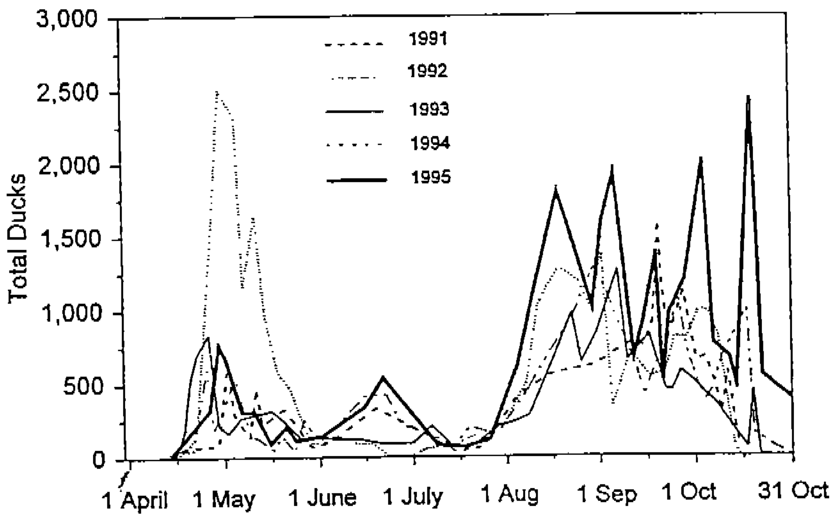

Figure III-1-7. Numbers of ducks observed on aerial surveys of ERF, 1991–1995.

Ducks

Duck species utilizing ERF in 1995 were similar to previous years (Table III-1-1). Dabbling ducks comprised more than 99% of the ducks counted. Mallards (*Anas platyrhynchos*), American wigeon (*A. americana*), green-winged teal (*A. crecca*), northern shoveler (*A. clypeata*) and northern pintail (*A. acuta*) were the most common species observed. Numbers of combined duck species are presented for 1991–1995 (Fig. III-1-7). In spring, numbers of ducks peaked and declined rapidly in late April. The small spring peak may be more typical of duck migration than a high peak, such as 1992 (Fig. III-1-7). Mean numbers of ducks were highest in Area A in spring (Table III-1-2). The highest mean density in spring occurred in Area D (Fig. III-1-8).

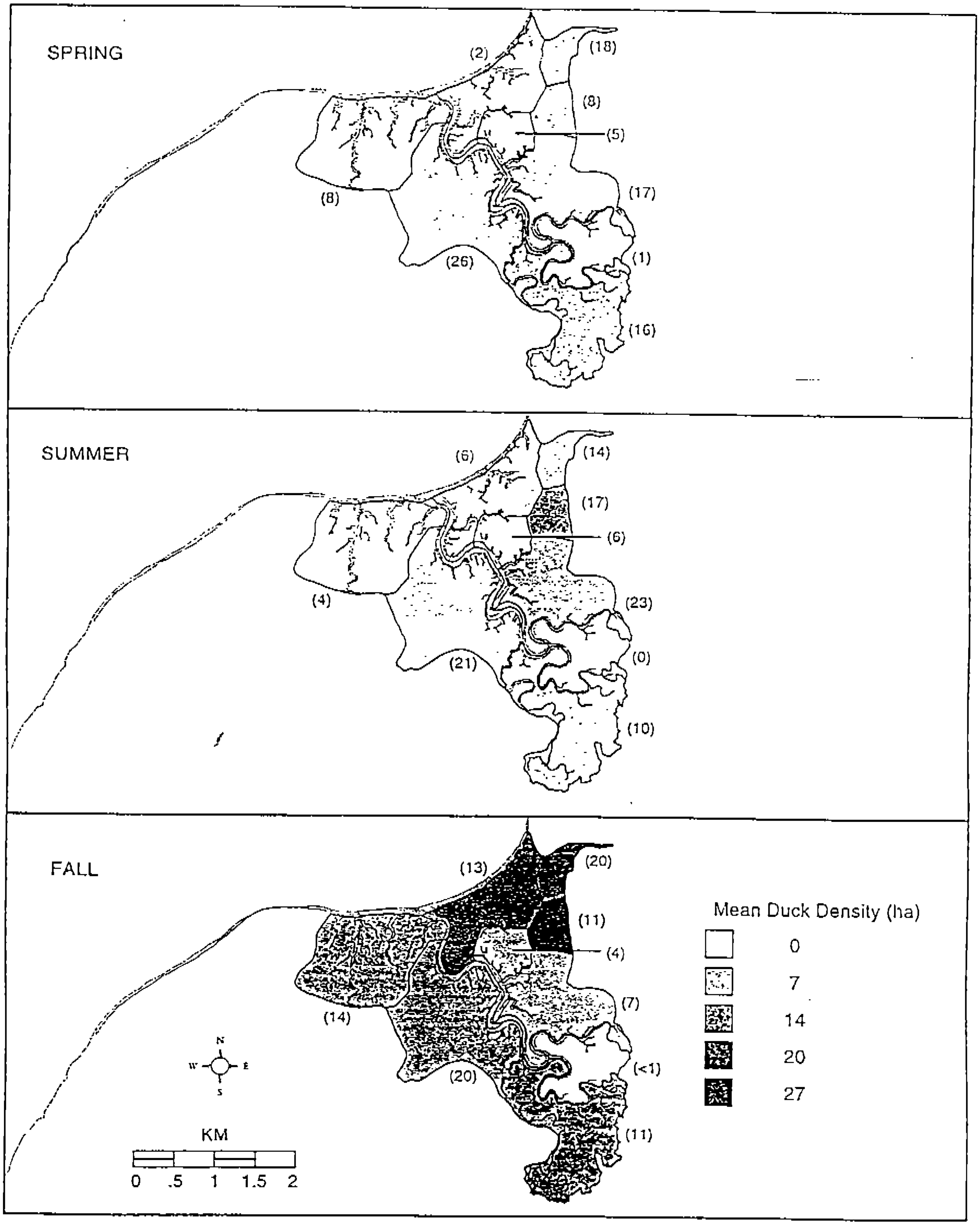

Figure III-1-8. Mean densities of ducks on ERF study areas in spring, summer and fall 1995. The numbers in parentheses are the percentage of total ducks observed in each study area. The area (ha) of permanent and intermittant ponds in each study area were used to calculate densities.

Summer numbers were similar to 1994 and higher than earlier years, probably due to favorable water conditions and cessation of firing on ERF. Numerous broods were observed on ERF. The late June peak in numbers was primarily due to flocks of male American wigeons staging for molt. The highest mean numbers of ducks in summer occurred in Area A, but highest duck densities were in Areas C/D and D (Table III-1-2, Fig. III-1-8). The mean density indicated for ducks in summer was higher than in spring in 1995 (Fig. III-1-8) because the lower numbers recorded over a longer period in summer yielded a higher average density than the high peak numbers recorded in spring (Fig. III-1-3).

Fall numbers were generally higher than in recent years; however, high variability occurred between surveys (Fig. III-1-7). This variability was probably a combination of natural migratory movements and disturbance from hazing and helicopter activity. Because of the prolonged mild fall in 1995, ducks remained longer in ERF and in Cook Inlet than usual. While freeze-up forced ducks off ERF during mid-October, the Cook Inlet coastline was ice-free, and ducks, particularly mallards and green-winged teal, remained in the area until mid-November. Ducks were able to re-occupy ERF during the last two weeks of October and early November when ice melted periodically.

The highest mean numbers of ducks occurred in Areas D and A in fall. Areas C, Bread Truck and Racine Island were utilized least (Table III-1-2). Mean fall densities of ducks were highest in Areas D and C/D (Fig. III-1-8). In addition to the standardized areas within ERF, ducks in fall were counted in selected ponds and numbers converted to mean densities (Fig. III-1-5). The importance of the C/D and D ponds was apparent (Fig. III-1-5). The main ponds in Area A were also utilized extensively, and this is an area that is actively hazed for much of the fall.

To determine the mean seasonal population of ducks on ERF, data from 1988–1991, 1992–1995 and for all years were combined (Table III-1-3). The decline in mean duck numbers from the 1988–1991 period to 1992–1995 period is likely a result of human disturbance on ERF. Because population levels have been similar over the years, particularly in fall (Fig. III-1-7), these estimates may be useful as a minimum average duck population during a season.

Bald eagles

Numbers of bald eagles (*Haleateetus leucocephalus*) in 1995 (Table III-1-1) were the lowest recorded since aerial surveys began in 1988. Numbers are not directly comparable to pre-1994 years because perimeter surveys specifically for bald eagles were not conducted due to the extensive human activity on ERF. Ground counts of eagles in 1995 were also low (Burson, pers. comm).

Shorebirds

Numbers of shorebirds were combined for all species since individual species were not identified from the air (Table III-1-1). Numbers of shorebirds observed were generally less than previous years, possibly due to wet conditions in 1995 which limited exposed mudflats. Common species on ERF include least (*Calidris minutilla*), semipalmated (*C. pusilla*) and western sandpipers (*C. mauri*), dowitchers (*Limnodromus spp.*) and greater and lesser yellowlegs (*Tringa* spp.).

Gulls and terns

Gull species were combined for aerial surveys (Table III-1-1). They include mew gulls (*Larus canus*), glaucous-winged gulls (*L. glausescens*) and herring gulls (*L. argentatus*). Arctic terns (*Sterna paradisaea*) were common into July.

Abundance and distribution of waterfowl in Upper Cook Inlet

Twenty-five surveys of UCI were conducted in 1995. Numbers of swans, geese and ducks observed in UCI during the survey period are presented (Fig. III-1-9). Numbers of waterbirds observed are presented by survey date and area (Table III-1-4).

Swans

Use of UCI marshes by swans was most concentrated in spring when peak numbers reached 8000 birds in late April (Fig. III-1-9, Table III-1-4), comparable to spring counts of 9000 obtained by Butler (1987). Due to the prolonged fall, swans migrated at a leisurely rate through UCI, peaking in late September, but large

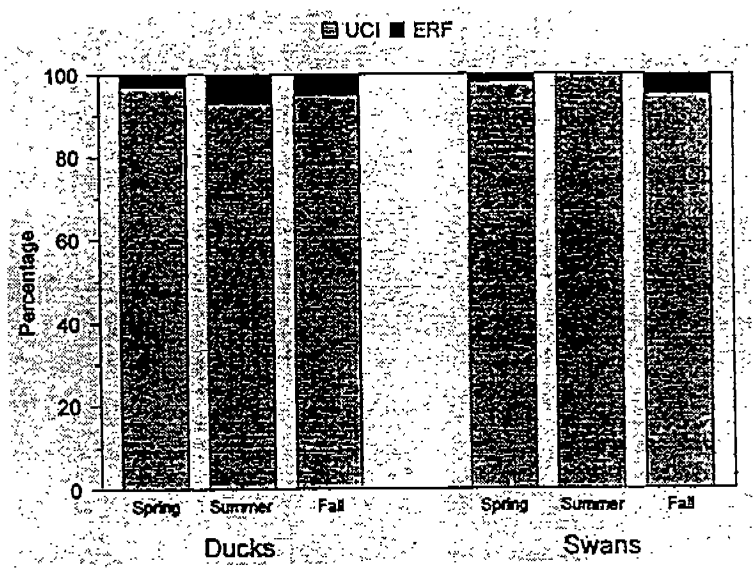

Figure III-1-9. Ducks, geese and swans counted on upper Cook Inlet coastal wetlands in 1995.

Table III-1-4. Number of birds, by species or species group, observed during aerial surveys of UCI, 1995. Only complete surveys of UCI are included. Observations from Chickaloon Bay are not included due to the low number of surveys.

	4/23	4/28	5/03	5/09	5/19	5/25	6/09	6/26	7/18	7/26	8/03	8/16	8/24	8/29	9/06	9/13	9/27	10/17
Swans	271	7902	1689	696	71	12	10	26	1	2	2	7	58	35	108	106	567	233
Geese																		
Greater white-fr.	1000	972	771	491	59	2	82	166	0	27	245	377	430	100	12	111	0	0
Lesser snow	14569	20088	1193	639	2	0	0	0	0	0	0	0	1	0	0	0	7	0
Canada	29603	35535	5431	2338	192	43	556	332	96	275	0	470	1062	1082	1748	1790	1340	235
Subtotal geese	45172	56595	7395	3468	253	45	638	498	96	302	245	847	1493	1182	1760	1901	1347	235
Ducks																		
Green-winged teal	0	245	2253	1274	123	28	20	39	23	16	85	1392	77	2416	2357	842	962	2580
Mallard	700	897	66	158	104	29	283	285	408	569	265	319	374	2988	4143	782	2145	7396
Northern pintail	664	13868	2525	1751	403	53	41	698	78	56	120	3021	3626	2967	5168	880	1362	205
Northern shoveler	0	12	84	849	78	54	0	14	0	0	0	0	0	226	300	30	12	0
American wigeon	0	30	650	718	163	106	60	1252	56	150	245	493	3328	1491	4387	1402	385	110
Canvasback	0	0	13	161	32	0	0	0	2	0	0	0	0	25	40	11	0	0
Redhead	0	0	21	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scaup	0	180	101	948	1595	55	42	109	15	25	45	50	30	300	312	327	568	12
Common eider	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Black scoter	0	0	0	0	99	0	0	0	0	0	0	0	0	0	0	0	80	0
Goldeneye	0	0	0	44	7	0	0	0	0	10	0	0	0	0	0	3	4	0
Bufflehead	0	0	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Merganser	0	16	6	5	17	0	0	10	0	0	0	0	0	0	8	0	0	0
Unidentified duck	3250	2800	7096	3874	494	125	1227	2097	1202	1689	3025	4044	37730	17544	15526	17449	19675	558
Subtotal ducks	4614	18048	12838	9802	3117	450	1673	4504	1784	2515	3785	9319	45165	27957	32241	21726	25193	1086
Other birds																		
Arctic Loon	0	0	0	7	6	2	0	16	11	24	4	6	22	4	0	0	0	0
Horned grebe	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0
Red-necked grebe	0	0	0	2	21	0	0	3	3	44	0	20	4	0	0	0	2	0
Bald eagle	0	4	3	73	9	1	2	16	0	0	0	1	9	5	3	7	1	2
Northern harrier	0	0	0	0	0	0	0	2	0	0	0	0	10	0	0	0	0	0
Peregrine falcon	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Sandhill Crane	0	59	15	5	47	25	43	19	34	11	0	18	44	42	289	5	0	0
Shorebird	0	0	300	11201	499	5	0	0	1147	1628	60	200	0	200	100	11	0	0
Jeager	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
Small gull	0	0	26	0	0	0	0	0	13	0	0	0	0	40	0	3	0	0
Large gull	92	276	601	2309	3901	2023	474	14	963	432	174	155	2	127	32	83	50	0
Arctic tern	0	10	44	13	134	15	0	0	22	37	0	0	1	0	0	0	0	0
Common raven	0	10	4	0	6	0	0	11	0	2	0	0	1	0	6	1	0	0

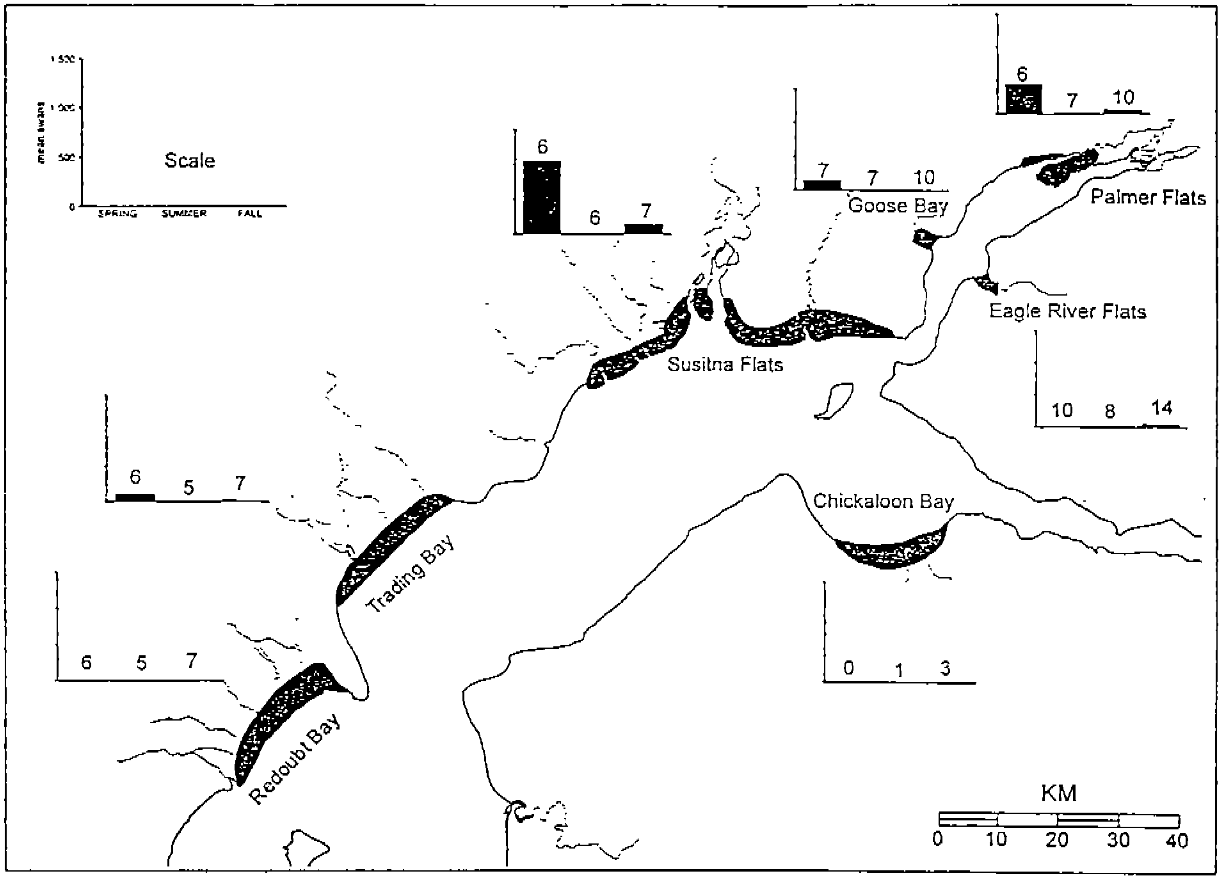

Figure III-1-10. Mean numbers of swans observed on upper Cook Inlet coastal wetlands in spring, summer and fall 1995. The number of aerial surveys flown for each area and season is above each bar.

concentrations did not occur (Fig. III-1-9). Highest mean numbers occurred on Susitna Flats and Palmer Hay Flats during spring and fall (Fig. III-1-10), probably reflecting wetter habitat of these marshes. The largest concentration of swans recorded occurred at Swan Lake, near the mouth of the Big Susitna River, where 1600 swans were observed on 26 September on a non-survey flight.

Geese

Three subspecies of Canada geese—Taverner's, lesser, and cackling (*B.c. minima*)—utilized UCI in spring. Combined numbers of these subspecies comprised 65% of the total spring goose numbers. White-fronted geese, combining Tule and Pacific subspecies, comprised 3% of spring numbers and snow geese

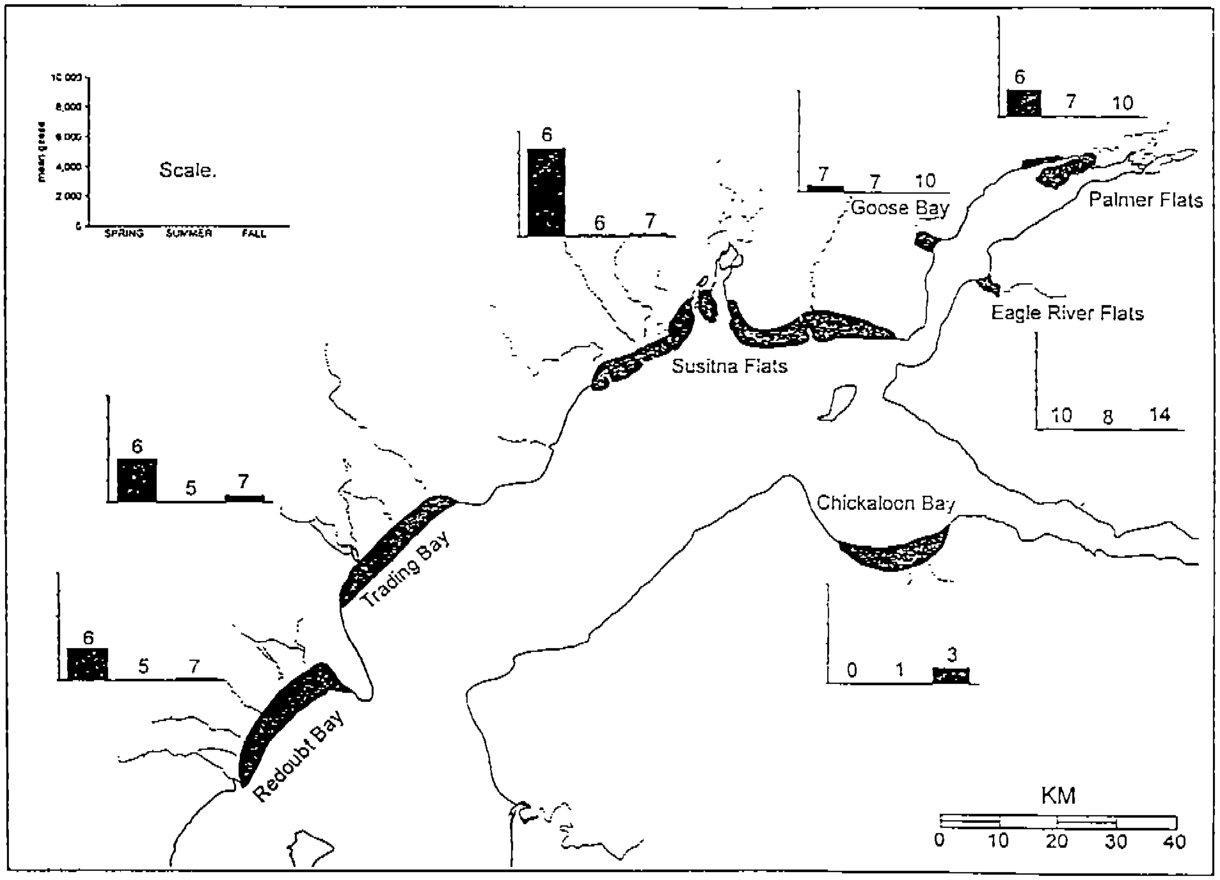

Figure III-1-11. Mean numbers of geese observed on upper Cook Inlet coastal wetlands in spring, summer and fall 1995. The number of aerial surveys flown for each area and season is above each bar.

comprised 32%. Small numbers of black brant (*Branta bernicla*) occurred in spring (< 1%). Goose numbers followed a trend similar to swans, and peaked rapidly in late April at over 55,000 total geese (Fig. III-1-9). In spring, mean numbers of geese were highest on Susitna Flats, followed by Trading Bay (Fig. III-1-11, Table III-1-4). Butler (1987) found that spring goose numbers in UCI varied from 50,000 to 100,000, depending on habitat availability in UCI and elsewhere in Alaska.

Lesser Canada geese are considered the primary breeding goose in summer, followed by the Tule white-fronted geese. Numbers of breeding geese are generally low, but they are also difficult to observe until they form molt and brood flocks. A July 1993 Alaska Department of Fish and Game survey of post-

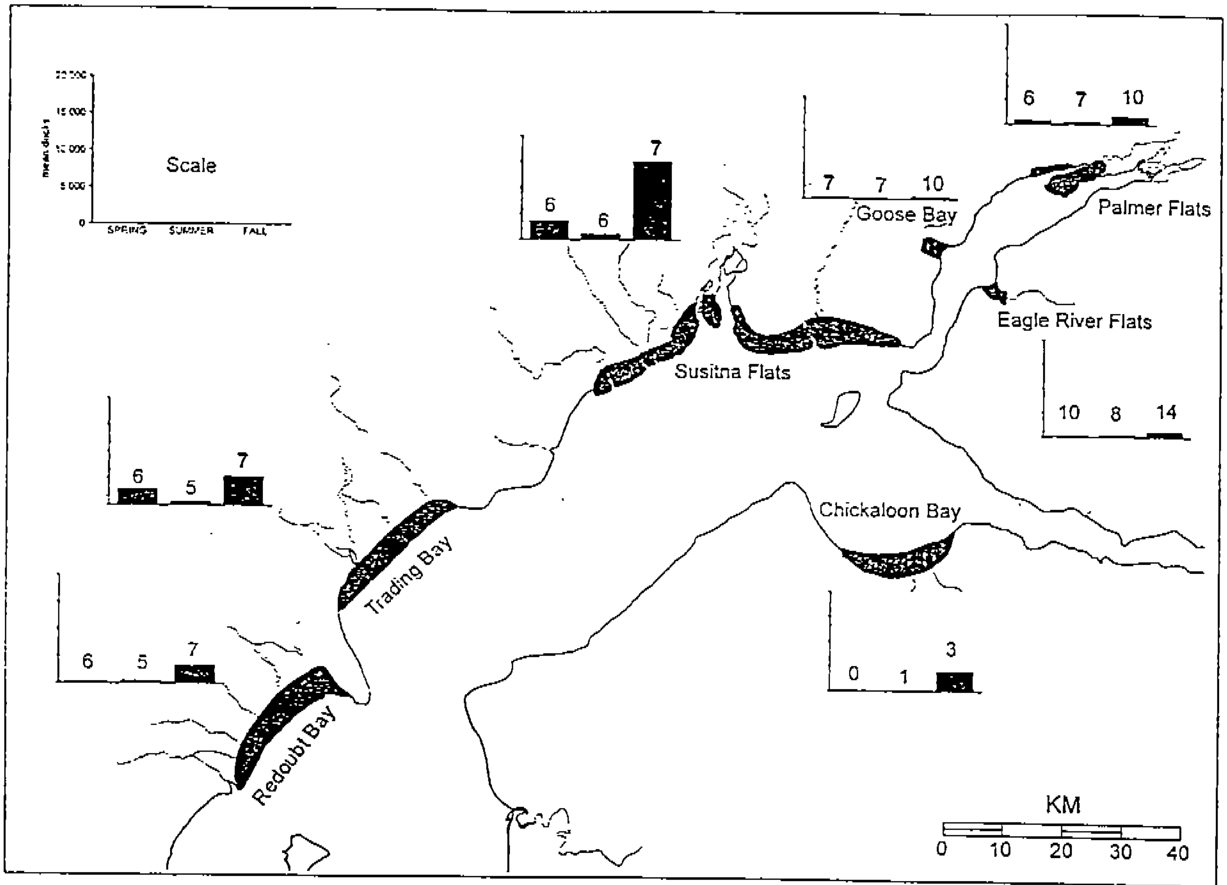

Figure III-1-12. Mean numbers of ducks observed on upper Cook Inlet coastal wetlands in spring, summer and fall 1995. The number of aerial surveys flown for each area and season is above each bar.

breeding Canada geese in Cook Inlet found approximately 2500 geese (Rothe, pers. comm). In fall, Canada geese, primarily lesser and Taverner's subspecies, comprised 71% of the fall flight of geese. Tule white-fronted geese comprised 12% of total fall goose numbers. Small numbers of snow geese (< 1%) were observed. Numbers of geese indicated a gradual increase through late September and early October (Fig. III-1-9) with no large concentrations. Mean fall goose numbers were highest on Chickaloon Bay, followed by Trading Bay (Fig. III-1-11).

Ducks

The species composition of ducks utilizing UCI was similar to ERF (Table III-1-4). Dabbling ducks comprised 97% of observations, primarily northern pintails, mallards, American wigeon and green-winged teal. Diving ducks comprised 3%

of total ducks, and two species, common eider (*Somateria mollissima*) and black scoter (*Melanitta nigra*), were observed on UCI but not ERF. These two species comprised less than 1% of total UCI duck numbers.

Duck numbers peaked in late April in UCI, approaching 20,000 (Fig. III-1-9), then declined rapidly. Mean numbers of ducks were highest on Susitna Flats, followed by Trading Bay (Fig. III-1-12). A small peak in late June reflected pre-molting flocks of male American wigeon, similar to that observed on ERF. Numbers increased rapidly in mid-August, peaked in late August at over 45,000 birds, then declined gradually (Fig. III-1-9). Mean numbers in fall were highest on Susitna Flats (Fig. III-1-12). The prolonged mild weather in fall permitted birds to remain in UCI into November.

Waterfowl utilization of ERF compared to UCI

Mean seasonal densities of major waterbird species groups and bald eagles are presented by marsh (Table III-1-5). A comparison of total numbers of ducks, geese and swans counted on ERF and UCI is presented as a percentage (Fig. III-1-13). A comparison of waterbird numbers in UCI marshes and ERF necessitates a description of major habitat differences. Intertidal mudflats provide extensive feeding habitat for ducks and shorebirds and loafing habitat for geese throughout UCI. Intertidal mudflats extend up to two miles in width at low tide off Susitna Flats, Trading Bay, Redoubt Bay and Chickaloon Bay. Productive intertidal mudflats are minimally available in Knik Arm, including ERF, Goose Bay and Palmer Hay Flats, where the shoreline is much more abrupt, and the influence of freshwater is much greater. During fall, these mudflats appear to be preferred by ducks for feeding (Fig. III-1-14). The difference in numbers of ducks on mudflats versus vegetated marshes is partially due to better visibility on mudflats. A comparison of duck densities on inland habitat reveals that considerably higher densities were recorded on inland marshes of ERF in fall than on inland marshes of UCI (Fig. III-1-15). This difference may be partially due to better coverage of ERF than UCI during aerial surveys, to hunting on other UCI marshes, or to greater productivity of ERF marshes.

Table III-1-5. Mean densities of major waterbird groups on UCI and ERF by season, 1995. The number of aerial surveys flown in each area and season is in parentheses.

	Chickaloon Bay	Goose Bay	Palmer Flats	Redoubt Bay	Susitna Flats	Trading Bay	ERF
Area(km^2)	56	13	41	77	149	58	10
Spring	(0)	(7)	(6)	(6)	(6)	(6)	(10)
Swans	ns	11.8	10.8	0.0	7.0	1.9	1.3
Geese	ns	51.0	67.1	38.5	56.5	69.0	48.9
Ducks	ns	28.6	23.3	4.3	25.3	50.9	23.0
Loons	ns	0.0	0.0	0.0	0.0	0.0	0.0
Bald eagles	ns	0.0	0.0	0.0	0.1	0.0	0.1
Sandhill cranes	ns	0.6	0.1	0.0	0.0	0.2	1.4
Shorebirds	ns	0.6	0.3	0.1	4.3	23.3	7.8
Gulls	ns	0.6	6.8	0.5	8.8	2.8	8.9
Arctic terns	ns	0.5	0.3	0.0	0.1	0.0	1.9
Common ravens	ns	0.0	0.1	0.0	0.0	0.0	0.0
Summer	(1)	(7)	(7)	(5)	(6)	(5)	(8)
Swans	0.0	0.0	0.2	0.0	0.0	0.0	0.0
Geese	0.0	0.0	3.8	0.8	0.8	0.1	4.4
Ducks	0.9	5.7	15.7	4.2	6.7	5.9	32.3
Loons	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Bald eagles	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sandhill cranes	0.0	0.1	0.1	0.1	0.0	0.0	1.0
Shorebirds	1.2	7.5	0.4	0.0	2.0	0.2	19.7
Gulls	0.0	0.2	2.6	0.1	1.3	0.5	2.0
Arctic terns	0.0	0.1	0.2	0.0	0.1	0.0	0.3
Common ravens	0.0	0.0	0.0	0.0	0.0	0.0	0.
Fall	(3)	(10)	(10)	(7)	(7)	(7)	(14)
Swans	0.0	0.1	1.7	0.1	2.1	0.2	5.7
Geese	21.7	0.7	1.7	2.0	2.3	6.6	19.0
Ducks	53.4	40.4	42.1	28.9	76.9	54.0	111.3
Loons	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bald eagles	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Sandhill cranes	0.0	0.0	0.0	0.2	0.0	0.3	0.7
Shorebirds	0.2	0.0	0.0	0.0	0.3	0.0	2.5
Gulls	0.0	0.1	0.2	0.1	0.2	0.2	0.2
Arctic terns	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Common ravens	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Limitations and potential biases in data

Survey methodology

To minimize variability in data collected from aerial surveys, attempts are made to standardize survey technique, survey platform, observers, weather conditions, time, disturbances to the survey site, and tide stage. Standardization

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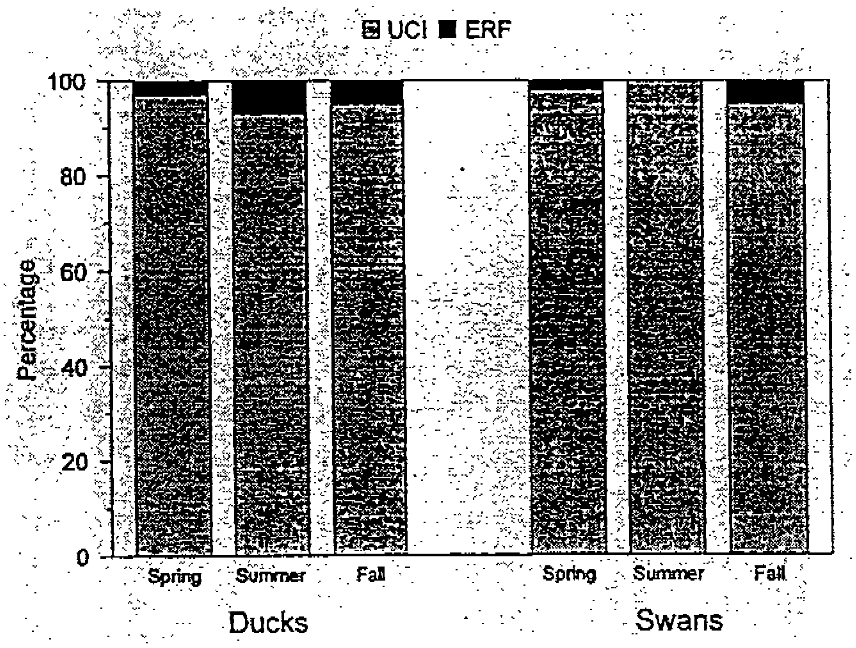

Figure III-1-13. Percentage of ducks and swans observed on upper Cook Inlet coastal wetlands and ERF.

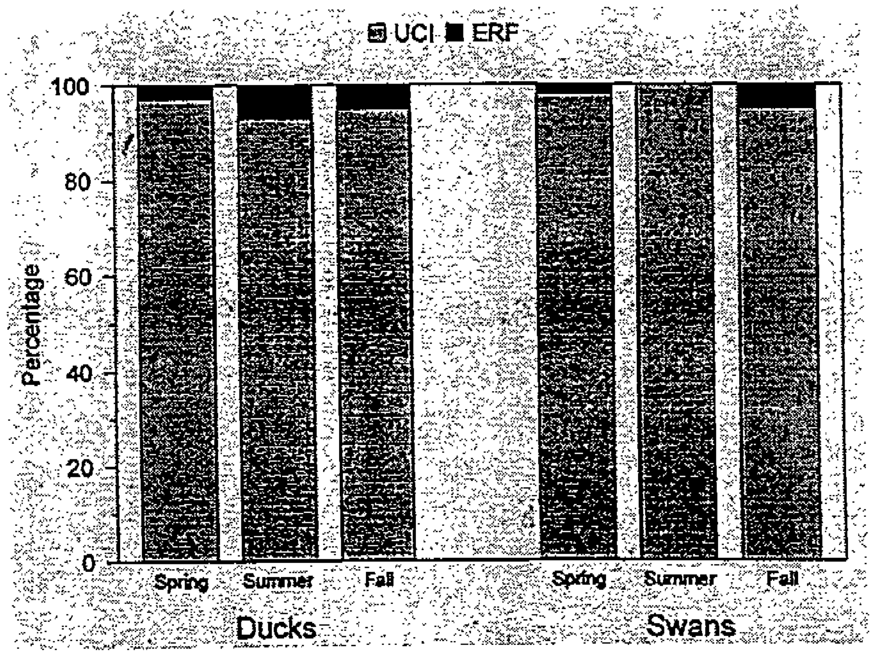

Figure III-1-14. Percentage of ducks observed on intertidal flats of Redoubt Bay, Susitna Flats, Trading Bay and ERF in spring, summer and fall, 1995.

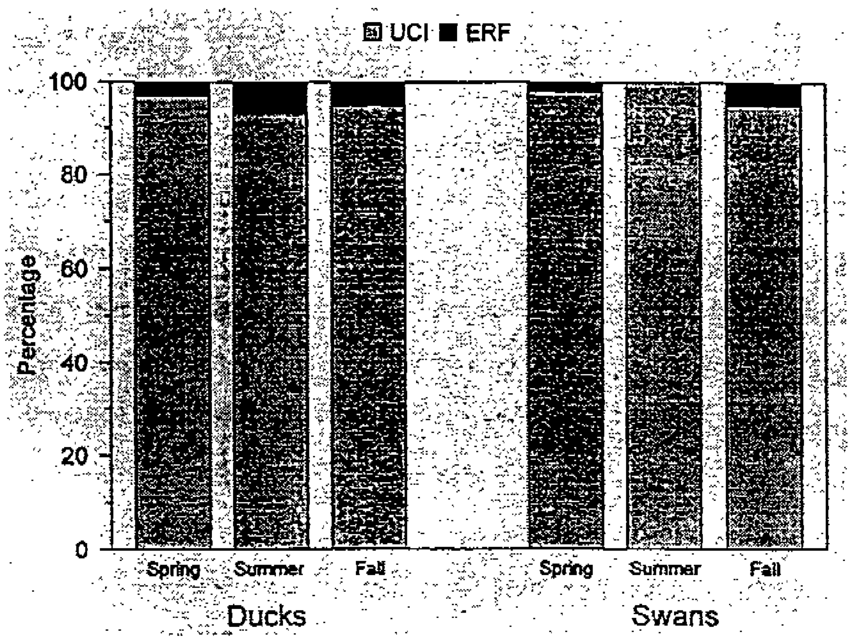

Figure III-1-15. Mean densities of ducks observed on inland areas of Redoubt Bay, Susitna Flats, Trading Bay and ERF in spring, summer and fall, 1995.

for weather conditions, observers, survey technique and platform has been possible on ERF. Difficulty of obtaining a preferred flight time because of other Army and reseafch activities on ERF has precluded standardization of other variables. Surveying during periods of disturbance would bias duck numbers and densities down for ERF when comparing to less disturbed areas. Lack of standardization has been a problem since surveys were initiated on ERF in 1988.

On UCI it was possible to standardize timing to tides, which are very important in determining waterbird use of the main UCI marshes (less so for ERF with limited intertidal habitat). Due to the extremely wet year extensive wetlands were available throughout the summer and fall on UCI. While all attempts were made to survey these wetlands, it is likely that UCI marshes did not receive as intense survey coverage as ERF, which biased duck numbers and densities in favor of ERF during direct comparisons. This bias was probably not large.

Data collection and analysis

The numbers and species of waterfowl observed on a marsh, assuming standard survey conditions, are related to bird size and color, flock size and amount of ground cover. Generally a correction factor is developed for different times of year, different habitats and different species, if an estimate of actual numbers by species, rather than an index, is desired. Correction factors are similar for ducks of similar size and color in similar habitat (e.g. mallards, American wigeon and northern shovelers in fall) but might be quite different from the smaller green-winged teal. Because duck species in summer and fall eclipse plumage are often difficult to distinguish during aerial surveys, they are combined as a group unless identification is possible. On ERF summer and fall estimates of numbers by species are biased towards the most identifiable species. For example, species such as northern shovelers are underestimated from the air because they are difficult to separate from American wigeons, northern pintails and mallards. Green-winged teal are underestimated in dense vegetation, but their preference for open water and tidal guts may compensate, and their small size makes them easy to identify if seen. A direct comparison of vegetated wetland habitats to intertidal mudflats should also use a visibility correction factor.

Correction factors have not been developed for ERF because data have been used to compare annual differences as an index and species composition has not varied dramatically. If the data are to be used for population estimates for individual species then correction factors should be applied. Correction factors are obtained by comparing simultaneous ground and air counts. Lacking correction factors, the data may still be used as a minimum population of birds present. Turnover rates, estimated from radio-telemetry data, can be used to calculate seasonal minimal populations of dabbling ducks. An upper population might be calculated by using just the peak counts for a population average for a season.

Hazing and human disturbance

The combined activities of hazing and research activities, with helicopter and hovercraft support, probably have reduced waterbird utilization of ERF compared to an undisturbed state. Geese and swans are probably most affected, followed by ducks. Eagle River Flats was used as an impact zone during summer and fall until 1991, which likely had a detrimental impact on bird use prior to the cessation of firing. The only way to obtain undisturbed counts would be to cease all activities on ERF, and that is unlikely in the near future.

RECOMMENDATIONS

- Continue aerial surveys at a level comparable to recent years, but classify all observations by individual pond where possible.
- Establish correction factors for spring, summer and fall for duck species by conducting aerial surveys concurrent with ground counts.
- Standardize maps of ponds and gullies for all research and survey groups, including a numbering system, based on the geographic information database developed by CRREL. Maps should be available and utilized for all future monitoring work.

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III-2. WATERFOWL USE AND MORTALITY AT EAGLE RIVER FLATS

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INTRODUCTION

The main impact of white phosphorus (WP) contamination at Eagle River Flats (ERF) has been the poisoning of ducks and swans. Since the problem was noticed in the early 1980's, several hundred to several thousand ducks have died each year. The main objective of the waterfowl study in 1995 was to detect year to year changes in waterfowl mortality due to remediation or natural attenuation of white phosphorus. A second goal was to measure mortality in a non-contaminated reference area for comparison with ERF. Third, we checked for waterfowl mortality in areas thought to not be contaminated. Finally, we continued to evaluate the extent of WP poisoning in swans by observing feeding patterns and locations of carcasses.

METHODS

Relative waterfowl mortality

In order to detect changes in mortality among years, we counted duck carcasses along permanent transects that were established in 1992 (Fig. III-2-1). These transects were designed to obtain a large enough sample of carcasses to use as an index to mortality that could be compared among years. There were two types of transects: belt and edge transects. Belt transects, 10 m wide, were either circular, surrounding ponds, rectangular, following UTM grid lines, or radial, radiating out from a central location. Edge transects followed edges of ponds that were

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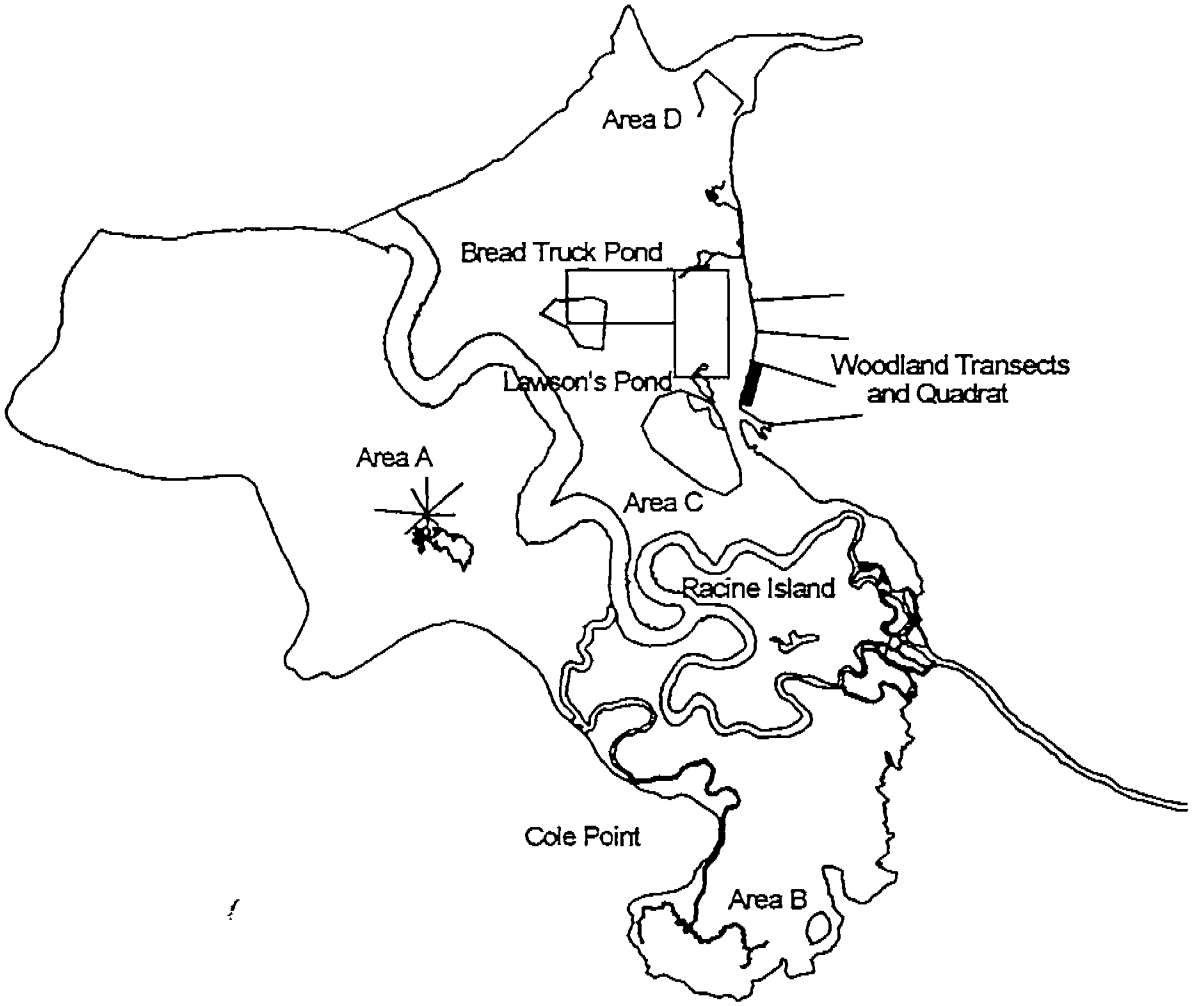

Figure III-2-1. Transects used to monitor mortality in and around Eagle River Flats in 1995.

heavily used by waterfowl. Belt transects were walked by one or two observers in a zigzag pattern to detect all carcasses. Edge transects were surveyed by canoe or walked if the water was too shallow. Each transect was covered at least once every 6 days. Previous studies (CRREL 1993) indicated that after 9 days some carcasses sink low in the water, start to decompose, and might not be seen. Transects were monitored from April 28 until May 30 and from August 17 to October 20, 1995.

During spring migration, almost all dead or dying ducks are eaten by predators or scavengers, primarily bald eagles. Some are consumed where they are captured and some are carried to other locations. Thus, in the spring, we supplemented transect counts with counts of feather piles on (1) a 1-ha quadrat in the woodland immediately adjacent to Area C, and (3) belt transects, 15 m wide by 400 m long extending into the woodland from the edge of ERF (Fig. III-2-1). Four of these latter transects were randomly positioned near area C and have been walked since 1993. Counts of woodland areas were made once at the end of spring migration in late May. Spring mortality rate was also measured by observation of bald eagles eating or removing dead or sick ducks from ERF during fixed observation periods of 2 hours. Eight of these timed observations were conducted in 1995.

The number of ducks dying within an area depends not only on the amount of WP contamination, but also on the exposure rate of ducks, i.e., the number of ducks using a contaminated area. We measured exposure rate by counting all ducks in each area from Cole Point in each morning throughout the field season. Although the counts from Cole Point do not represent all the ducks present, we assume that they represent a constant proportion of the total ducks and are thus useful for making comparisons among years. On days when fog or logistics precluded counts from Cole Point, populations were estimated by taking the average of the adjacent days.

Reference areas

We measured mortality in three reference or control areas in other parts of Cook Inlet. Control areas were located by helicopter flights over Palmer Hay Flats, Goose Bay, and Susitna Flats (Fig. III-2-2). We searched areas which contained concentrations of ducks on habitat similar to that at ERF. Mortality rate was estimated by the same methods used at ERF: exposure rate was measured by summing daily counts of ducks in the ponds adjacent to the transect (within 100 m), and carcasses were counted on the transects at approximately 6 day intervals. Counts of ducks in control areas were made from a helicopter, except in spring on Susitna Flats where duck hunting camps provided enough height to view the ponds from the ground. Edge transects, similar to those described above, were placed around each reference area.

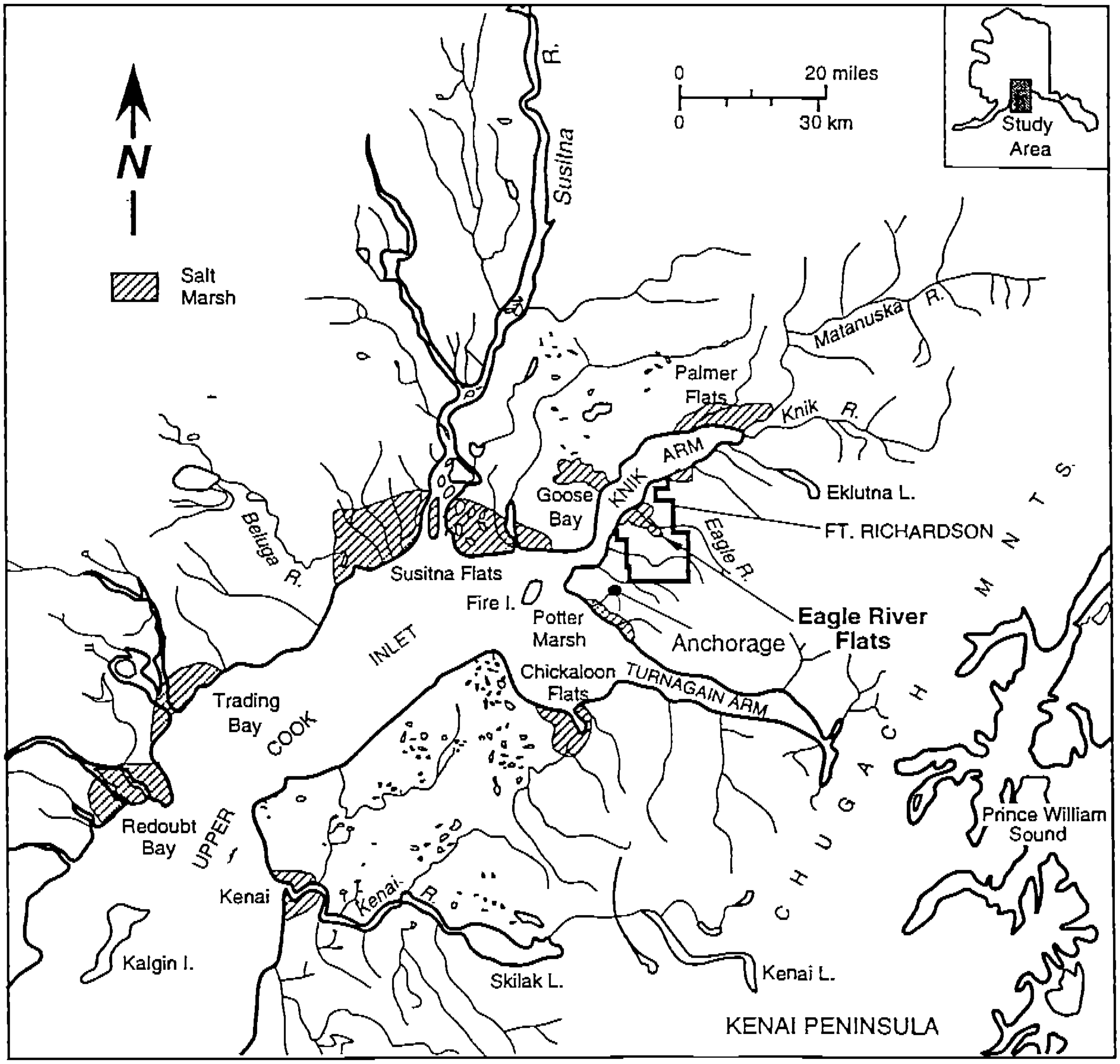

Figure III-2-2. Upper Cook Inlet, showing tidal salt marshes (shaded) including ones used a reference areas.

New transects

We established additional transects in areas B and D. Few carcasses have been found in these areas and white phosphorus has not been detected in sediments. These transects were walked, canoed, or surveyed from the air once at the end of the spring field season. The purpose of these transects was to see if hazing and other activity in contaminated areas might force ducks into areas which are used infrequently and thought to be uncontaminated but which may have some WP.

Swan use and mortality

Numbers and locations of swans were recorded during daily censuses from Cole Point. We also monitored swan movements and locations whenever we were on ERF. Other groups cooperated in this effort. We checked all areas that swans visited for possible swan mortality.

Analyses

For analysis, all transects in an area of ERF were combined and compared to the exposure rate in that area. For example, the belt and edge transects at A were summed, the circular belt transect, the rectangular belt transect, and the edge transect were summed at C, and the circular belt transect and the rectangular transect were summed at Bread Truck. The first count of carcasses on each transect is not included in the analysis because we do not know when these moralities occurred or the exposure rate before our first count from Cole Point.

Differences in mortality among years were detected with analysis of covariance with year and area as main effects and duck exposure rate as a covariate. Because of the large number of zeros for transect counts, the data were transformed by adding 0.1 to all counts and taking the square root. Chi-square analyses were also used to detect differences in mortality rate among years. These analyses compared the number of carcasses in relation to the total exposure rate in each year. The chi-squared analysis does not assume a normal distribution, and thus is a more valid test for data in which there are many zeros.

RESULTS

Differences in mortality between years

Spring mortality

The level of duck use of contaminated areas of ERF was much lower than in previous years. In areas C, A, and Bread Truck (BT), the exposure rate was

Table III-2-1. Mortality and exposure rate on transects within ERF, spring of 1992 through 1995. Exposure rate is the number of ducks observed using an area summed over the days of observation.

		Feather piles or carcasses		
Year	*Exposure rate*	*Transects within ERF*	*Woodland transects*	*Woodland quadrat*
		Area C		
1992	6769	74	80	117
1993	2428	18	18	37
1994	2291	1	4	11
1995	749	0	0	0
		Area A		
1992	4016	24		
1993	4032	9		
1994	3807	0		
1995	986	0		
		Area BT		
1992	976	19		
1993	526	3		
1994	891	0		
1995	290	0		
		Area B		
1995	654	1		
		Area D		
1995	805	0		

approximately 30 percent of that in previous years (Table III-2-1). Very few carcasses or feather piles were found in spring 1995. No carcasses or feather piles were found on permanent transects within ERF (Table III-2-1). No feather piles were found on the woodland transects or on the woodland quadrat. A total of 11 carcasses or feather piles were found by NEILE personnel and others, but none were on transects. This was the lowest count of carcasses for any previous field season. Values of zero preclude statistical analysis and produce mortality ratios of zero (Fig. III-2-3, III-2-4). It is tempting to conclude that mortality was low, but with this low exposure rate, such a conclusion would be premature.

No carcasses were found on the new transect in area D, but one feather pile, from a northern shoveler, was found on the new transect in area B.

As in 1994 the rate of predation on sick or dying ducks was much lower than in 1992 or 1993 (Table III-2-2). Twelve hours of observation were spent overlook-

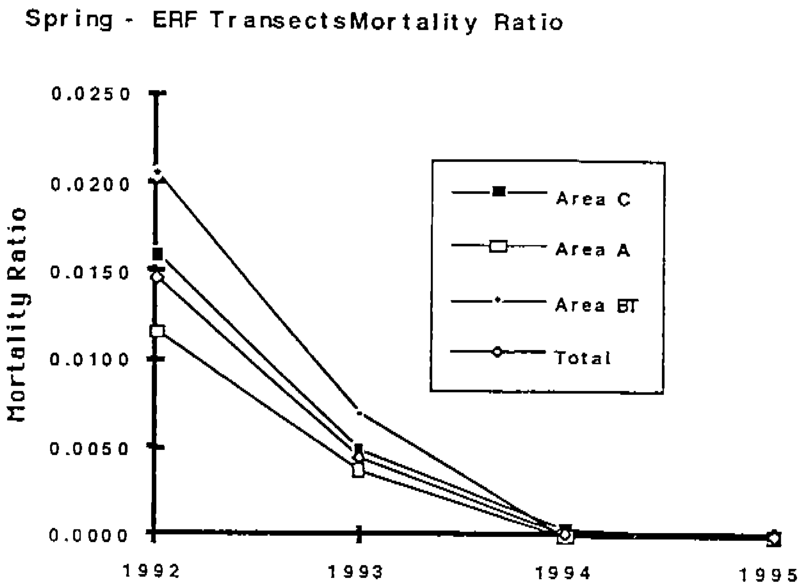

Figure III-2-3. Mortality ratio (ratio of carcasses found on transects to exposure rate in that area) on transects within ERF in spring 1992–1995.

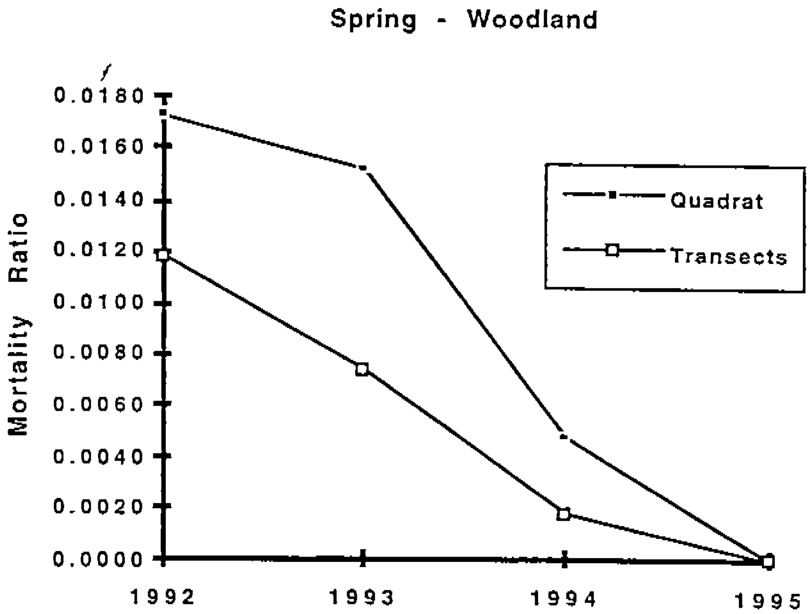

Figure III-2-4. Mortality ratio (ratio of carcasses found on transects to exposure rate in that area) on woodland transects and the woodland quadrat adjacent to ERF in spring 1992–1995.

Table III-2-2. Predation observations during standardized observation periods in spring, 1992 through 1995.

Year	*Hours observed*	*Number of predation events*	*Ducks* present*
1992	31	67	2574
1993	79	19	6241
1994	22	0	1680
1995	12	1	840

* Number of ducks in the area being observed, summed over each observation period.

ing area C or an area including C/D, BT and part of coastal east. Only one instance of a bald eagle picking up a carcass was observed. Four additional hours of observation were made for which the number of ducks present is not known. No predation events were observed during these four hours. Again, the zeros prevent statistical comparisons, but it is evident that predation events were rare compared to previous years.

Fall mortality

More carcasses were found at ERF in Fall than have been found since 1992, a year of very high mortality. A total of 210 duck carcasses were found, 109 of which were on transects. As in previous years, these were mostly mallards (110 carcasses), northern pintail (56 carcasses), and green-winged teal (29 carcasses). We were not able to identify the other carcasses. Fifty three carcasses were found on the permanent transects in areas A, C, and BT (Table III-2-4). In addition to these 53, 16 were found on the first check of the transects, but are not included in the analysis because we do not know the exposure rate for these carcasses (see Methods).

The increased number of carcasses in 1995 resulted from an increase in exposure rate (Table III-2-3). More than four times as many ducks were counted than in any previous year. The increase in duck use was especially marked in area C and Bread Truck. Because of this increase in exposure rate, despite the higher number of carcasses counted, the overall mortality rate decreased from 1994 to

Table III-2-3. Exposure rate and counts of duck carcasses on transects during fall, 1992–1995.

	Area A		*Area C*		*BT*		*Total*	
Year	*Carc.**	*E.R.*†	*Carc.*	*E.R.*	*Carc.*	*E.R.*	*Carc.*	*E.R.*
1992	93	1709	24	769	9	366	126	2844
1993	7	1605	6	1938	3	511	16	4054
1994	9	1467	5	1062	7	1072	21	3601
1995	15	2889	29	8694	9	5713	53	17296

* Carc. = Carcasses

† E.R. = Exposure Rate, measured as the number of ducks present in an area, summed over the number of days between transect counts.

Table III-2-4. Analysis of covariance of number of carcasses counted on transects in 1992 through 1995.

Source	*d f*	*Sum of squares*	*F*	*Prob. of > F*
Model	12	51.83	12.98	0.0000
Error	83	27.61	$R^2 = 0.65$	
Total	95	79.45		
		Effects		
Year	3	24.01	24.06	0.0000
Area	2	4.33	6.50	0.0024
Exposure	1	8.17	24.54	0.0000

1995. Analysis of covariance showed a significant difference in mortality among years, considering 1992 to 1995 (Table III-2-4), as did the chi-square analysis (X^2 = 526.20, df = 3, p = 0.0000). The overall difference between years is caused by a difference between 1992 and 1993 as reported previously (Reitsma and Steele 1994), but also by a significant decrease between 1994 and 1995. Total mortality (summing all areas) was lower in 1995 than in 1994 (X^2 = 6.41, df = 1, p = 0.0113) as was mortality in Bread Truck (X^2 = 9.34, df = 1, p = 0.0022). Mortality rate declined, but not significantly in area C (X^2 = 0.509, df = 1, p = 0.4755), and in area A (X^2 = 0.156, df = 1, p = 0.6928). These statistical results are reflected in the mortality ratios, made by dividing the number of carcasses by the exposure rate (Table III-2-5, Fig. III-2-5). There was a slight decrease in areas C and A, and a more dramatic decline in the Bread Truck Pond.

The increase in exposure rate was partly due to higher total populations of ducks in fall 1995 compared to previous years, but primarily due to a different

Table III-2-5. Ratios of carcasses counted on transects to the exposure rate in the appropriate area. Spring counts or carcasses include feather piles as well as carcasses.

Year	1992	1993	1994	1995
		Fall		
Area C transects	0.0312	0.0031	0.0047	0.0033
Area A transects	0.0544	0.0044	0.0061	0.0052
Area BT transects	0.0246	0.0059	0.0065	0.0016
Total transects	0.0443	0.0039	0.0058	0.0031
		Spring		
Area C transects	0.0159	0.0050	0.0002	0
Area A transects	0.0117	0.0039	0	0
Area BT transects	0.0205	0.0070	0	0
Total transects	0.0146	0.0045	0	0
Woodland quadrat	0.0173	0.0152	0.0048	0
Woodland transects	0.0118	0.0074	0.0017	0

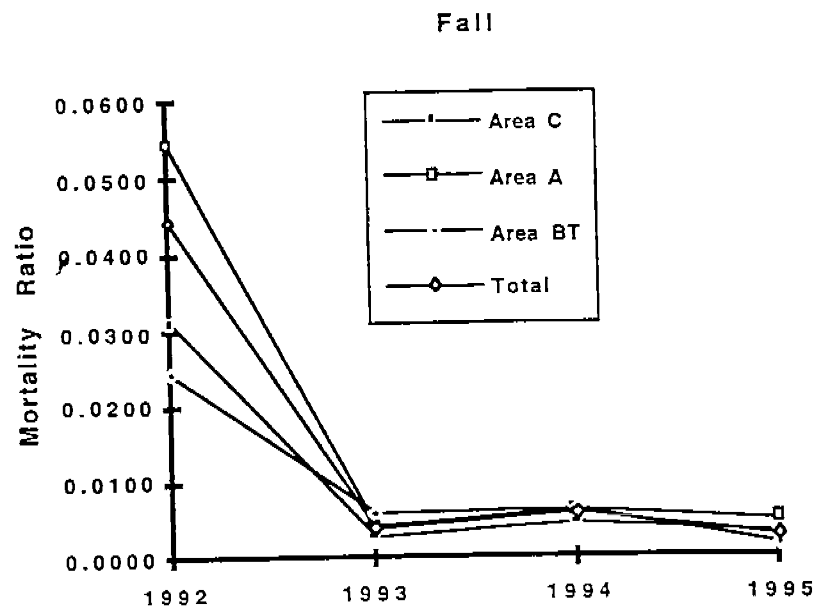

Figure III-2-5. Mortality ratio (ratio of carcasses found on transects to exposure rate in that area) on transects within ERF in fall 1992–1995.

distribution of ducks within ERF. In 1994, many more ducks were present in non-contaminated areas, mainly B, D, coastal east and coastal west, than in contaminated ones, C, A and BT (Fig. III-2-6). This difference is especially pronounced after August 25, when hazing began. In 1995, ducks were more evenly

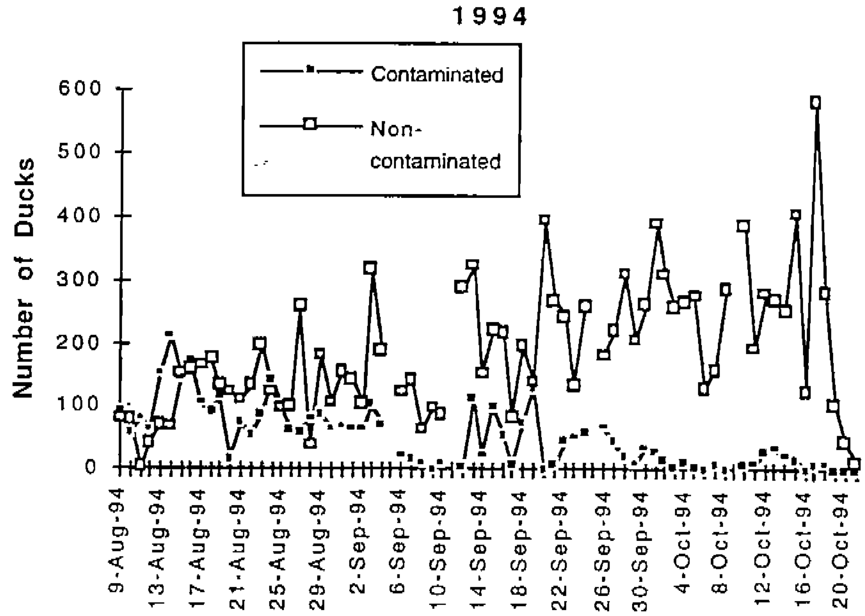

Figure III-2-6. Ducks counted from Cole Point in contaminated (area A, C and Bread Truck) and non-contaminated areas (all others) in fall 1994.

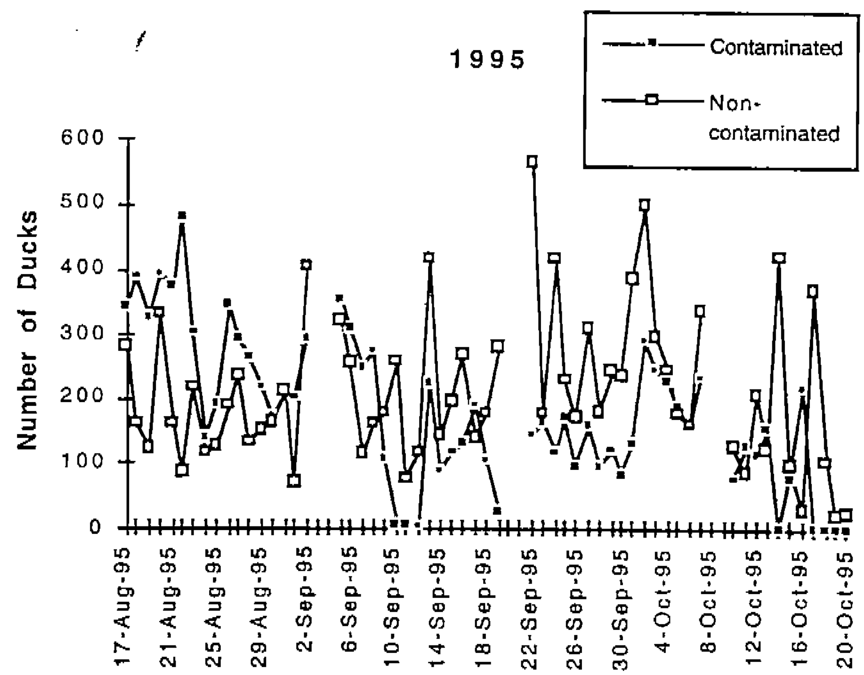

Figure III-2-7. Ducks counted from Cole Point in contaminated (area A, C and Bread Truck) and non-contaminated areas (all others) in fall 1995.

Table III-2-6. Carcasses found on transects in Racine Island, Lawson's Pond and in other areas of ERF, fall 1994 and 1995.

Year	*Racine Island*	*Lawson's Pond*	*Other areas**
1994	28	19	41
1995	18	16	101

* These were found by NEILE personnel and others. The amount of effort spent searching is not standardized.

distributed between contaminated and non-contaminated areas (Fig. III-2-7). This increase in populations in areas A, C and BT accounts for the higher exposure rate in contaminated areas in 1995.

Counts of carcasses on transects in two highly contaminated areas, Racine Island and Lawson's Pond, were lower than in 1994 (Table III-2-6). It is impossible to get accurate counts of the number of ducks using these areas because the vegetation shields a large percentage of the open water from our observation station at Cole Point. Therefore, we cannot compare the mortality rate between years. These results merely mean that significant numbers of ducks are still dying in these areas.

Two checks of the new transects in areas B and D yielded no carcasses.

In summary, spring mortality rate was similar in 1992 and 1993, but dropped significantly in 1994 and appeared to remain low in 1995, although the low exposure rate precludes strong conclusions about mortality rate in 1995. In fall, mortality dropped in 1993 and remained low in 1994 and dropped slightly in 1995 despite higher use of the flats by ducks.

Mortality in reference areas

Three reference or control sites were located. First, on Goose Bay, two rectangular transects were placed in an area of shallow water with emergent sedges and other vegetation similar to vegetation between C/D and Bread Truck at ERF. Second, transects were placed around two adjacent ponds near the western end of a string of ponds running between the Little Susitna and Big Susitna Rivers. We called this area Little Susitna. Third, a transect was placed around a larger pond

Table III-2-7. Mortality and exposure rate on transects in non-contaminated reference areas, spring and fall 1995. Exposure rate is the number of ducks summed over the days between transect checks.

Area	*Exposure rate*	*Carcasses or feather piles*
	Spring	
Goose Bay	151	0
Little Susitna	377	0
Big Susitna	635	0
Subtotal	1163	0
	Fall	
Goose Bay	54	0
Little Susitna	4000	1
Big Susitna	1353	0
Subtotal	5407	1
Total	6570	1

between Little Susitna and the mouth of the Big Susitna River. We called this third area Big Susitna. The latter two areas were shallow ponds with muddy bottoms similar to habitat in areas C or Bread Truck.

These areas were not identified until late in the spring migratory period (May 18) and duck use was relatively low, although similar to that at ERF during the same period. In fall, duck use was much greater and we measured mortality in these areas until the beginning of hunting season in September. No carcasses were found on transect checks in the spring (Table III-2-7), although two feather piles were found that dated from before the transect checks. (Our procedure eliminated carcasses from ducks that died before the first check because the exposure rate is not known before censuses are made. See Methods). In the fall, one feather pile was found on the transect at Little Susitna. No carcasses were found on the other transects. Summing exposure rate in spring and fall results in a mortality ratio of 0.00015, a value more than an order of magnitude lower than most mortality ratios at ERF. Because this estimate of mortality is based on only one carcass, it is evident that a much bigger sample size is needed to accurately estimate mortality on non-contaminated sites. However, it is also evident that mortality rate at ERF is much higher than background mortality.

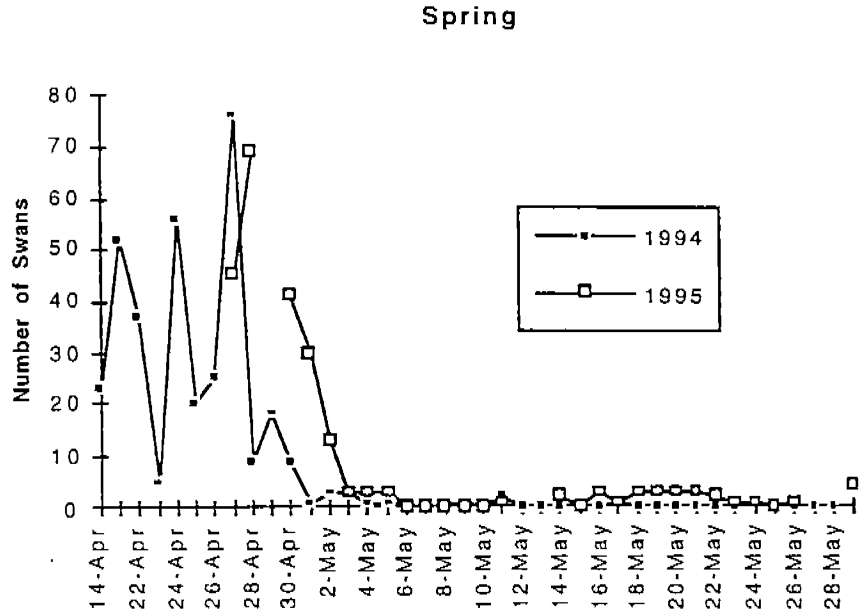

Figure III-2-8. Counts of swans from Cole Point, spring 1994 and 1995. Counts include all areas of ERF.

Swans

Swan numbers were low in the spring of 1995 (Fig. III-2-8). A total of 235 exposure days for swans and a high count of 69 swans on 29 April resulted in only one mortality (Table III-2-7). On May 2, a swan carcass was found in area A. Our field season (starting April 27) may have begun just after the peak migration season this spring. By 4 May, swan numbers had dropped to less than four per day for the rest of the migration period. By missing the early part of the migration period in spring 1995, we have underestimated the total number of exposure days for swans in the spring, but it is unlikely that any mortality went unnoticed as swan carcasses are visible for a least several weeks.

Fall swan migration peaked in late September in 1995, as it did in 1994 (Fig. III-2-9). A total of 3172 exposure days for swans and a high count of 414 swans on 28 September resulted in 4 deaths (Table III-2-7). All four deaths (4 adult tundra swans) occurred in Area D and were first observed (from Cole Point) on 2 October. These birds were collected for WP analysis. We observed no swans in contaminated areas prior to these deaths; however, Mike Walsh

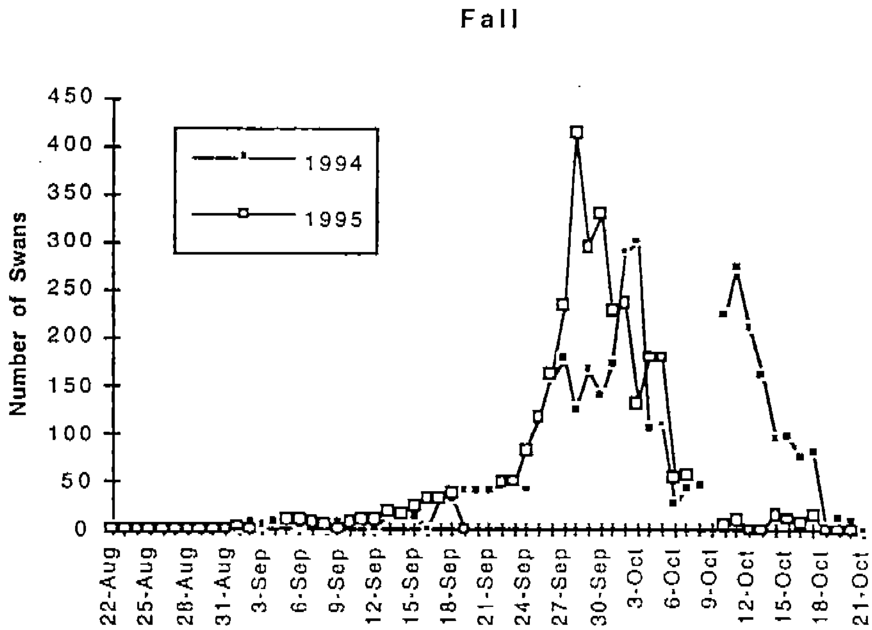

Figure III-2-9. Counts of swans from Cole Point, fall 1994 and 1995. Counts include all areas of ERF.

(CRREL) noted 6 swans in Area A in the early morning of 9 September well before the observed mortality. Swans may have been visiting contaminated areas after dark and before the first field crew arrived at ERF in the mornings.

DISCUSSION

The overall mortality rate at ERF declined between fall 1994 and fall 1995, despite an increase in duck use and number of carcasses found on transects. This decline was statistically significant at the Bread Truck and when all transects were combined. This decline, despite increased duck use, suggests that the declines in mortality rate reported in previous years (Reitsma and Steele 1995) were real and not an artifact of hazing and other activity on the Flats. The fact that the greatest decline in mortality occurred at the Bread Truck suggests that natural attenuation or remediation efforts may have been most successful in this area. The Bread Truck Area contains a large amount of intermittent pond that dries out between flooding high tides, allowing white phosphorus to oxidize (Walsh and Collins 1995). The high water levels in 1995 (Collins, this volume) may have caused more ducks to feed over sediments that had been exposed in the past and thus had been depleted of white phosphorus. Also, the high sedimentation rate in Bread Truck and other areas (Lawson et al., this volume) may be burying contaminated sediments and limiting exposure to ducks.

The increase in duck use in contaminated areas despite a relatively small increase in total ducks using the Flats in fall 1995 points out the effectiveness of hazing in previous years. In 1994, most of the ducks on the flats were in non-contaminated areas, while logistical problems limited hazing in 1995 and ducks were much more common in contaminated areas.

The overall mortality rate has declined since 1992 by more than an order of magnitude but is still higher than in reference areas outside of ERF. Despite an overall exposure rate similar to that at some areas of ERF, only one carcass was found on reference transects. In order to compare reference and remediated areas statistically, we will need a larger sample size. Another spring and fall season of measurements on reference areas should be sufficient for comparison to ERF.

The fact that mortality rate continues to decline before full-scale remediation has begun suggests that the no action alternative may be sufficient to remediate at least some areas of ERF. The decrease in mortality rate is slow and it may be several years before it has declined to an acceptable level, but the advantage of the no action alternative is that it leaves habitat intact for ducks and other species that use ERF. Eagle River Flats supports a diverse avifauna including 8–10 species of shorebirds, sandhill cranes, arctic terns, herring and mew gulls, four species of swallow, kingfishers, several hawk species, and ravens, in addition to ducks, three species of geese, and swans. In fact, ERF may be more important as a staging area for shorebirds than it is to ducks. Dredging and draining ponds may decrease the quality of the habitat for any of these species (although it may increase it for others). The overall value of ERF as a wildlife habitat should be carefully considered before a remediation method is chosen.

Transects and other observations in areas B and D indicate that increased use of these areas because of hazing in contaminated ponds has not forced ducks into previously unidentified contaminated areas.

The pattern of the 1995 fall migration of swans closely followed that of fall 1994. Swans in both falls first used areas B and D exclusively and only after many days were seen in other areas of ERF. It is possible that this heavy use of areas B and D is due to hazing, but observations of swans suggest that they do not react to direct pyrotechnic assaults when flying over contaminated areas. It is likely that Areas B and D are preferred habitat for swans due to deep water and associated food. In 1995, as in 1994, swans were not seen in contaminated areas prior to swan carcasses being found. Thus we do not know where these birds are exposed to white phosphorus. Swans may move into contaminated areas before dusk and after observers have left the Flats and depart before observers arrive in the morning, or there may be an as yet unidentified hot spot of white phosphorus in deeper water that is accessible to swans but not to ducks. Areas D and B have not been sampled extensively. Forty-five sediment samples have been taken in B and 49 in D (Racine 1995). A small "hot spot" could have been missed. Swans frequent the larger pond in area C/D where 4 of 49 sediment samples have detected white phosphorus, although at low levels (maximum concentration was 0.012 µg/g, Racine 1995). It is possible that this pond contains enough white phosphorus to supply lethal doses to swans.

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III-3. ANALYSIS OF WHITE PHOSPHORUS IN BIOTA AT EAGLE RIVER FLATS, 1995 FIELD SEASON

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INTRODUCTION

The primary objective of this proposal was to determine the presence of WP in biota collected from ERF. These samples could include eggs, ducks dying in unusual locations or unusual numbers, uncommon species found dead such as swans, cranes, etc. The intent was to determine if WP was associated with the death of the wildlife species.

METHODS

Biological samples were collected at ERF, frozen, and shipped to Dartmouth Medical School for analysis of WP. At collection, a field incidence form was completed and the location where the carcasses were found was noted on a map provided. At Dartmouth, carcasses were thawed enough so that tissue and/or organs could be dissected free of the carcasses. The remainder of the carcass was frozen in case further analyses become necessary. Tissue was finely minced with scissors in 40-mL vials, 10 mL isooctane added and shaken for 1 hour to extract WP. Gizzard contents were collected by gently scraping from the gizzard and washing the fine materials from the gizzard with deionized water. These samples often were not homogeneous and contained various mixtures of vegetative matter, sand, sediments and secretory fluids for the digestion of food. The quantities of water needed to collect the gizzard contents greatly varied from 5 to 50 mL. All contents and rinse water were retained for analysis of WP. In some cases the contents and rinse water were greater than the capacity of the sample bottles. In those cases, the contents were divided into separate vials. The quantities of WP determined in the separate vials were summed to give the reported value.

RESULTS

Results are presented in Table III-3-1. Thirty-one biological samples were collected and shipped to Dartmouth. In the spring of 1995, 5 samples were collected and in the fall of 1995, 26 samples were collected.

In the spring, a coyote was found near the EOD pad. Analysis of its muscle revealed no WP. There was very little fat on the carcass and an analysis of that tissue was not possible. A sandhill crane also was negative for WP. Of the commonly poisoned species, a tundra swan and two pintails were found dead. The swan and one pintail were positive for WP with very small quantities (0.0238 and 0.0493 μg WP) in the gizzards.

In the fall, only avian species were found and collected. Twenty-six samples were found, shipped and analyzed. Of these birds, 20 had detectable WP. Five of 6 pintails had WP. Three of 5 green-winged teal had WP. Eight of 11 mallards had WP. And 3 of 4 swans had WP. Stated another way, 6 of the 26 birds collected in the fall at ERF did not have WP. This represents a 20% incidence of death that is not obviously associated with WP. The quantities of WP found in gizzards ranged from 0.273 μg to 21.4 mg.

Area C remains highly contaminated and most of the birds that were positive for WP were from that area. Of birds positive for WP, 3 were found in Area A and 3 in Area D.

Table III-3-1. White phosphorus analysis of Eagle River Flats autopsies (1995).

Date collected	Species	Sex	Collection location	ID #	Gizzard contents (µg WP)
2-May	Tundra swan	male	W. of A Pond within 200 m of A Tower	-	0.0238
4-May	Coyote*	-	Behind Canoe Pt. Tower in woods	-	not detected
7-May	Pintail	male	E. Side Pond @ BTP (Bread Truck Pond)	-	0.0493
10-May	Sandhill crane	-	South end of horseshoe-shaped pond beneath Cole Pt. toward Racine Is.	-	not detected
11-May	Pintail	female	E. Side Pond @ BTP	-	not detected
10-Aug	Pintail	female	200 ft. from C Tower	182	2.71
18-Aug	Pintail	female	South of area C Tower	1	not detected
19-Aug	G-w Teal	male	W. end of C Pond	14	0.592
21-Aug	Mallard	male	West A Pond	36	0.231
24-Aug	Mallard	female	Racine Island	43	1.19
25-Aug	Mallard	male	Area C	65	1.29
26-Aug	Mallard	female	Lawson's Pond stake #9	87	125
26-Aug	Mallard	female	Area C near Clunie Creek in Pond	79	0.273
26-Aug	Mallard	female	CD area near CD Bluff	76	not detected
29-Aug	Mallard	female	CD Channel N of Clunie Creek	91	not detected
31-Aug	Pintail	female	4 m. south of stake #5, on C-edge transect	114	not detected
31-Aug	Pintail	male	Area A	185	80.9
2-Sep	Pintail	male	Canoe Pt. channel	183	0.132
6-Sep	Pintail	female	North Pond of C Pond	134	2.08
7-Sep	Pintail	female	BTP	152	0.606
8-Sep	G-w teal	female	BTP	186	11.4
10-Sep	G-w teal	-	Near the mouth of Big Susitna River	951129BE1	not detected
14-Sep	G-w teal	male	BTP, northwest corner	180	5.12
14-Sep	G-w teal	male	BTP, northwest corner	181	0.444
2-Oct	Tundra swan	-	Area D, ponded area	199	23.66
2-Oct	Tundra swan	-	Area D, ponded area	200	578.23
2-Oct	Tundra swan	-	Area D, ponded area	201	1456.2
2-Oct	Trudra swan	-	Area D, ponded area	202	not detected
7-Oct	Mallard	male	20 m. E. of mid E-W UTM stake on BTP rectangle	208	not detected
13-Oct	Mallard	male	Mid-C Pond	214	21400
14-Oct	Mallard	male	15 m. south of Lawson's Pond transect stake #1 between C-Pond & Clunie Creek	215	49.5

* leg muscle

DISCUSSION

Approximately 20% of the birds collected at ERF did not have detectable WP in their gizzards. At present it is not certain if WP that is associated with or causes death could degrade to undetectable quantities either prior to death or subsequent to death, but prior to freezing of the carcass. In the birds with no WP, we have analyzed adipose tissue and skin. In every case, we found no WP. WP is more stable in lipid tissues (Nam et al. 1994); thus, this seems to confirm that these individuals were indeed devoid of WP. Since there is no other toxicant identified at ERF associated with avian mortality, it is most probable that a natural death rate is contributing to the deaths observed at ERF. More work needs to be done to actually identify this natural death rate. It is at present uncertain if avian species can be poisoned lethally with WP and still survive long enough for depuration (degradation) of WP from the animal prior to its death.

Of the birds with WP in their gizzards, the quantities were quite variable. This very wide range was seen previously with quantities of WP ranging over five orders of magnitude in gizzards (Roebuck et al. 1995).

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III-4. MOVEMENT, DISTRIBUTION AND RELATIVE RISK OF WATERFOWL AND BALD EAGLES USING EAGLE RIVER FLATS

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INTRODUCTION

The U.S. Army has used Eagle River Flats (ERF), Fort Richardson, Alaska, since 1945 as an impact area for artillery shells, mortar rounds, rockets, grenades, illumination flares, and Army/Air Force Door Gunnery Exercises. In August 1981, hunters discovered large numbers of duck carcasses in ERF. Since that time, the Army and other federal and state agencies have been involved in identifying the cause of the waterfowl mortality. On February 8, 1990, the Army temporarily suspended firing into Eagle River Flats due to the suspected correlation between explosives and duck deaths (Quirk 1991). In July 1990, a sediment sample collected from ERF was suspected of containing white phosphorus (WP). By February 1991, it was concluded that WP in ERF was the cause of waterfowl mortality (CRREL 1991).

ACKNOWLEDGMENTS
We thank the U.S. Army 6th Environmental Center, U.S. Army 6th Infantry Division (Light), the Cold Regions Research and Engineering Laboratory, and the U.S. Army National Guard. Special thanks to William Gossweiler, Project Manager for financial support of this project, Bill Smith and Laurel Angel, Public Works, Fort Richardson, Alaska, for providing logistical support, Lt. Col. Mark Stigar, Capt. Brian Keese, Chief Warrant Officer 3 Jimmy Keyes, and Chief Warrant Officer 2 Ron Gilson for their superior helicopter flying skills in capturing waterfowl and bald eagles, conducting telemetry and surveying bald eagle nests, and Don Elias, Denver Wildlife Research Center, for editorial comments. We followed criteria outlined by the Animal Welfare Act and the Denver Wildlife Research Center Animal Care and Use Committee during this study. Also, a Section 7-Rare and Endangered Species Consultation was completed prior to the start of the study.

Waterfowl populations, overall, have been decreasing continent-wide (U.S. Fish and Wildlife Service and Canadian Wildlife Service 1989). Many factors affect their numbers, such as the availability of breeding, loafing and feeding habitat. ERF is an important spring (April to May) and fall (August to October) waterfowl feeding and staging area. Contamination of waterfowl feeding areas in ERF with WP represents a serious hazard. During fall migration, August to September 1993, movement, distribution, turnover rate and site-specific exposure of waterfowl species most susceptible to white phosphorus poisoning was determined at Eagle River Flats (Cummings et al. 1994). Sixty-two ducks of five species were captured mainly in areas C, C/D and Bread Truck with mist nets and swim-in traps. Of those, radio transmitters were attached to 12 mallards, 11 pintails and 11 green-winged teal. Tracking data indicated that during August (pre-hazing) telemetry species ranged over the entire Flats. Mallards tended to concentrate in areas A and B, Racine Island and the C/D transition area. Pintails used area C and Bread Truck. Green-winged teal used the C/D transition area and shallow pools in areas A and C. Post-hazing, most waterfowl concentrated in areas B and the C/D transition area. The average daily turnover rate of waterfowl species using the Flats during August and September was about 3%. Using this turnover rate and the data from ERF aerial waterfowl surveys, it is estimated that about 5400 ducks used the Flats during fall migration (August to October). Waterfowl most susceptible to white phosphorus represent about 3900. Eight telemetry ducks were found dead (23%) on ERF: Racine Island (1), area A (3), area C (2) and the C/D transition area (2).

During spring migration, April–May 1994, 34 ducks, 20 dowitchers and 10 bald eagles were captured on ERF using various capture techniques. All birds were fitted with radio transmitters. This included 27 mallards, 4 green-winged teal and 1 northern pintail. Of the 10 eagles, 3 were fitted with satellite transmitters. All eagles transmitters are expected to last 2 years. Tracking data indicated that mallards and teal averaged 6.8 days (range 1–17 days) on the Flats. Average daily turnover for waterfowl was about 5%. Waterfowl mortality during the spring migration period was about 12%. Waterfowl, mallards and teal tended to concentrate in areas C, C/D and D. Waterfowl spent more time in areas B and D, and off the Flats post-hazing. Bald eagles spent an average of 2.9 days on the Flats. Most of the telemetry contacts with eagles were in the wooded areas bordering ERF. Transmitters from three scavenged ducks were found in trees surrounding ERF and at an eagle nest site on the Flats. Eagles fitted with satellite transmitters moved to Kodiak Island and Cordova, Alaska, in late November. No eagle mortality has been documented as of March 1995. Dowitchers spent an average of 6.8 days on the Flats and mainly foraged in highly contaminated areas without any mortality (Cummings et al. 1995).

In 1995, we continued to focus on issues outlined under the CERCLA process for ERF. In the conceptual site model, waterfowl and bald eagles are listed as receptors to the exposure and effects of white phosphorus. On ERF, bald eagles are considered the top avian scavengers of waterfowl poisoned by white phosphorus. In this case, both waterfowl and bald eagles are considered to be prime species in the ERF food chain that would have direct exposure to white phosphorus and be a significant part of the Ecological Risk Assessment. The objectives, as outlined below, of this study are designed to contribute to remedial decisions concerning ERF. The objectives were:

- Determine the daily and seasonal movements and distribution, turnover and mortality rates of waterfowl most susceptible to white phosphorus poisoning at ERF;
- Determine the hazards that waterfowl poisoned by white phosphorus pose to bald eagles at ERF; and
- Establish baseline data for waterfowl and bald eagles with respect to proposed remediation actions.

METHODS

Beginning August 1, 1995, we captured ducks on Eagle River Flats with swim-in traps, mist nets or net-guns. Bald eagles were captured with cannon nets, padded leg-hold traps or net-guns. Ducks and eagles were individually banded with U.S. Fish and Wildlife Service bands. We color-marked ducks on the right wing with a 2.5- × 7.5-cm patagial tag except for green-winged teal, which were marked with a 1.25- × 7.5-cm tag, made from coated nylon fabric (Armorlite, Codey, Inc., Pawtucket, RI). We used pink for mallards, white for northern pintails, and blue for green-winged teal. Eagles were marked with a 10-cm-diameter dumbbell-shaped patagial tag of either white, red, orange, blue, pink, yellow or a double-colored tag combination. The capture and release locations and date, band number, weight, age and sex and other pertinent measurements were recorded for each bird. In addition, all birds were fitted with radio transmitters. Transmitters for mallards and northern pintails weighed 9.1 g; green-winged teal, 3.6 g; and bald eagles, 88 g (satellite). Satellite transmitters had a standard transmitter (16 g) attached so that daily movement data could be collected and birds could be located if satellite transmitters indicated a problem. Eagle transmitters are expected to last for up to 24 months. Waterfowl transmitters were programmed to be active during August, September and October and again during April, May and June 1996. Each transmitter was positioned on the upper back of each bird. Transmitters were attached with a Teflon ribbon harness (Cummings et al. 1993).

Birds (eagles from both 1994 and 1995) were tracked from fixed telemetry towers located on opposite sides of ERF. Each tracking tower was equipped with a notebook containing radio tracking forms, a directional yagi antenna, a compass for determining telemetry bearings, and a two-way radio for communications. Birds were located simultaneously from two fixed tracking towers and/or one mobile unit. The birds were assumed to be near the point where the bearings crossed, and each bearing location was entered onto a radio tracking form. Birds were also tracked on foot, from hovercraft or National Guard helicopter, to determine their status. Towers could receive radioed birds up to 25 km from the Flats. Helicopters were used to track birds up to 90 km from the Flats in areas such as the Susitna Flats, Palmer Hay Flats and Chickaloon Flats.

Following capture and release of eagles (April) and ducks (August), a location for standard radio transmitters was determined daily between 0700 to 1000 and 1500 to 1800 and 2000 to 2200 h during April and May, and August, September and October. Birds that could not be detected as moving or did not move more than 10° in 2–3 days were visually located to determine their status. Dead birds were recovered, or remains were collected to determine the cause of death.

Data from eagles fitted with satellite transmitters were compiled by the Argos Data Collection system, which is a cooperative venture between CNES, the French Space Agency, NASA and NOAA. The Argos data collection receiver is simultaneously carried on two TIROS-family NOAA satellites, which are in 85-km circular orbits. The eagle satellite transmitters or platform transmitter terminals (PPT) are programmed to turn on for 8 hr every 96 hr and will send a message every 60 s. The PTTs differentiated from each other by a unique code built in by the manufacturer. The received messages are recorded and retransmitted to ground stations at Fairbanks, AK; Wallops Island, VA; and Lannion, France. The messages are relayed to Suitland, MD, processed and the data made available to users (DWRC).

In 1993, ERF was divided into seven areas representing sites that waterfowl used for foraging and loafing. Since that time, telemetry data have been plotted and analyzed based on these seven areas. The areas were synonymous with areas used by the U.S. Army to identify specific areas on ERF. The seven areas are A, B, RI (Racine Island), C, C/D, D, and BT (bread truck). Areas A, RI, C and BT have documented high levels of white phosphorus. The activity on different areas of ERF was determined by counting the number of telemetry locations within an area, divided by the total number of telemetry locations for that bird and expressing it as a percentage. These data from radio-instrumented birds were used to address concerns about the relative risk to respective species and to establish baseline data with respect to proposed remediation actions. In addition, these data were used to evaluate the effects of hazing on birds using ERF. Waterfowl movements and distribution in hazed and non-hazed areas were compared pre- and post-hazing.

The daily turnover rate of instrumented birds on ERF was determined by dividing the number of radio-instrumented ducks that departed ERF each day by the total (by species) instrumented. The daily turnover rate was used to determine the relative WP risk to birds using ERF.

Daily activity budgets for radio-instrumented bald eagles nesting on the periphery of ERF were documented. In addition, nesting success of bald eagles nesting on the periphery of ERF was compared to that of bald eagles nesting at Susitna and Chickaloon Flats.

RESULTS

Waterfowl

From August 1 to 17, 1995, 96 ducks were captured, banded and released. Of those, 17 mallards, 16 northern pintails and 21 green-winged teal were each fitted with backpack transmitters (Table III-4-1). The movement of instrumented ducks following release indicated that transmitters did not appear to inhibit movements or activities. Observations indicated that the behavior of instrumented ducks did not differ from that of other ducks in its associated flock. On some occasions,

Table III-4-1. Waterfowl, dowitchers and bald eagles with radio transmitters on Eagle River Flats.

	1993	*1994*	*1995*
Mallards	12	27	17
Pintails	11	1	16
Green-winged teal	11	4	21
Bald eagles	0	10	14
Dowitchers	0	20	0
Banded only	28	2	28
Total	62	64	96

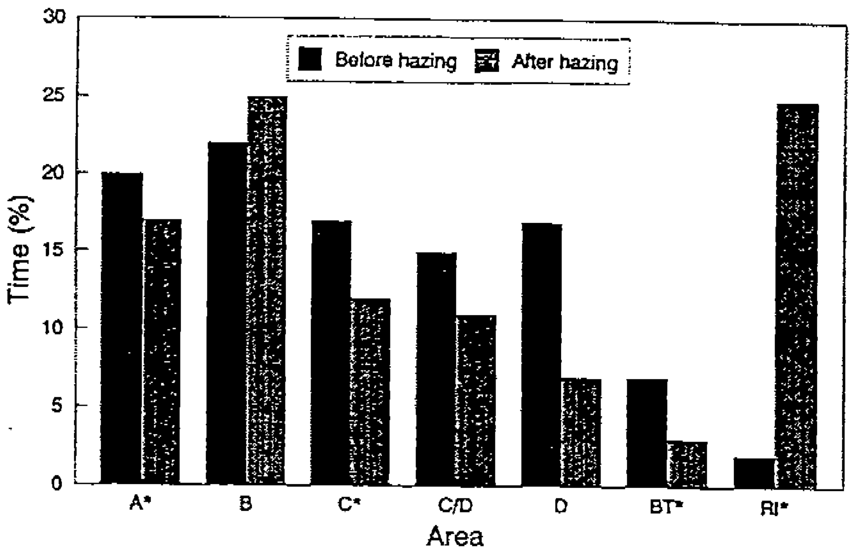

Figure III-4-1. Distribution of mallards on ERF from August 1 to October 17, 1995. The asterisk denotes areas of high WP concentrations. Attempts were made to haze ducks from these areas.

instrumented birds were observed leading flights of ducks. However, about 10% of the instrumented ducks were in various stages of molt when captured. These ducks were noted to remain in the capture/release areas longer than the same species that had completed molt.

Duck movements and distribution on ERF during the fall varied by species. Mallards (n = 17) spent the majority of their time from August 1 to September 5 (pre-hazing) in areas B, A and D (Fig. III-4-1). Use of these areas represented about 60% of the time mallards spent on ERF. Several mallards were documented moving to various locations near ERF, such as the Palmer Hay Flats and Susitna Flats. They spent about 32% of their time off-site (Fig. III-4-2). Mallard use of most contaminated areas on ERF decreased uniformly following the start of the hazing program (September 5) except for RI where use increased substantially (Fig. III-4-1). As hazing continued, the time mallards spent off ERF increased about 18% over pre-hazing levels (Fig. III-4-2).

Northern pintails (n = 16) use patterns were different than mallards (Fig. III-4-3). Pintails spent about 87% of their time in areas A, C/D and D and about 20% of

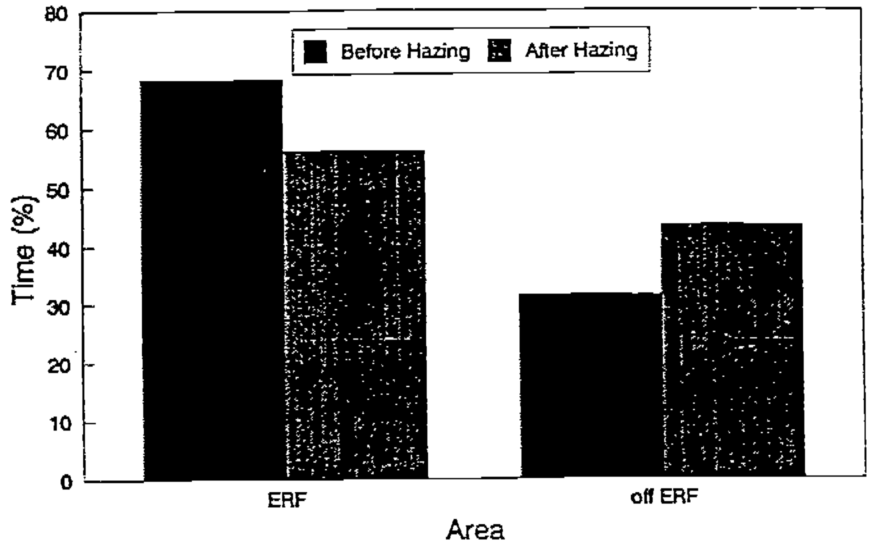

Figure III-4-2. Time mallards spent on and off ERF from August 1 to October 17, 1995.

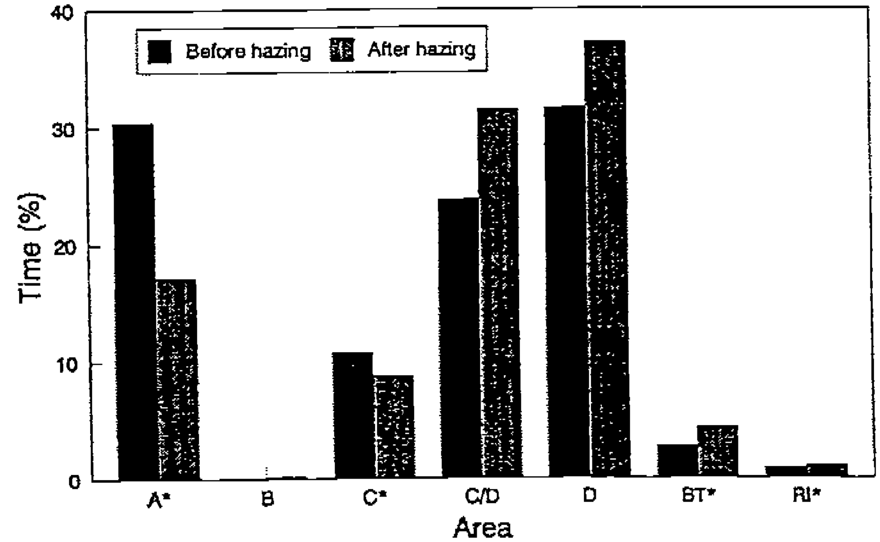

Figure III-4-3. Distribution of northern pintails on ERF from August 1 to October 17, 1995.

their time off the Flats prior to hazing. The use of areas B, BT and RI represented about 5% of pintails' time on ERF (Fig. III-4-3). When hazing began (September 5) on ERF, use of area A and C by pintails decreased as much as 50% and the amount of time doubled that they spent off ERF (Fig. III-4-4).

Green-winged teal (n = 21) use patterns of ERF were similar to pintails (Fig. III-4-5). Teal spent about 63% of their time in areas A and D prior to hazing (Fig.

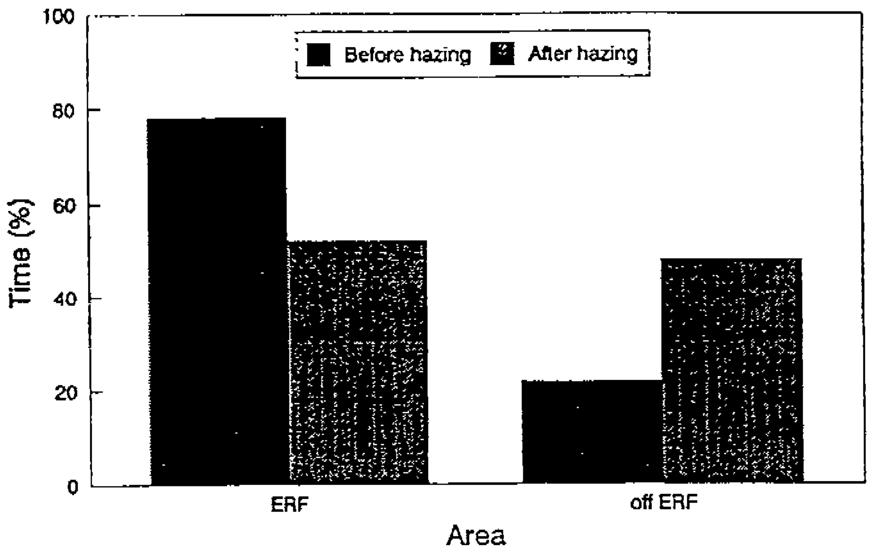

Figure III-4-4. Time northern pintails spent on and off ERF from August 1 to October 17, 1995.

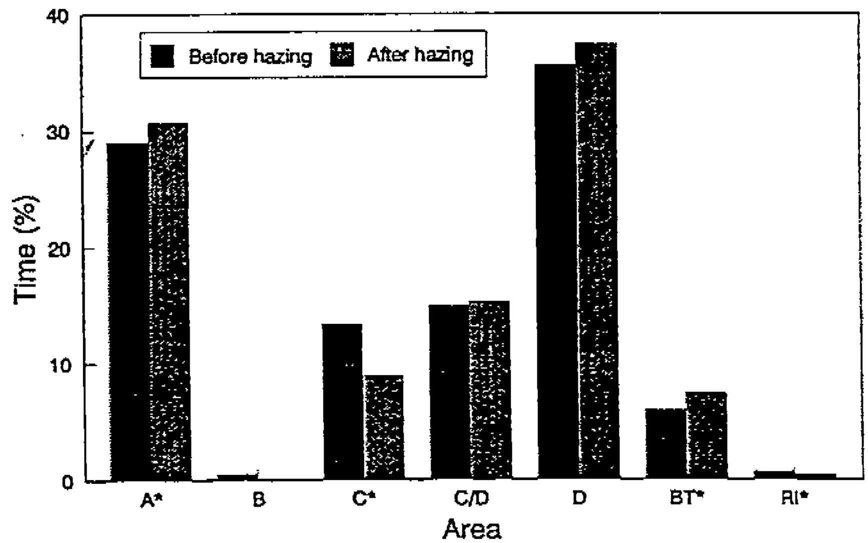

Figure III-4-5 Distribution of green-winged teal on ERF from August 1 to October 17, 1995. The asterisk denotes areas of high WP concentrations. Attemps were made to haze ducks from these areas.

III-4-6). Teal spent <1% of their time in areas B and RI. When hazing began, slight increases were noted in the used areas C/D and D. Also, it should be noted that even though use patterns in areas A, D and BT changed only slightly

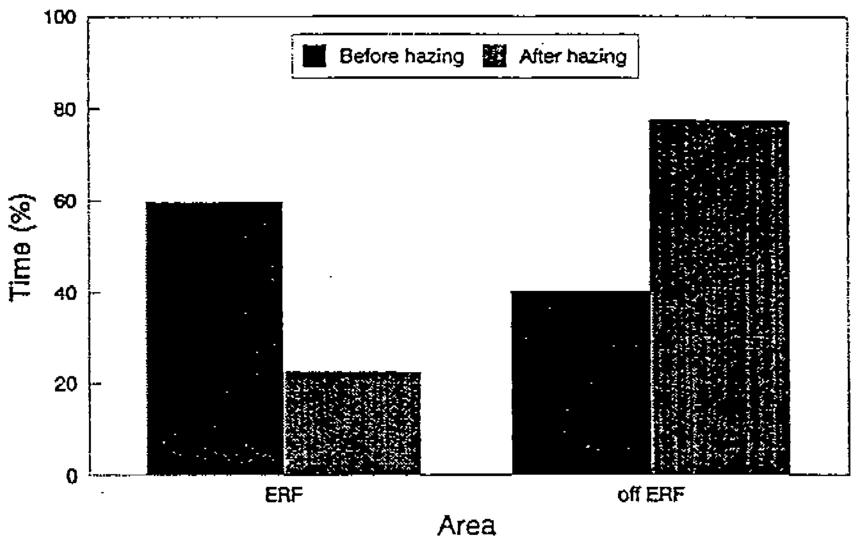

Figure III-4-6. Time green-winged teal spent on and off ERF from August 1 to October 17, 1995.0

between pre- and post-hazing, that teal were using shallow mudflats and ponds in these areas that are not considered contaminated and are not hazed.

Table III-4-2. Fall waterfowl use of ERF, August 1 to October 17, 1995.

	Mallard	*Pintail*	*Green-winged teal*
Birds (no.)	17	16	21
Avg. days on ERF (no.)	39.9	45.9	26.9
Range (no. days)	1–78	6–72	1–51

The average number of days spent on ERF by mallards (n = 17) was 40, range 1–78; pintails (n = 16) was 46, range 6–72; and teal (n = 21) was 27, range 1–51 (Table III-4-2). At the conclusion of the study, October 17, 7 mallards, 6 pintails and no teal remained on ERF (Table III-4-3). These birds were observed using small areas of open water in areas B and D, the Eagle River and several of its drainages. The average daily turnover rate for waterfowl (mallards, pintails and teal) was about 3.8%. Teal had the greatest average daily turnover of 4.7% (Fig. III-

Table III-4-3. Waterfowl captured and the number remaining of ERF through October 17, 1995.

	Mallards		*Pintails*		*Green-winged teal*	
Period captured	*Captured*	*On ERF*	*Captured*	*On ERF*	*Captured*	*On ERF*
August 1–7	14	5	8	2	6	0
August 8–17	3	2	8	4	15	0

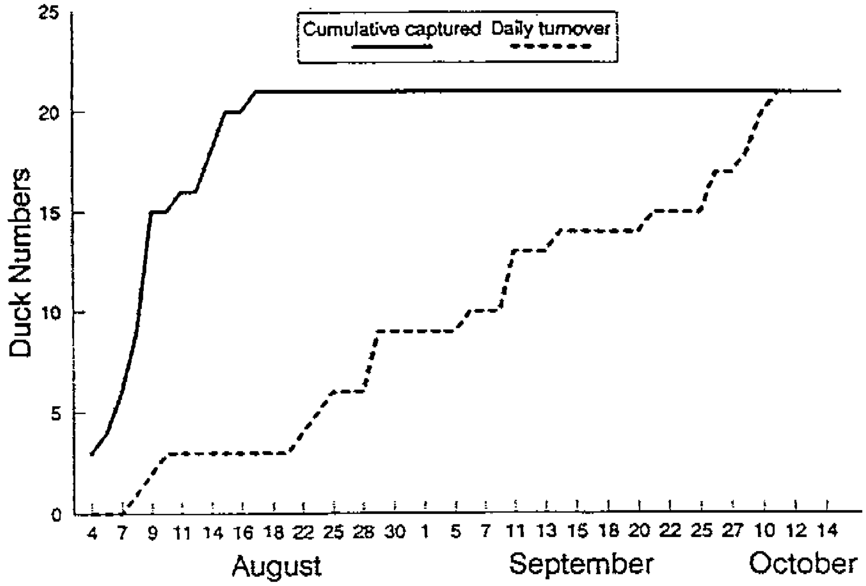

Figure III-4-7. Daily turnover of green-winged teal on ERF from August 1 to October 17, 1995.

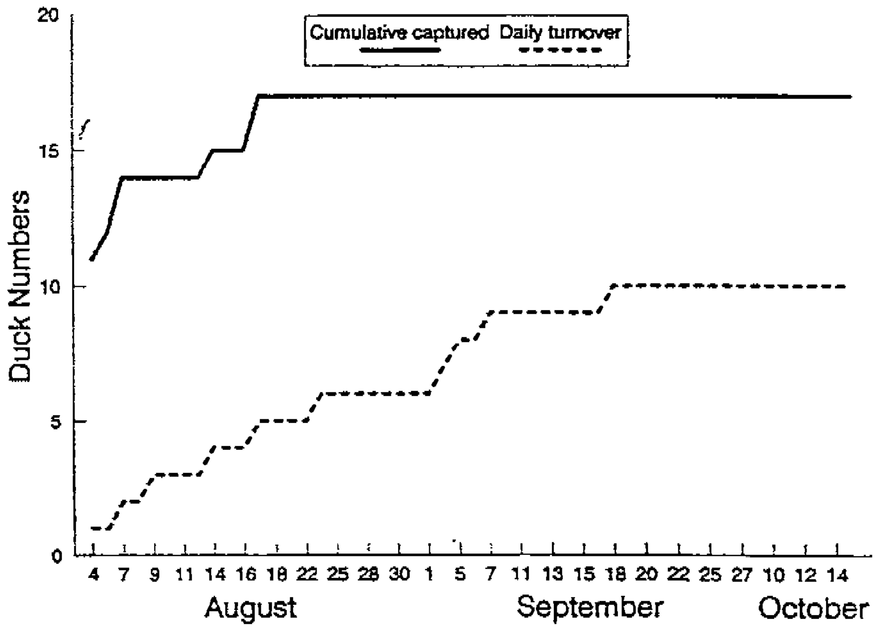

Figure III-4-8. Daily turnover of mallards on ERF from August 1 to October 17, 1995.

4-7), mallards 3.7% (Fig. III-4-8) and pintails 3.1% (Fig. III-4-9). The greatest turnover of waterfowl occurred prior to September 5 where 47% mallards, 37% pintails and 43% teal departed ERF (Table III-4-4).

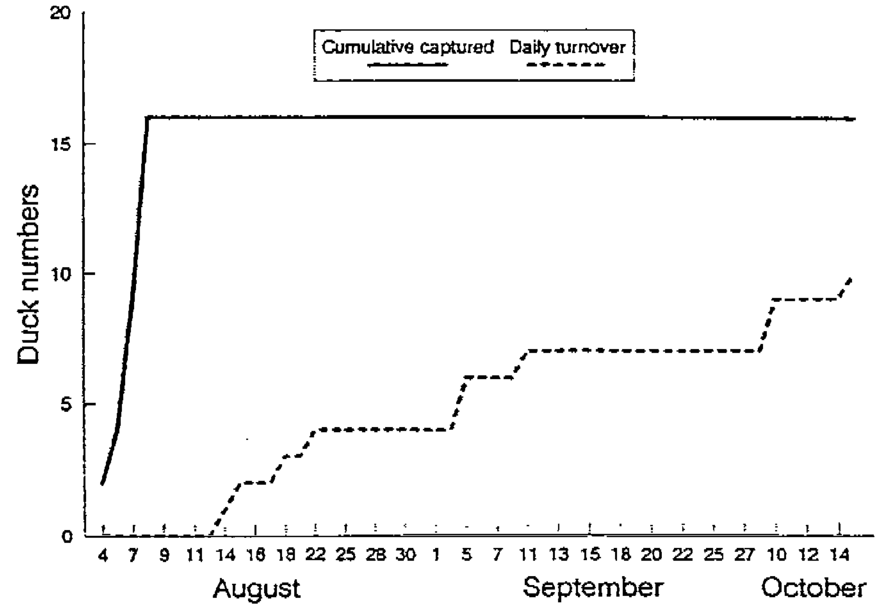

Figure III-4-9. Daily turnover of northern pintails on ERF from August 1 to October 17, 1995.

Table III-4-4. Status of waterfowl on ERF from August 1 to October 17, 1995.

	Number of ducks					
		Mortality		Remaining	Remaining	Observed
Species	Radioed	On ERF	Off ERF	through Sept. 5	through Oct. 17	off ERF
Mallard	17	4	0	9	7	11
Pintail	16	0	1	10	6	11
Green-winged teal	21	1	1	12	0	14
Total	54	5	1	31	13	36

Table III-4-5. Fall waterfowl mortality on ERF, August 1 to October 17, 1995.

	Mallard	Pintail*	Green-winged teal*
Mortality (no.)	4	0	1
Avg. days (no.)	15.75	0	48
Range (no. days)	1–28	0	48

* One pintail and one green-winged teal were recovered off ERF (shot by hunters).

The mortality of instrumented ducks using ERF from August 1 to October 17 was five ducks or about 9% (Table III-4-5). The four mallards found dead during this period were on the Flats between 1 and 28 days, whereas the green-winged teal was on the Flats for 48 days. In addition, two other ducks, one teal and one pintail, were shot by hunters on the Susitna Flat on September 10 and 30, respectively (Table III-4-6). Also, one mallard captured August 18, 1993,

Table III-4-6. Mortality of waterfowl using ERF in 1995.

			Mortality	
Species	*Capture date*	*Cause of mortality*	*Location*	*Date*
Mallard	8/5	WP	Area B	8/7
Mallard	8/1	WP	Area A by tower	8/9
Mallard	8/2	WP	Woods behind EOD pad	9/2
Mallard	8/3	WP	Area C/D	9/7
Green-winged teal	8/2	Hunters	Mouth of Big Susitna River	9/10
Green-winged teal	8/9	WP	Near Eagle's Nest Point	9/26
Pintail	8/8	Hunters	Susitna Flats	9/30

was found dead in area C/D August 26, 1995, and one pintail captured August 9, 1995, was found dead August 31 in area C. Both birds were collected and frozen for residue analysis.

Bald eagles

From April 24-31, 1995, 14 bald eagles (13 adults and one 2–3 year old) were captured on ERF and each fitted with backpack transmitters (Table III-4-1). Of the 14, 8 adult eagles were fitted with a satellite transmitter coupled with a standard transmitter. Two of those were breeding adults from two nest sites surrounding ERF. Telemetry and observational data of instrumented eagles, excluding the two nesting birds, indicated that eagles spent an average of 1.2 days (range 1–25) on the Flats during the spring (Table III-4-7) and an average of 0.2 days (range 1–50) on the Flats during the fall (Table III-4-8). Instrumented eagles were only located in areas A, C and C/D during the spring (Fig. III-4-10) and areas A and C/D during the fall (Fig. III-4-11). Most of the time was spent in the

Table III-4-7. Bald eagle use of and mortality on ERF, May 1–25, 1995.

	Eagles captured in 1995	*Eagles captured in 1994*
Eagles (no.)	14	7
Capture period	April 24–30	May 1–19
Avg. days on ERF (no.)	1.2*	4
Range (no. days)	1–4	1–4
Mortality (no.)	0	0
Observed off ERF (no.)	8	1

*The two eagles nesting on ERF were not used in calculating the average or range.

Table III-4-8. Bald eagle use of and mortality on ERF, August 1 to October 17, 1995.

	Eagles captured in 1995	*Eagles captured in 1994*
Eagles (no.)	14	7
Capture period	April 24–30	May 1–19
Avg. days on ERF (no.)	0.2*	0
Range (no. days)	1	0
Mortality (no.)	0	0
Observed off ERF (no.)	11	1

*The two eagles nesting on ERF were not used in calculating the average or range.

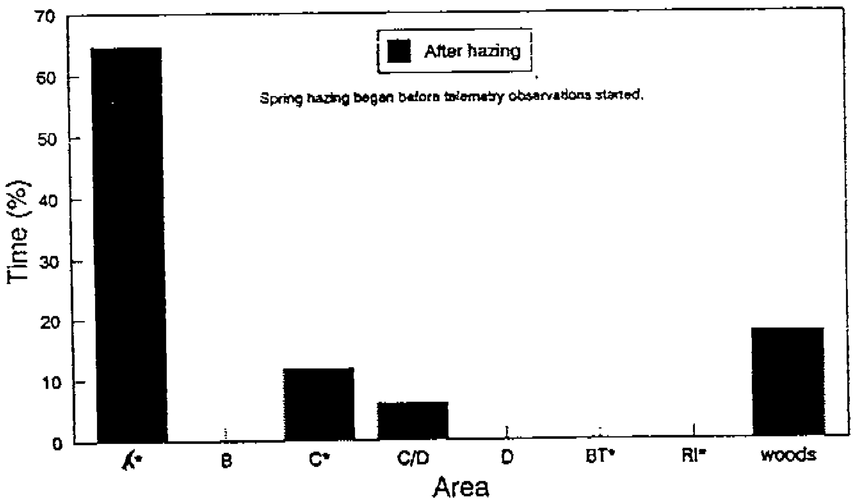

Figure III-4-10. Distribution of bald eagles on ERF during spring migration from April 25 to May 31, 1995.

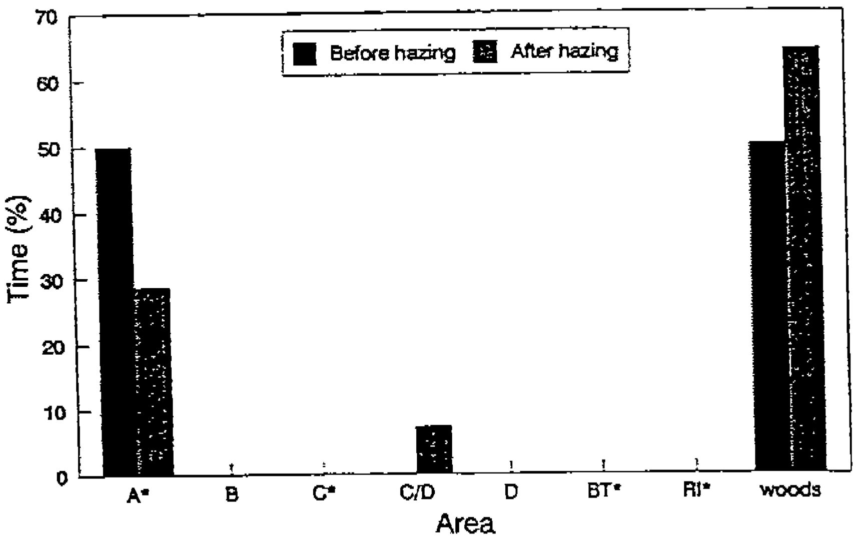

Figure III-4-11. Distribution of bald eagles on ERF during fall migration from August 1 to October 17, 1995.

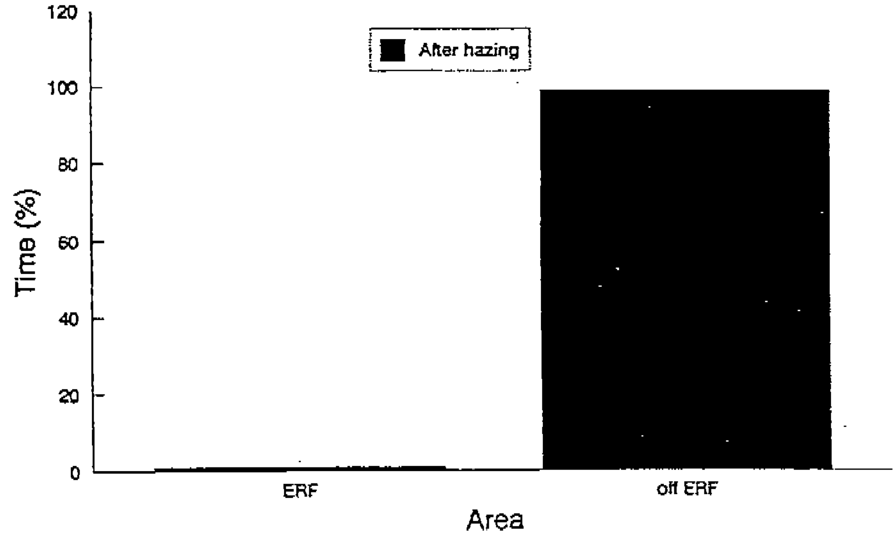

Figure III-4-12. Time bald eagles spent on and off ERF during spring migration from April 25 to May 31, 1995.

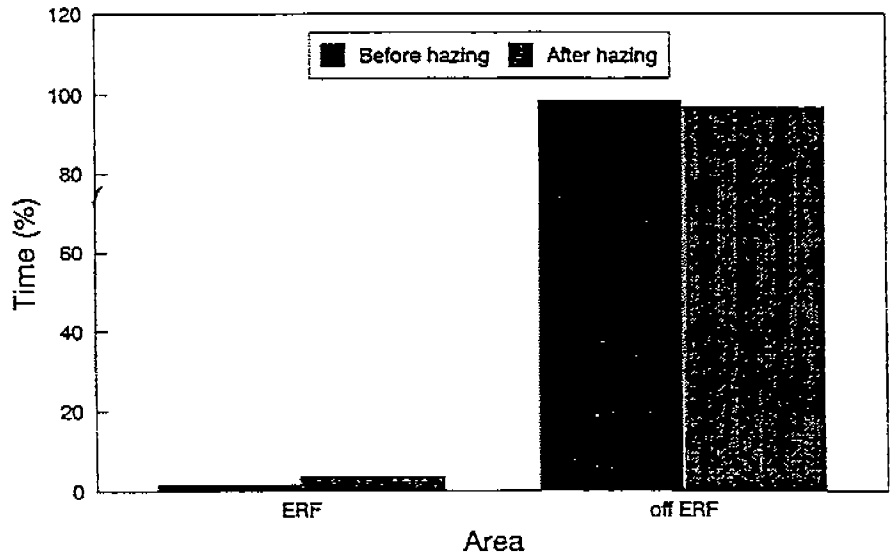

Figure III-4-13. Time bald eagles spent on and off ERF during fall migration from August 1 to October 17, 1995.

wooded areas surrounding ERF (Fig. III-4-12, III-4-13). Eagles (satellite) that did not nest in the woods surrounding ERF were located with a 300-km radius of the Flats.

In addition, nesting success of eagles on ERF did not differ significantly from eagles nesting on Susitna or Chickaloon Flats. Eagles on ERF (nest = 3) produced an average of 1.3 eggs and fledged an average of 0.33 eaglets. Eagles on Susitna Flats (nest = 10) produced an average of 1.6 eggs and fledged an average of 0.6 eaglets. Eagles on Chickaloon Flats (nest = 7) produced an average of 1.0 eggs and fledged an average of 0.28 eaglets.

No eagle mortality occurred during their use of the Flats or within the 268-km contact area. To date, eagles are en route to wintering areas near Prince William Sound, Washington. Eagles will continue to be monitored until spring of 1997, which is the life expectancy of the transmitters.

DISCUSSION

Daily waterfowl movements indicate that all species moved among areas quite readily. However, each species show a preference for certain areas on ERF. Mallards preferred area B; pintails, area C; and teal, area D. All species had in common area A. However, we found that species segregated into specific areas within Area A. Teal preferred ponds that were shallow (< 8 cm) or had extensive mudflats. On several occasions, teal were observed foraging in mudflats after a high tide. Waterfowl distribution data from 1995 was similar to 1993 and 1994. The only exception was that teal used pools in area D in 1995 more extensively than in 1993 or 1994. We attribute this to variations in tide cycles and below normal water levels on the Flats in these years.

Distribution data indicate that ducks as in previous years used a larger portion of ERF in August than in September. This can be attributed to the start of the hazing program on September 5. However, pintail use patterns post-hazing indicated an increase in the use of area C. We attribute this to the restrictive hazing guidelines of which hazing was not started until 0800 each day and was limited when dredging operations were initiated.

Mortality during 1995 (n = 5) was 9% or about half of the number of ducks that died during fall migration in 1993. The difference could be attributed to a number of factors, such as more efficient hazing, re-distribution of waterfowl into uncontaminated areas and higher water levels which dispersed foraging waterfowl into areas that were probably void of WP. In 1995, waterfowl were located in portions of areas A and D that had not been used in past years.

Turnover rates for waterfowl in 1995 was lower than in 1993 or 1994. We suggest that the lower turnover rate for 1995 might be an effect of our trapping effort. In 1995, all waterfowl were captured and instrumented within 13 days, which allowed for a longer exposure time on ERF. In previous years, trapping covered about 40 days. Because of the extended trapping period, we probably unintentionally reduced the average time waterfowl spend on the Flats.

In conclusion, we feel that the movements of waterfowl on ERF were influenced by hazing, to a lesser degree, the presence of researchers, or initially obstructions in certain areas, i.e., dredge or equipment. The turnover rate during the fall on ERF is low, which makes ducks at a greater risk to WP poisoning. However, the combination of the estimated turnover rate, mortality, and population number will give a much clearer picture of the number of waterfowl lost during August, September and October.

RECOMMENDATIONS

Assessment endpoints

The biological assessment endpoint for ERF is the reduction in waterfowl mortality. To measure this endpoint, we suggest that monitoring susceptible waterfowl (mallards, pintails and/or teal) with the use of telemetry can give a realistic waterfowl mortality rate that occurs across the entire ERF. By increasing the number of transmitters from 54 (1995) to 150, the standard deviation is reduce from 4 to 2%. In addition, there could be a greater reduction in the SD or confidence limits if mortality is actually >9%.

Of importance is being able to determine if remediation actions reduce mortality. Because waterfowl use the entire ERF, remediation of one area doesn't necessarily mean that mortality will decrease. Waterfowl might redistribute themselves to other sites. Telemetry can account for this whereas transects being tied to a specific ponded site can not. Transects can not relate to the entire ERF.

Use of telemetry

Telemetry:

- Reduces human exposure to UXOs;
- Supports measuring the assessment endpoints with relatively good confidence limits;
- Generates excellent data on waterfowl distribution, movements, turnover and mortality which are all factors effecting remediation;
- Costs <$80,000 per year if 150 transmitters are used; and
- Has no impact on the behavior of radioed birds or other birds using ERF.

In addition, it is considered a standard method for projects of this type.

It is recommended that telemetry data be integrated into the risk assessment process, that future remediation actions be assessed with telemetry birds, that mortality on ERF be assessed by instrumenting >100 waterfowl with mortality transmitters and that eagles fitted with satellite transmitters will continue to be monitored.

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IV-1. HAZING AT EAGLE RIVER FLATS

Corey Rossi

USDA Animal and Plant Health Inspection Service, Animal Damage Control

INTRODUCTION

During parts of April, May, August, September and October of 1995 under Agreement #95-73-02-2158 (formerly agreement #12-34-73-2158), USDA-APHIS-Animal Damage Control (ADC) continued efforts to keep migratory waterfowl from being poisoned by white phosphorus in the U.S. Army's Eagle River Flats (ERF) Impact Area at Ft. Richardson, near Anchorage, Alaska. The work involved the use of a variety of traditional hazing methods over discrete, limited areas within ERF, with other less contaminated areas remaining as undisturbed sanctuaries.

OPERATIONAL AREAS

The standard operational areas, i.e., Area A, Racine Island, C Pond, Lawson's Pond and Bread Truck Pond, again received aggressive attempts to deter waterfowl from their use. Because the exact boundaries of the operational areas are not clearly defined, ADC again established estimated boundaries and perimeter buffer zones, then sought to haze waterfowl from the area within the perimeter of the buffer zones. This has been a common practice in all of our operational areas. The significance of this approach is: (1) the exact location of the source of the toxicity within the given area still has not been clearly identified, and (2) waterfowl present within the buffer zones surrounding an operational area tend to decoy additional waterfowl which often land within the contaminated zones.

METHODS

Several standard hazing methods were used. Up to 20 propane cannons (an increase of 5 from last year) were strategically located around the open water areas within the marsh. Efforts were made to vary firing intervals and collocate them with visual scare devices like scarecrows and mylar tape. Scarecrows were of the traditional clothed-frame design. Mylar tape was strung in difficult to reach areas that appeared attractive to ducks. Mylar tape was deployed to a lesser degree in 1995 than in 1994, primarily due to its limited long-term efficacy and the difficulty in gathering and disposing of it at season end.

Additional static devices included eagle effigies and another device known as the electronic guard. Eagle effigies were of painted plywood construction and built in a standing configuration, as well as a suspended "in flight" configuration. The electronic guard consists of a siren and flashing strobe light, both of which activate automatically on 6- to 8-minute intervals to deter waterfowl during hours of darkness.

To augment the effectiveness of these static devices, two ADC personnel walked or canoed through the marsh to service the devices and deter birds that had landed or were attempting to land in critical areas. Personnel used 15-mm pyrotechnics, shell crackers and 20-in. skyrockets to frighten birds from areas of concern. As in 1994, personnel were in the field 7 days per week, during almost all daylight hours. A bird was considered successfully hazed if it responded to our stimuli and left the immediate area for another portion of the marsh. We recorded all mortalities and reported them to the New England Institute of Landscape Ecology (NEILE) personnel. Mortalities were generally assumed to be due to white phosphorus poisoning. In 1995 we again intensified our hazing efforts to include *all* waterfowl within our operational areas. In past seasons, we had often left grazing geese and loafing widgeons unmolested, but we have learned that these species often inadvertently decoy those species more susceptible to white phosphorus poisoning.

RESULTS

Spring

From April 17 to May 26, 1995, a total of 3406 ducks and 30 swans were hazed at Eagle River Flats, by 6 ADC personnel. A total of 685.5 staff hours were expended in the field over 40 days of hazing. All mortalities found were reported to NEILE for addition to their data.

Fall

From August 23 to October 23, 1995, a total of 16,864 ducks, 397 Canada geese, and 78 swans were hazed at Eagle River Flats, by six ADC personnel. A total of 1,257.5 staff hours were expended in the field over 59 days of hazing. Once again, all mortalities were reported to NEILE for addition to their data.

DISCUSSION

The spring 1995 total of "ducks hazed" reveals a dramatic increase (almost 400%) over the same period in 1994. This is due, in part, to an earlier (about 14 days), more aggressive hazing operation and possibly, to a lesser degree, increased waterfowl use of the marsh. A two-week cessation of hazing was imposed at the beginning of the spring and fall migrations in 1994. Its purpose was to allow researchers an opportunity to record overall waterfowl numbers, behavior, and mortality independent of hazing activities. It was mutually agreed that such a cessation would be of no value to researchers during the spring 1995 season. The earlier hazing start date and subsequent increase in "total ducks hazed," probably accounts for the modest number (10) of mortalities recorded during the spring 1995 season.

The fall 1995 season presented a different set of circumstances. During discussions with researchers from NEILE and DWRC, it was determined that a two-week cessation in hazing (at the beginning of the fall migration) would be of value to researchers. ADC adjusted its proposed start-up date accordingly to September 5, 1995. This plan was altered rather unexpectedly in late August, as NEILE researchers began to report a dramatic increase in duck use of the marsh, with a corresponding increase in duck mortality. ADC responded to this development as quickly as personnel availability would allow. Although ADC managed to activate some equipment and a small emergency field team by August 26, it wasn't until about September 5 that ADC's originally planned operation was fully implemented. As might be expected, about 75% of the waterfowl mortality in NEILE's fall 1995 totals occurred prior to September 7, 1995.

During the periods of hazing cessation in 1994, ADC was still present at ERF assisting other groups and remaining on standby in the event that hazing might need to be initiated immediately to protect waterfowl. This procedure was not implemented in 1995, and its absence contributed to increased waterfowl mortality. If hazing cessations are implemented in the 1996 season, it would seem prudent to have a full hazing crew standing by and assisting other groups as in the past.

Excessive flooding and the subsequent destruction of the Route Bravo Bridge (Eagle River crossing) resulted in significant logistical problems for ADC personnel from September 20, 1995 until season conclusion. The alternate route from the 992 building to the EOD Pad required additional travel time, and the inability to cross Eagle River limited equipment maintenance trips to Racine Island. This problem was exacerbated by the loss of helicopter use (due to a lack of funding) during October.

Once the bridge and the helicopter were unavailable, emergency safety guidelines were implemented to protect personnel in the event of an injury/emergency. The guidelines required field personnel to be monitored by a

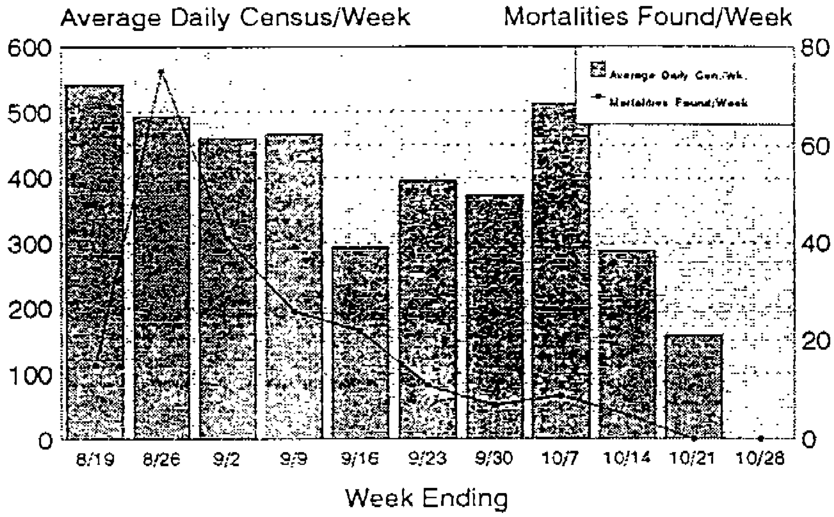

Figure IV-1-1. NEILE daily duck census vs. NEILE mortality count per week.

remote observer during activities in the marsh proper. The observer was required to maintain visual and radio contact with the field crew. This required ADC to maintain three personnel (instead of two) when other field crews were not present. Such logistic problems hampered ADC hazing operations and may have ultimately contributed to increased mortality.

Efforts to obtain an accurate census of the waterfowl using the marsh can be very difficult during active hazing periods. In an attempt to remedy this situation and to help us evaluate our own efficacy, ADC altered the morning hazing start-up schedule to allow researchers time to get daily pre-hazing waterfowl counts. This procedure allowed some exposure to contaminated areas by foraging waterfowl during the early morning hours. This additional exposure did not seem to notably increase duck mortality. NEILE's data indicate a steady drop in duck mortality while duck use of the marsh remained fairly constant (Fig. IV-1-1).

Hazing operations often distribute waterfowl to an area outside of NEILE's observation range. The observable consequence of hazing, i.e. ducks outside of the census area, could conceivably be interpreted as "there are no ducks using the

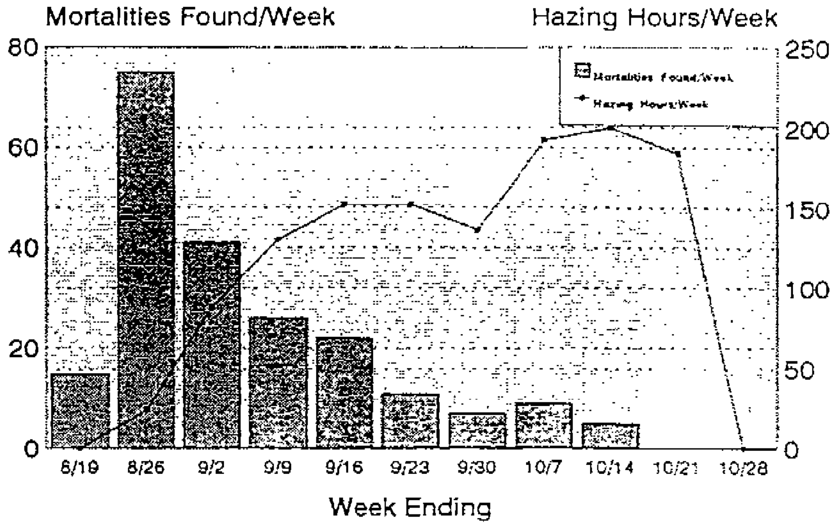

Figure IV-1-2. NEILE mortality count per week vs. hazing manhours per week.

marsh, thus no exposure, thus no mortality." This same explanation for reduced mortality could be used during the winter when there simply are no ducks in the area. The later morning start allowed ADC to demonstrate a decrease in duck mortality as hazing efforts increased (Fig. IV-1-2) without a corresponding decrease in duck use of the marsh as hazing efforts increased (Fig. IV-1-3).

Using Neile mortality information, ADC attempted to identify and protect "new" areas where mortalities were found. In 1995, no previously unknown hot areas were identified. However, hazing efforts were occasionally expanded around currently protected areas.

Although ADC's original hazing schedule outlined a tentative completion date of October 20, 1995, a contingency provision in our 1995 proposal allowed ADC to continue operations until all contaminated areas had frozen over.

There were no "new" tools/procedures involved in ADC's 1995 hazing operations. With only minor exceptions, ADC employed the same techniques that have proven to be successful in previous seasons. However, ADC increased its emphasis on vigorously harassing the birds while they were still airborne over the protected areas. Waterfowl are more difficult to deter from an area after they have landed. The persistence in deterring airborne waterfowl may have

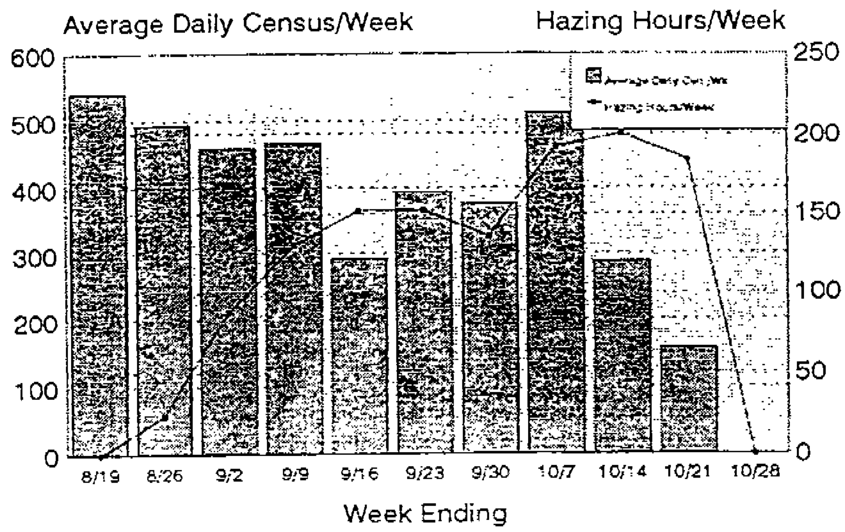

Figure IV-1-3. NEILE daily duck census vs. hazing man-hours per week.

contributed to fewer swans being hazed in fall 1995 than in fall 1994. At this time, field personnel armed with pyrotechnics are the most essential component in a successful waterfowl deterrent operation.

One tool, mentioned only briefly in last year's report, was the hovercraft. The hovercraft proved useful in shuttling equipment and personnel to difficult access areas. In addition, it demonstrated much promise as a hazing tool. The two original hovercrafts were rendered inoperable due to accidents during the fall 1994 season, and an assessment of their true potential was cut short. The hovercrafts have since been repaired, and two additional crafts were purchased during the fall 1995 season.

The hovercraft operation manual describes it as an aircraft, rather than a boat. And in its purest sense, that is exactly what it is. The steering mechanism of a hovercraft is more closely related to that of a helicopter than that of a boat. By establishing designated paths through the flats, and emphasizing thorough operator training, ADC plans to overcome the craft's weak points and make it an indispensable tool for hazing and personnel/equipment transit.

The 1995 season again witnessed a tremendous increase in the amount of helicopter time available to ADC. In the past, the helicopter had been used by ADC for occasionally shuttling equipment to and from the field. In 1995 it often remained on standby at the EOD Pad. While extremely useful and convenient, the increased helicopter time occasionally hindered ADC operations as our personnel began to alter daily planning and become more dependent on the helicopter. This trend seemed to be affecting other field teams as well, thus creating helicopter scheduling problems. ADC plans to use the hovercrafts to reduce the potential of this occurring next year.

CONCLUSIONS

In spite of an impressive increase in the number of migrating ducks this fall and some untimely logistics complications, ADC believes the hazing operation was successful. U.S. Fish and Wildlife Service (USF&WS) sources reported increased reproductive success in 1995 for most of the dabbling duck species (except pintail) potentially impacted by white phosphorus at Eagle River Flats.

Although waterfowl mortality was high from late August through early September 1995, NEILE's mortality figures indicate low mortality *during* active hazing operations, the only exception being situations where waterfowl began using hot areas not currently protected by ADC operations. These areas were quickly identified and hazing operations were immediately implemented.

As in previous seasons, ADC observations, DWRC telemetry work, and waterfowl surveys by USF&WS and NEILE all indicated a dramatic decrease in waterfowl numbers in ADC-protected areas when compared to those in established sanctuary areas.

The effective protection of waterfowl was further enhanced by a contingency provision initiated in the 1994 proposal, which allowed ADC's operations to continue until all of the contaminated areas had frozen over (regardless of the date). This contingency provision will be proposed again for the 1996 season.

IV-2. EVALUATION OF AQUABLOK™ ON CONTAMINATED SEDIMENT TO REDUCE MORTALITY OF FORAGING WATERFOWL

Patricia A. Pochop, John L. Cummings and Christi A. Yoder

Denver Wildlife Research Center

INTRODUCTION

For 50 years the U.S. Army has used Eagle River Flats (ERF) of Fort Richardson, Alaska, as an impact area for explosive ordinance. In August 1981, hunters discovered large numbers of duck carcasses at ERF. On 8 February 1990, the Army suspended firing into ERF because of a correlation between waterfowl mortalities and contamination of the flats by chemical debris from ordnance (i.e. white phosphorus [WP]; Quirk 1991). In February 1991, WP ingestion was causally linked to waterfowl deaths (CRREL 1991), and efforts to reduce hazards began. One strategy to prevent ingestion of WP by ducks may be the use of physical barriers applied to the substrate.

In 1993, we evaluated the feasibility of applying two materials, ConCover™ (recycled paper mulch [99%] and polymers [1%]) and AquaBlok™ (calcium bentonite/organo clays, gravel and polymers), to provide a physical barrier to foraging waterfowl. Laboratory trials were performed to determine if either

ACKNOWLEDGMENTS
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product would stand up to field trials. Visual inspections during laboratory trials, indicated that the ConCover™ was immediately penetrated by the water and readily torn up by mallard (*Anas platyrhynchos*) activity. In contrast, daily inspections of the AquaBlok™ indicated it appeared to maintain its structure under duck use. Therefore, the AquaBlok™ was used in the pilot study.

The pilot study was conducted from 14 to 30 June 1993 at ERF. During the pretreatment all of the mallards died in the control (six) and half of the mallards died in the AquaBlok™ (three) pen within the first six days. During the post-treatment (six days), all of the control (six) mallards and none of the AquaBlok™ mallards died. Observations of the AquaBlok™ 42 days post-application indicated that algae was growing on it. During a follow-up trial 6–13 August, more control than treated ducks died up to 55 h of exposure. However, there were no differences in mortality after 70 h. Removal of the plastic panels surrounding the enclosure was believed to have allowed contaminated sediment to migrate on top of the barrier and probably explains these results.

Because the posttreatment period of the 1993 pilot study was successful, a definitive study was conducted in 1994. Our objectives were to evaluate the stability of AquaBlok™ when applied to an isolated pond up to 0.5 ha in size and to measure its effects on waterfowl foraging behavior and mortality. Two ponds, one in Area C and one on Racine Island, were selected based upon WP concentrations in the sediment and because treating the Racine Island pond would not interfere with other research activities. The pond in Area C was used as the control and the pond in Racine Island was treated with about 141,200 kg of AquaBlok™. During pretreatment, 23 mallards died in the control pen and 15 died in the treated pen over 10 days; during posttreatment, 24 mallards died in the control pen and 3 mallards died in the treated pen over 20 days. It was suspected that unevenly covered craters were responsible for the three mortalities observed in the treated pen. Foraging observations indicated that during pretreatment, the mallards in the treated pen fed more than those in the control pen. However, control ducks fed more frequently posttreatment.

ERF falls under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) process because of its designation as a Superfund site. Potential remediation actions that will interrupt the exposure pathway, as presented in the Conceptual Site Model (CH2M HILL 1994), need to be investigated. This will generate data that can be used in feasibility studies to determine their efficacy as remediation strategies. Subsequently we are continuing to evaluate AquaBlok™ as per the ERF Task Force recommendations on data needs. Our objective in 1995 was to continue to evaluate the effectiveness of the 1994 AquaBlok™ application. Our hypothesis was that the frequency of mortality observed on Racine Island before the 1994 treatment was the same as observed in 1995. Vegetative recovery was an issue that needed to be examined because the application of the AquaBlok™ appeared to mechanically destroy the vegetation. Follow-up was important to determine if the vegetation could reestablish on the barrier. Another issue was to determine if WP could migrate into the AquaBlok™ barrier, which would reduce its effectiveness. Therefore, samples of the AquaBlok™ were sent to a contract lab for gas chromatographic analysis. A third issue was if ice would impact the barrier, because some areas on ERF are impacted by ice heaving. Thus, we needed to measure the potential impact of ice heaving on the barrier. Finally, tide plots were constructed in two areas on ERF to measure the impacts of tide events and water actions on vertical displacement and horizontal movement of the AquaBlok™ barrier.

METHODS

Study site

Two sites on ERF were used for this study, one located in Area C and the other on Racine Island. Area C includes a single large pond (~15 ha) with a connected series of smaller ponds and inlets along the east edge of ERF (Racine

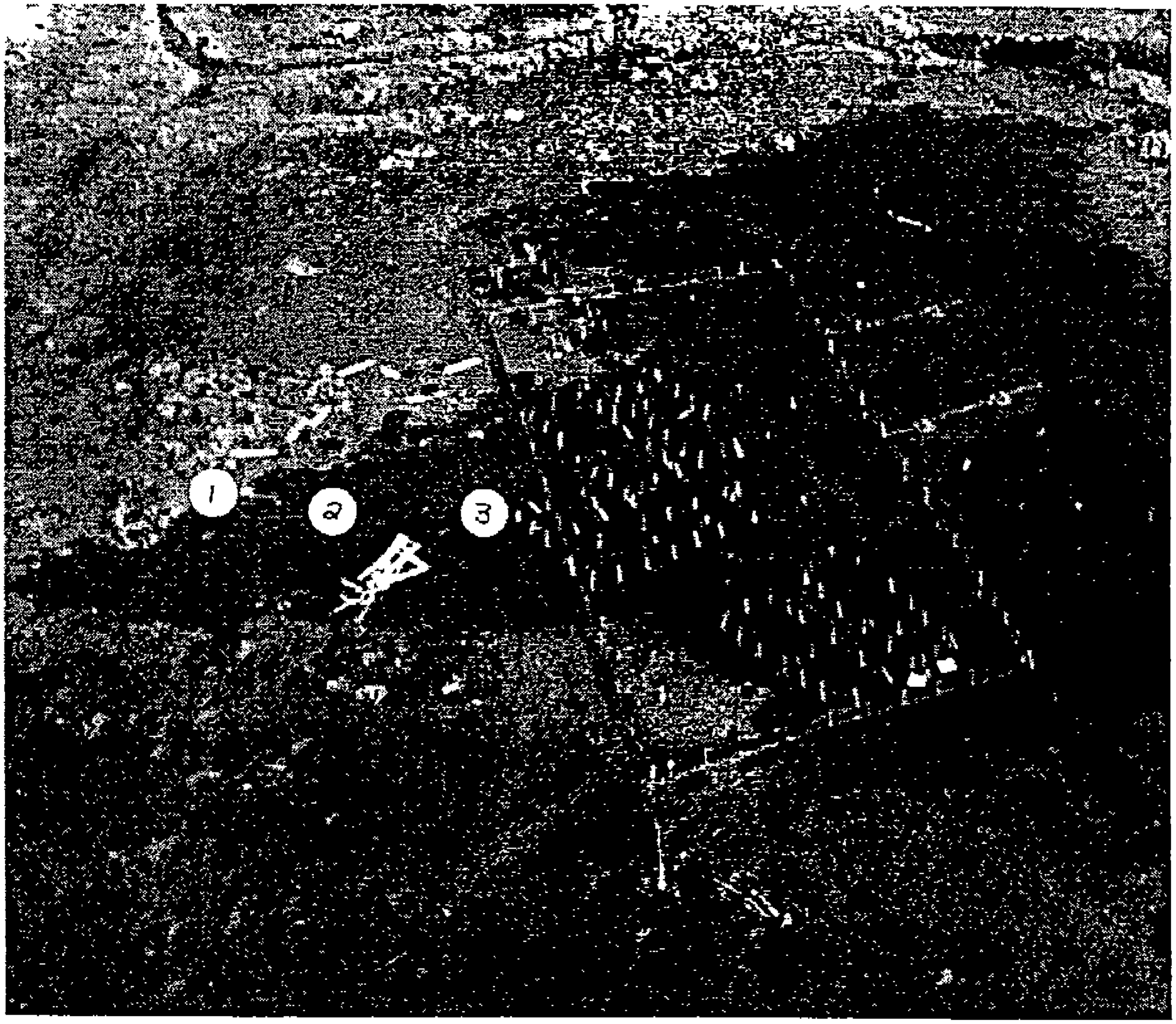

Figure IV-2-1. Area C, where the three pairs of tide plots were installed next to the 1994 control pen to measure vertical displacement and horizontal movement of AquaBlok™, 10 May through 14 September.

and Walsh 1994). A 3200-m^2 pen was used as the control pen in 1994 (Fig. IV-2-1). However, a control was not used in 1995 because distribution of WP varies widely on ERF resulting in differences in mortality in discrete areas. For example, pretreatment results in 1994 showed 96% mortality in the Area C pen compared to 62% mortality in the Racine Island pen over 10 days. This effect (34% difference) was considered to be stronger than any temporal effects that might occur. Several years of mortality data have been taken from pens in Area C to support this theory (Cummings 1993, unpublished data). However, for the

AquaBlok™ barrier to be considered effective enough to be used as a remediation action on ERF ≤5% mortality should be observed in pen studies.

In the northwest portion of the large pond in Area C we installed three pairs of tide plots (Fig. IV-2-1). One of each of the three pairs of plots was installed with a form to measure vertical movement of AquaBlok™ and one was installed without a form to measure horizontal flow of AquaBlok™.

Racine Island, which is formed by two channels of Eagle River, has a large pond formed by an old channel which is surrounded by bulrush marsh and a smaller pond to the north (Racine and Walsh 1994). The smaller pond, which has numerous water-filled impact craters associated with it, was used as the treated pen. This pen was irregularly shaped but encompassed approximately 4500 m^2 during the 1994 pretreatment and 4000 m^2 during the 1994 posttreatment. The size was reduced during the posttreatment because there was not enough AquaBlok™ to treat the farthest northwest corner of the site. The pen encompassing the pond was constructed of polypropylene netting (2-cm mesh) at a height of 2 m above the sediment. Three pairs of tide plots were installed in the northwest corner of the site (Fig. IV-2-2) as described in Area C.

Vegetative recovery

Photographs of the Racine Island pen were taken from a height of approximately 240 m during 21 July 1991, 30 August 1994 and 16 August 1995. A grid (1 × 1 cm) was placed over each photograph and the amount of each grid's vegetation was estimated. Values of all cells were added together and divided from the total of number of cells (incomplete + complete) determined to cover the pen area.

Barrier effectiveness

Water depths were measured each morning. The six stakes with stream gauges were left in place from 1994 (Pochop et al. 1994). The gauges were located inside the pen within 1 m of the netting, two in craters and four distributed

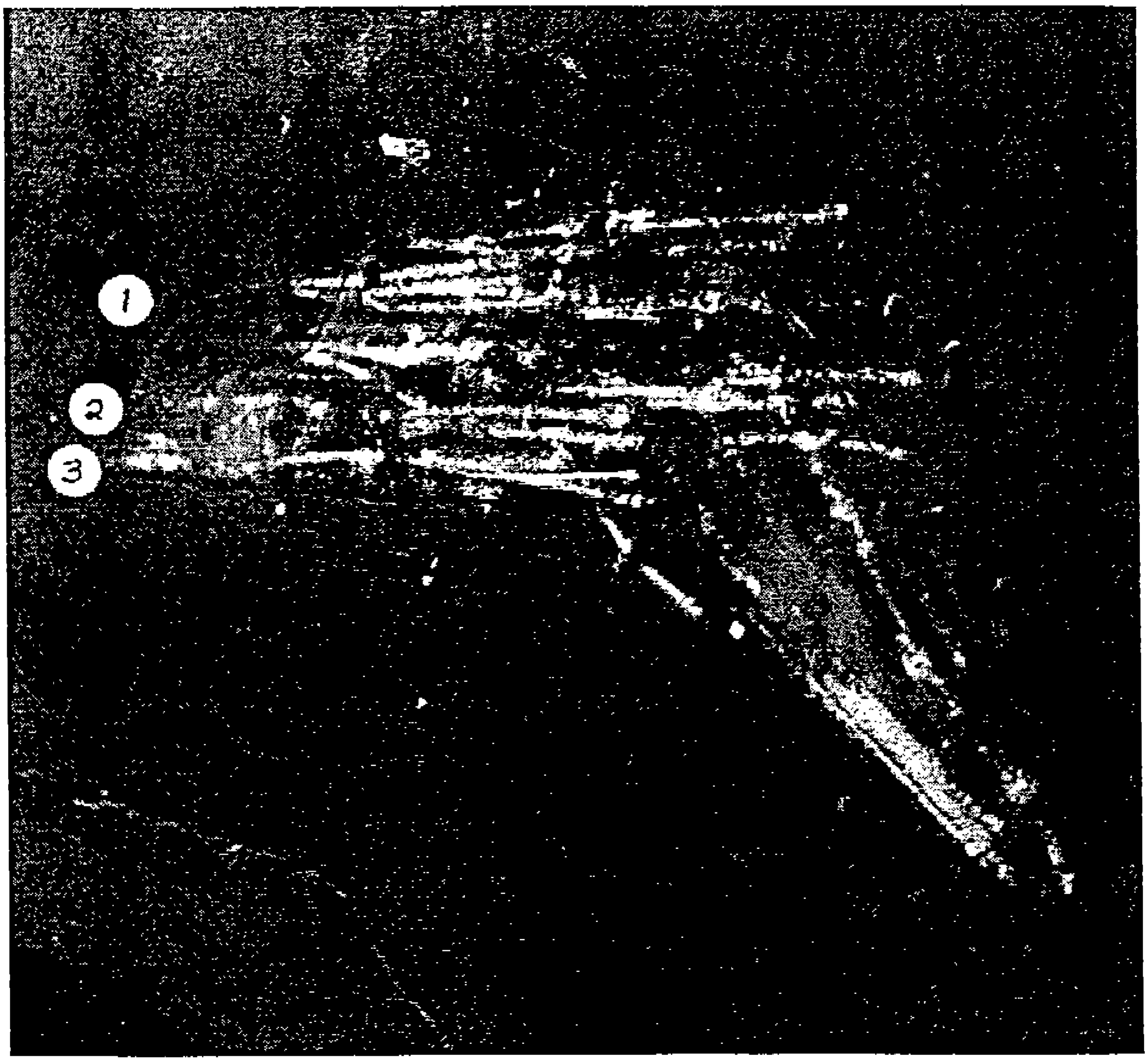

Figure IV-2-2. Racine Island pen, where the three pairs of tide plots were installed next to the 1994/1995 treated pen to measure vertical displacement and horizontal movement of AquaBlok™, 10 May through 14 September.

throughout the large pond. The stream gauges were realigned with the AquaBlok™/sediment surface before taking measurements.

Core samples were collected to determine the thickness of the AquaBlok™ application and sedimentation as described in Pochop et al. (1994).

We collected 15 AquaBlok™ samples from immediately outside or inside the pen for WP analysis; samples were collected near previous sample locations.

This involved the collection of AquaBlok™ to an approximate depth of 3 cm from a 30 cm^2 area. Any samples taken from inside the pen had new AquaBlok™ applied to the area to reduce any holes that would affect the integrity of the barrier. The sample was placed in an acid-washed 500-mL sample jar and taken to a contract lab (ChemTrack, Anchorage, AK) for gas chromatographic analysis.

Before introducing ducks into the pen, two craters believed to have been unevenly treated with AquaBlok™ via helicopter and associated with the deaths of three mallards in 1994 were again covered with AquaBlok™. In one crater, 100 kg of AquaBlok™ was applied and in the other 200 kg was applied by hovering in the helicopter about 2 m above the crater and pouring AquaBlok™ as evenly as possible throughout the crater.

To determine waterfowl mortality, 24 wing-clipped mallards were placed into the enclosed pond for 46 days. By day 3, two mallards were observed escaping from the enclosed pen. Therefore, the height of the pen was increased to about 3 m by installing new stakes (5 × 5 × 300 cm) and attaching the bottom of the new polypropylene netting to the top of the existing netting. A rope was strung tightly across the tops of the stakes and supported the top of the netting. Throughout testing, supplemental food was available *ad libitum* on two floating platforms in the pen. We conducted surveys via helicopter or foot to determine the number of live or dead mallards in the pen each day. Observations of foraging activity were not conducted because the vegetation was too tall to see the ducks feed. However, observations conducted in 1994 indicated ducks continued to sample the sediment even when supplied with supplemental food (Pochop et al. 1994). The test mallards were released to the wild from the pen on 9 August. On day 46, during the high tide, an individual on a small rubber raft was pulled throughout the pen area to determine if any carcasses were present that could not be detected using other methods.

Ice effects

Observations of the ice melt during the spring break-up indicated that the ice was melting from the top down (e.g. no heaving occurred). Therefore, no measurements or samples could be taken in or near the AquaBlok™ pen.

Tidal impacts

On May 10, three paired plots (1 × 1 m) were established on Racine Island and in Area C to measure vertical displacement and horizontal movement of AquaBlok™ as it relates to tide action. On each of the paired plots, a metal form 8 cm wide was placed around one plot so that the top of the form was even with the bottom sediment. AquaBlok™ (70 kg) was poured evenly into the plot. In the remaining plot the AquaBlok™ was applied into a form placed on top of the bottom sediment and then the form was removed. Metal stakes (0.8 cm dia. × 90 cm) were placed in the corners of the plot without the form to mark the corners of the plot. Additional metal stakes (two/corner/distance) were then placed at 90° angles at each of the corners 30 and 60 cm from the corner stake to aid in measuring horizontal flow.

Pairs of plots within each area were established at water level and at 30 and 60 cm below water level. However, this was highly dependent upon the pond bottom (i.e. the two deeper pairs of plots on Racine Island were placed in craters).

RESULTS

Vegetative recovery

The amount of vegetative cover estimated to be in the Racine Island pen in the photographs was 51.8%, 45.9% and 76.4% in 1991, 1994 and 1995, respectively (Fig. IV-2-3). Vegetation appeared to encroach into the pond area over the years the photographs represent.

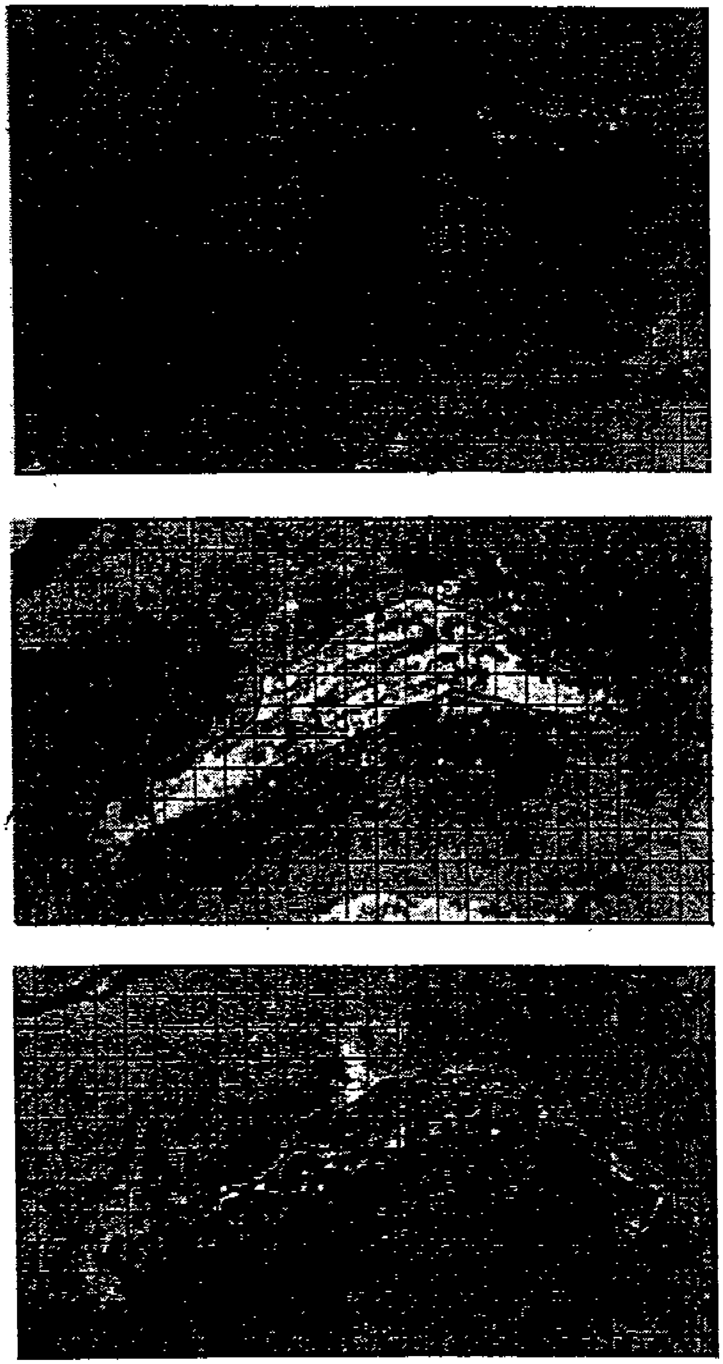

Figure IV-2-3. Racine Island pen, 21 July 1991 (top), 30 August 1994 (middle) and 16 August 1995 (bottom). A grid system similar to the one shown (each grid was approximately equivalent to a 10- × 10-m area of the pen) was used to estimate vegetative coverage.

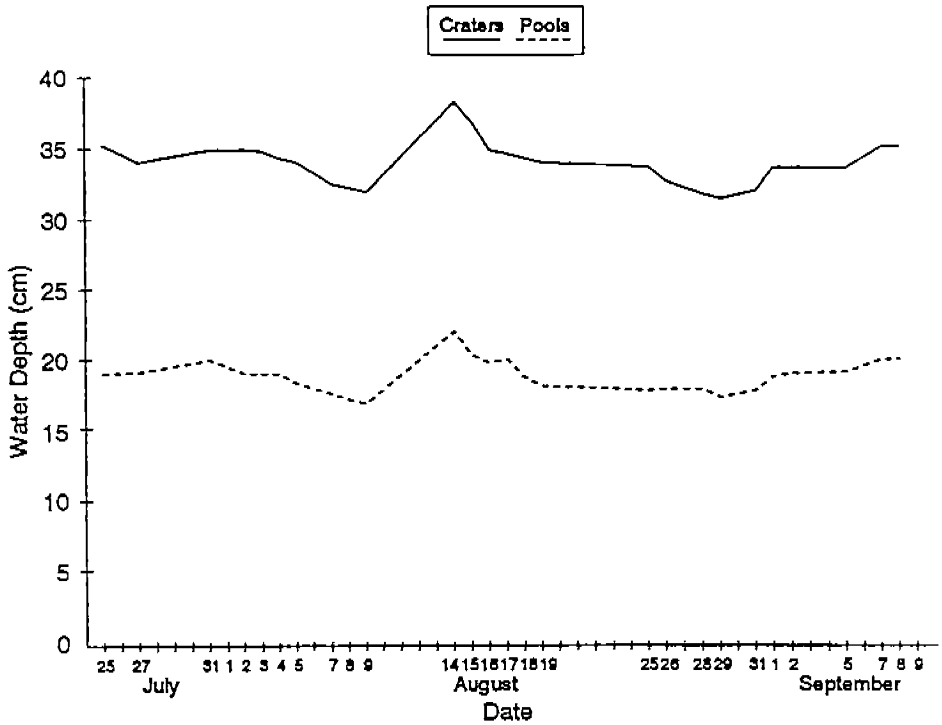

Figure IV-2-4. Water levels in the treated (Racine Island) pool, 25 July through 9 September 1995.

Barrier effectiveness

Water depths ranged from 15–25 cm in pools and from 30–40 cm in craters (Fig. IV-2-4). The pools and craters were deepest 14 August because of a flooding tide event.

WP concentrations from AquaBlok™ samples in the treated pen ranged from <MLOD to 0.02 mg/kg (mean = 0.01 ± 0.01 s.e; Table IV-2-1).

The thickness of the AquaBlok™ ranged from 3.0 to 6.7 cm over level ground (mean = 5.2 ± 0.3 s.e.) and craters appeared to be unevenly covered with the thickness ranging from 6.1 to 21.9 cm (mean = 14.5 ± 2.0 s.e.; Table IV-2-2). This indicates a reduction in the thickness of AquaBlok™ of only 0.5 cm from 1994 values. Sedimentation on top of the AquaBlok™ ranged from 0.2 to 1.1 cm (mean = 0.6 ± 0.1 s.e.).

No carcasses were found during the 46 days mallards spent in the pen. The number of ducks observed in the pen decreased from 24 to 12 after the first 600 h,

Table IV-2-1. Mean concentrations of WP in the treated (Racine Island) pool at ERF.

Date	*Concentration (mg/kg)*
5-25-95 AquaBlok™	n[1] = 9/15 mean = 0.01 s.e. = 0.01 Range = 0.01–0.02
6-21-94 Posttreatment pen	n[1,2,3] = 19/29 mean = 1.27 s.e. = 0.84 Range = 0.01–18.95
6-21-94 Pretreatment pen	n[1,2] = 24/29 mean = 1.59 s.e. = 1.06 Range = 0.01–18.95
6-8-93 (CRREL 1994)	n = 4 mean = 0.11 s.e. = 0.10 Range = 0.01–0.42

[1]Samples below Method Limit of Detection (<MLOD) were not included in mean. Number of samples used in the mean/total number of samples taken.
[2]The average of duplicate subsamples was used to calculate mean.
[3]Five samples were not included in mean because the size of the posttreatment pen was reduced.
The MLOD value was <0.01 mg WP/kg sediment.

and from 9 to 4 during the final 504 h before release (Fig. IV-2-5). Even though primaries were initially clipped, ducks were beginning to replace feathers at the start of the test. Duck disappearance was attributed to feather replacement and escape from the pen.

Tidal impacts

Vertical displacement of water by AquaBlok™ in Area C ranged from 10 to 12 cm (Fig. IV-2-6). This was the amount of swelling above the initial 8-cm thickness at which the AquaBlok™ was applied. Tide action and water currents eroded from 2 to 8 cm of AquaBlok™

Table IV-2-2. Thickness of AquaBlok™ and sedimentation from core samples taken outside of the treated (Racine Island) pen at ERF.

	Measurement (cm; mean ± s.e.)		
	1994	*1995*	
Location	*AquaBlok™*	*AquaBlok™*	*Sedimentation*
Beginning of run			
Initial drop	~30	16.1 ± 2.1 to 24.5 ± 0.4	1.0 ± 0.3 to 1.1 ± 0.3
Dry ground	9.1 ± 0.8	4.7 ± 0.4 to 6.7 ± 0.4	0.4 ± 0.1 to 0.6 ± 0.1
Wet ground	----	5.0 ± 0.4	0.8 ± 0.4
Crater (edge)	4.6 ± 0.4 to 19.0 ± 1.3		
(bottom)	~15.2 to ~25.4	21.9 ± 1.0	0.6 ± 0.1
Middle of run			
Dry ground	----	5.4 ± 0.5	0.6 ± 0.2
Crater (edge)	----	6.1 ± 0.6 to 15.4 ± 0.1	0.2 ± 0.1 to 0.6 ± 0.1
End of run			
Dry ground	7.0 ± 1.3	3.0 ± 0.6	0.9 ± 0.1
Wet ground	2.7 ± 0.2 to 6.1 ± 0.3	6.2 ± 1.2	0.5 ± 0.1

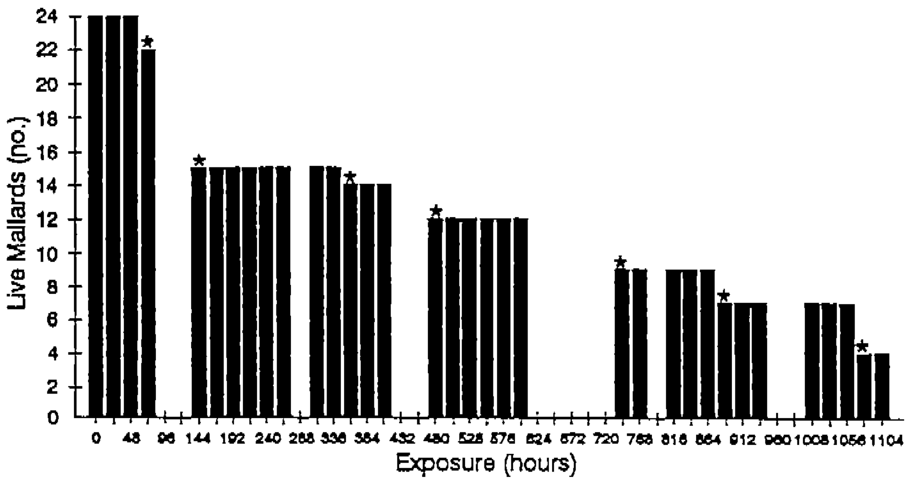

Figure IV-2-5. Counts of live mallards (n = 24) adjusted for observer error that were observed in the treated (Racine Island) pen, 25 July through 9 September 1995. The asterisk indicates that the reduced number of ducks in the pen is attributed to escaping under or flying over the perimeter fence.

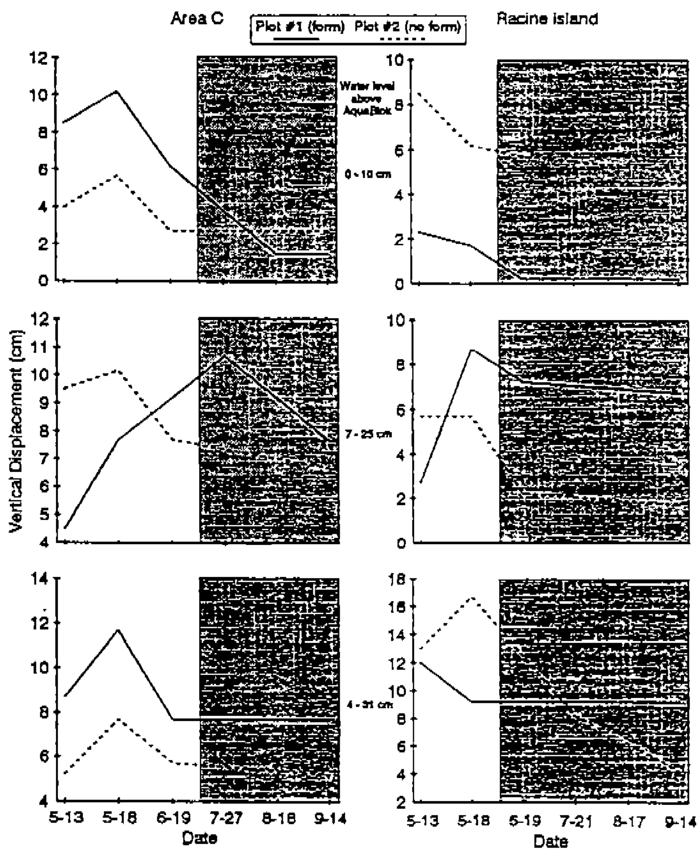

Figure IV-2-6. Vertical displacement of water and erosion of AquaBlok™ from tide plots (1 × 1 m) in Area C and on Racine Island, 10 May through 14 September 1995. Data are the amount of swelling above the initial 8-cm thickness at which the AquaBlok™ was applied. The May 13 data were collected 1–3 days after the plots were installed and before the first tide event. Plant growth (shaded area) obscured tide plots by July in Area C and by the June on Racine Island.

material in Area C over 127 days or five flooding tide cycles. On Racine Island, vertical displacement of water by AquaBlok™ ranged from 2 to 12 cm. Tide actions and water currents eroded from 2 to 3 cm of AquaBlok™ during the same period. The small amount of vertical displacement observed on Racine Island in plot #1, 0–10 cm water level above AquaBlok™ was probably due to vegetation which prevented the form being placed as far into the sediment as the other plots with forms. Plant growth obscured tide plots by July in Area C and by June on Racine Island.

Horizontal movement of the AquaBlok™, based on bentonite material only, in Area C averaged 15.8 cm (range 7–25 cm) over 127 days or five flooding tide cycles and on Racine Island averaged 10.3 cm (range 5–14 cm) during the same period (Fig. IV-2-7). Vegetation again obscured tide plots as described earlier. The movement of AquaBlok™, based on gravel, averaged 5.8 cm in Area C and 9.9 cm on Racine Island after four flooding tides.

DISCUSSION

The number of ducks observed in the pen varied for several reasons. First the type of survey (helicopter, foot or boat) affected the observers' ability to locate ducks. The most reliable censuses were conducted by helicopter. However, environmental conditions were sometimes such that helicopters could not fly and surveys had to be conducted by foot. Second, on some days ducks were simply easier to flush out of the grass to be counted than on other days. Whether this was due to variability in helicopter pilot ability or different weather conditions is unclear. Finally, some mallards escaped and some ducks were suspected of being visitors. We were able to capture one of the ducks that escaped on 28 July and confirm it was one of ours. However, other mallards observed flying out of the pen could have been wild ducks just visiting the area to feed or loaf.

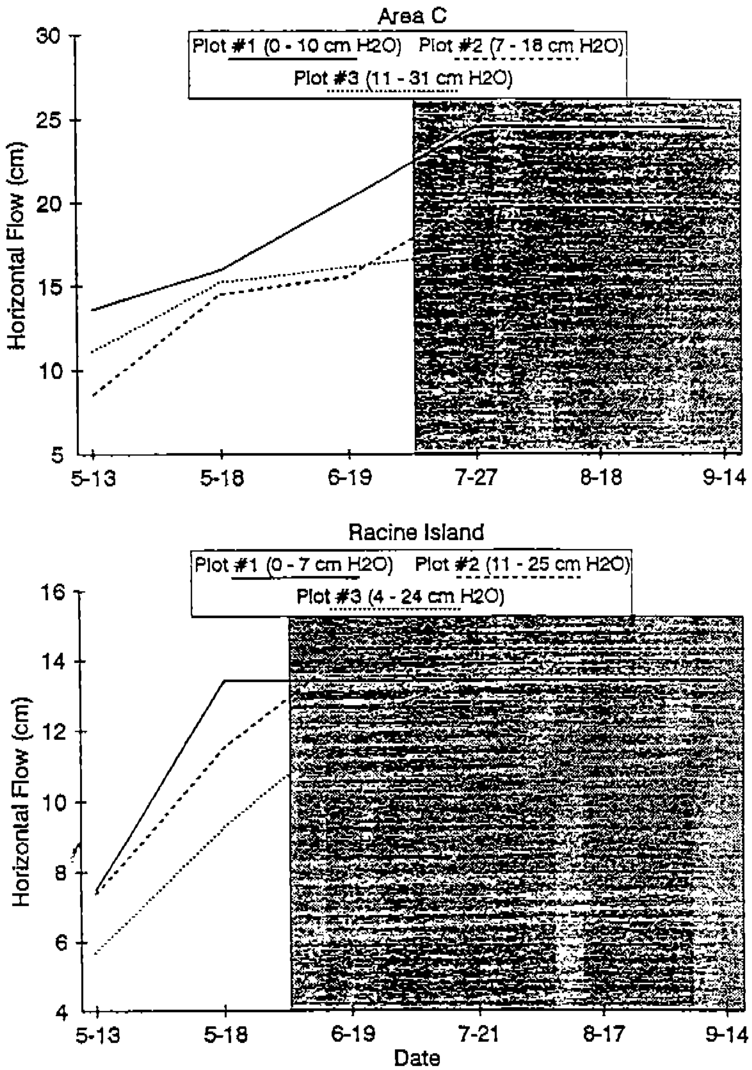

Figure IV-2- 7. Horizontal flow of AquaBlok™ from tide plots (1 × 1 m) in Area C and on Racine Island, 10 May through 14 September 1995. The May 13 data were collected 1–3 days after the plots were installed and before the first tide event. Plant growth (shaded area) obscured tide plots by July in Area C and by June on Racine Island.

We feel that the chances of a mortality occurring and it not being observed were small for several reasons. First, the pen was visited on a regular basis as it was in 1994 when all mallard carcasses were observed. Second, the occurrence of a predator picking up a carcass and removing it from the pen was not observed in any of the pen studies that were conducted on the Flats since 1992. Third, no feather piles or scavenged bones were ever found in the pen except for a fledgling yellowlegs (*Tringa* spp.), which probably got caught in the net and could not escape. Fourth, the helicopter parted the grass as it moved across the pen, making it easier to see areas in the center of the pen. Then, after counts were conducted, water levels were measured and this involved a person walking around the pen and observing the vegetation around the edge of the pen for carcasses. Finally, carcasses could not have floated away in any of the flooding tides because they would have gotten hung up in the netting of the pen.

The water levels in 1995 were similar to the levels observed during the 1994 pretreatment but were higher than the 1994 posttreatment levels. This affected the study because ducks in the 1994 posttreatment were forced to feed in the deepest areas such as craters where the potential for picking up high concentrations of WP was greatest, therefore creating a stronger test of the AquaBlok™. However, because water levels were similar to the 1994 pretreatment levels when 13 of 24 ducks died the AquaBlok™ still proved its effectiveness during a second year of exposure to weather, tide effects and water actions.

Vegetation in the Racine Island pen was lush by June 1995, and it appeared that the process used to apply the AquaBlok™ only temporarily affected the vegetation in the area. Areas where the AquaBlok™ was too thick to allow the vegetation to grow through it was beginning to show some signs of plant invasion. We expect that as sedimentation/organic matter deposition occurs more plant growth will occur on these areas.

The thickness of the AquaBlok™ in 1995 varied similarly to the thickness in 1994. The loss of material between the two years is misleading because core samples could not be taken in exactly the same locations due to loss of integrity of the barrier. For example, taking a core sample compacts the portions of the AquaBlok™ closest to the wall of the sampler, and then as the core sample is removed it expands and may even tear. Further, cores were taken from outside of the pen, where there was high human traffic so the differences observed are a worst-case scenario.

WP concentrations in the AquaBlok™ material were negligible. The concentrations that were observed were probably residue from the underlying sediment that could not be avoided in the taking of the sample. The only way to determine if a sample of AquaBlok™ was contaminated with WP in the barrier itself would be to take ice cores of the barrier and section the sample. Samples of the AquaBlok™ and underlying sediment could then be analyzed separately and the results compared.

Displacement of water by tide plots in both Area C and Racine Island were similar. The one exception (Plot #1, 0–10 cm water level above AquaBlok™) was set higher above ground than the other tide plots with forms causing the AquaBlok™ to spill over and erode quicker than the other plots. Erosion of the AquaBlok™ was greater in Area C than on Racine Island tide plots. Area C tide plots were in a large pool with little to no vegetation to protect them from tide action or water currents until late in the growing season. The Racine Island tide plots were protected by vegetation early in the growing season. Protection by vegetation is important because tide action varies between large and small ponds. High tides flow and ebb into large ponds (i.e. Area C) slowly in contrast to small ponds (i.e. Racine Island) into which tides quickly flow and ebb (Racine 1995, pers. comm.).

Horizontal movement of AquaBlok™ on Racine Island was more cohesive than in Area C. In Area C the bentonite component of AquaBlok™ moved farther than the gravel component. This was also likely a result of vegetation protecting the tide plots on Racine Island from tide action or water currents in contrast to tide plots in Area C, indicating that most of the horizontal movement of AquaBlok™ on Racine Island was probably due to normal settling. Only plot #3 (in a crater) on Racine Island continued to be affected beyond the first tide event and was only affected until the second tide event.

AquaBlok™ coverage varied but didn't break down and the movement observed was small. It reduced mortalities during the first season of application and eliminated them in the second. Vegetative growth was inhibited by the AquaBlok™ application method in the first season of application. However, in the second season vegetative growth was lush and only inhibited in areas where the AquaBlok™ application was thickest. We expect that as sedimentation and organic matter deposition progresses plant growth will also occur in those areas. Although no formal evaluation was done, fish and invertebrates were observed in areas treated with AquaBlok™.

FEASIBILITY OF USING THE AQUABLOK™ AS A REMEDIATION METHOD

Successes and limitations

AquaBlok™ has many attributes which make it an ideal covering material for ERF. Vegetation, initially knocked down by the aerial application, will eventually grow through the barrier with almost complete recovery observed by the next season. The pH under which the AquaBlok™ has been tested (pH 6 to $\leq$9) has proven to have little impact on the barrier. Further, the level of salinity which would cause the barrier to flocculate is unknown. However, if a particular area known to have an extreme pH or salinity needed to be treated, other clays similar to bentonite but known to be pH/saltwater resistant could be formulated in a compound similar to the AquaBlok™. A permeability test was conducted on the AquaBlok™ and found to be very good (10^9; Nachtman 1995, pers. comm.). In addition, no change in aggregate distribution was observed over the year that the AquaBlok™ was in place on ERF (Nachtman 1995, pers. comm.). Most importantly, AquaBlok™ was able to reduce/eliminate waterfowl mortality in the 1994/1995 tests on Racine Island. It is uncertain what amount of maintenance would need to be done on the AquaBlok™, but on Racine Island the 1994 winter/1995 spring had no measurable impact; therefore, no maintenance needed to be done (i.e. the retreatment of the two craters was related to the application).

There are also some limitations of using AquaBlok™ as a remediation method on ERF. It is unknown what can be expected in long-term effectiveness of the AquaBlok™, and this is tied to the effects of ice on the barrier. Ice plucking would most likely be the most destructive force on the AquaBlok™. The 1994 winter/1995 spring did not cause any measurable damage to the barrier; however, conditions were such that ice did not freeze deeply into the sediments which creates the conditions for ice plucking.

Data gaps

The most important piece of data that should be considered is that AquaBlok™ as a remediation method on ERF eliminates waterfowl mortality. Data gaps that are less important because inferences can be made on data already collected are whether WP can be transported into the barrier, the effects of ice on the barrier (ice plucking), impacts of salt water, maintainability, and particle size limitations in manufacturing the product. In the case of salt water, inferences can be made on sites that have similar characteristics to Racine Island and Area C where the AquaBlok™ was tested successfully. These sites would probably be appropriate to consider using AquaBlok™ as a remediation method. Further, tests are currently being conducted by the manufacturer to determine at what salt concentration the bentonite material will begin to flocculate. However, tests results will not be available for about another three months. In the case of maintainability, site history could be evaluated to give some idea on what can be expected on a site-by-site basis. Ice plucking and erosion would be the biggest issues that would affect the maintainability of the AquaBlok™, so areas known to be high risks for these two forces in the natural sediments would be lower considerations for applying the barrier. AquaBlok™ would be somewhat more resistant than the natural sediments to these forces but until it is known by how much, the barrier would be considered as susceptible as the natural sediments to evaluate it in the worst-case scenario. In the case of whether there would be a particle size limitation in formulating the AquaBlok™, the function of the gravel must be considered. The gravel acts as an anchor to help the bentonite seal to the sediments to which it is applied. The use of smaller gravel, pebbles or sand would not be recommended because the smaller particles would need more bentonite and polymers added to account for the greater surface area, thus increasing costs.

Measure of success

The most effective method to measure the effectiveness of AquaBlok™ is to conduct pen studies. Waterfowl, such as mallards, are the most effective and nondestructive samplers available. Further, an actual measure of reduction in mortality can be measured, especially when the experimental design includes both a pretreatment and posttreatment test. In areas that are larger than 0.5 ha, treated pens can be smaller than the actual pond size to sample areas where the barrier is applied. The disadvantages of conducting pen studies are trying to limit the amount of traffic on the AquaBlok™ and eliminating sample bias when pens are smaller than the treated area. If several areas on ERF are treated with AquaBlok™ and the majority of contaminated areas on the flats have been remediated then, a radiotelemetry study would become the most effective means of determining the effectiveness of the clean-up.

Where to apply AquaBlok™

AquaBlok™ can be applied to any pond in ERF (Fig. IV-2-8). However, there are some limitations in data knowledge and the product itself which should be considered. Ponds which have similar characteristics to Racine Island and Area C on ERF in which the AquaBlok™ product has been tested will make the best

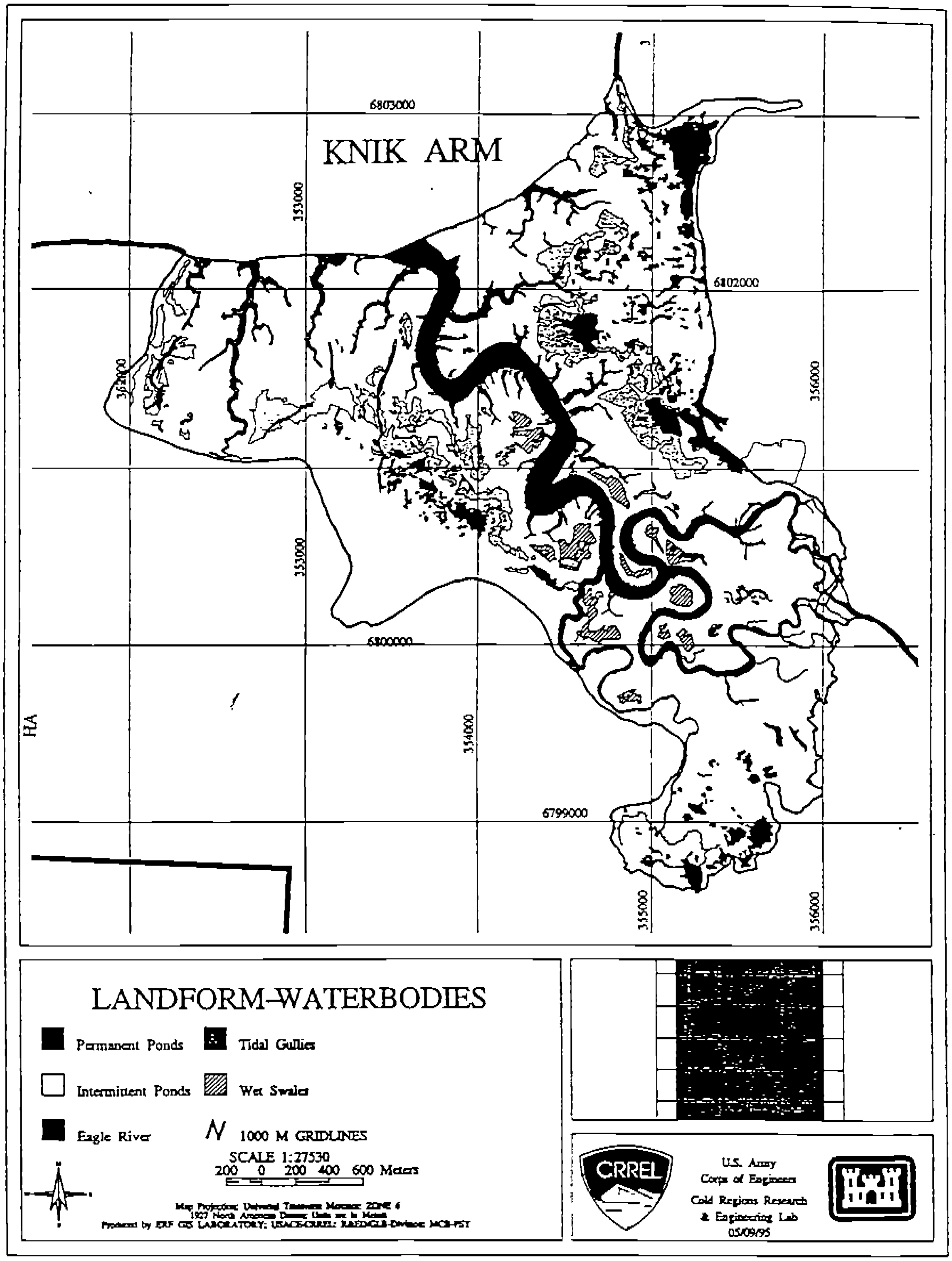

Figure IV-2-8. Possible permanent ponds that could be treated with Aqua-Blok™ as a remediation method.

candidates for treatment with this product. It is also apparent that there are certain characteristics that have not been tested but would make sense to consider when deciding to use AquaBlok™ as a treatment. Areas of low gully encroachment (≥10 years for the gully to cause the pond to drain) would be target areas because it is unknown how much damage would occur to the barrier once a gully began to drain a pond. Some areas on ERF have characteristics that would make applying AquaBlok™ the best choice, such as, any combination of the following; areas of low sedimentation, highly vegetated areas, wet areas (difficult to dry), small areas (too small to dredge).

Costs

1994/1995 study

The cost of the initial application of AquaBlok™ to the 0.5 ha used in the 1994 study was about $26,000 ($0.15/kg materials and $0.02/kg manufacturing). This cost did not include the gravel (supplied by the U.S. Army), labor (two U.S. Army personnel to operate heavy equipment) or application ($1,616/h Blackhawk helicopter for a total of 9 h to apply the AquaBlok™, UH1 helicopter 1.5 h support at $463/h, supplied by the U.S. Army). Also, NewWaste Concepts personnel oversaw the production (Product Quality Control) and contributed labor to the study project at no cost to the U.S. Army. It cost an additional $1,350 ($4.50/kg materials, manufacturing and labor) to treat the two craters in 1995 that were unevenly covered from the previous year's application. This additional cost did not include the 0.5 h of UH1 helicopter ($547/h, supplied by the U.S. Army) time and labor (provided by DWRC) used to apply the AquaBlok™.

The costs associated with the 1994/1995 study are reasonable estimates of what it would cost the U.S. Army to treat small areas (≤0.5 ha) on ERF. To treat larger areas on ERF (>1 ha) a cost assessment would need to be conducted. This is primarily because a cement mixer ($400/day) would not be able to handle the larger production needed to treat large areas. A machine would need to be built to handle the production of the AquaBlok™. At this point the manufacturer has a prototype that could be developed, but actual development would need a commitment from one of the companies currently using the manufacturer's products to spread out development costs. Also, factors that need to be considered before treating large areas are that more people and equipment will need to be figured into the cost, and an appropriate storage area (protection from moisture) for storing the finished product until application would need to be obtained. An advantage of the U.S. Army using AquaBlok™ is that it can use resources already available (materials, storage and some equipment and labor) with input from the manufacturer on set-up and design, product manufacturing on site (manufacturing of the product is key to making it work), and application strategies.

The best cost estimates the manufacturer was able to provide at this time for the AquaBlok™ was $80,000/ha not including the application. For larger areas, where the cost of producing the material per ha would actually go down, an estimate of $6,000,000 to treat 320 ha was obtained which includes applying the AquaBlok™ by truck.

Application

To apply AquaBlok™ by Blackhawk helicopter (1995 cost $2,252/h), drop bags (U.S. Army already owns 10 PVC bulk bags, Model HD 32-36, Springfield Special Products, Springfield, MO), a fork lift, a front-end loader, riggers and a UH1 helicopter (1995 cost $547/h) for support was needed. This method to apply the AquaBlok™ was relatively quick and efficient. However, this method of application could be expensive.

Another method to apply AquaBlok™ would be to truck it over ice using a dump truck (9,000-kg capacity) and either a road grader, or low-ground-pressure bulldozer to smooth it. A top-coat could be formulated onto the AquaBlok™ to delay activation of bentonite until after the ice melted. Although uneven melting of ice or heaving of ice by flooding tides could cause the AquaBlok™ to be unevenly distributed in the pond, trucking it over the ice is probably the most economically feasible method of application, especially for large areas.

A method using a pneumatic pumping system could be tried but little is known about how effective it would be. The pump and pipes from the dredge could be used but the technique itself could be cost-prohibitive. Further, it is possible that there could be an additional detrimental effect by introducing high volumes of air causing disturbance of the water and resulting in the possible resuspension of contaminants in the marsh waters which would then resettle on top of the AquaBlok™ layer.

Cost/benefit analysis

Things that generally would need to be considered in any cost/benefit analysis in deciding to use AquaBlok™ as a remediation method are as follows. AquaBlok™ is less expensive than other methods of cover (i.e. Plastic Membrane Barrier System). It is possible to manufacture the product on-site, thus reducing costs. AquaBlok™ is easy to apply with several application methods and there are specific reapplication methods that can be used, i.e. spot treating can be done using either hovercraft or UH1 helicopters. AquaBlok™ is a tried and tested product which was able to produce satisfactory results. Finally, bentonite slurries and mats are used extensively in the arena of environmental engineering of landfills, ponds, drilling, etc. and are a multi-layer defense in the minimization of resuspension of contamination.

RECOMMENDATIONS

We feel that the data collected indicate that AquaBlok™ is a promising strategy for waterfowl mortality reduction on ERF. Investigations over a second season have shown AquaBlok™ will be most effective in ponds where vegetation is present to help stabilize the barrier. The formulation of AquaBlok™ used in the study used gravel of varying sizes to anchor the bentonite to the bottom sediment so that a seal could be created. However, the larger sizes of gravel used could interfere with current dredging activities on ERF. Future studies should incorporate smaller gravel or a biodegradable material to help anchor the bentonite to the substrate so that dredging can remain a viable option as the potential for gully erosion may begin to threaten treated ponds. Further, ice core sampling of the existing AquaBlok™ application would be useful in determining any WP movement into the barrier.

CONCLUSIONS

The results of a study conducted in 1994 indicated that AquaBlok™ could reduce mortality of waterfowl when applied to a WP contaminated pond up to 0.5 ha in size. Our objective in 1995 was to continue to evaluate the effectiveness of this barrier. Vegetation recovered from 45.9% in 1994 to 76.4% in 1995. Vegetative cover in 1991 was only 51.8%, indicating that after the initial mechanical effect of the treatment application, there was no adverse impact on the vegetation by the AquaBlok™. WP analysis of AquaBlok™ indicated <MLOD to 0.02 mg/kg (mean = 0.01 ± 0.01 s.e.) of WP and was probably contamination from the sediment below the barrier. No mortality of waterfowl was observed during a second year of AquaBlok™ exposure to weather and tide events. AquaBlok™ thickness was reduced from 0 to 5 cm from values in 1994. However, this was largely influenced by heavy traffic (animal and human) and limitations in the sampling method. Tide plots indicated that erosion and movement of AquaBlok™ were lowest on Racine Island, where vegetation was important in stabilizing the barrier. We feel that the data collected indicate that AquaBlok™ is a promising strategy for hazard reduction on ERF.

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IV-3. INTRINSIC REMEDIATION OF WP PARTICLES IN INTERMITTENT PONDED AREAS OF ERF

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INTRODUCTION

White phosphorus (WP) is extremely toxic, but has the potential to form non-toxic phosphates (PO_4^{-3}). To do so, the solid millimeter-size WP particles found in ERF sediments must either dissolve in water or sublime to form WP vapor. In the anoxic, saline sediments of permanently ponded areas of ERF, complete conversion to phosphate is extremely slow (perhaps taking hundreds or thousands of years). However, not all ponded areas of ERF are permanently covered with water. During some summers with extended periods between flooding high tides, water levels in ERF drop and the size of some ponds may be reduced significantly as was observed during the summers of 1992, 1993 and 1994 when intermittent ponded areas were exposed to the atmosphere. Evaporation and drainage desaturate exposed sediments, and water in the sediment pores is replaced by air. In sediments with free pore space, WP can change phase from solid to vapor and diffuse away or be oxidized. Diffusion continues as long as there is free pore space. Both the rate of sublimation and diffusion increases with temperature. The detection of unsaturated sediments in ERF implies that there is potential for intrinsic remediation, and studies were conducted in 1994 and 1995 to evaluate this potential.

In 1994 sediment moisture and temperatures, as well as the persistence of planted WP particles (spherical particles with an initial diameter of 1.8 mm), were monitored in Area C at locations within the main pond, on the mudflat, and the river levee. Between May and the end of August, sediments were unsaturated within the top 5 cm at least part of the summer at all sites except one, and there was decrease in the amount of WP between at all sites except the permanently flooded sites. While loss of WP was significant, it was not complete at any site indicating that more than one summer with favorable drying conditions is needed for complete removal of large WP particles (>1.8 mm diameter or >5.6 mg). Unsaturated conditions were detected down to 30 cm at monitoring sites on the river levee, mudflat, and two intermittent pond sites, indicating that WP loss is possible at depth. However, at depth, loss is likely to be slower due to sediment consolidation, lower temperatures, and longer periods of saturation.

Laboratory experiments were conducted in conjunction with this 1994 field study. WP particles like those used in the field study were incubated in sediments at constant moisture contents (degree of saturation = 0.45, 0.64, 0.82, 1 or > 1) and temperatures (4, 15 or 20°C). WP particles were persistent at moisture contents at or above saturation. WP particles incubated well below saturation (s = 0.45 or 0.64) were lost rapidly (24 hr) at 20°C, within 30 days at 15°C, and persisted over the time interval tested (approximately 60 days) at 4°C. For samples incubated slightly below saturation (s = 0.82) results were variable, with significant loss in some samples and no change in other samples.

Also in 1994, we revisited a location in the intermittent pond of Area C where we had previously (August 1992) examined the variability in WP contamination around a highly contaminated site (Racine et al. 1993). Samples were taken at one-meter intervals out to five meters along eight axes around the center point (Site 883). This area was subaerially exposed (i.e., not covered by water) during June and July in 1993, and part of June, the later part of July and August in 1994. During the 1995 field season we repeated the close interval sampling to determine if the pattern and level of contamination had changed. In addition, WP particles were isolated and measured from a sample collected at the center point as was done in 1992 (Racine et al. 1993).

Finally, we also collected samples from the crater (Miller's Hole) produced in

May 1992 by the in place detonation of an 81-mm WP smoke round UXO by high explosives. Miller's Hole is also located in the intermittent pond at Area C. Since the detonation, we have been sampling this site each spring and fall to monitor changes in white phosphorus concentrations. WP particle size distribution was also determined. Particle size distribution at these intermittent ponded sites was compared with particle size distribution at a permanently flooded site where we previously found high concentrations of (Racine Island).

METHODS

Sample collection

Site 883 was relocated based on UTM coordinates and the presence of the stubs of some lath that were used to mark the site in 1992 and 1994. The UTM coordinates for Site 883, the center point of the close interval sampling, are 354,981.6E, 6,801,183.8N (Fig. IV-3-1). The site is located 160 m west of the site of the observation tower in Area C. Samples were taken at the center point and at 1-m intervals out to 5 m along eight axes around the center point (Site 883) for a total of 41 samples on June 1,1995 and an additional 41 samples on September 17, 1995. Eight duplicates were taken also, four in June and four in September. These duplicates included two sites that had high WP concentrations in previous years and two sites that were randomly selected. An additional two liters of sediment were taken for sieving in the laboratory to isolate and measure WP particles.

Miller's Hole was relocated by lath placed in previous years, by UTM coordinates (355,066.9 E, 6,801,176.5 N) (Fig. IV-3-1), and by physical appearance. In previous years, a grab sample was collected from the bottom of the crater and a composite sample around the rim of the crater. The same procedure was used this year, except sample volume was reduced from 500 mL to 120 mL to avoid excess removal of the contaminated sediment. Samples were taken on June 1 and September 17, 1995.

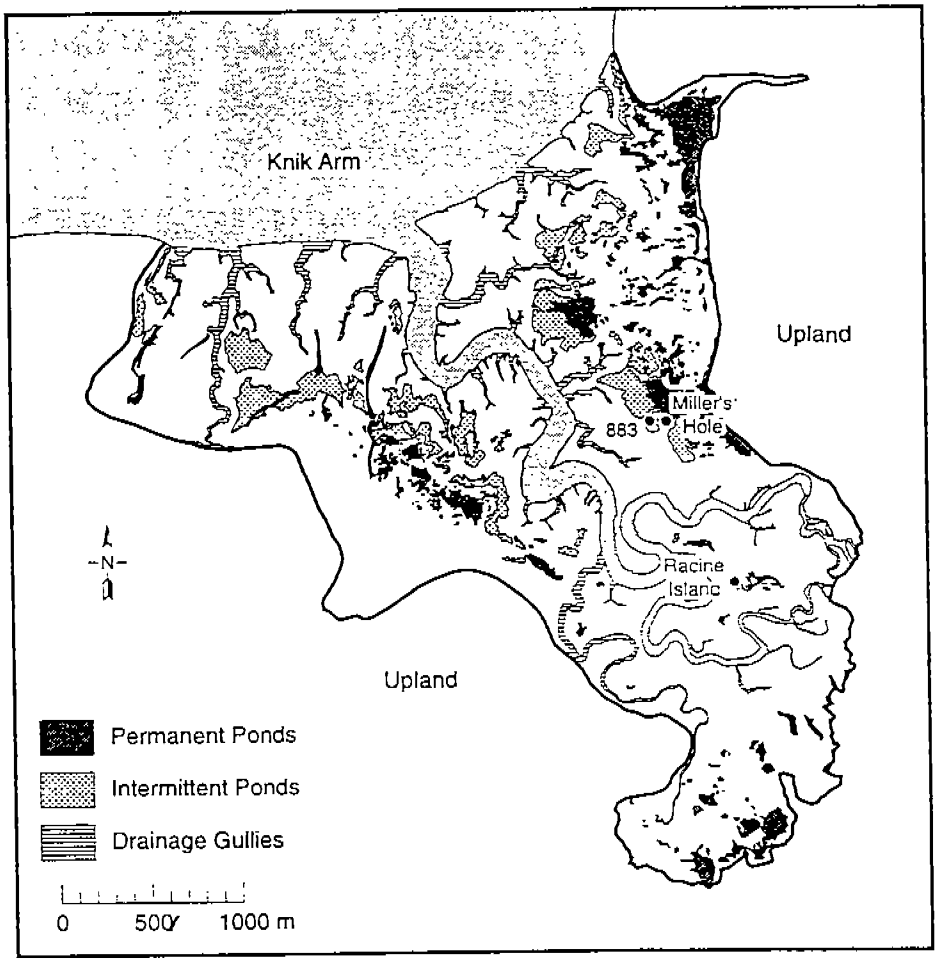


Figure IV-3-1. Map of Eagle River Flats showing locations where sediment samples were obtained.

Sediment was also obtained from a permanently flooded contaminated site, and sieved in the laboratory to isolate and measure WP particles. The site was on Racine Island Site 1246 (UTM 355,449 E, 6800231 N), which had a WP concentration >3000 µg/g. WP particles have been observed in samples previously collected from this site (Fig. IV-3-2), but the size distribution is not known.

Lab analysis

WP concentrations in grab samples were determined by solvent extraction and gas chromatography (EPA SW-846 Method 7580, Walsh and Taylor 1993).

WP particle size distribution was determined by rinsing a volume of sediment through a successive series of 30, 35, 60 and 140 mesh sieves, which have

Figure IV-3-2. Particles of white phosphorus (WP) isolated from sediment collected from Racine Island in 1994. Lead shot, shown for scale, is 2.7 mm in diameter.

openings of 595, 500, 250, and 105 µm. The material left on each sieve was transferred to a water-filled petri dish and examined using a dissecting microscope. If particles were found, they were measured using a caliper with 0.1-mm gradations. When all visible WP particles were removed from a sample, or if particles were not visible in a sample, the sample was examined for the presence WP by two additional methods.

The first method was solid-phase microextraction/gas chromatography (Zhang and Pawliszyn 1993), a method that allows detection of minute quantities, less than 1 picogram, of WP. SPME fiber assemblies were obtained from Supelco (Bellefonte, PA). These assemblies are composed of a fused silica fiber coated with a stationary phase (we used 100-µm polydimethylsiloxane). The fiber is attached to a holder that resembles a modified microliter syringe. The fiber is exposed to a sample for a short period of time, during which analytes adsorb to the stationary phase. Then the fiber is placed into the injection port of a gas chromatograph to thermally desorb the analytes. We used the SPME fibers as follows. The sample was transferred to a glass jar equipped with a septa-cap, then shaken vigorously by hand, and SPME was exposed to the headspace for 5 min

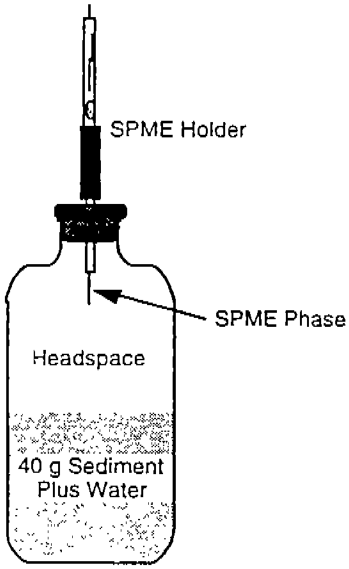


Figure IV-3-3. Solid phase micro-extraction (SPME) of a sediment sample to test for the presence of WP. Following exposure to the headspace above a sample, the SPME phase is transferred directly to the injection port of the gas chromatograph.

(Fig IV-3-3). Then, the SPME phase was immediately transferred to a heated (200°C) injection port of a portable gas chromatograph (SRI Model 8610, Torrence, CA) equipped with a nitrogen-phosphorus detector. The polydimethylsiloxane fused silica column (J & W DB-1, 15 m × 0.53 mm id, 3 µm film thickness) was maintained at 80°C and the carrier gas was nitrogen set at 30 mL/min. Typical chromatograms are shown in Figure IV-3-4.

The second method used to test for the presence of WP in the material left on the sieves involved spreading the sample in a thin layer on an aluminum pie pan and heating the sample until all water evaporated. If WP particles were present, they were detected by the observation of a localized area of intense smoke and flame, and the formation of a bright orange residue. Particles greater than 0.3 mm in diameter (26 µg) can be detected using this method (Walsh et al 1995).

The data for WP concentrations were plotted based on UTMs, and symbols were used to represent four concentration groupings (<0.001, 0.001 to 0.099 µg/g, 0.1 to 9.2 µg/g, and >10). Nonparametric statistics were used to compare the concentrations found in 1992 and 1995. Nonparametric statistics were used since the data are not normally distributed.

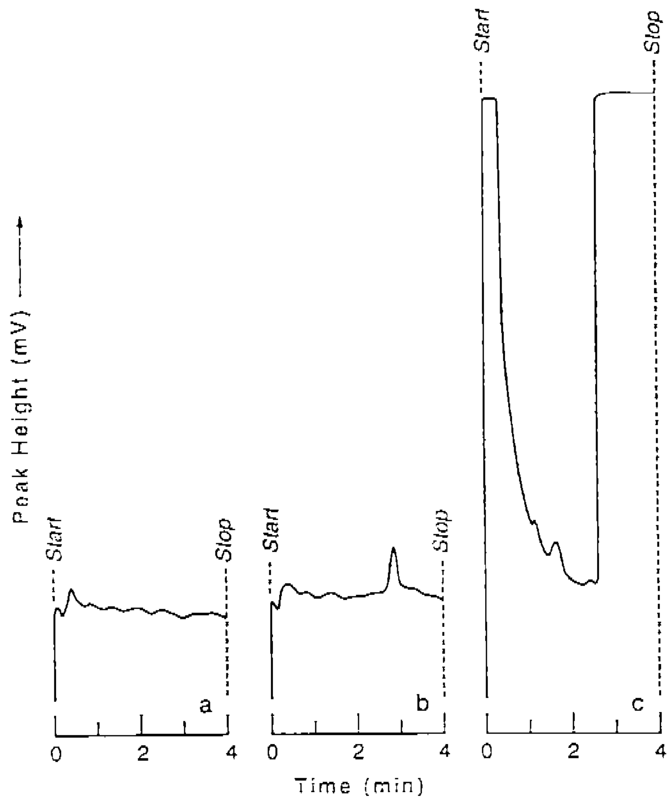


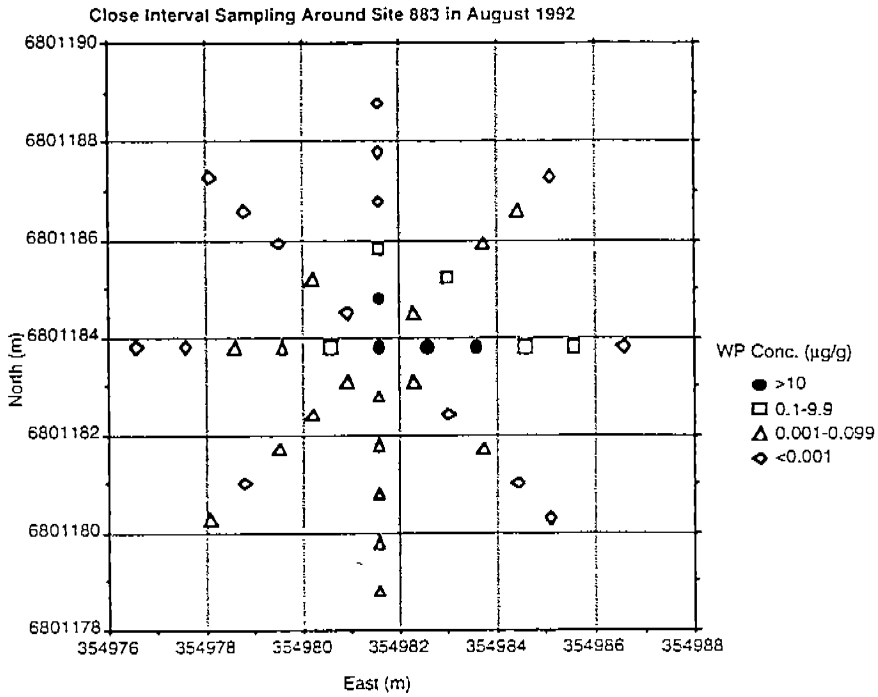
Figure IV-3-4. Typical chromatograms obtained by SPME/GC analysis for WP. a) blank (WP not detectable), b) trace amount (picograms) of WP present, c) large (mg) particle of WP present.

RESULTS AND DISCUSSION

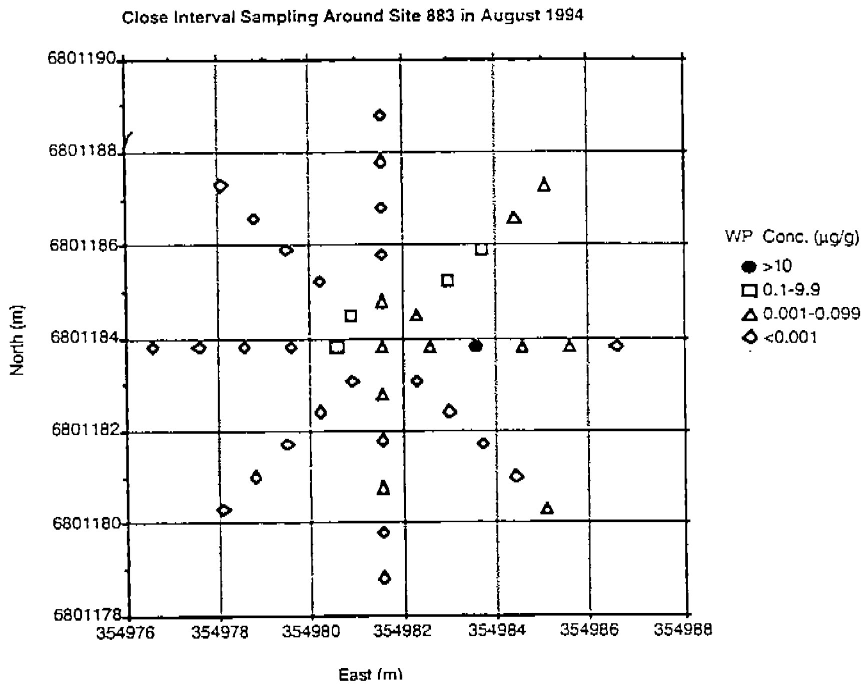
Pattern of contamination around site 883

Sediments at site 883 were desaturated during the summers of 1993 and 1994 when weather conditions and the length of time between flooding tides were favorable for pond shrinkage. During 1995, flooding tides occurred monthly and sediments at this site were continually saturated and usually underwater. These flooding tides, however, contributed new sediment to the site.

Results of additional sampling within a 5 m radius of this contaminated site in the intermittent pond of Area C confirmed that WP concentrations have changed since the area was first sampled in 1992 (Fig. IV-3-5). Concentrations

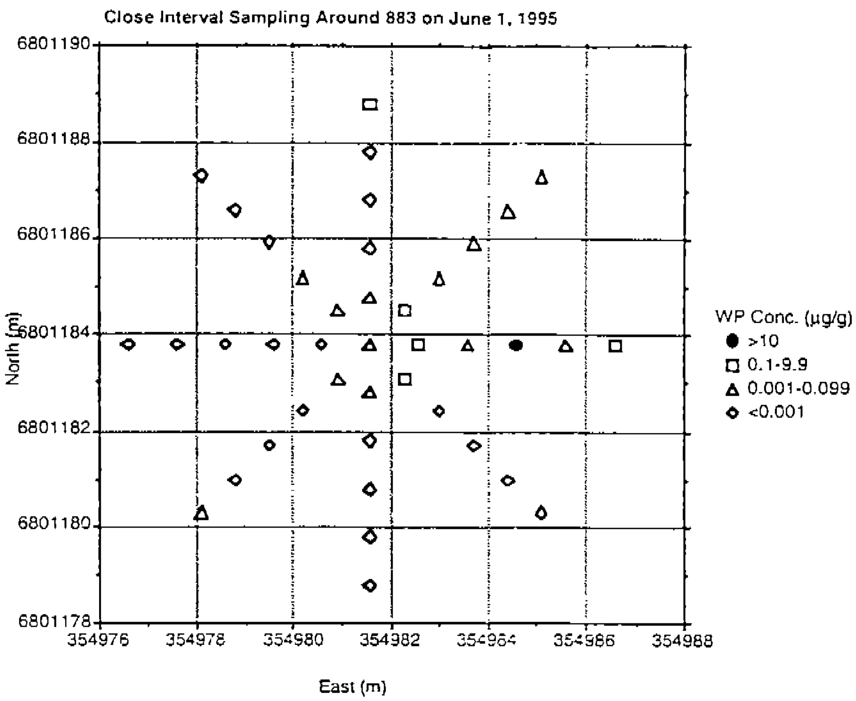


a. 1992



b. 1994

Figure IV-3-5. Pattern of WP contamination found during August 1992, August 1994, June 1995, and September 1995 around a site in the intermittent pond of Area C.



c) June 1995

Figure IV-3-5. Pattern of WP contamination found during August 1992, August 1994, June 1995, and September 1995 around a site in the intermittent pond of Area C.

found in 1994 were significantly different from those found in 1992. There was no significant difference between August 1994 and June 1995. However, there was a significant decline over the summer of 1995, possibly due to sedimentation. Comparing the concentrations ranges of 41 samples taken in the fall of 1995 at the same locations as 41 samples in the fall of 1992, the number of samples with WP concentrations greater than 10 µg/g declined from four to zero, and the number of samples below 0.001 µg/g has increased from 15 to 28 (Fig. IV-3-6). The decline in WP concentrations since 1992 is readily apparent in a percentile plot showing results from all samples (Fig. IV-3-7). In 1992, only 37% of the samples were non-detects, whereas in September 1995, 65% of the samples were non-detects.

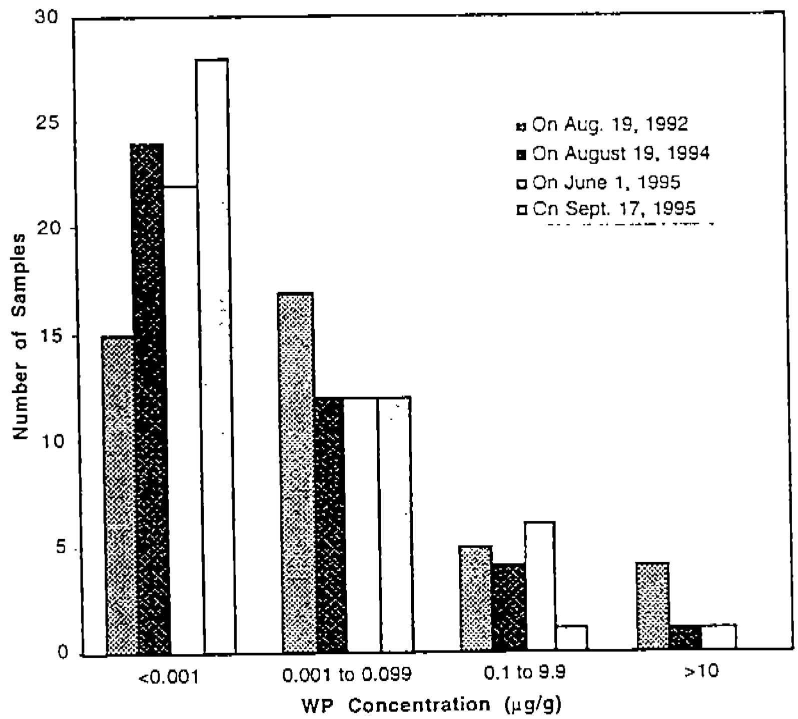


Figure IV-3-6. Number of samples in different concentrations ranges in 1992, 1994 and 1995 at a site in the intermittent pond of Area C.

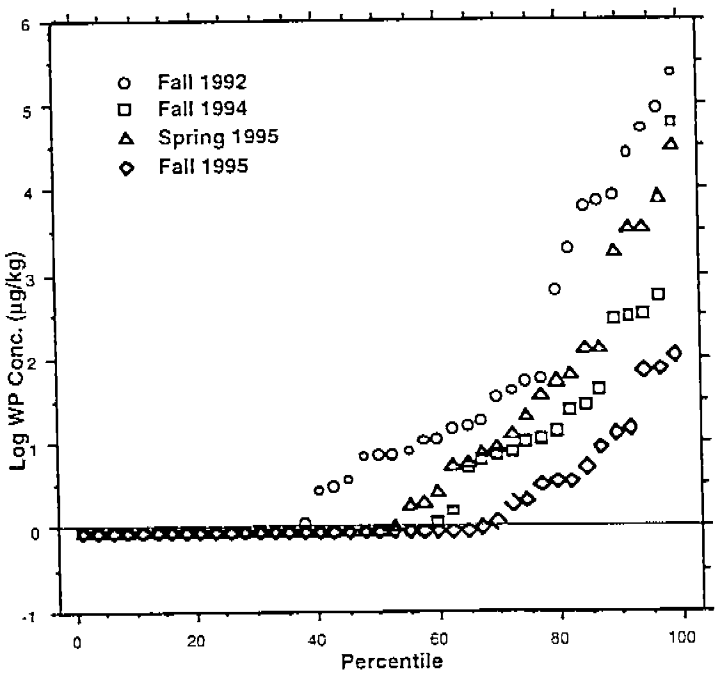


Figure IV-3-7. Percentile plot of WP concentrations found in 1992, 1994 and 1995 around a site in the intermittent pond of Area C.

Table 1. WP concentrations found at Miller's Hole, a crater produced by the detonation of a WP UXO.

Date sampled	Days since explosion	Concentration (µg/g) Center	Rim
5/20/92	0	2394	979
6/18/92	29	5,572	0.237
8/21/92	93	184	0.00427
6/23/93	399	187	0.0175
8/27/93	464	81.5	0.00177
5/16/94	726	49.5	34.1
8/30/94	832	9.5	<0.00088
6/1/95	1107	10,497	0.0051
9/17/95	1215	166	0.0006

WP concentrations found in Miller's Hole

Samples were also obtained from the crater produced from the in place detonation of a WP UXO in 1992. The crater is also in the intermittent pond of Area C. The rim of the crater, which had a WP concentration of nearly 1000 µg/g when sampled in 1992, had concentrations of 0.0051 and 0.0006 µg/g when sampled in the June and September 1995 (Table IV-3-1). The bottom of the crater, which is 32 cm below the rim, still has high concentrations of WP. The bottom of the crater was exposed to the atmosphere in 1993 and 1994, but for much shorter lengths of time then the rim. The apparent increase in concentration in the crater bottom suggests that underlying sediments may have been brought to the surface, possibly by ice plucking or frost heaving.

The depth of WP contamination at this site is unknown, but may be quite deep since the high explosive charge used to destroy the UXO was placed on top of the shell, so the force of the explosion would have driven the WP filler into the sediment. The crater produced following the explosion of this UXO resembles that produced by a HE round, and is much larger than that which would be expected from a WP projectile that exploded on impact. WP projectiles contain only a small bursting charge that serves to rupture the shell. [For example, a 61-mm HE mortar round contains 0.37 kg (0.8 lb) of HE, whereas a 61-mm WP mortar round contains only 0.01 kg (0.4 oz) of HE (Dept. of the Army 1977).] Therefore a WP projectile would displace little if any sediment. The depth to which WP is present elsewhere in ERF is most likely a function of how far a shell penetrated the soft mud prior to detonation. It will also depend on the type of fuse used with the shell. A point detonating fuse will allow some penetration into the soft mud while a proximity fuse will cause the projectile to explode above the surface, prior to any penetration into the mud.

WP particle size distribution

WP particles were isolated from sediments collected from three locations, site 883, Miller's Hole and a site on Racine Island. These sites vary in the length of time that their sediments have been desaturated, ranging from several weeks for site 883, to possibly a few weeks for Miller's Hole, to no time for the Racine Island sample. In both the Racine Island and Miller's Hole samples, many particles were readily found in the first 500 mL of sample sieved (Fig. IV-3-8). For site 883, 1000 mL of sediment was sieved and only one particle was found.

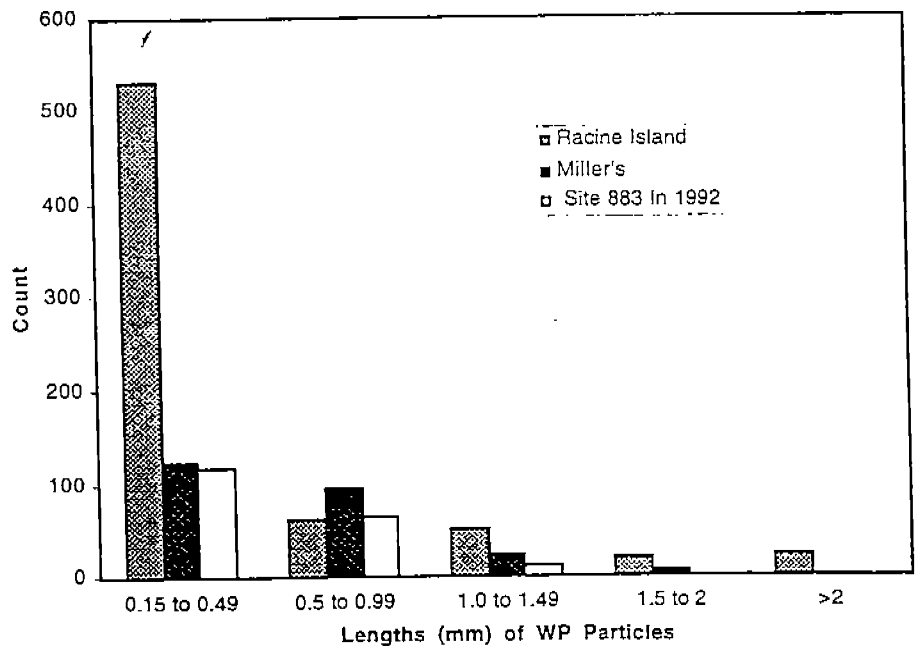


Figure IV-3-8. Size distribution of WP particles found in 500-mL sediment samples collected from a permanently saturated (Racine Island) and two intermittent ponded sites in ERF.

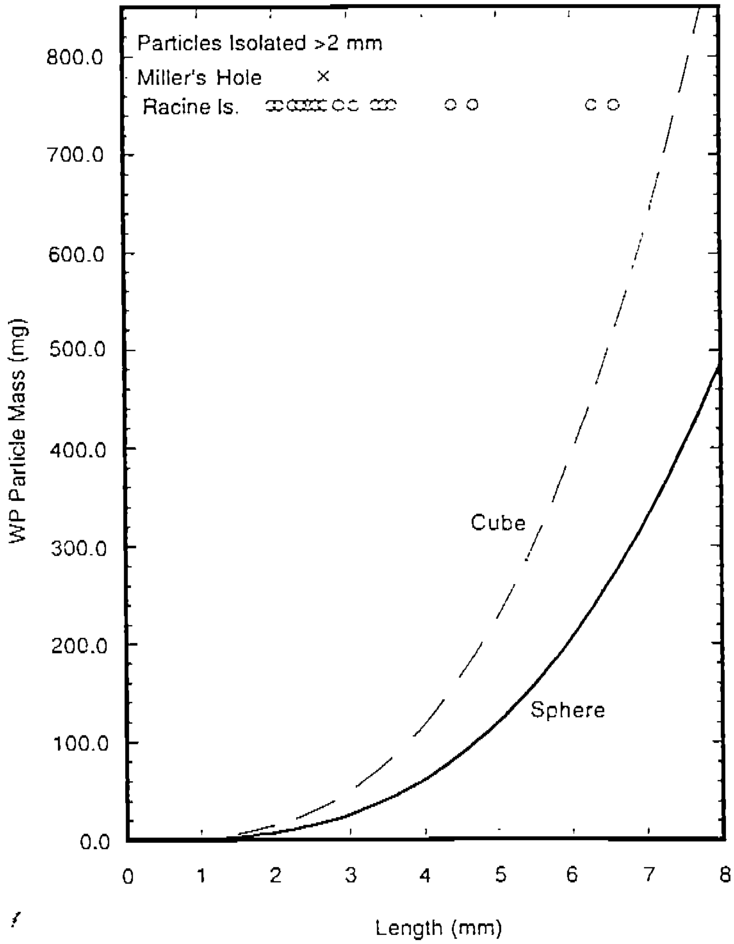


Figure IV-3-9. Mass of cubic or spherical WP particles corresponding to the range of the lengths of particles measured in samples in ERF.

The widest range of sizes was found in the permanently saturated site (Racine Island) (Fig. IV-3-8, IV-3-9, IV-3-10). In this sample, gravel size (>2 mm) pieces of WP were found, some of which were over 6 mm in length. However, the vast majority of the particles isolated were in the smallest class (0.15–0.49 mm), and many WP particles were smaller than 0.15 mm, as indicated by the abundant "smoke" coming from the material that passed through the sieve.

WP particles were less abundant in the Miller's Hole sample. Only one particle measured over 2 mm in length, and most of the particles were in the smallest size category. And finally, 1000 mL of sediment collected in 1995 from site 883 were sieved, and only one particle was found (1.7 mm diameter). These results contrast with those obtained in 1992 when 270 mL of sediment from this site

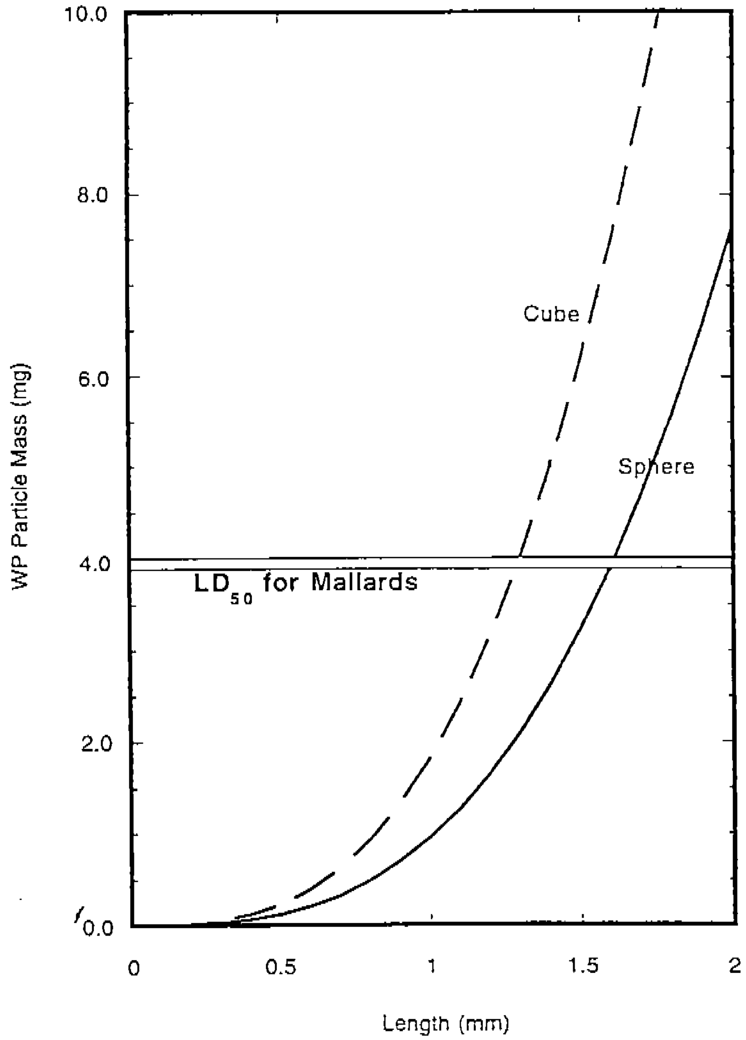


Figure IV-3-10. Mass of WP equivalent to LD_{50} (4 mg/kg, Sparling et al. 1995) for mallards (weighing 0.75 to 1 kg) and the corresponding range of lengths of cubic or spherical WP particles.

were sieved, and over 100 WP particles were isolated. Desaturation has resulted in the loss of the smallest of the particles. The one particle isolated most likely was originally much larger in size.

We hypothesize that when sediments are exposed and desaturate, the smallest WP particles are the least persistent and are lost relatively rapidly since small particles have large surface-to-volume ratios and sublimation occurs from the particle surface. Larger particles are much more persistent, but shrink during periods of desaturation.

One way to relate these particle length measurements to particle mass is to assume the particles are cubes or spheres, use length measurements to compute volume, and multiply the result by the density (ρ) of WP (1.82 g/cm^3 or mg/mm^3). For example, for a particle that measured 1 mm, the following estimates of mass are obtained:

Mass of Cube = $\rho l^3 = (1.82\ mg/mm^3)(1\ mm)^3 = 1.82\ mg$

Mass of Sphere = $\rho(4/3)\pi r^3 = (1.82\ mg/mm^3)\ (4/3)\pi\ (1/2\ mm)^3 = 0.95\ mg$

These assumptions about shape probably lead to overestimates of particle mass since they are based on the longest dimension measured, and the particles found in ERF sediments are actually irregular in shape, ranging from slivers to nearly cubes or spheres (Fig. IV-3-2). However, these assumptions are useful for estimating sizes of particles that are potentially hazardous to waterfowl. The LD_{50} for particulate WP was estimated to be 4 mg/kg (Sparling 1994) for male mallards. For 1.25-kg mallards (Hines, no date), WP particles ranging from 1.4 mm (cube) to 1.7 mm (sphere) would represent the LD_{50} (5 mg). Green-winged teal, another waterfowl species at risk, are smaller than mallards (0.4 kg) so particles ranging from 0.96 mm (cube) to 1.2 mm (sphere) would represent the LD_{50} (1.6 mg). As a generalization, the ingestion of a single WP particle approximately 1 mm or greater in length presents serious risk to waterfowl. Most of the particles found in sediment from the permanently flooded site were small. Many small particles ingested together could collectively-provide a lethal dose, if selected or accidentally ingested by waterfowl.

CONCLUSIONS

Samples collected from two intermittent pond sites have provided additional data to assess the potential for intrinsic remediation of ERF sediments. At the first site (883), overall concentrations found in grab samples have declined since the first samples were taken in 1992. The number of WP particles found by sieving samples of sediment from this site has decreased from over 100 particles in a 270-mL sample in 1992 to 1 particle in a 1000-mL sample in 1995.

Local topography at the second site (Miller's Hole) has strongly influenced the rate of intrinsic remediation at this site. Because this contaminated point was produced by the detonation of a WP UXO with high explosives, a deep crater was formed. The rim of the crater, due to its higher elevation, has desaturated more frequently and for longer time periods than the bottom of the crater. Today, WP is barely detectable in the rim of the crater, while high concentrations persist in the bottom of the crater.

The size distributions of WP particles found at both of these sites were compared qualitatively to that obtained from a permanently saturated site. Not only were there many more particles at the permanently flooded site, the range of particle sizes was broader, from less than 0.15 mm to over 6 mm. Very large particles were absent from sites in the intermittent ponded areas. Since a single WP particle greater than 1 mm diameter potentially provides a lethal dose to waterfowl, a sampling protocol designed to detect particulate WP would be useful.

Both intermittent sites provide excellent sampling locations for long-term monitoring of intrinsic remediation in the intermittent pond areas of ERF.

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IV-4. ENHANCEMENT OF INTRINSIC REMEDIATION OF WP PARTICLES BY SEDIMENT WARMING IN INTERMITTENT PONDED AREAS OF EAGLE RIVER FLATS

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INTRODUCTION

The most important condition for loss of WP particles from ERF sediments is desaturation of the sediments, which occurs in summers with long periods between flooding tides. A secondary factor is sediment temperature. Since the vapor pressure of WP increases exponentially with temperature, loss of WP particles can be significantly accelerated by warming unsaturated sediments.

A field study was performed to test the effectiveness of passive solar warming techniques on increasing sediment temperature and promoting the loss of planted WP particles.

A laboratory experiment was also performed using an active heating method to briefly warm sediments from 13° to 45°C. The purpose of the laboratory experiment was to test the hypothesis that heating the sediments would increase the vapor pressure of the WP sufficiently to initiate oxidation, which in turn would generate heat to sustain continued sublimation and oxidation after the outside heat source was removed.

METHODS

Field

Three passive solar heating techniques were tested at sites within the main pond (UTMs 354,893.4E, 6801210.7N, elev. 4.85 m) and on the adjacent mudflat

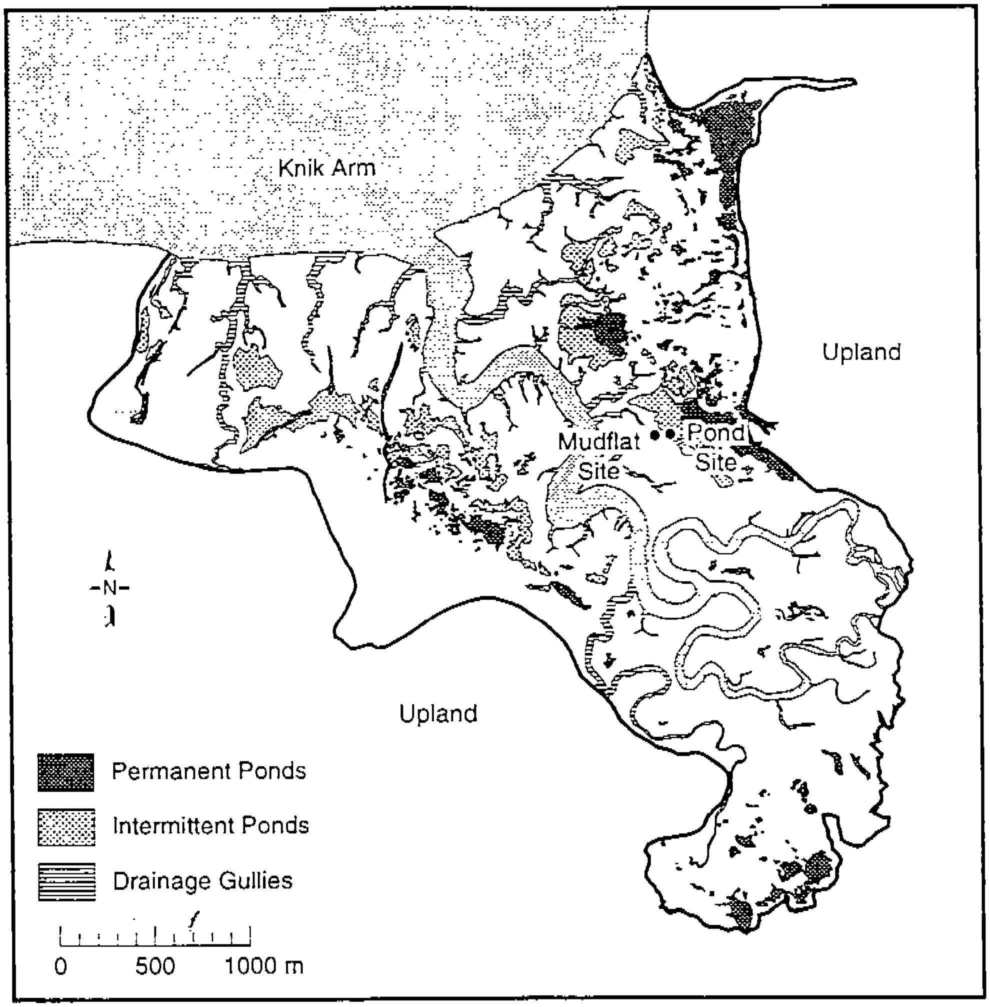

Figure IV-4-1. Map of Eagle River Flats showing location of study sites where passive solar warming techniques were tested.

(UTMs 354,836.9E, 6801216.9 N, elev. 4.87 m) of Area C (Fig. IV-4-1). These sites were chosen since they had the potential to desaturate between the monthly flooding tides during the summer of 1995. Both sites were used for the field study in 1994 to assess natural attenuation in the sediments of Area C (Walsh and Collins 1995).

Four materials plus controls were evaluated on 1×1 m^2 plots arranged in a Latin Square design (Natrella 1966) (Fig. IV-4-2, IV-4-3).

One technique tested was the application of black sand to change the surface albedo. The sand (Black Beauty, Reed Minerals, Highland, IN) was applied to a thickness of 1 mm over each 1×1 m^2 plot (1 L/ m^2) (Fig. IV-4-4).

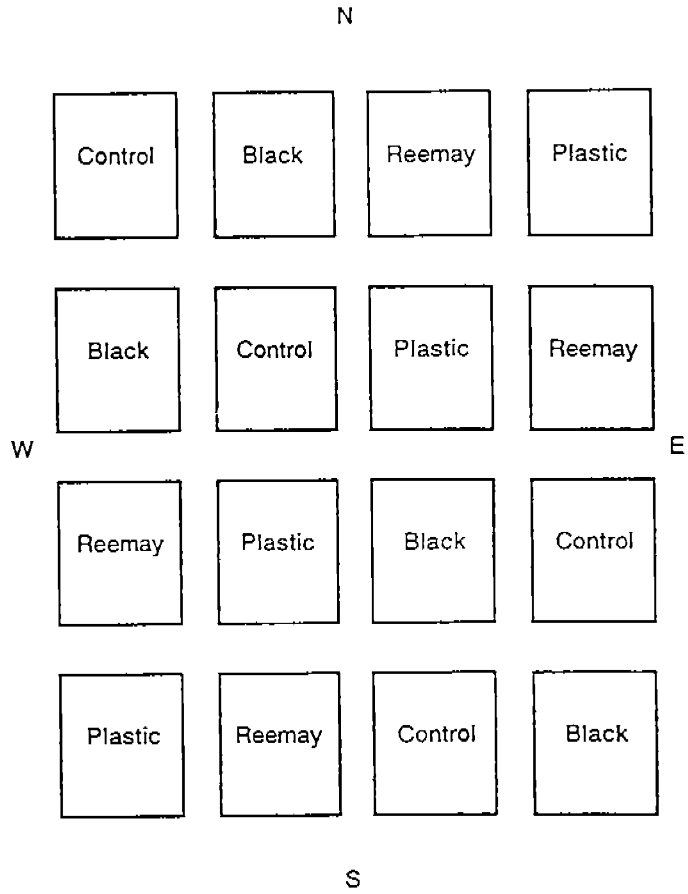

Figure IV-4-2. Arrangement of 1-m^2 plots. Control = Bare, Black = Black Sand, Reemay = spun-bonded polyester fabric, Plastic = Fast Start (porous polyethylene).

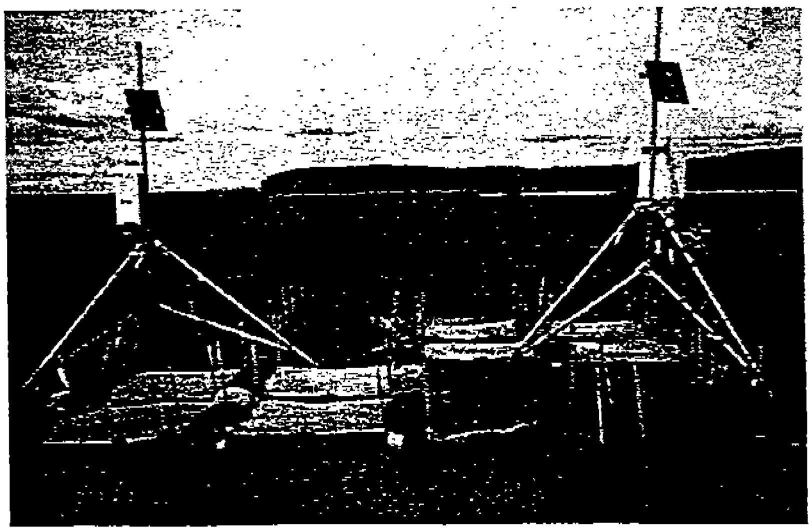

Figure IV-4-3. Plots at mudflat site.

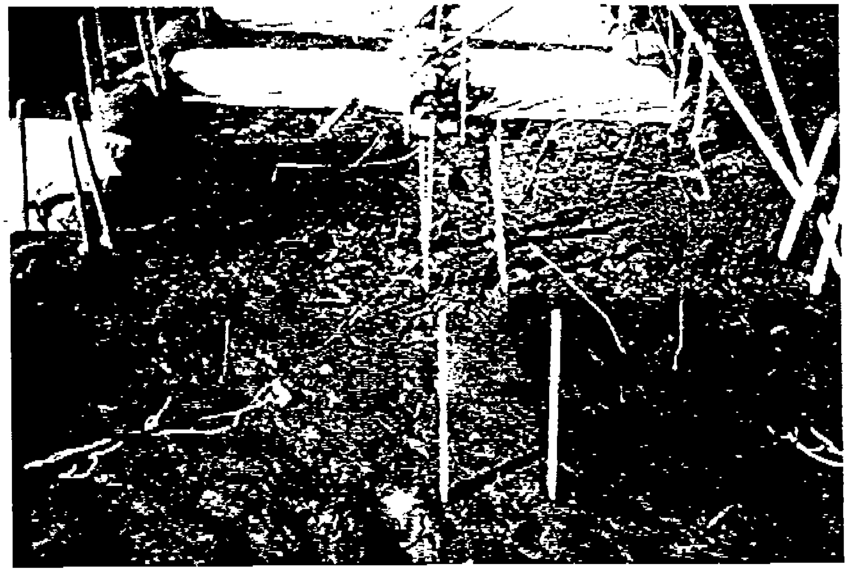

Figure IV-4-4. Control and black sand plots.

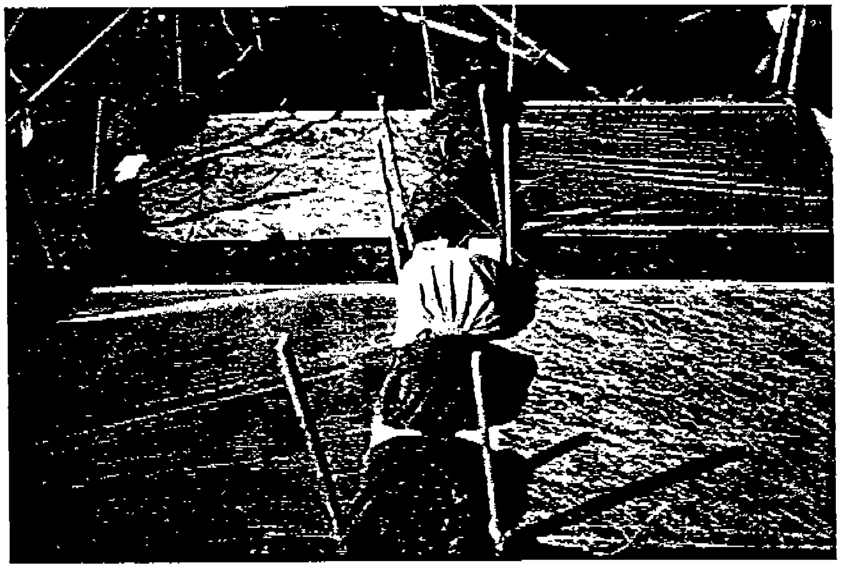

Figure IV-4-5. Reemay and Fast Start (plastic) plots.

Also evaluated were three types of synthetic row covers. The first was Reemay, a spun-bonded polyester, the second was Fast Start, a porous polyethylene, and the third was burlap. The Reemay and Fast Start were tested at the mudflat site, and the Reemay and burlap were tested at the pond site. Fabrics were held in place using two-by-fours and sand bags. The wood maintained an air gap between the fabric and the surface of the sediment (Fig. IV-4-5).

Within each plot, sensors were installed to monitor temperature and moisture conditions (Walsh and Collins 1995). Sediment temperatures were monitored at 5-cm depth using Campbell Scientific (Logan, UT) Model 107B soil/water thermistor probes. Sediment moisture status was monitored at 5 cm using Campbell Scientific Model 257 (Watermark 200) soil moisture sensors. Output from both sensors was taken every 10 minutes, and the hourly and 24-hour averages recorded by a Campbell CR10 Measurement and Control Module and an SM716 Storage Module. Also within in each plot were planted three WP particles (1.8 mm diameter, 5.56 mg), that were made in the laboratory (Walsh and Collins 1995). These particles were recovered in September to determine if WP mass had decreased. To determine if the WP particles had changed, one sediment sample from each plot containing a planted particle was sieved so that the WP particle could be physically examined. The remaining two samples containing particles were placed into isooctane to extract WP residue prior to analysis by gas chromatography.

Near-surface ground water levels at each site were monitored using Druck pressure transducers. The Druck transducers were placed within piezometers that were installed during 1994. Output was recorded using Campbell CR10 dataloggers.

A set of tensiometers was installed at each site to provide another measure of near-surface sediment moisture. Two SoilMoisture® (SoilMoisture Equipment Corp., Santa Barbara, CA) Series 2725 tensiometers equipped with dial gauges were installed, one at 10-cm depth and another a 25-cm depth. At 5-cm depth we installed a SoilMoisture® Model 2100F Soil Moisture Probe equipped with a Model 5301 current transducer instead of the dial gauge. The current transducer converted soil moisture tension measurements into an analog output that was recorded on a datalogger.

Laboratory

A laboratory experiment was also performed using a more aggressive method to heat sediments with planted WP particles. Unsaturated sediments that were collected in 1994 from the intermittent pond of Area C were spread into duplicate 50- × 30- × 7-cm aluminum pans, and sufficient water was added to saturate the sediments. The mud samples were gently agitated for 24 hr to consolidate the sediments. Then the mud samples were placed in an environmental chamber at 13°C (typical average temperature for ERF sediments during the first part of June). Tensiometers were inserted to monitor moisture contents and four thermistors inserted into one sample to monitor temperature. When tension reached 10 cbars, WP particles were planted at 3-cm depth, and a hot air gun (Model HG 501, Master Appliance Corp. Racine, Wisconsin) was used to heat one sample briefly to 45°C. Then the heated sediment sample was cooled to 13°C and WP particles recovered 24 hr after the heating event.

RESULTS AND DISCUSSION

Field

Prior to initiation of field work, a literature review was conducted to identify potential techniques that might be appropriate to raise sediment temperatures in the intermittent ponds of Eagle River Flats.

Manipulation of soil temperatures has become a common practice in agriculture where the concept of the greenhouse has been extended to the field through the use of row covers (Wells and Loy 1985). Row covers utilize natural light to heat soil and enhance the yield of many crops. In cold regions, they improve plant growth in the early part of the growing season, and provide some frost protection. In some parts of the world, such as Australia, Israel, and California, row covers are used during fallow periods to heat soil to >45°C to kill soil-borne pathogenic fungi, nematodes and insects and some weeds. The most common row covers are polyethylene or polyester.

The color and opacity of the row color influences solar heating efficiency (Lamont 1993). Black plastic absorbs most incoming radiation, then reradiates infrared (longwave thermal) radiation. Since most of this solar energy is reradiated back to the atmosphere, black plastic may raise or lower soil temperatures depending on the degree of contact with the soil surface (Marion and Pidgeon 1992). Clear plastic and fabrics such a Reemay transmit up to 95% solar radiation, and trap longwave (thermal) radiation, therefore they are more effective than black plastic at raising soil temperatures (Table IV-4-1). Fabrics such as Reemay are also self-ventilating. Slits or pores may be punched into plastic row covers to provide ventilation.

Moisture conditions during summer 1995

The conditions during the summer of 1995 were expected to be unfavorable for intrinsic remediation because of the prediction of monthly high tides exceeding 31 ft (Anchorage Tide Tables). Piezomenters and tensiometers installed at both study sites provided data on the actual flooding frequency in the west portion of Area C. In June prior to the flooding tides, water surface elevation at the mudflat site dropped to 0.6 m below the sediment surface (Fig. IV-4-6). Surface sediments were dewatered as indicated by the rise in tension to almost 10 cbars (24-hr average) (Fig. IV-4-6). Similarly, water surface elevation at the pond site dropped to 0.3 m below the sediment surface (Fig. IV-4-7), and tension rose accordingly.

To predict future favorable years for intrinsic remediation, we have been using a threshold of 31 ft for the height of the tide (predicted for Anchorage) needed to flood the flats. Although the actual flooding tide height will vary depending on the river discharge, wind conditions, etc., data obtained during the summer of 1995 show that this estimate is conservative. The highest predicted tide for June 12 was 31.6 ft, yet sensors indicated that Area C did not flood until June 13 when the highest predicted tide was 32.3 ft (Fig. IV-4-8, IV-4-9). Similarly, a 31.1-ft tide was predicted for July 11, yet sensors indicated flooding occurred with the predicted 31.9-ft tide on July 12. In August, a predicted tide of 31.5 ft appeared to flood the flats.

Table IV-4-1. Maximum temperatures recorded at various locations where passive solar warming techniques have been evaluated.

		Maximum temp. (°C)				*Mean maximum temp. (°C)*				
Depth (cm)	*Site*	*Bare*	*Clear plastic*	*Black plastic*	*Spun-bonded polyester*	*Bare*	*Clear plastic*	*Black plastic*	*Spun-bonded polyester*	*Ref.*
5	Benalla, Victoria, Australia	45.5	52	39		40.5	48.5	35		1
5	Riverside, CA		52	27			40	25		2
2	Weslaco, Texas	44	58							3
5		39	53							
10		33	46							
20		32	38							
30		31	36							
1	Frankston, Victoria,	45	61			35	54			4
5	Australia	42	55			33	47			
10		34	47			30	41			
15		32	42			28	37			
20		28	38			26	34			
25		28	35			25	31			
30		27	33			24	28			
1	Irymple, Victoria,	54	67			43	56			5
5	Australia	45	58			37	50			
10		40	53			33	45			
15		39	48			32	42			
20		37	45			31	40			
25		36	43			30	38			
30		35	41			29	37			
5	Frankston, Victoria,	41.7	53.3			30	41.2			6
15	Australia	35	42.2			27.1	33.7			
25		30	34.4			25.3	29			
5	Irymple, Victoria,	51.1	58.3			42.4	50.4			7
15	Australia	43.3	49.4			35.9	42.3			
25		38.3	45			33.3	38.3			
5	Sde-Eliyahu, Israel					30.4	49.5	39.7		8
15						28.2	36.1	31.4		
5	Steuben County, NY	36	45							9
10		31	40							
15		28	33							
0	Hanover, NH	25		15	39	13.9	17.1	8.9	24.4	10

References

1 (Kassaby 1985)
2 (Ramirez-Villapudua and Munnecke 1988)
3 (Hartz et al. 1985)
4 (Porter and Merriman 1985)
5 (Porter and Merriman 1985)
6 (Porter and Merriman 1983)
7 (Porter and Merriman 1983)
8 (Horowitz et al. 1983)
9 (LaMondia 1984)
10 (Marion and Pidgeon 1992)

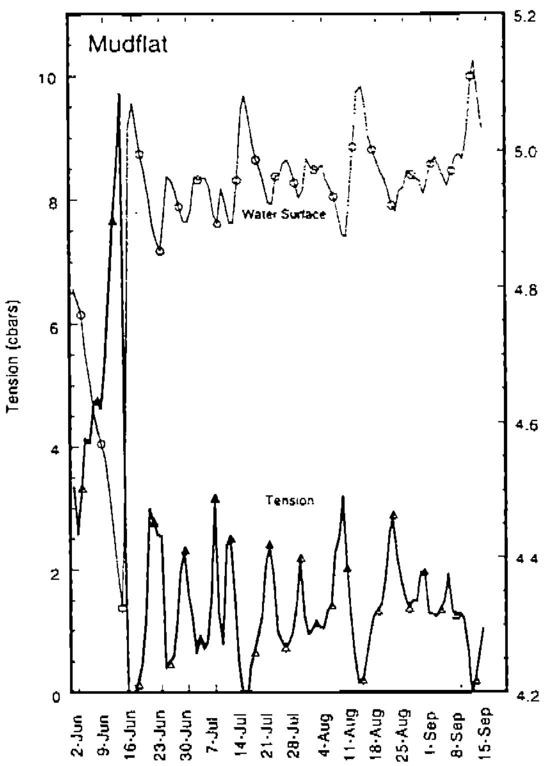

Figure IV-4-6. Water surface elevations and sediment tension (24-hr averages) at the mudflat site.

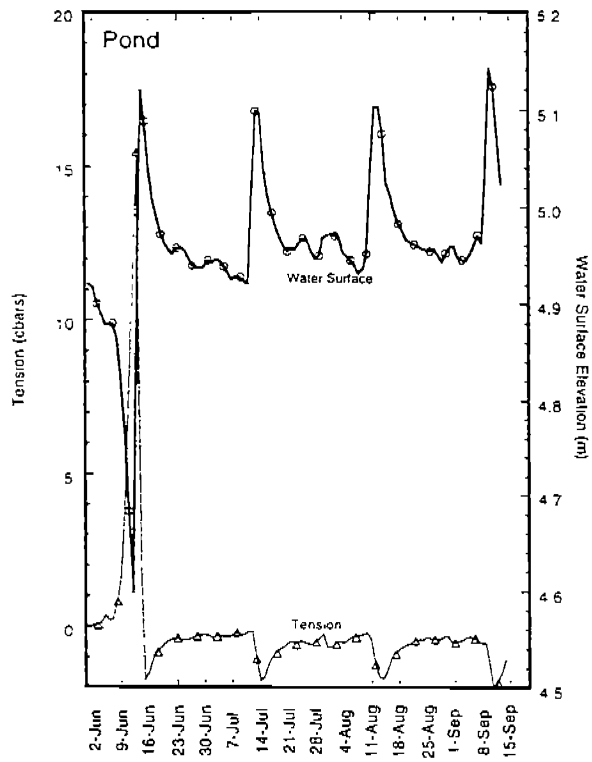

Figure IV-4-7. Water surface elevations and sediment tension (24-hr averages) measured at the pond site.

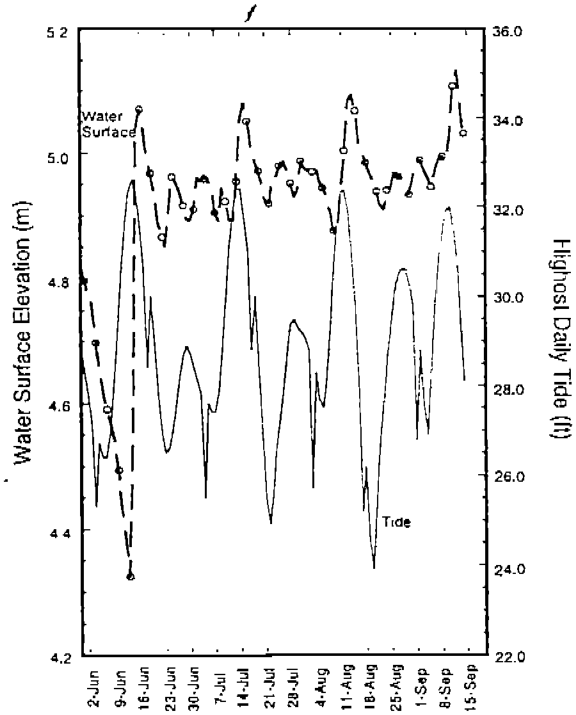

Figure IV-4-8. Water surface elevation at mudflat site and predicted high tides (for Anchorage).

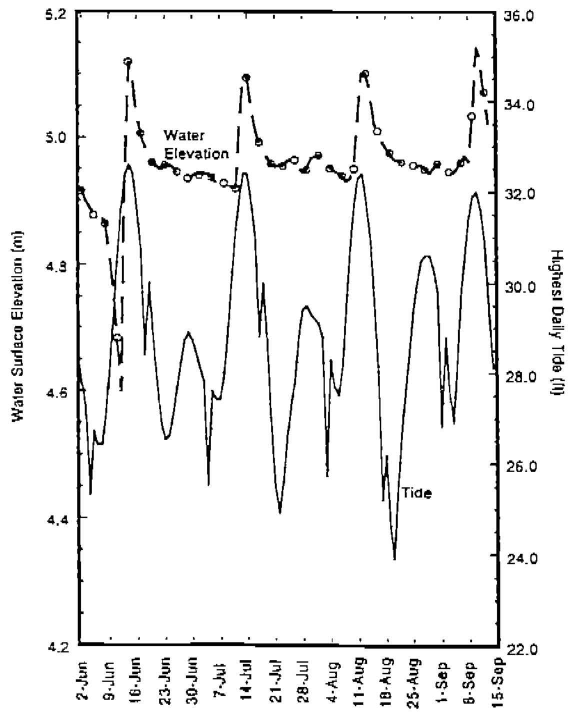

Figure IV-4-9. Water surface elevation at the pond site and predicted high tides (for Anchorage).

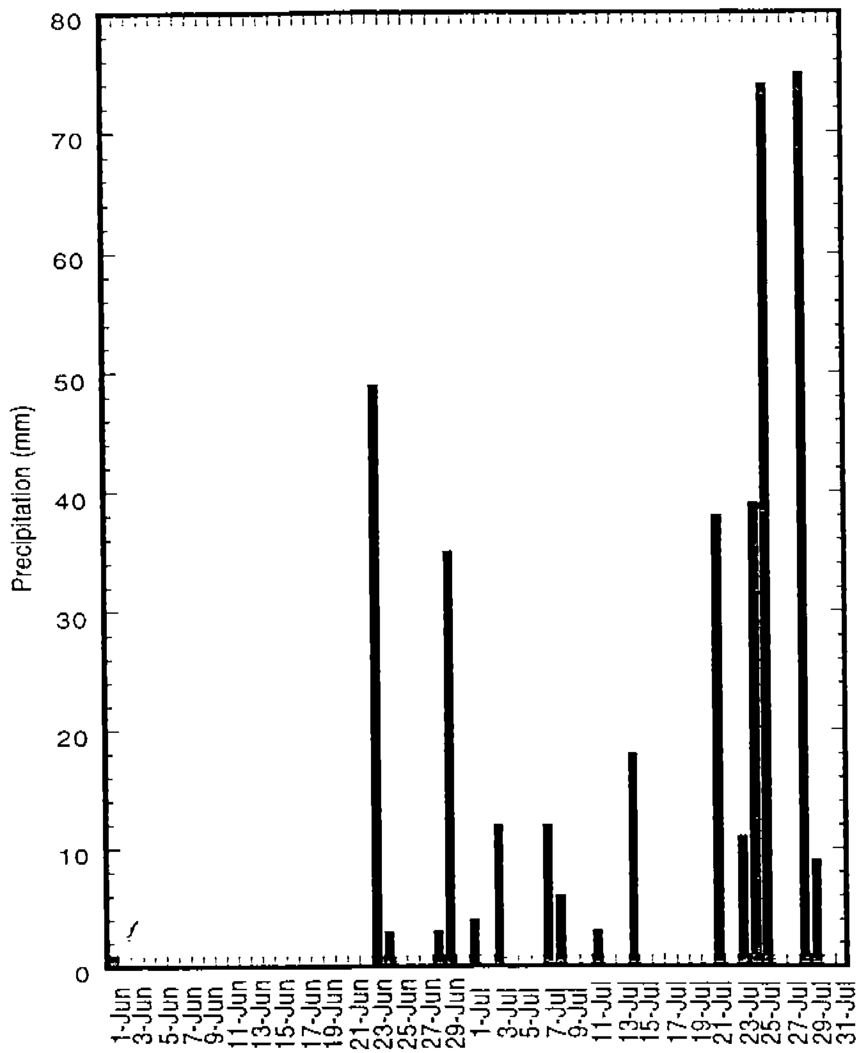

Figure IV-4-10. Precipitation in Anchorage during June and July 1995.

After the series of flooding tides in June, frequent precipitation prevented desaturation of the surface sediments in the intervals between flooding tides (Fig. IV-4-6, IV-4-7, IV-4-10).

Mudflat site

At the mudflat site, all three treatments slightly increased sediment temperatures relative to controls (Fig. IV-4-11, IV-4-12). For the period of May 28 to June 12 (prior to the June flooding tides), the maximum increase was 2.5°C for the black sand and 4°C for each of the row covers. The average increase was 1°C for

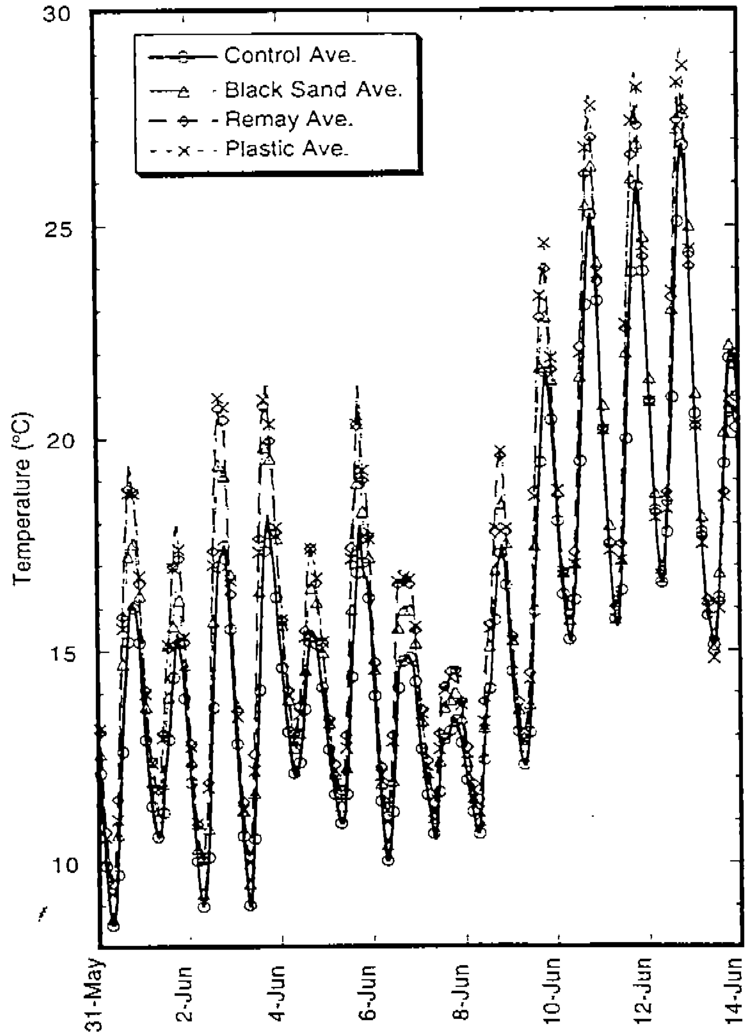

Figure IV-4-11. Diurnal temperature (average of four replicates) variations in sediment (5-cm depth) under control (bare) and three treatments during first two weeks of June.

the black sand and 1.5°C for each of the row covers. The flooding tides covered the black sand with new sediment, so that after the tides sediment temperatures were indistinguishable from the controls. Both fabric row covers were intact after each flooding tide. Immediately after the flooding tides, the sediment temperatures under the row covers were less than the control, then gradually became greater than the control. The cooling effect was caused by wet, new sediment that was deposited on the top of the row covers (making them opaque), and once dry, the layer of sediment was removed by wind.

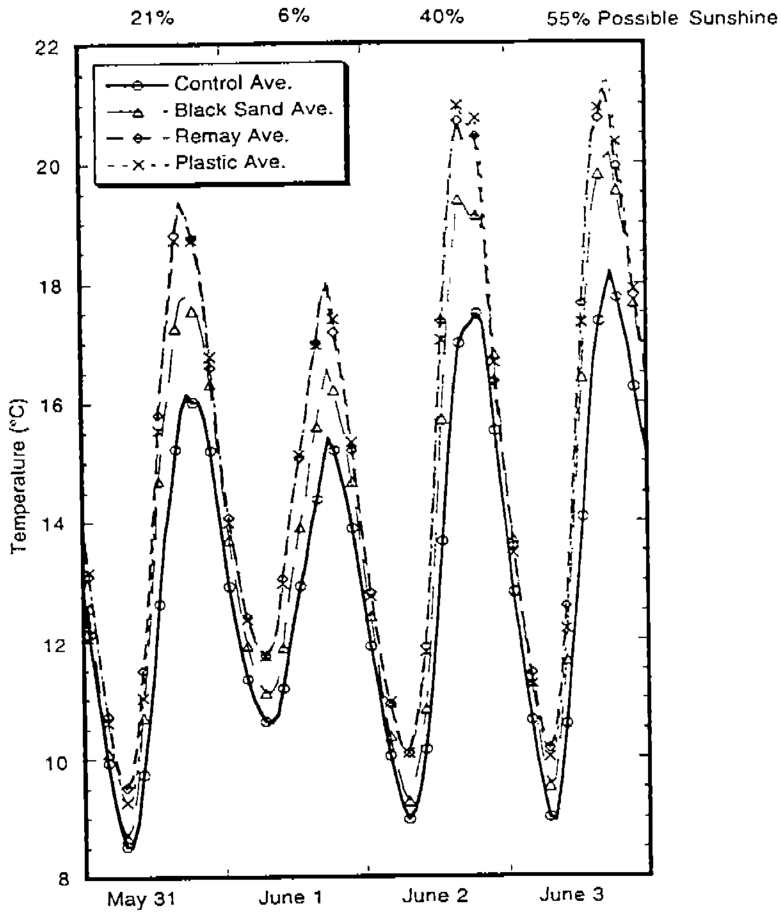

Figure IV-4-12. Diurnal temperature (average of four replicates) variations in sediment (5-cm depth) under control (bare) and three treatments May 31 to June 3 and percent possible sunshine.

Because of monthly flooding tides during the summer of 1995 and frequent rainfall during July, August and September, sediments were saturated except for a few days prior to the June flooding tides. None of the treatments appeared to significantly inhibit evaporation during this brief period of favorable drying conditions (Fig. IV-4-13).

When WP particles planted at each site were examined, the only physical difference noted was dimpling on the surfaces. Particles under the Fast Start (porous plastic) had the most severe dimpling, with some voids appearing on the surfaces. However, the masses of the remaining particles, as determined by GC, were essentially unchanged, except for a few particles under the Reemay and one par-

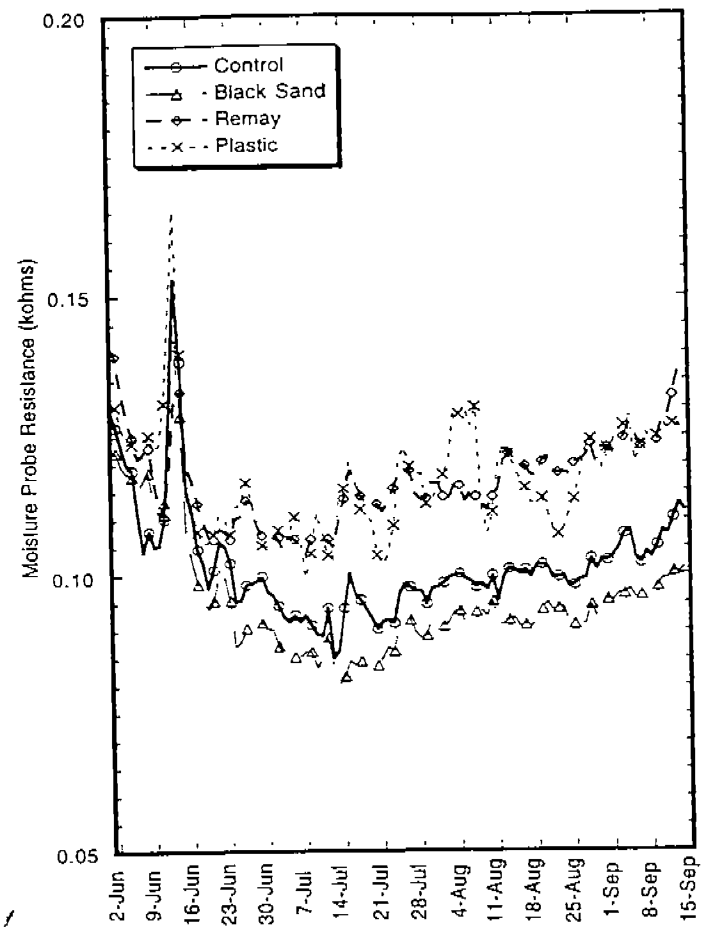

Figure IV-4-13. Moisture probes resistances at 5-cm depth for control (bare) and three treatments at mudflat site. A rise in resistance indicates that the sediments are drying.

ticle in the control plot (Table IV-4-2). The length of time that the sediments were unsaturated was too short to result in significant changes in the mass of these large particles. Since loss is from the surface of the particles, the initial loss of mass is small compared to the total mass of the particle, but accelerates as the surface area to volume ratio increases (Fig. IV-4-14).

Pond site

Results for the pond site were similar to that observed at the mudflat site for the control, black sand, and Reemay. Burlap, which was tested instead of the porous plastic, reduced sediment temperatures, probably due to dark surface color.

Table IV-4-2. Mass of WP residue found by solvent extraction and gas chromatography in sediments containing planted WP particles under passive solar warming treatments. WP particles were planted in May and the residue recovered in September.

		*WP mass (mg) remaining**			
Row	*Dup*	*Control*	*Sand*	*Reemay*	*Plastic*
1	1	2.09	5.25	5.47	4.72
1	2	4.45	4.02	5.11	5.21
2	1	0.48	4.70	5.82	5.28
2	2	5.11	3.75	0.001	6.20
3	1	5.58	5.48	4.62	4.27
3	2	5.87	5.29	2.58	4.67
4	1	5.65	5.48	1.26	5.75
4	2	4.50	5.68	5.14	5.73
Mean†		4.22	4.96	3.75	5.23
Std. dev.		1.93	0.72	2.18	0.65
Min		0.48	3.75	0.001	4.27
Max		5.87	5.68	5.82	6.20
Median		4.81	5.27	4.86	5.24
Geometric mean		3.43	4.91	1.37	5.19

*Nominal initial mass 5.56 mg

†Means not significantly different by Kruskal-Wallis test ($p=0.478$)

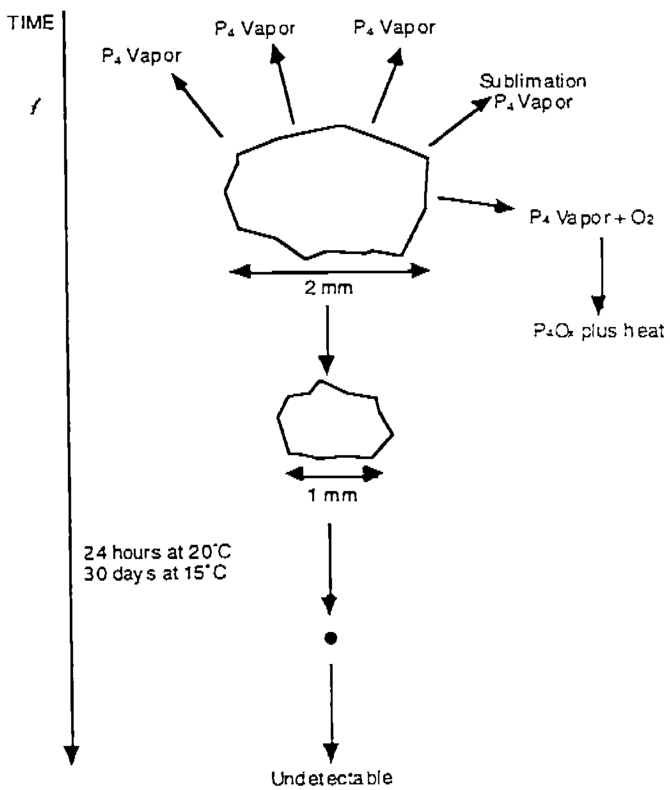

Figure IV-4-14. Conceptual model of the decay of a WP particle in unsaturated sediment.

Conditions for application

If a decision is made to utilize these passive solar warming techniques, desaturation of the surface sediments should precede application. Favorable conditions will occur in 1997 when an extended period between flooding high tides is predicted between early May and the end of July. If combined with an active pond drainage program, large areas pond sediments could be dried.

Material costs: The cost of materials normalized to area treated for this experiment were as follows:

Reemay	$0.40/m^2$
Black Sand	$0.17/m^2$
Fast Start (porous plastic)	$0.90/m^2$
Burlap	$1.80/m^2$.

Cost of application: In agricultural applications of Reemay, the fabric is laid using a modified mulch laying machine. Such a device could be attached to an all-terrain vehicle, which could easily traverse intermittent ponds during dry periods. UXO hazard could be minimized by remotely controlling the vehicle, or by sweeping the area with a magnetometer to determine safe traverses.

A sand spreader attached the same equipment could be utilized to spread black sand.

Effectiveness: Three of the treatments were successful at raising sediment temperatures. The magnitude of the increase was not as high as has been reported elsewhere (Table IV-4-1).

Field conditions during 1995 were unsuitable for determining if the treatments could significantly enhance intrinsic remediation.

Implementability: Conventional equipment may be used to accomplish these treatments, and each treatment is non-intrusive.

Onsite activity requirements (monitoring): To determine success, monitoring sites similar to those used in this experiment should be set up.

Frequency of monitoring: Frequency of monitoring would be limited to installation of sensors and WP particles at start of summer and removal at the end.

Data may be downloaded from the dataloggers periodically during the season or at end of season.

Recommendations: We recommend that attention be focused on assisting the dewatering of surface sediments, through pond drainage, and perhaps by remote tilling, prior to considering the application of solar warming techniques. If used, solar warming would provide the most benefit for the cost in regions where the time that the sediments are unsaturated is short, such as near the boundary between intermittent and permanently flooded ponds.

Laboratory

Previously we determined that loss of WP particles in unsaturated sediment was much slower at 15°C (30 days) than at 20°C (24 hr). In this experiment we briefly warmed unsaturated sediments that were initially cool (Fig. IV-4-15) to see if one warming event would result in rapid loss of WP particles.

Even though the sediments were heated well above the autoignition temperature of WP, the mean (±std. dev.) mass of remaining particles was 4.5±1.2 mg, which is not significantly different then the control (5.7±0.3 mg). For this experiment, the heat was focused on the center of the sample, an area 17 cm in diameter. Approximately 3 kg of sediment actually reached 45°C after an expenditure of 840 W-hr of electricity. Longer heating periods were not tested since the costs of field application would be too high.

CONCLUSIONS

Based on results of field studies, the application of row covers or black sand is a tool that may be used to raise sediment temperatures slightly, but are not effective at removing WP unless sediments are desaturated longer than a few days.

A brief interval at high temperatures (up to 45°C) failed to rapidly remove WP from the sediments. The average WP mass remaining in the heated sedi-

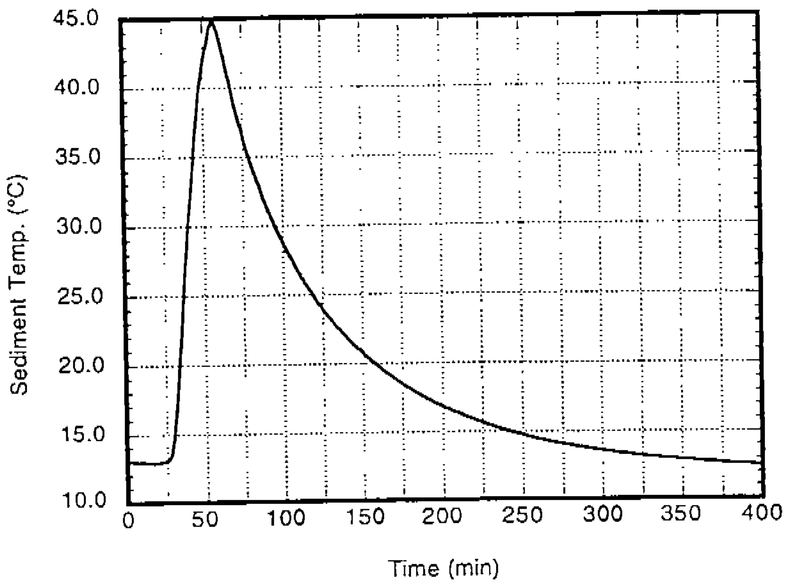

Figure IV-4-15. Temperatures in sediments equilibrated in a cool environmental chamber, and briefly warmed with a heat gun. Heat source was applied at 25 min and removed at 55 min. WP particles were recovered 24 hr after the heating event.

ments was not significantly different from the control, indicating that a longer period of heating would be necessary to accelerate WP loss. However, the energy requirements for prolonged heating in situ would be prohibitive.

Given that intrinsic remediation is occurring in some parts of ERF in areas that naturally desaturate, ways to enhance natural drying should be employed where possible before active methods of raising sediment temperatures.

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IV-5. POND DRAINING TREATABILITY: 1995 STUDIES

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INTRODUCTION

Eagle River Flats is an estuarine salt marsh complex located at the mouth of Eagle River on Ft. Richardson, Alaska. Eagle River Flats has served as the artillery impact area since the late 1940s. In 1990 we identified white phosphorus (WP) from smoke munitions as the cause of the death of large numbers of waterfowl occurring each year in Eagle River Flats (Racine et al. 1992a,b). Additional work has been done since then to quantify the nature and extent of WP contamination (Racine et al. 1992c, 1993, Racine and Cate 1994).

Work by M.E. Walsh (1993, 1994) has shown that if excavated pond bottom sediments contaminated with particles of WP are subaerially exposed long enough so that sediment moisture dries below saturation, WP particles within the sediment will sublime (pass from the solid to the gaseous state) and oxidize. Work last year (Walsh and Collins 1995, Walsh et al. 1995) shows that WP contamination in intermittently flooded pond bottom sediments will decline in situ if the sediments are subaerially exposed long enough for the sediment to dry below saturation. Since the vapor pressure of WP and hence the rate of sublimation is temperature dependent (Walsh 1993), how fast the WP particles will sublime will depend on how long the sediments remain unsaturated and under what sediment temperature conditions.

If WP-contaminated pond bottom sediments that normally remain saturated are subaerially exposed long enough so that sediment moisture falls below saturation, WP particles within the sediment may begin to sublime and disappear. Artificially draining a pond, either temporarily or permanently, will expose much of the WP-contaminated bottom sediment, thus possibly allowing for the in situ sublimation of WP particles. The Bread Truck (BT) pond, an isolated, shallow, highly contaminated pond northwest of Area C and west of C/D area, appears to lend itself to a pond draining treatment based on surveys and initial draining tests conducted last year (Collins 1995).

Past surveys (Collins 1994) of distributary channel systems draining the area in the vicinity the BT pond shows that the heads of one or more gullies come to within 40 m of the edge of the pond. There is a greater than 1.5 m vertical elevation difference from the pond bottom to the bottom of the gully at the base of the head wall. Permanently draining BT pond by excavation of a drainage ditch between the BT pond and one of the gullies was one possible treatment considered. Because of the permanent and drastic nature of draining the pond with an excavated ditch, temporarily draining the pond by pumping down the water level was a more acceptable treatment to initially attempt. Temporarily draining a pond would allow later restoration of the pond as waterfowl habitat.

Last year's work in the BT pond, however, showed that even when pond levels were lowered to expose pond bottom sediments, if the sediments were not exposed sufficiently long enough to dry below saturation, no reduction in the WP-contamination would occur. The water levels in the pond have to be lowered as quickly as possible after the last monthly flooding high tide to give the pond bottom sediments as long a chance as possible to dry. This means that a high-capacity pump system to remove as much water as possible, as quickly as possible, needs to be used to lower the pond level to ensure the longest possible subaerial exposure time for the WP-contaminated pond bottom sediments.

STUDY OBJECTIVES

The overall objective of this treatability study was to assess if pond draining is a viable option for remediation of one or more of the WP-contaminated ponds in Eagle River Flats. To achieve that objective several tasks were undertaken to determine if pond draining was technically feasible and what environmental conditions occur in the pond-bottom sediments following draining.

Task One was to design, purchase, deliver and install in the BT pond a large dewatering pump system to be used to temporarily drain the BT pond. Lowering of the water level by pumping would allow detailed observations of the response of the pond to the lower water level.

Task Two was to determine environmental conditions in the BT pond before and after temporarily draining the pond. We planned to install instruments and sensors within and adjacent to the BT pond to monitor pond water levels, sediment moisture levels, sediment temperatures, and near-surface ground water levels. We also wanted to determine interactions of surface water runoff and the near-surface ground water table, which might affect the final achievable water level in the pond.

Task Three was to determine rate of surface water inflow into the C/D area from the adjacent uplands and how that rate of inflow might influence water levels in the BT pond.

SITE DESCRIPTION

The Bread Truck (BT) pond is an isolated pond located east of the Eagle River and northwest of the Area C pond complex (Fig. IV-5-1). The BT pond consists of an inner permanently flooded pond with an area of 33,000 m^2 (3.3 ha). An outer intermittently flooded pond area of 5.4 ha surrounds the permanent pond, mainly on the west and south. Additional adjacent and connected intermittently flooded ponds on the north total another 1.0 ha. The pond area is surrounded on three sides by higher, vegetated mudflats (Racine et al. 1993). On the fourth side, to the east, the pond is bounded by a sedge and bulrush marsh complex called the C/D area. The elevation on this side of the BT pond is lower than the other three sides, allowing some flow between BT pond and the C/D area at certain water levels. To the east of the C/D area is an upland bluff marking the eastern boundary of Eagle River Flats.

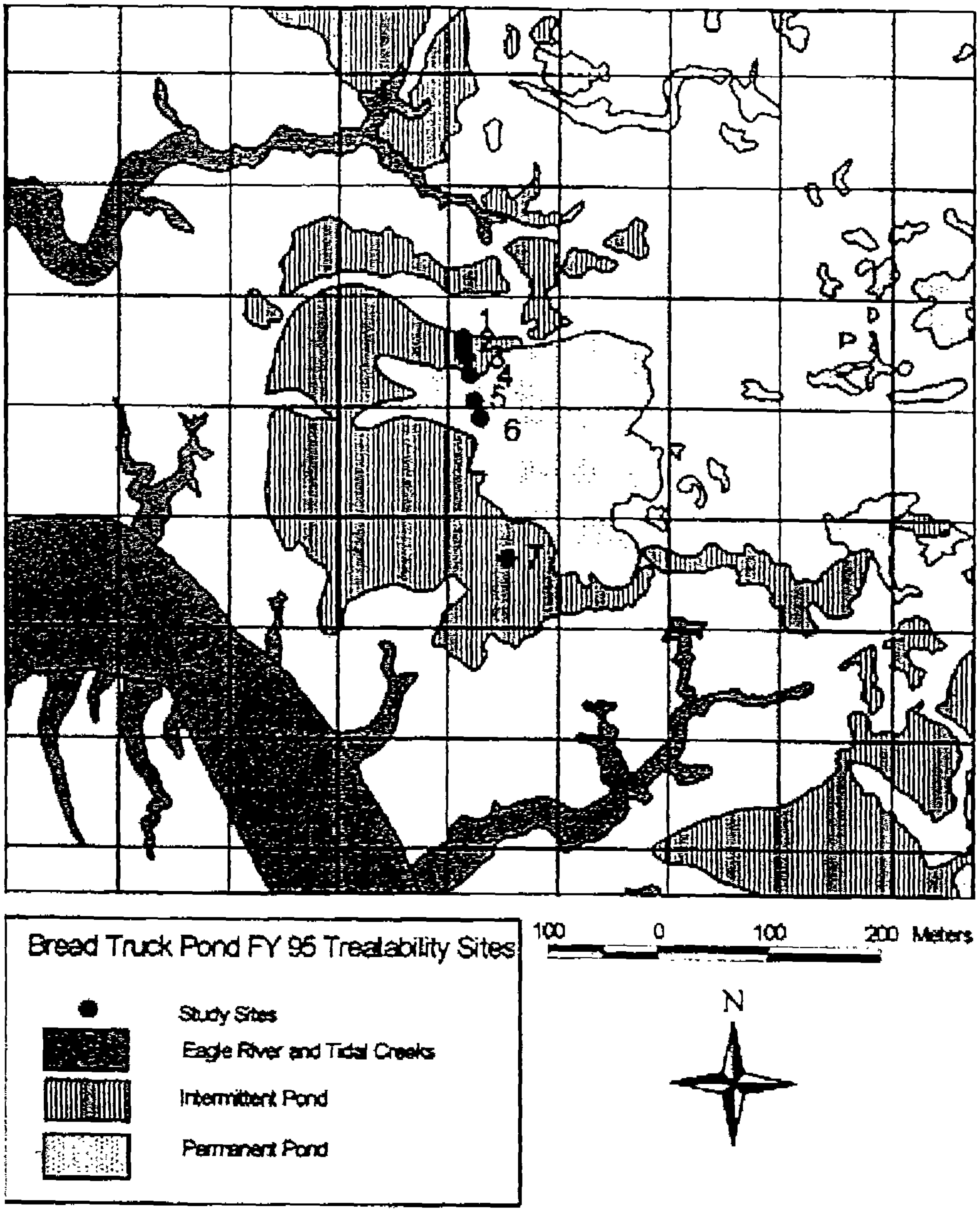

Figure IV-5-1. Bread Truck Pond and surrounding area within Eagle River Flats.

Distributary channels or gullies leading to Eagle River are located on the south and north side of BT pond (Fig. IV-5-1). These allow tidal inflow into the pond during flooding high tides and provide drainage ways for the area during the tidal ebb. The gullies are undergoing headward erosion that may eventually lead to permanent drainage of the BT pond. The gully just to the northwest of BT pond has exhibited net headwall recession rates of up to 3.5 m per year during 1993 and 1994 (Lawson et al. 1994, 1995). Erosion increased dramatically during 1995 with headward erosion of 15 m or more (Lawson et al., this volume). If such headward erosion rates continue, erosion could cause natural drainage of the pond within the next 2–5 years rather than the 10–15 years predicted previously.

The BT pond basin is subject to periodic filling under certain flooding high tide conditions. How often the pond is flooded and refilled during the summer depends on the maximum height of the monthly series of peak high tides. Some years will have only one or two monthly series of flooding high tides during the summer. Other years, such as 1991 and 1995, had a flooding high tide every month of the summer. The monthly peak high tides, if above about 31 ft Anchorage tidal datum (or about 4.79 m MSL), will spill over a threshold into the pond basin from the nearby distributary gully, refilling the pond basin. Depending on the height of the flooding high tide, the water will fill the intermittently flooded pond areas up to a water surface elevation of about 4.95 m. The water level in the pond will then slowly drop as water flows out of the pond through the distributary channels. Additional drops in the water level below the threshold elevation occur as evaporation reduces the amount of water in the pond and possible groundwater flow out of the pond.

Minimum pond bottom elevations within the permanent pond are about 4.50 m, giving a maximum depth following filling by a flooding high tide of about 0.47 m. Minimum elevations for the intermittently flooded pond area range from 4.75 to about 4.95 m, giving a maximum depth following filling by a flooding high tide of zero to 0.15 m (Collins 1995)

The C/D area (Fig. IV-5-2) east of BT pond consists of a complex of small permanent ponds, sedge marsh, sedge bog, and open low scrub (Racine et al. 1995). A narrow, deep permanent pond runs adjacent to the upland bluff along the eastern end of the area. This pond is up to 2 m deep. A series of shallower, intercon-

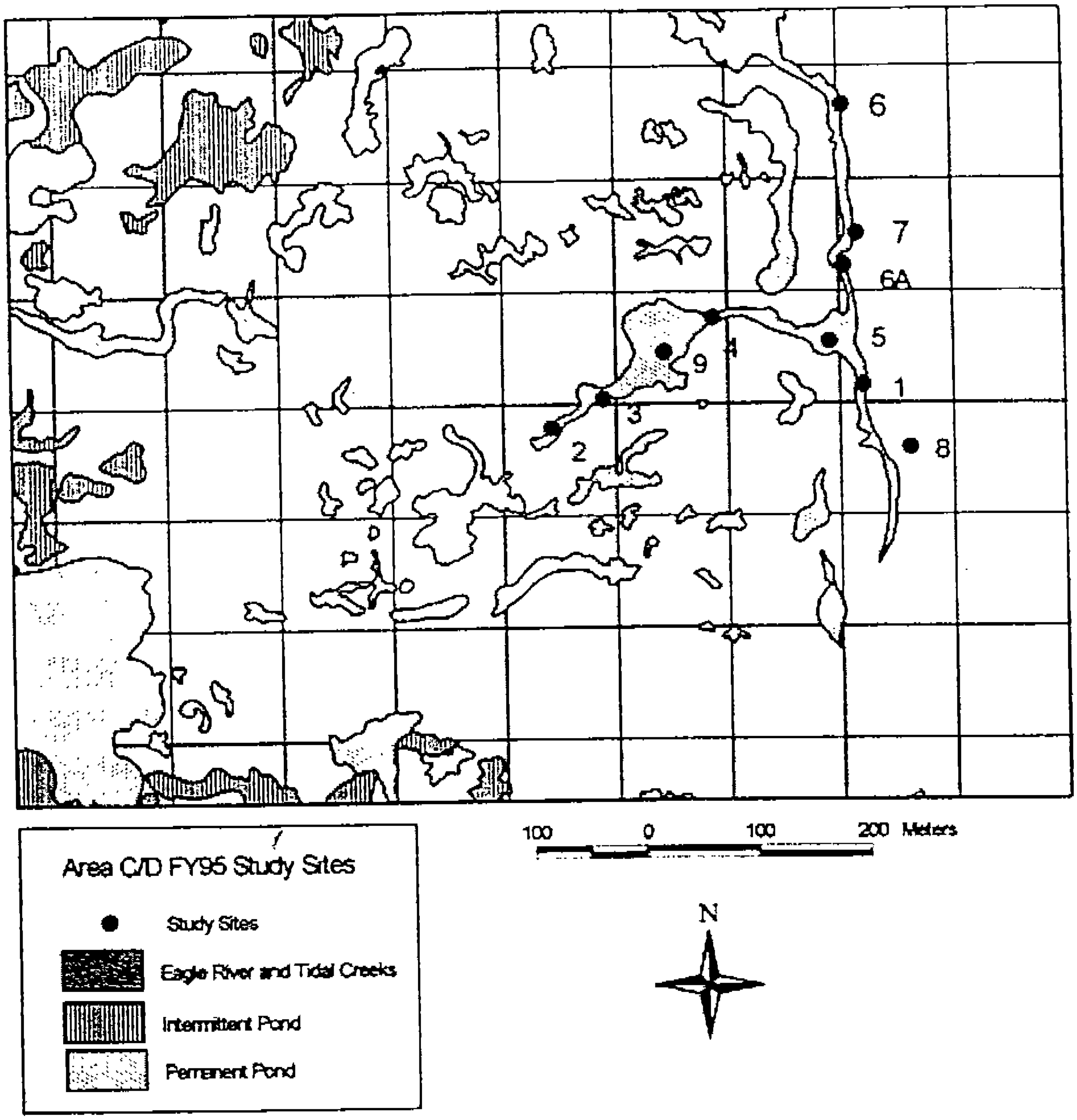

Figure IV-5-2. C/D Area showing narrow pond adjacent to upland bluff and interconnected ponds extending to the west toward Bread Truck pond.

nected permanent ponds extend westward toward BT pond perpendicular to the first pond and the upland bluff. Based on surveys conducted in 1994 there is no-channel connecting the ponds in the C/D area with the BT pond (Collins 1995). Any flow between the two areas is overland flow through the vegetation.

TASK I: PUMP SYSTEM FOR POND DRAINING*

Methods

Equipment

We planned to temporarily pump down the water level in the BT pond to determine the effects of draining on the pond bottom sediments. This information then would be used to evaluate the feasibility of permanently draining the pond. A large-capacity dewatering pump would be capable of pumping down the pond in several days, with the exact time depending on the amount of inflow of water from adjacent areas as the water level in the pond was lowered. To maintain a drained condition throughout the summer, the pumping would have to be repeated at the end of any monthly flooding high tide cycle.

To meet these needs, specifications for a pump system were developed based on the following assumptions:

Assuming a surface area of 3.3 ha, or 33,000 m^2, and an average depth of 0.3 m for the permanently flooded pond area, and a surface area of 6.4 ha and an average depth of 0.1 m for the intermittently flooded pond area, the total volume to be pumped would be 16,300 m^3. Using a single pump with a capability of pumping 2,200 gal./min (0.1388 m^3/s), this volume could be pumped in 32 hr. This assumes that there is not an inflow of additional water from adjacent areas as the water level in the pond is lowered. Interactions of surface water runoff from adjacent areas such as the C/D marsh complex may affect the length of time required to pump down the pond and the final achievable water level in the pond. This pumping down of the pond using a large dewatering pump would have to be repeated at the end of each monthly flooding high tide cycle if the pond is to be maintained in a drained condition throughout the summer.

The periodic nature of the tides requires a fully integrated system capable of autonomous operation with only occasional fueling. The system should be capable of operating continuously for 48 hours without refueling. Refueling will be

* This section was prepared by Charles Collins and Michael Walsh.

conducted using helicopter transport in an area of restricted access. The generator must therefore be located on shore near the permanent pond edge, separate and away from the pump to allow the transfer of fuel in a safe manner. A secondary concern is the possible ingestion of a live UXO into the pump, causing an explosion during pumping operations. Locating the generator and controls away from the pump reduces the possible equipment losses and avoids the possibility of spillage of fuel and oil. Because of human safety concerns, the pumping system should be capable of automatic operation. Once the system is turned on initially after installation, the pump will continue operating until the pond is pumped dry. The system will then automatically shut down. There will likely be limited continuous water flow into the pond from the surrounding high water table. A detection system should sense when the water depth reaches a desired level, and automatically start the system to again pump out the water.

Static head calculations were then made to determine the theoretical head at full flow. This in turn would determine the size pump needed to produce the required flow.

Based on the length of discharge line required and a maximum static head of 2.45 m (8 ft), an electric-powered pump with a 6-in.-diameter discharge would produce the required discharge of approximately 2100–2200 gal/min (0.1325–0.1388 m^3/s). This would allow pumping down of a pond the size of BT pond within two to three days, depending on height of the initial water level in the pond and the amount of inflow from the adjacent marsh areas. The pump would be mounted on a floating platform, allowing it to be anchored over the deepest part of the pond and to rise and fall with changing water levels. A diesel-powered electrical generator to power the pump would be mounted on a separate floating platform. Mounting of the power supply on a separate float platform allowed it to be placed away from the pump in case the pump ingested and exploded an UXO, thus reducing any potential overall damage. Integrated controls allowed automatic control of the generator and automatic startup and stopping of the pump system, controlled by float switches that would cycle the pump as the pond emptied or started to refill. A review of a number of pump manufactures identified one vendor who was able to design, build and integrate such a system.

Once funds became available, the requisition process was initiated in March 1995. The pump and generator units, because of the integrated controls, had to be purchased as a single system. Because the projected costs of the system were greater than $50,000, the requisition process could not be done in-house at CRREL and had to be sent to the Procurement Office at New England Division, Corps of Engineers. There, problems with justifying a sole-source purchase continued to hold up the processing of the requisition. Finally, after repeated rewrites of the sole-source justification, the contract for the purchase of the system was awarded in July. Delivery date of the pump system would be ninety days after award of the contract. The specifications of the system as ordered are given below.

Pump subsystem specifications. A high-capacity pump capable of pumping seawater is required to remove water from the ponds. The pump should be electrically powered from a remote source to reduce the possibility of fuel contamination of the ponds. This pump is to be mounted on floats and have the capability for airlifting by Blackhawk helicopters (UH-60) to the center (deepest portion) of each pond. The weight of the pump and float system must be less than 8,000 pounds. In order to pump each shallow pond dry within 36 hours, a 2,000 gallon per minute (gpm) pump capacity is required. The required static discharge head is eight feet, maximum. The pump suction will be direct (no suction hose or pipe) and located approximately flush with the bottom of the floats. The pump discharge will incorporate a quick coupler for attaching the discharge hose The discharge line will consist of two ea. 100-foot lengths of flexible rubber hose, two ea. 10-foot lengths of flexible rubber hose, 26 ea. 20-foot lengths of polyethylene pipe, two ea. 10-foot lengths of polyethylene pipe, and two ea. five-foot lengths of polyethylene pipe. All hose and pipe shall have mating galvanized quick couplers on both ends. The flexible hose will be used from the pond to the shore, and the rigid pipe will run over dry land. The pump Total Dynamic Head (TDH) shall be sufficient to pump at least 2,000 gpm of seawater (s.g. = 1.03) through the total length of discharge piping specified (770 ft), with a vertical lift of 8 ft. The pump motor shall be 3-phase, 480-V, 60-Hz, totally enclosed/fan-cooled (TEFC) type and be sized to continuously operate the pump under the specified maximum discharge conditions. All electrical wiring shall meet the National Electrical Code (NEC). Electrical connection to the pump motor shall be through a waterproof quick-disconnect fitting. The power cable shall be capable of operating submerged in salt water, be 230 ft long, and incorporate waterproof quick disconnects at both ends to mate with the generator and motor fittings. Cable insulation should be EDPM or equivalent with a neoprene cover, rated for operating conditions from –40°C to +90°C and 600 V. The electrical power cable shall be four-conductor, with one conductor to bond (ground) the motor to the generator set. Wire shall be sized appropriately to experience a voltage drop of less than 10% over the 230-ft length at full-load motor operating current. A float switch, or other type of adjustable on/off switch, shall be included on the pump module to detect water levels and actuate the generator and pump controls while in the automatic operating mode. The adjustment should include the capability for adjustment so the system will turn on when water levels are between the range of 6–12 inches above the pump inlet while the "off" position should be adjustable between water levels of 0–6 in. above the pump inlet. This switch shall be connected through a 230-ft-long control cable back to the generator. The control cable shall be connected to the switch mechanism and the generator using waterproof quick-disconnect fittings. The control cable must also withstand saltwater immersion and will be strapped to the power cable in the field.

Generator subsystem specifications. The generator will be remotely located from the pump by up to 230 ft. The generator shall be diesel-powered, with output of 480 V AC, 3-phase, 60 Hz, and be sized to be capable of starting and continuously operating the pump motor. A 2-KVA, 115 V, single phase transformer and one ground-fault protected 115-V duplex outlet shall be provided. The transformer shall be mounted inside the weatherproof control panel, with a weatherproof duplex outlet mounted outside of the control panel. The generator module shall include a removable, skid-mounted fuel tank sub-module with appropriate valved disconnects sized to provide for 48 hours of continuous operation under full load. The generator module shall be mounted on floats sized so the module will float when all tanks are filled to capacity. This module will be anchored in the field so it will float during high tides but not drift away. The generator module must also be capable of being airlifted by helicopter. The total weight of the generator module shall be less than 8,000 lb. All electrical switches and controls shall be located on the generator module. All wiring shall meet the National Electrical Code (NEC). Controls will include the capability for manual system operation, automatic operation controlled by the float switch on the pump module, or by a timer powered by the generator battery. The timer shall be adjustable to set up to four start times and four stop times within a 24-hr period. In all operating modes, an adjustable time-delay shall be built in to allow the generator to warm up prior to energizing the pump motor. Electrical meters will include voltage, current and frequency. The generator shall include appropriate circuit breakers, ground-fault protection, and weatherproof (to withstand blowing rain) NEMA 4 enclosures for all electrical controls. All wires into the enclosure shall be routed through waterproof strain relief fittings. Connectors, when used, are to be waterproof. Engine indicators will include a tachometer, hour-meter, engine temperature gauge, fuel pressure gauge, and oil pressure gauge. Engine protection shall be provided to shut down for low coolant level (or high engine temperature), low fuel level and low oil pressure. The shut-down protection system shall include provisions for the operator to determine what malfunction caused the shut-down. The generator shall be enclosed in a weather protective housing.

Test requirements. The system shall be fully assembled and tested at (or near) the factory prior to shipment to assure proper operation and that the system meets the specified volumetric discharge at the specified pressure head (with appropriate corrections if fresh water is used for the pumping tests). The Government (USA CRREL) shall be notified 10 days prior to the test in order to send a representative (at the Government's option) to view the tests.

The total weight of the pump system platform as delivered is 1293 kg (2850 lb). The total weight of the generator system platform is 2885 kg (6360 lb). A full load of fuel will add another 680 kg (1500 lb). Both the pump platform and generator platform are airliftable by UH-60 Blackhawk helicopter (maximum sling lift capacity of 4080 kg (9000 lb)). The pump and generator units are shown in Figure IV-5-3.

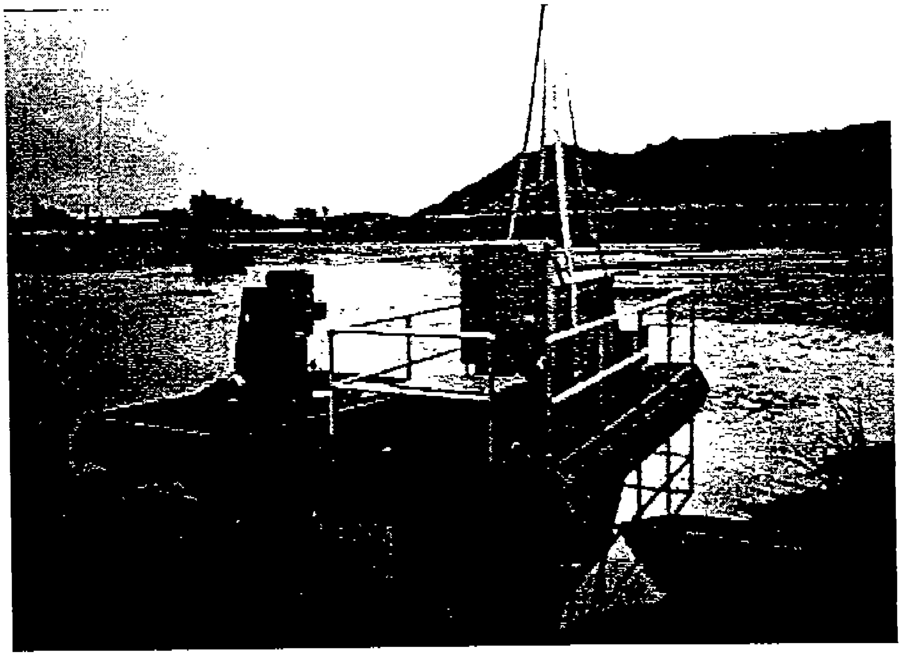

Figure IV-5-3. Pump and generator systems deployed in a pond during the initial tests.

Results and discussion

During the first week of September the contractor completed the pump system and conducted a performance test at the contractor's facility in Montana. M.R. Walsh and C. Collins attended the tests to confirm that the pump system met the design specifications. The floating pump and generator set platforms were set up on the edge of a pond. The discharge line was laid out over a 20-ft-high hill and back to the edge of the pond. The head of the set up was higher than any situation we foresaw in ERF. The pump ran and discharged water through the discharge line for several hours. The rate of discharge through the 8-in. polyethylene pipe was monitored with an ultrasonic flowmeter. Water flow averaged 2100 gal./min during the test, more than meeting the design specifications, especially considering the pump was pumping against the higher head. After the final tests, the pump system was shipped by truck to Anchorage, arriving on 12 September.

Because the delivery of the pump system occurred so late in the season, we made the decision to not deploy the pump to the BT pond that fall. Instead we deployed the system in Clunie Inlet to completely test the system and to run the generator for the initial 40-hr break-in period. This would allow us to check fueling procedures and fuel consumption rates, and to ensure that all sensors and controls were operational after the four-day truck trip from Montana. We deployed the generator platform on the edge of Clunie pad and the pump in Clunie Inlet. We laid the 8-in. discharge line down parallel to the access road back to the edge of the EOD pad where we set the line to discharge into the Area C pond.

Initially we had some problems getting the controls to start the pump. It turned out that a control wire connection had come loose during transport; the loose wire shorted out and blew a fuse in the control panel. After we repaired the wire and replaced the fuse, the system was started normally. Water was pumped for approximately seven hours a day for five days until the generator had the required forty hours of running time on it. Following the completion of the test, the system was pulled out, the discharge line disassembled and the components shipped back to Ft. Richardson DPW for winter storage.

Since the pump system was not deployed in Bread Truck pond, many of the criteria for fully assessing the implementability of this treatment option are not yet available. Other parameters are available. The various parameters are summarized below with known parameters given and unknown parameters identified.

Cost

The cost of treatment will be calculated per unit area of pond treated for one season.

The capitol cost of the pump, generator system and discharge line is $60,000. The capitol costs should be amortized over three years (or whatever is decided is the useful life of pump system): $20,000/yr.

The operating cost includes fuel, labor to assemble system, and helicopter time to sling-load equipment to the site and to sling-load fuel to refuel the generator on a periodic basis. Deployment of pump, generator and pipe system will require at least three sling loads by an UH-60 Blackhawk (total time, ~ 2 hr at $1600/hr). An estimated 24 man-hours (3 people × 8 hr) will be required to initially set up equipment in pond. An additional 24 man-hours (3 people × 8 hr) will be required for preliminary preparation, preventive maintenance on generator, sling load preparation, etc., prior to deployment into the field. Based on the field test conducted at Clunie Creek, fuel consumption is approximately 4.5 gal/hr under full load, giving a run time under full load of 49 hr. Depending on actual experience, the generator will have to be refueled at least once each month, requiring one hour of UH-1 helicopter time to sling-load fuel tank to the site (at $800/hr). An estimated two man-hours (two people × 1 hr) will be required to refuel equipment. Three-month deployment would consume approximately 650 gal. of fuel and require three hours of helicopter support.

The total cost per year to treat the pond will then be divided by the total area of the pond (8.7 ha) to arrive at a cost per hectare per year.

Effectiveness

The effectiveness of the treatment will depend on the following factors:

- The time required to lower the pond level;
- The average pond water levels throughout the season;
- The percent decrease in pond surface area following pumping;
- The total time pond bottom remains subaerially exposed; and
- The estimated rate of WP removal in exposed pond bottom sediments.

Treatment of pond may have to been repeated for one or more additional years, depending on the rate of WP removal in exposed pond bottom sediments.

Implementability

Draining by pumping is non-permanent and reversible.

Pumping technology uses conventional equipment and components, although they are integrated into a single system.

The applicability of pumping technology to other sites within Eagle River Flats will be assessed after a full season's test in BT pond. This will include a list of site data needed for an assessment, such as elevational data, pond area and volume estimates, access concerns, surface water hydrology of surrounding area, and projected tidal flooding events. Experience with pumping technology at the Bread Truck Pond will then be used to estimate applicability to other sites within ERF.

Initial surveying and measurements indicate that the contaminated pond in the center of Racine Island may be amenable to pumping as a treatment option. See Lawson et al. (this volume) for additional details on an initial assessment of that site.

TASK II: DETERMINE ENVIRONMENTAL CONDITIONS IN THE BREAD TRUCK POND BEFORE AND AFTER LOWERING THE POND LEVEL*

Methods

Surveying

We conducted a detailed survey to determine horizontal coordinates and elevations of sample locations and instrumented sites in the BT pond in September. Surveying was done using a Leitz SET4C electronic total station and a triple reflective prism mounted on a 1.45-m-tall prism rod. One person ran the total station while two people occupied each site to be surveyed with the prism rod. We used a benchmark (Bread Truck BM) near the north shore of BT pond that had been previously surveyed. Universal Transverse Mercator (UTM) horizontal coordinates and the elevation were known for the BM.

To conduct these surveys, the electronic total station was set up over the BM and the instrument back sighted to the reference azimuth mark. For Bread Truck

* This section was prepared by Charles Collins and Marianne Walsh.

BM, this was Ruth Point BM on the upland bluff to the northeast. The two-person party moved to each location to be surveyed and the prism rod placed on the ground at each site. To achieve uniformity in surveying elevations, the tip of the prism rod was placed inside a bucket that was in turn placed on the pond bottom surface. This provided a uniform bearing surface for the rod tip, keeping it from sinking down into the soft surface. The triple prism was sighted on by the total station and the horizontal angle and distance and the vertical distance from the total station to the triple prism were then measured and recorded. Based on the horizontal angle and distance from the control point, the vertical distance between total station and the triple prism, the height of the total station above the control point, and the height of the prism above the survey point, a set of UTM horizontal coordinates and an elevation for each survey point was then later calculated.

Instrumentation

Seven instrumented sites were installed in the BT pond in May to monitor environmental conditions in the pond bottom sediments. Six of the sites were located in a transect from the northern edge of the pond, through the shallower, intermittently flooded pond area (Fig. IV-5-4), to the deeper, permanently flooded pond area. The seventh site was located in the shallow intermittently flooded pond area on the south side of BT pond. Sites ranged in elevation from 4.85 m to 4.56 m. UTM coordinates and elevations for the seven study sites are given in Table IV-5-1.

Prior to any activity occurring at a site, the area around each site, as well as the path between sites, were checked for UXOs. A visual inspection of the surface was made prior to walking in the immediate vicinity to prevent sediment from being stirred up and limiting visibility. Additionally, a hand held magnetometer, a Heliflux Model GA-52C Magnetic Locator, was used to scan the area to detect any buried ferrous metal objects. If nothing was detected then we proceeded with sensor installation at the site. If an object was detected, the spot was marked and flagged, and another site selected.

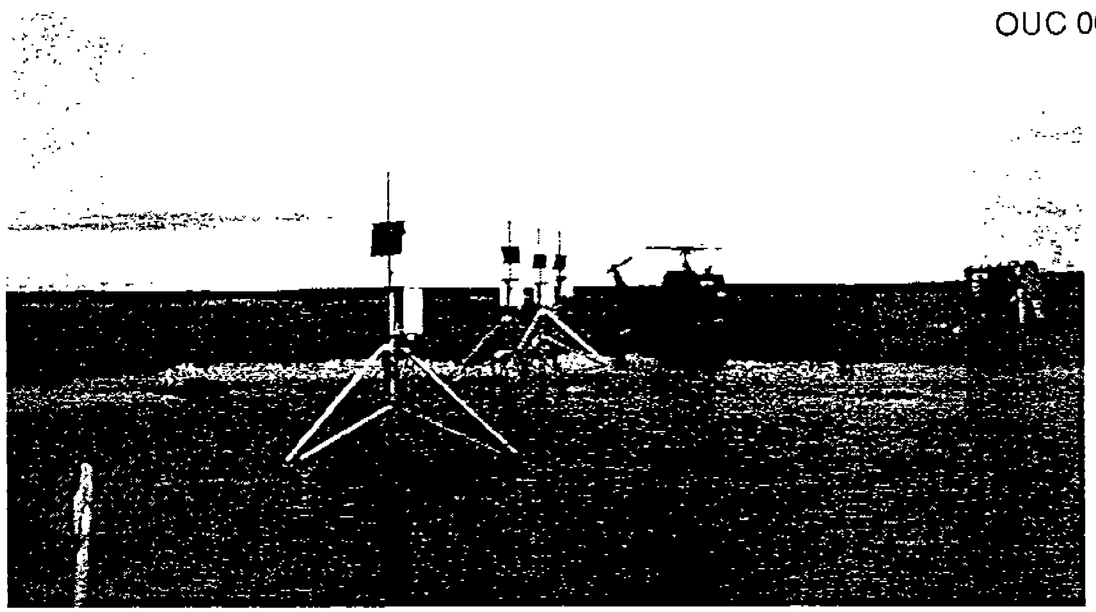

Figure IV-5-4. Four of the instrumented sites along a transect from the northern edge of the Bread Truck pond. Cases attached to metal tripods contain dataloggers.

Table IV-5-1. Bread Truck Pond sampling summary.

	BT-1	*BT-2*	*BT-3*	*BT-4*	*BT-5*	*BT-6*	*BT-7*
Location, East	354,512.0	354,513.7	354,515.34	354,519.03	354,523.5	354,529.0	354,554.0
, North	6,801,864.1	6,801,856.5	6,801,847.7	6,801,830.3	6,801,808.3	6,801,791.3	6,801,665.1
Elevation (m)	4.81	4.79	4.79	4.77	4.79	4.56	4.85
Site type	Int. pond	Int. pond	Int. pond	Int. pond	Edge of perm. pond	Perm. flooded	Int. flooded, south side of pond
Water surface level	—	—	—	—	—	Cont.*	—
Air temp.	—	—	—	—	—	Cont.	—
Sed. temp.	Cont.	Cont.	Cont.	Cont.	Cont.	Cont.	Cont.
Sed. moisture	Cont.	Cont.	Cont.	Cont.	Cont.	Cont.	Cont.
Tensiometer	Per.	Per.	Per.	Per.	—	Per.	—

* Cont. = continuously; Per. = periodically.

The seven sites were instrumented using electronic dataloggers to monitor sediment moisture levels and sediment temperatures on a continuous basis. Site BT-6, located in the deepest portion of the pond, was also instrumented to monitor pond water levels on a continuous basis.

The dataloggers used for the seven instrumented sites are the Model CR10 datalogger system manufactured by Campbell Scientific, Inc. (CSI), P.O. Box 551, Logan, Utah 84321. This system consists of the CR10 measurement and control module, the CR10 wiring panel, the PS12 12-V power supply and charging regulator, and the SM716 storage module. All of the components are housed in a weather-resistant fiberglass-reinforced polyester enclosure that in turn is attached to the central mast of a galvanized steel tripod, consisting of three adjustable legs and a central mast with a total height of 3 m (Fig. IV-5-4).

Measurement of pond water level

Pond water levels were monitored at one location within the BT pond (Site BT-6) using a CSI UDG01 Ultrasonic Depth Gage. The depth gage is attached to the end of a bracket arm that is in turn attached to the center mast of the tripod. The sensor is suspended on the bracket arm approximately 2.5 m above the water surface. The sensor measures the distance from the bottom of the sensor to a surface by bouncing an ultrasonic pulse off the surface, listening for the return echo. The distance to the surface is determined from the time from transmit to the return of the echo. The speed of sound in air is dependent upon the air temperature, so air temperature is also measured by the datalogger at the same time. The signal from the depth gage sensor is processed by the datalogger, corrected for the air temperature, and stored. Readings were taken by the datalogger every ten minutes and averaged every hour. Accuracy of the depth gage sensor for the setup we used is ±1 cm.

The elevation of the bottom of the depth gage sensor was established by surveying from the Bread Truck BM. Water surface elevations were then determined by subtracting the measured distance from the sensor bottom to the water surface from the elevation of the bottom of the sensor.

Measurement of temperature and sediment moisture. Air temperature was measured using a CSI Model 107 air temperature thermistor probe inside a six-plate gill radiation shield mounted on the center mast of the 3-m tripod at Site BT-6. A measurement was taken every ten minutes and averaged every hour.

Sediment temperatures were measured using CSI Model 107B soil/water thermistor probes that use the Fenwal Electronics UUT51J1 Thermistor probe, which has an accuracy of <±0.2°C over the range of 0°C to +60°C. Soil temperature probes were placed at 5- and 10-cm depths at each of the seven locations in BT pond. Soil temperature probes were installed by attaching sensors to a wooden lath at the proper spacing. The lath was pushed into the sediment until the sensors were at the proper depths. The leads for the two sensors were then wired into the wiring panel of the datalogger. Measurements on each of the two sensors were taken every ten minutes and averaged every hour.

In-situ sediment moisture conditions were monitored using CSI Model 257 (Watermark 200) soil moisture sensors, which estimate soil water potential in the range of 0 to 2 bar. The output from the sensors is the ratio of excitation voltage to signal voltage from which resistance is calculated. Resistance is functionally related to soil water potential. A sensor in saturated sediment will give a resistance near zero, and as sediment dries, resistance increases. These sensors have internal gypsum tablets that reduce the error associated with changing salinity (Campbell Scientific 1994). An example plot of soil resistance versus gravimetric sediment moisture content is given in Figure IV-5-5.

The soil moisture sensors were also placed at depths of 5 and 10 cm at the seven locations. They were installed by attaching sensors to a wooden lath at the proper spacing. The lath was pushed into the sediment until the sensors were at

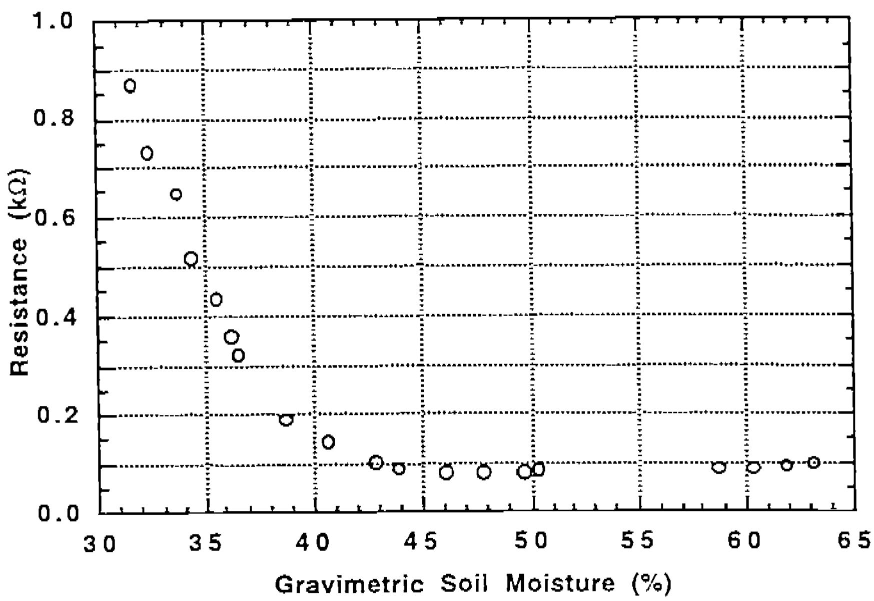

Figure IV-5-5. Soil resistance versus soil gravimetric moisture content of a typical intermittently flooded pond bottom sediment.

the proper depths. The leads for the two sensors were then wired into the wiring panel of the datalogger. The sensor resistance is measured by the datalogger and stored in memory. The datalogger measured the resistance once every ten minutes, averaged the measurements once an hour, and stored the averaged measurement in memory.

A series of Soilmoisture® Series 2725 tensiometers were installed at each of the four sites to assist in monitoring near-surface sediment moisture. They provide a direct analog readout of soil suction in centibars, indicating whether the sediment they are placed in is saturated or not. The tensiometers consist of a sealed hollow plastic tube filled with water with a porous ceramic tip at the bottom. As the sediment surrounding the buried ceramic tip dries out, water is drawn out through the ceramic tip, creating a suction within the hollow tube. The resulting suction is read by an attached dial gauge that is graduated from 0 to 100 centibars (kPa) of soil suction. Two tensiometers each were installed at each of BT pond sites with the ceramic tip buried at 10- and 25-cm depths.

Groundwater surface elevations. Near-surface groundwater surface elevations in the vicinity of the pond were planned to be monitored with a series of shallow, small-diameter piezometers. Because of safety concerns, placement of the piezometer tubes by hand as was done last year (Collins 1995) was ruled out. A remote-controlled drill and sampler unit being developed by M.R. Walsh (this volume) was to be used to place piezometers in the BT area and the area between BT pond and C/D area. Because of procurement problems, this unit was not available in time to install piezometers this field season. Therefore, no near-surface groundwater elevations are available for the BT pond or C/D areas.

Organic content and drying potential. The drying potential of the sediments of the BT pond was estimated by characterizing samples of sediment from the BT pond. A bulk composite sample, approximately 20 kg, was taken of the bottom sediment in the area of BT-2 and BT-3. A portion of the sample was used to determine organic content of the sediment [ASTM Standard D2974-88] (ASTM 1988) The sediment was oven dried at 105°C for 24 hr. The sediment was pulverized and mixed, and a series of subsamples was taken. The subsamples were placed in pre-weighed crucibles, weighed and heated at 550°C for 16 hr to burn off organic material. The subsamples were cooled in a desiccator and re-weighed to determine percent organic content by dry weight.

Air-entry value. Using a standard Tempe Pressure Cell (SoilMoisture Equipment Corp., Santa Barbara, CA), a moisture retention curve (Hillel 1982) for BT pond sediment was determined. This curve was used to estimate the air entry value, which gives an indication of how far the water table must drop before surface sediments become unsaturated. It also gives an estimate of the tensiometer reading corresponding to the onset of unsaturated conditions as sediments dry. To generate the curve, air pressure was applied to a core of saturated sediment placed on a porous ceramic plate in the Tempe Pressure Cell. Air pressure was incrementally increased and the amount of water forced out of the sediment was recorded. The air entry value corresponds to the pressure at which capillary forces are overcome and air begins to penetrate the sediment matrix.

Placement of WP particle

In mid-May, WP particles were planted at Sites BT1–BT7 within BT pond as part of the study of draining on natural attenuation of WP (Walsh and Collins, this volume.) In the field laboratory, sediment plugs were formed from pond bottom sediment typical of that found in the BT pond. A WP particle (1.8 mm diameter, 5.56 mg), previously made in the laboratory (Walsh and Collins 1995), was placed at a depth of 3–5 cm within each plug. Each plug was then placed within a nylon mesh bag, the bag tied off, and survey tape and string attached. At each of the seven sites, three of the nylon mesh bags containing the sediment plugs were buried in the pond bottom sediment at a depth of 5 cm. Sediment plugs were left undisturbed until September.

On 15 September the nylon bags containing the sediment plugs and WP particles were recovered for visual examination. These plugs were placed in plastic bags in a cooler, returned to our lab, and examined. If a WP particle was found, its diameter was measured using a micrometer, and the appearance of the particle and the surrounding sediment noted.

Results

Because of procurement delays of the pump system and the unusually wet summer, the pond remained flooded throughout the entire summer. This included both the deeper permanent pond and the shallower intermittent pond areas. Sediment at all seven sites in both types of areas remained saturated throughout the summer.

Pond water levels

The water surface elevation for the BT pond from 31 May to 15 September is given in Figure IV-5-6. The plot shows that the pond was flooded by a series of high tides each month during the period. During June there were three flooding tides. The first flooding event occurred on the morning of 13 June during a high tide with a predicted height of 32.3 ft (Anchorage tidal datum). A high tide of 31.6 ft on the previous day did not flood the pond. Two additional high tides flooded the pond on the mornings of the 14th and 15th (predicted heights of 32.6 and 32.4 ft.) A high tide of 31.6 ft on the 16th did not flood the pond. In July there were three flooding events with tides of 31.9, 32.4, and 32.4 ft. A tide of 31.8 on 15 July only caused a very slight rise in water levels.

In August there were six flooding events, with the high tides ranging from

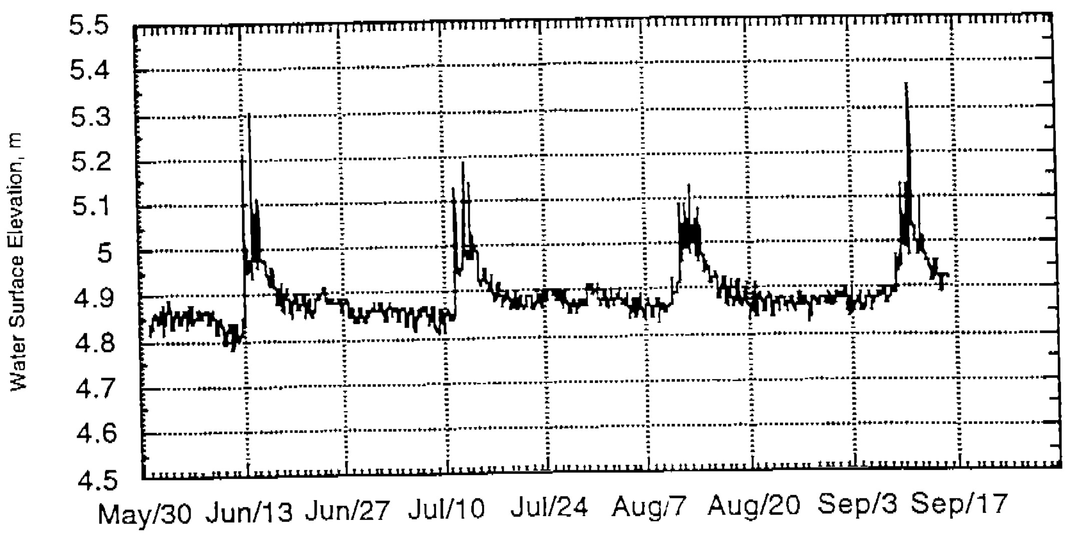

Figure IV-5-6. Water surface elevation for the Bread Truck pond from 31 May to 15 September.

31.1 to 32.7. Higher tides in the morning often resulted in a lower flooding level than lower tides that occurred in the evening. For example, a 31.7-ft tide on the morning of the 10th did not flood the pond while a tide of 31.1 ft in the evening of the 11th resulted in flooding. The differences are due to differences in river stage height at the time of the high tide. The river undergoes a diurnal fluctuation in its stage with the peak in the late afternoon or evening.

These data are consistent with flooding observations in Area C (Walsh and Collins, this volume). There, Area C also did not flood until June 13 when the highest predicted tide was 32.3 ft even though there was a predicted tide of 31.6 ft on June 12. A 31.1-ft tide on July 11 did not flood, while flooding occurred with the predicted 31.9-ft tide on July 12. In August, a predicted tide of 31.5 ft did flood. We have been using a threshold of 31 ft for the height of the tide (predicted for Anchorage) needed to flood the flats. Although the actual flooding tide height will vary depending on the river discharge, wind conditions, etc., data obtained during the summer of 1995 show that this estimate is conservative. During moderate river stages, a tidal height of 31.6–31.8 ft is required to flood BT pond and Area C. During high river stages, a tidal height of 31.1–31.5 appears to be the threshold height.

Sediment temperature and moisture conditions

The minimum, maximum and mean sediment temperatures measured for the seven instrumented sites in BT pond are summarized in Table IV-5-2. Maximum measured sediment temperature at the 5-cm level was 27.09°C for BT-2. The mean temperature for all sites was 17.23°C. The sediment moisture sensors at all depths at both sites did not change during the summer, indicating that

Table IV-5-2. Minimum, maximum and mean sediment temperatures measured in BT pond.

	BT-1	*BT-2*	*BT-3*	*BT-4*	*BT-5*	*BT-6*	*BT-7*	*Mean*
Min.	10.96	10.6	11.16	10.95	11.28	11.58	8.02	10.65
Max.	25.93	27.09	24.72	24.2	24.93	23.95	27.75	25.51
Average	17.36	17.43	17.20	17.22	17.18	17.00	17.24	17.23
Date of max.	10-Jun-9 19:00	10-Jun-95 19:00	10-Jun-95 19:00	6-Jul-95 20:00	11-Jun-95 19:00	18-Jul-95 19:00	6-Jul-95 18:00	

the sediment remained saturated throughout the summer. Because of the monthly flooding tides and above average precipitation, all sites appeared to remain flooded throughout the summer.

Groundwater

Because of the lack of piezometers, no groundwater information was collected in the vicinity of BT pond or the C/D area this year.

Organic content and drying potential

Nine subsamples of sediment from BT pond were taken, weighed and heated at 550°C for 16 hr to burn off organic material. The subsamples were cooled in a desiccator and re-weighed to determine percent organic content by dry weight. The samples ranged from 2.0 to 5.3% organic material by dry weight, with the mean of the nine samples being 3.7%. Soils with an organic material content between 2 and 4% are considered to have moderate organic content. Soils containing greater than 4% organic material content are considered to have a high organic material content (Soil Conservation Service 1971).

Planted WP particles

The sediment plugs containing planted WP particles were recovered from Sites BT1–BT7 on 15 September. The WP particles were recovered from the cores and examined. All WP particles were recovered; none showed any evidence of sublimation. This is not surprising considering that the sites were flooded for the entire season.

Data assessment

Effectiveness.

- Water level data indicated pond remained flooded during entire summer;
- No significant sediment temperature increase;
- No significant sediment moisture decrease;
- No significant change in size of WP particles.

Implementability.

- Non-intrusive;
- Measurements using conventional sensors and equipment;
- Planted WP particles allow consistent observations of any change in mass of WP due to sublimation.

On-site activity requirements (monitoring).

- Instrument tripods installed at seven sites in pond at beginning of season; dataloggers installed on tripods at beginning of season;
- Sensors installed in sediment and interfaced to datalogger;
- Dataloggers and sensors removed at end of season; tripods left in place for future use.

Frequency of monitoring.

- Data collected hourly throughout season by datalogger; data downloaded periodically and at end of season;
- WP particles installed at start of summer and removed at the end

TASK III: DETERMINE RATE OF SURFACE WATER INFLOW INTO THE C/D AREA FROM THE ADJACENT UPLANDS*

Methods

Measurement of water salinity and temperature

Salinity and water temperature profile sites were established at eleven points within the C-D pond area. Sites were established in a transect along the edge of the pond parallel to the upland bluff and along a transect that ran through the pond system perpendicular to the upland. Periodic visits were made to sites; typically each site was visited immediately following a flooding high tide and at one-week intervals until the next flooding high tide. In this way, changes were moni-

* This section prepared by Edward Chacho and Charles Collins.

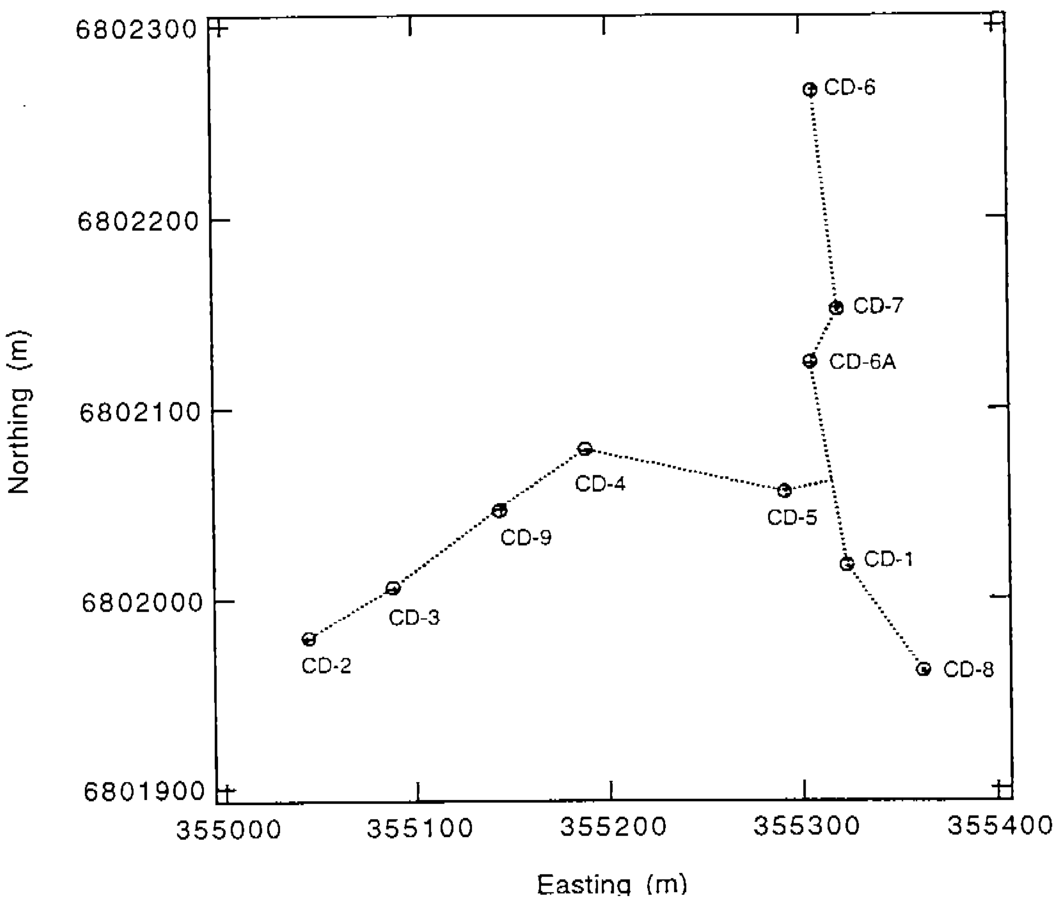

Figure IV-5-7. Location map showing sampling sites used in 1995 study.

tored over the intertidal flood period, as well as those resulting from the tidal flood.

The sampling sites were located along two transects referred to as the shore transect and the pond transect (Fig. IV-5-7). The shore transect consisted of five sampling points spread along a 350-m reach of the shore of the pond adjacent to the upland bluff. This transect was designed to investigate the variability of the groundwater input along the shoreline and the rate of shoreline change in the tracer parameters. Site CD-8 consisted of a visible groundwater seep and was assumed to be representative of the groundwater input throughout the study area.

The pond transect consisted of five sampling points extending from the shore to outer edge of the pond system extending perpendicular from the shore pond into the C-D area. This transect was designed to investigate the variability and rate of change in the tracer parameters across the width of the pond system. The

Table 3. Area C/D sampling site summary.

	CD-1	CD-2	CD-3	CD-4	CD-5	CD-6	CD-6A	CD-7	CD-8	CD-9
Location, East	355,320.9	355,042.5	355,088.1	355,187.6	355,290.8	355,306.3	355304.3	355,318.0	355,361.66	355,143.5
North	6,802,018.1	6,801,977.3	6,802,006.0	6,802,078.5	6,802,057.0	6,802,266.4	6802124.6	6,802,152.7	6,801,961.9	6,802,961.9
Elevation (m)									5.10	
Site type	Perm.* pond	Perm. pond	Perm. pond	Perm. pond	Perm. pond	Perm. pond	Perm. pond	Perm. pond	Upland spring	Perm. pond
Water surface level	Cont.	Cont.	—	—	—	—	—	—	—	—
Air temp.	Cont.	Cont.	—	—	—	—	—	—	—	—
Water temp. measurements	Cont., one level; periodic profile	Cont., one level; periodic profile	Periodic profile	Periodic profile	Periodic profile	Periodic profile	Periodic profile	Periodic profile	Periodically	Periodic profile
Water specific conductance measurements	Cont., one level; periodic profile	Cont., one level; periodic profile	Periodic profile	Periodic profile	Periodic profile	Periodic profile	Periodic profile	Periodic profile	Periodically	Periodic profile
Water sample for isotope ratio analysis	Periodically	Periodically	Periodically	Periodically	Periodically	Periodically	Periodically	Periodically	Periodically	Periodic profile

* Perm. = permanent; Cont. = continously.

sites were located at the inlets and outlets to the ponds (CD-5, CD-4, CD-3), as well as, in the interior of the larger ponds (CD-9, CD-2). UTM coordinates and elevations for the C/D study sites are given in Table IV-5-3.

The sampling schedule was based on the frequency of the flooding high tides which occurred during the 1995 summer (Fig. IV-5-8). The sampling schedule was coordinated with four inter-tidal cycles beginning in mid-June and ending in mid-September (Fig. IV-5-8). The before and after sampling of the high tides separating tide cycles 2 and 3 measured the impact of flooding high tides on the pond system, while tide cycles 2 and 3 included four periodically spaced sampling dates to investigate the recovery of the pond system following a flooding high tide. Sampling on tide cycle one was done primarily to measure if significant

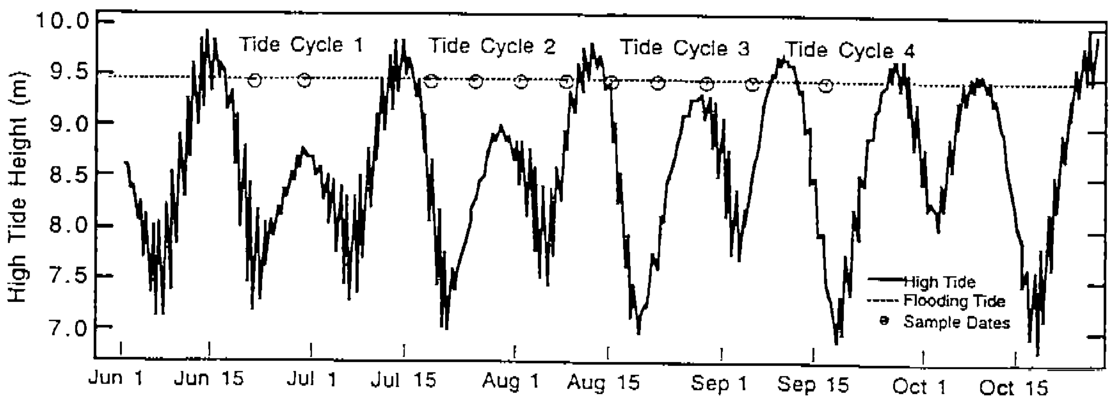

Figure IV-5-8. Sampling schedule in relation to the high tide cycle.

short-term changes occurred, to determine the feasibility of the sampling program.

Salinity and water temperature profiles at each site were measured manually over the side of a canoe with a YSI Model 30 Handheld Salinity, Conductivity and Temperature System. This is a microprocessor-based, digital meter with an attached YSI four-electrode conductivity cell sensor. Salinity and temperature readings were made simultaneously by holding the sensor at a given depth until the observed readings stabilized. Readings were taken at 5 and 10 cm below the surface, and then every 10 cm until the pond bottom was reached. Efforts were made to minimize disturbance to the stratigraphy of the water column at each site both in approaching the site and during the collection of the profile data.

Generally, two water samples were collected at each site following acquisition of the profiles. The profile data were examined on site and depths selected to acquire a representative sample of the near-surface and near-bottom profiles. The water samples were sent to a laboratory for O^{18} analysis as a means of tracing the movement of freshwater seepage across the pond system. The lab analyses have not been completed, at the writing of this report, results from this portion of the study will have to be presented in a future report.

Instrumentation

Continuous monitoring stations were installed at two of the sites. One site (CD-1) was located at the eastern edge of the C/D area next to the upland border. The second site (CD-2) was located at the far western end of the pond system that extended through the C/D area toward the BT pond. Each station included a HydroLab H20® Water Quality Multiprobe to measure salinity and water temperature at a fixed depth (45 cm below the surface) and a CSI UDG01 Ultrasonic Depth Gage sensor to monitor the pond water level. Data were acquired at 10-minute intervals and averaged to produce hourly values which were stored on a CSI CR10 datalogger system systems as described in Task II Methods above.

A standard Class A National Weather Service (48 in dia) evaporation pan was installed near the weather station at the EOD pad (Haugen, this volume). A NovaLynx Systems, Inc. Model 255-100 Analog Output Evaporation Gauge monitored changes in the pan water level. The evaporation gauge provides an electrical signal proportional to the water level. The electrical signal was from the gauge was recorded by a Campbell Scientific CR10 datalogger set up next to the evaporation pan. A CSI CR10 datalogger averaged data acquired at 10-minute intervals to produce hourly values.

Surveying

We conducted a survey of a portion of the C/D area east of the BT pond to determine horizontal coordinates and elevations of sample locations and instrumented sites there. Surveying methods were the same as described in Task I above, using a Leitz SET4C electronic total station and a triple reflective prism mounted on a 1.45-m-tall prism rod. One person ran the total station while two people occupied each site to be surveyed with the prism rod.

For survey control in the C/D area a temporary bench mark (C/D BM) was shot in from the Bread Truck BM. C/D BM was then occupied, and the instrument back-sighted to Bread Truck BM as a reference azimuth mark. Locations of sample sites and instrumented sites were then surveyed in the same manner as in BT pond area. A summary of sample site locations is given in Table IV-5-3.

Results

To illustrate the change with time of the salinity and water temperature profiles at a site, the profile data from each tide cycle are shown in Figures IV-5-9–IV-5-12, for the shore and pond transects. The salinity averaged over the full water depth at each site for all the sampling data is shown in Figures IV-5-13 and IV-5-16. The averaged data compare trends at each site over all the tide cycles.

In general, all the sites had relatively low salinity, less than 8 ppt, and with a few short-lived exceptions, the salinity not only decreased over each of the intertidal periods but also showed a decreasing trend over the entire summer. The inter-tidal trends appear to be the result of a constant freshwater input along the shore with a mixing zone that progresses from the shore. It appears that there

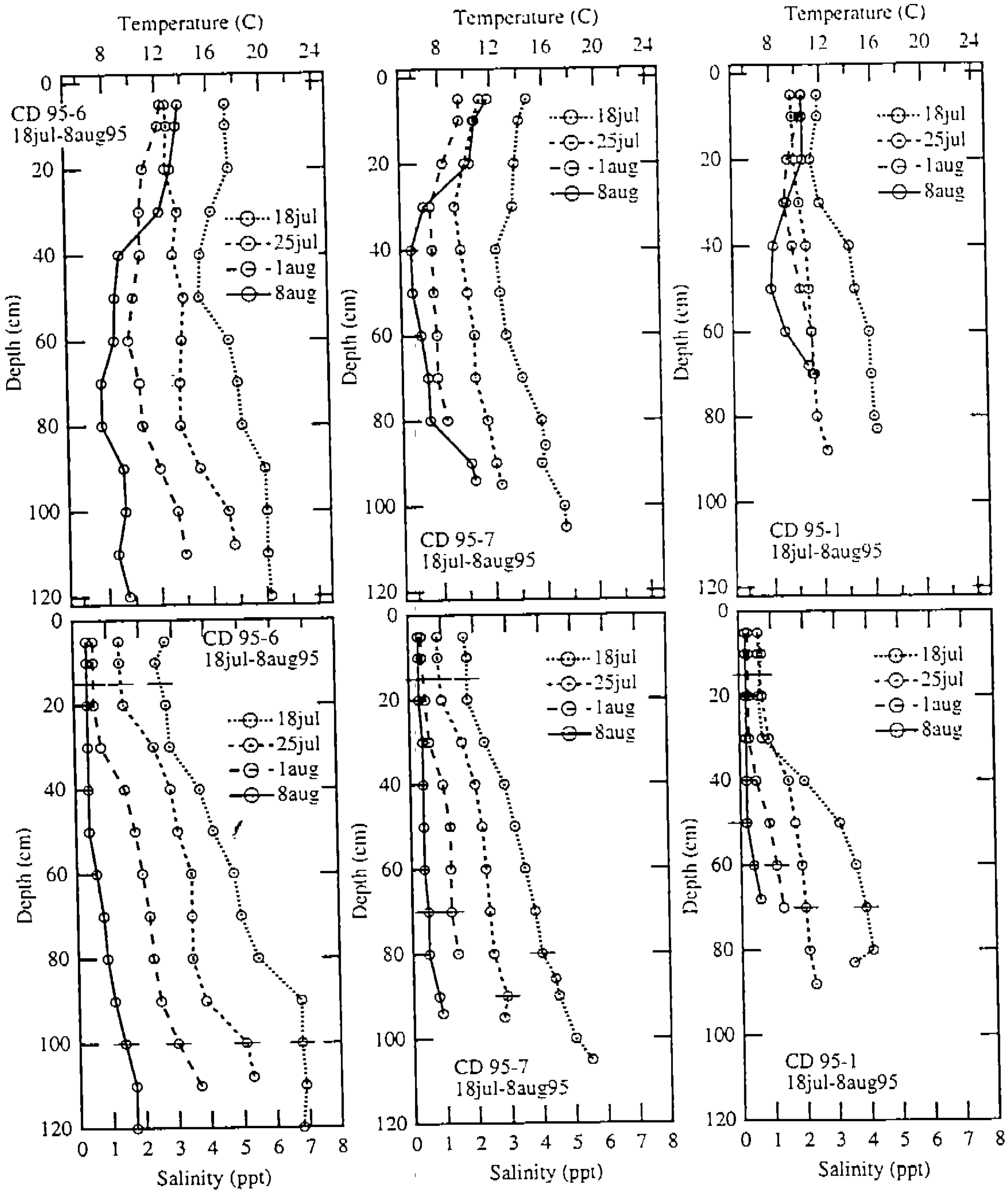

Figure IV-5-9. Salinity and water temperature profiles on the shore transect sampling sites in tide cycle 2, July–August 1995.

was not sufficient time for the mixing zone to extend across the pond before the next flooding high tide occurred. In years where the flooding tides were not as frequent, the mixing zone presumably would advance deeper into ponds. Contributing to the decreasing trend over the summer is a decrease in the salinity of

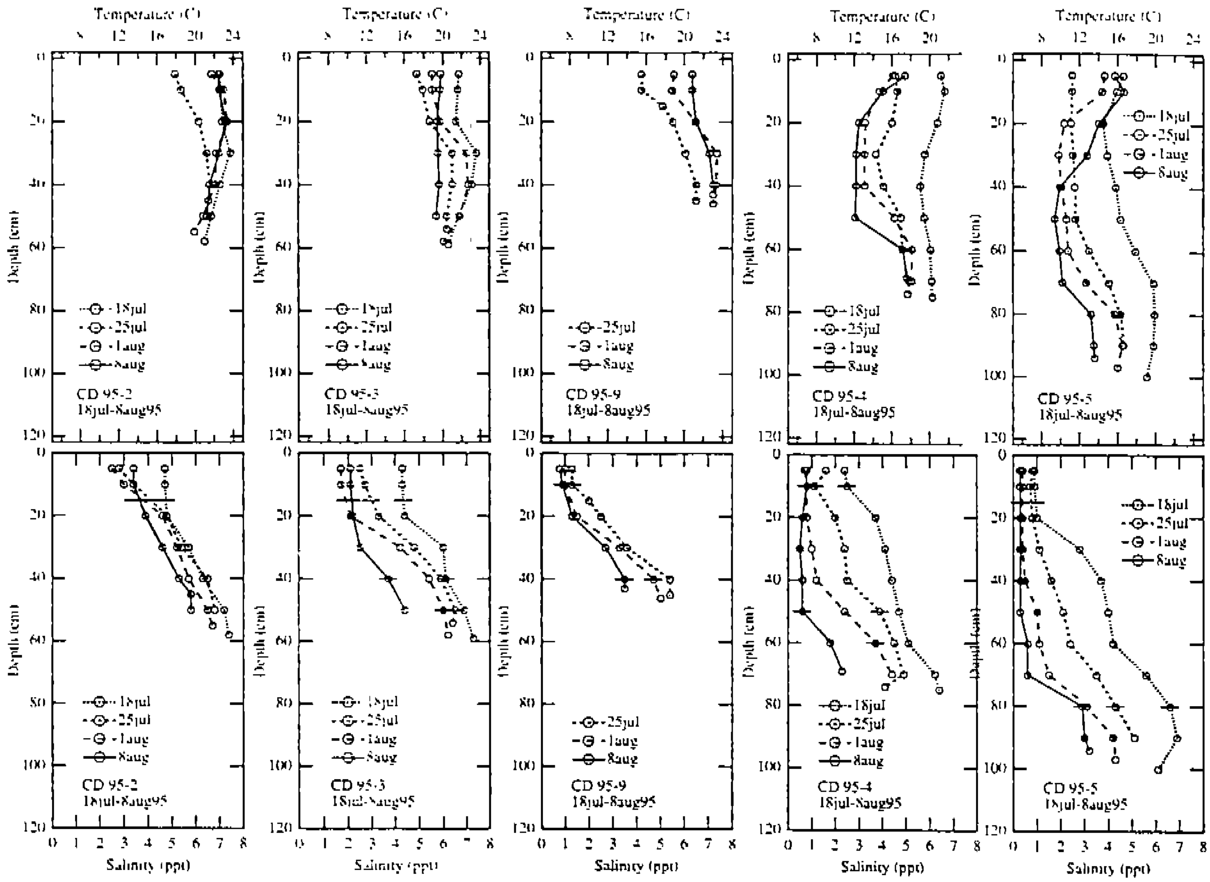

Figure IV-5-10. Salinity and water temperature profiles on the pond transect sampling sites in tide cycle 2, July–August 1995.

the flooding tides due to increases in the freshwater input in Cook Inlet. The data are discussed in further detail below.

Shore transect

The sites included in the shore transect had very similar characteristics throughout the sampling period. The typical pattern was a rise in the salinity during the flooding tides to a slightly brackish level, 2-5 ppt, followed by decreasing salinity over the entire inter-tidal period until a nearly freshwater salinity of less than 1 ppt was reached. A salinity of 0.3 ppt was a minimum that was consistently reached throughout most of the depth at each site by the end of the inter-tidal periods (Fig. IV-5-9 and IV-5-11) . This approaches the value of the salinity (0.1 ppt) measured at the freshwater seepage site (CD-8), indicating a near com-

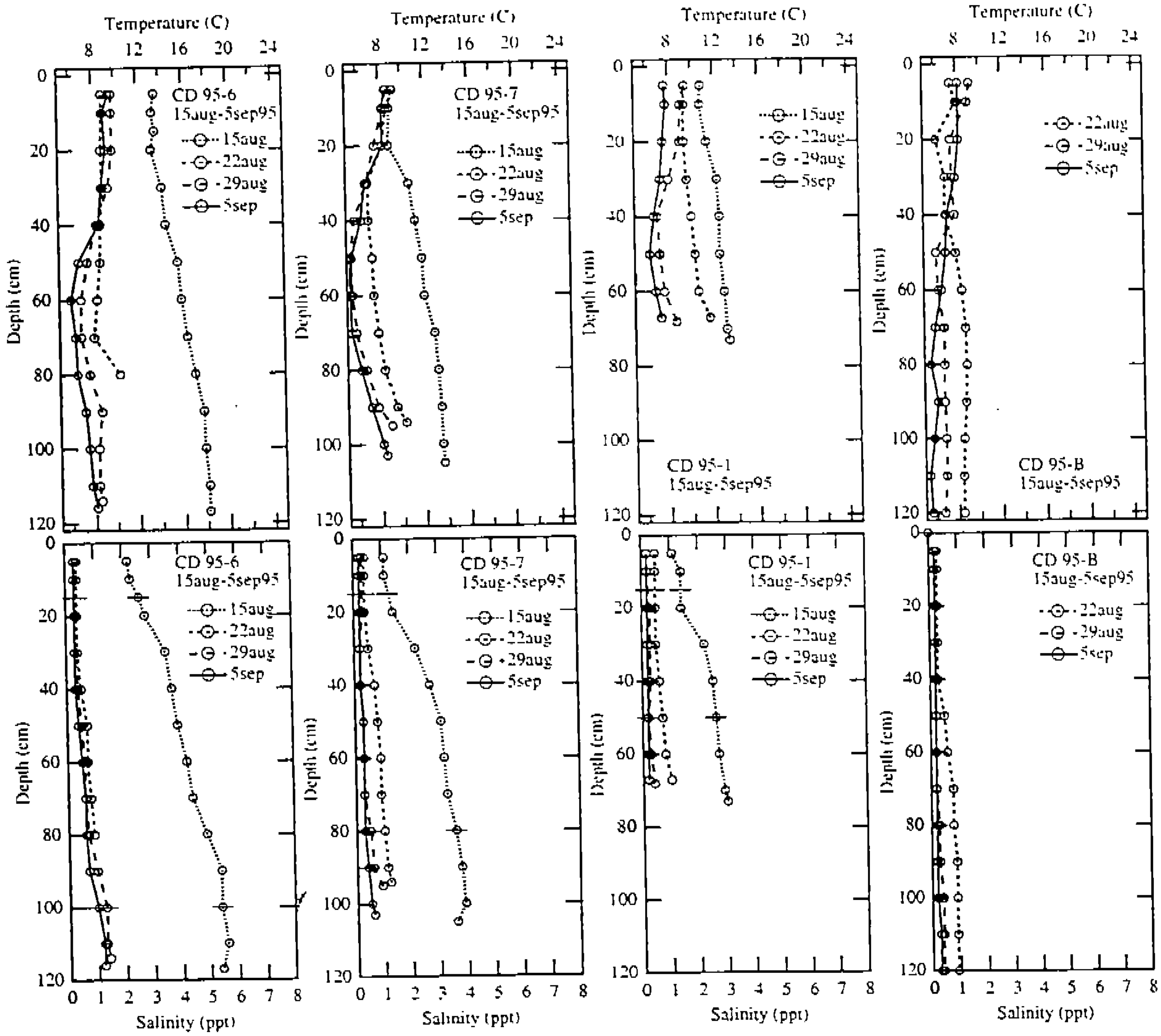

Figure IV-5-11. Salinity and water temperature profiles on the shore transect sampling sites in tide cycle 3, August–September 1995.

plete displacement of the tidal waters in the narrow pond along the shore by freshwater seepage during an inter-tidal period of about four weeks. A longer inter-tidal period may have resulted in a completely freshwater wedge progression from the shoreline. Progression of the freshwater wedge is described below in the pond transect discussion.

As measured by the average salinity at each site (Fig. IV-5-13), the salinity spike introduced by the flooding high tide decreased from north to south over the transect and also decreased at each site over the summer. The north to south variation of salinity following the flooding high tide may have resulted from ei-

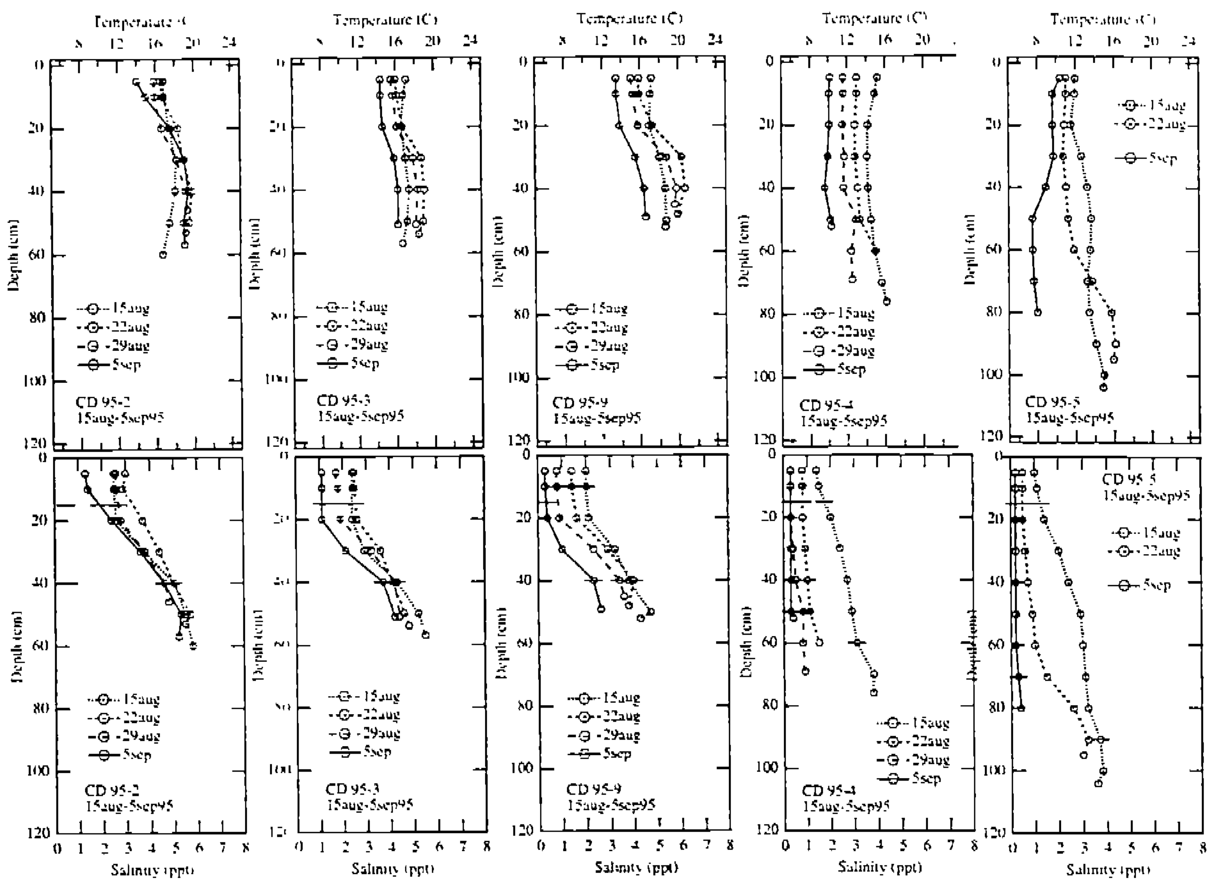

Figure IV-5-12. Salinity and water temperature profiles on the pond transect sampling sites in tide cycle 3, August–September 1995.

ther the preferred path of tidal water entering CD or from dilution of tidal water by freshwater entering from the south as a result of overflow from Eagle River during the high tide. Data from the isotope sample analysis and from the gully study (Lawson et al, this volume) may explain these observations.

At the three sites sampled during tide cycle 2, the change in the profile was nearly uniform at each site during the entire period until near freshwater salinity was reached (Fig. IV-5-9). This is also apparent in the profile averages (Fig. IV-5-13) where the salinity decrease is nearly linear over the inter-tidal period. This indicates a continuous, uniform influx of freshwater along the shoreline.

In tide cycle 3, the salinity spike introduced by the flooding high tide resulted in nearly identical salinity profiles with a slightly decreased average (Fig. IV-5-11 and IV-5-13). This was followed by a sharp decrease in salinity at all the sites to

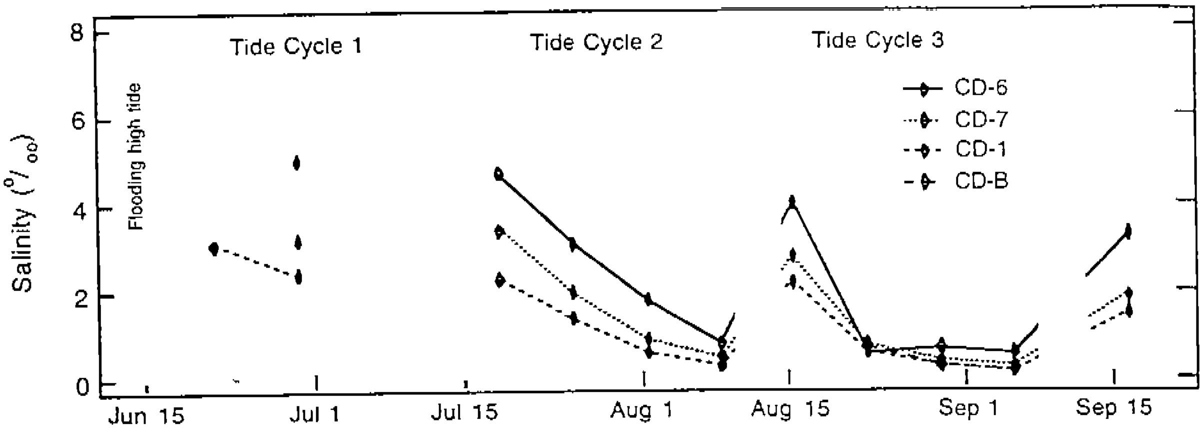

Figure IV-5-13. Average profile salinity at sampling sites on the shore transect in 1995.

near the minimum salinity values in one week. Slight decreases occurred over the remainder of the inter-tidal period with final salinity values that were nearly the same as those at the end of tide cycle 2. The pattern of salinity changes along the shore was not consistent between the two tide cycles. It is not clear why this difference occurred, the small difference in initial salinity values should not have resulted in such a fast change. The results of the isotope tracer study may provide some explanation.

The continuous salinity data from the data logger at CD-1 (Fig. IV-5-14) matches the average values very well due to the well-mixed water column at this site. These data can be used to fill the gaps in the manual data measurements. For example, in tide cycle 1, it is shown that the salinity continued to decrease throughout the inter-tidal period dropping below 1 ppt. In addition the salinity spikes introduced at the flooding high tides and the rapid salinity decreases immediately afterward are better illustrated by the continuous data. The decrease in salinity of the flooding tides is also documented.

The comparison of salinity to water surface elevation at CD-1 (Fig. IV-5-15) shows that the water surface elevation was nearly constant throughout the inter-tidal periods while the salinity had decreased significantly. This demonstrates that the salinity change following the tidal spikes was not a result of changes in the water depth.

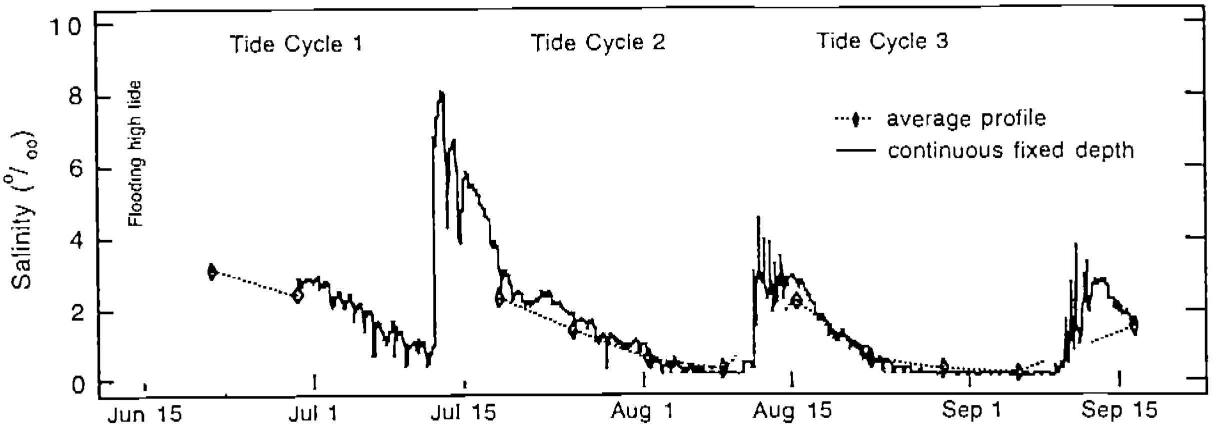

Figure IV-5-14. Comparison of the continuous salinity at a fixed depth and average salinity in the profile at CD-1 in 1995.

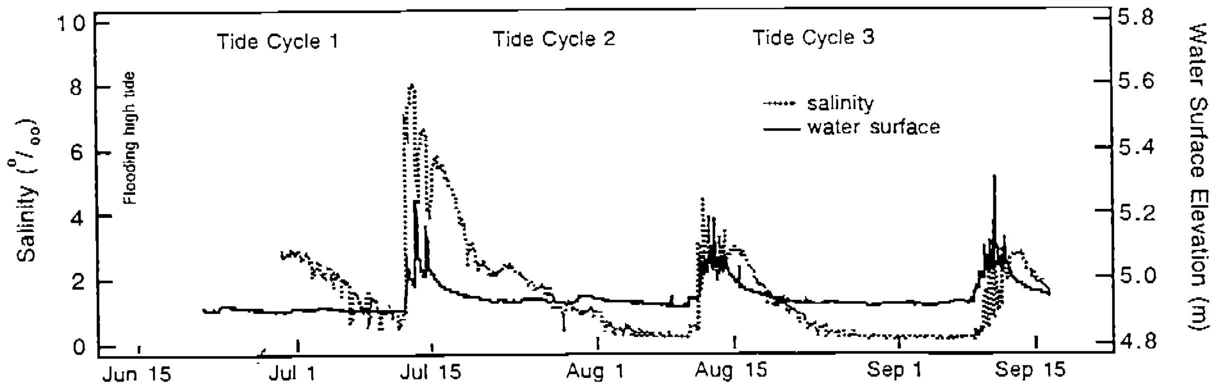

Figure IV-5-15. Water surface elevation and salinity at CD-1 in 1995.

Pond transect

As occurred at the shore transect sites, the salinity at a site on the pond transect generally decreased over the intertidal period. However, in contrast to the shore transect, the pond transect showed distinct differences between the sampling sites, where salinity on any given date was directly related to distance from shore. The effect of the flooding high tide on salinity change at a site was variable depending on distance from shore (Fig. IV-5-16). The salinity at the two sites nearest the shore, CD-5 and CD-4 (Fig. IV-5-10, IV-5-12 and IV-5-16), followed a pattern very similar to the northern sites on the shore transect (Fig. IV-5-9, IV-5-11 and IV-5-13). At these sites, flooding tides spiked the salinity to 2–5 ppt followed by decreasing salinity over the inter-tidal period until a nearly freshwater salinity of less than 1 ppt was reached. This indicates that the freshwater input at

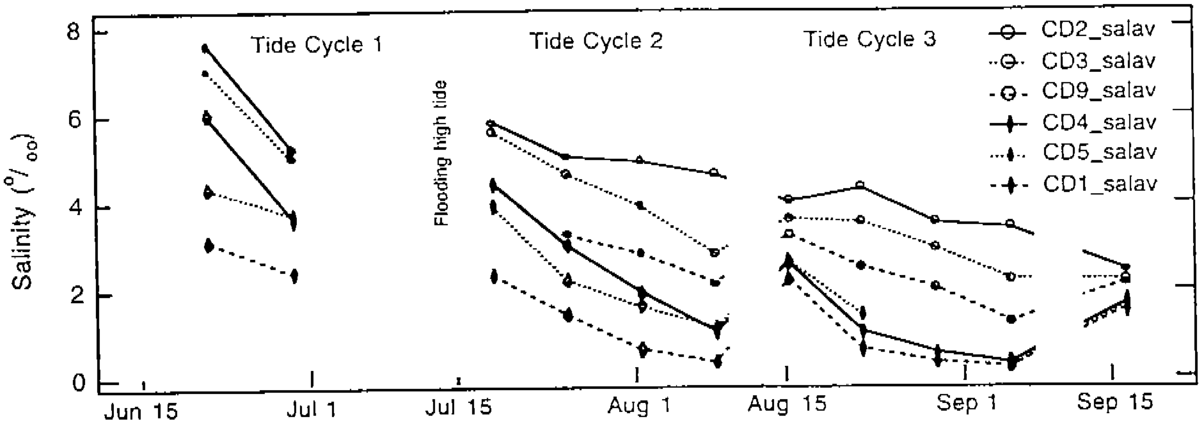

Figure IV-5-16. Average profile salinity at sampling sites on the pond transect in 1995.

the shoreline readily progressed to these sites within the inter-tidal period. The salinity at the next two sites, CD-9 and CD-3 (Fig. IV-5-10, IV-5-12 and IV-5-16), displayed a similar pattern of decreasing salinity over the inter-tidal period following the salinity spike of the flooding tide. However the salinity was maintained at a higher level throughout the study period with values never dropping below 1 ppt. There was a regular pattern of a small decrease in the salinity values over the full depth of the water column 3 (Fig. IV-5-6 and IV-5-12), indicating that the transitional zone of the freshwater wedge had reached this distance but had not fully mixed. At the outermost site, the salinity actually decreased with the flooding tide in tide cycles 2 and 3, and only decreased a small amount during the inter-tidal periods (Fig. IV-5-10, IV-5-12 and IV-5-16). The profiles show very little change at depth with freshening of the water column occurring primarily in the top 20 cm. This indicates little influence from the freshwater wedge from shore and poor mixing of the water column.

The isotope tracer study may provide further insight into the migration pattern of the freshwater wedge from the shoreline into the pond system.

Continuous salinity data were measured at the outermost site, CD-2, and are compared to the average salinity and the salinity measured at 45 cm (the depth of the sensor) in Figure IV-5-17. In contrast to CD-1, the continuous data do not match the averaged data very well due to the lack of vertical mixing at this site

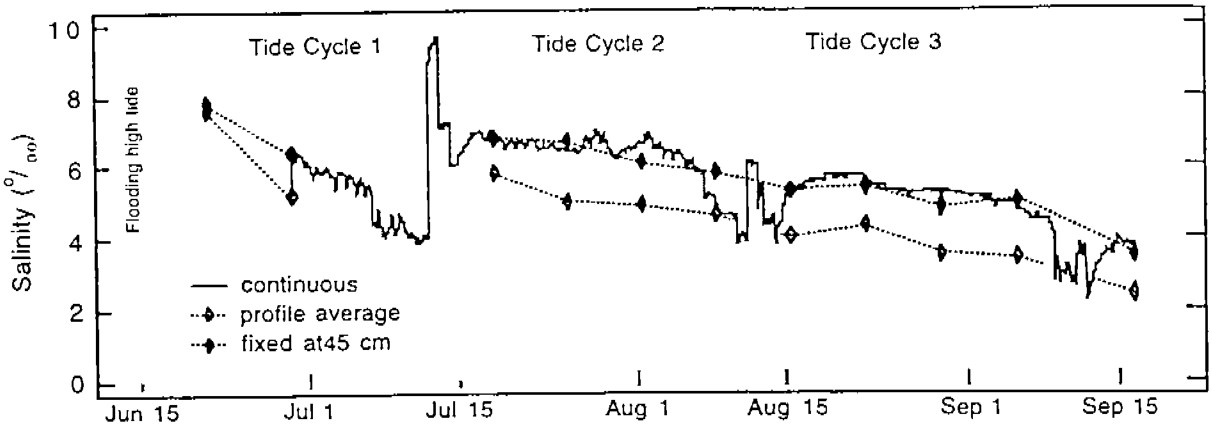

Figure IV-5-17. Comparison of the continuous salinity at a fixed depth, average salinity in the profile and salinity at fixed depth of 45 cm at CD-1 in 1995.

(Fig. IV-5-10 and IV-5-12). The continuous data does compare very well to the manual measurements at 45 cm depth. During tide cycle 2 and 3, the continuous data confirm that relatively little change in salinity had taken place suggesting that freshwater from the shoreline did reach this far into the pond system. The continuous data show a curious drop in salinity at the end of the intertidal period in tide cycle 1 and 2 that was not detected in the manual measurements. A similar drop occurred at the end of tide cycle 3 after the onset of the flooding high tides and it is not clear if it is a result of the tide. The salinity spikes from the flooding tides at CD-2 are higher than those at the shore (Fig. IV-5-14) but due to the relatively high salinity of the pond water at this site, the floods have little effect or actually result in a salinity decrease.

The comparison of salinity to water surface elevation at CD-2 (Fig. IV-5-18) shows no clear relationship except for the changes at the flooding tides. The water surface elevation was nearly constant throughout the inter-tidal periods while the salinity exhibited some fluctuations, which clearly can not be attributed to changes in water depth.

Water level changes

The water surface elevations at the shore and at the outer edge of the pond were nearly identical, that is any surface gradient across the pond was below the detection limits of the instrumentation used in this study. In the discussion that

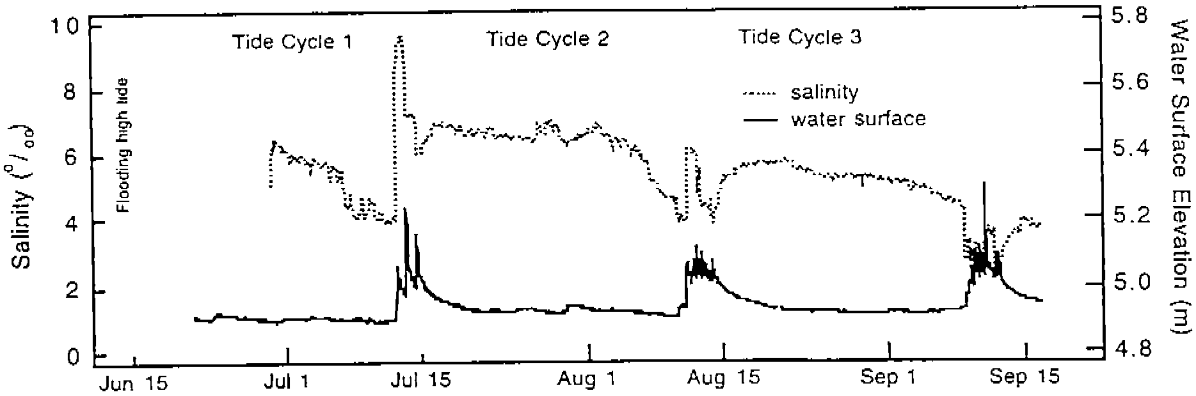

Figure IV-5-18. Water surface elevation and salinity at CD-2 in 1995.

follows the water surface elevation from CD-1 is considered to be representative of the entire pond system. The water surface elevation was relatively uniform during the inter-tidal periods without any significant long-term trends that indicate a rising or dropping water surface (Fig. IV-5-15). Daily fluctuations in the water surface level are compared to the daily resultant of precipitation and evaporation to determine the sensitivity of the water level to atmospheric moisture contributions (Fig. IV-5-19). The daily pan evaporation and precipitation (Haugen, this volume) measured at the EOD pad were combined for the atmospheric water contribution. Except for the periods of flooding high tides, the daily changes in the pond water level are fully accounted for by precipitation and evaporation. Due to frequent rainfall events that compensate for the evaporation effects and frequent flooding high tides that fill the ponds, the water surface level in the ponds was relatively uniform over the study period.

Estimation of surface water inflow rates

Based on the measured changes in salinity over time, estimates of fresh water inflow rates along the upland edge of the C/D pond area were calculated . The total area of the C/D pond system was 1.06 ha. The measured salinity profiles were used to calculate the thickness of the freshwater prism that slowly displace the more saline water following the last flooding monthly high tide. The size of the freshwater prism and the rate of its growth was used to estimate rate of freshwater inflow from the uplands.

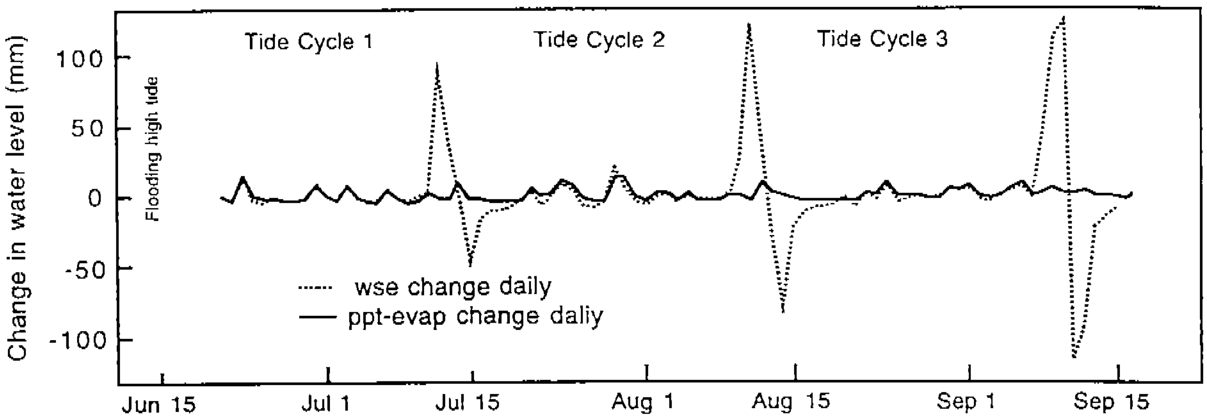

Figure IV-5-19. Comparison of changes in the pond water surface elevation and daily evaporation and precipitation in 1995.

The periodic water column profile measurements of salinity and temperature showed that a prism of fresh water discharged from a series of small springs and seeps along the upland border slowly displaced the brackish water that filled the ponds after a flooding high tide. The formation and extension of the prism of fresh water as it rides over and displaces the brackish water could be seen in the weekly measurements of the salinity of the water. From the measurements, rates of inflow of fresh water can be estimated.

<u>Model of rate of freshwater inflow.</u>

Shore pond, parallel to upland boundary:

Total area: 4,750 m^2

445 m long by 10.67 m wide.

Average depth: 1.5 m

Brackish water in shore pond is totally displaced by fresh water by 20 day after the last flooding high tide.

Total volume of fresh water: 7,125 m^3

2nd pond, perpendicular to Shore pond and upland boundary:

Total area: 6,985 m^2

335 m long by 20.85 m wide

Prism of fresh water after 20 days is approximately 1 m at near end and tapers to 0 cm at far end.

Total volume of fresh water: 3,490 m^3

The total volume of the fresh water prism in the two connected ponds after 20 days is approximately 10,615 m^3. This equates to 530 m^3/day of fresh water produced by runoff, seeps, and springs along the 445-m total length of upland boundary bordering the pond system. This is equivalent to 0.0061 m^3/s or only about 1/20 the pumping capacity of the pump system to be installed in the BT pond, indicating the system would be more than capable of keeping up with freshwater inflow from the C/D area. Because of the unusually wet summer this year with above-average precipitation in May, July and September, this freshwater inflow rate is probably higher than during an average summer. July precipitation, for example, was nearly 200% of normal (Haugen, this volume).

Data Assessment

Effectiveness.

- Measurement of change in salinity over time appeared to be an effective surrogate for determining rate of fresh water inflow directly.

Implementability.

- Hydrolab water quality sensors and hand-held water quality measurements from canoe are non-intrusive.
- Measurements made using conventional sensors and equipment.

On-site activity requirements (monitoring).

- Instrument tripods installed at two sites in pond at beginning of season. Dataloggers installed on tripods at beginning of season. Hydrolabs to measure water quality data installed on floats and interfaced to datalogger.
- Dataloggers and sensors removed at end of season. Tripods left in place for future use.

- Water column profiles of salinity and temperature taken by hand-held instrument from a canoe. All sites accessible by canoe.

  Frequency of monitoring.

- Data collected hourly throughout season by datalogger. Data downloaded periodically and at end of season.
- Water column profiles of salinity and temperature taken on a weekly basis between monthly high tide cycles

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IV-6. DREDGING AS A REMEDIATION STRATEGY FOR WHITE-PHOSPHORUS-CONTAMINATED SEDIMENTS AT EAGLE RIVER FLATS

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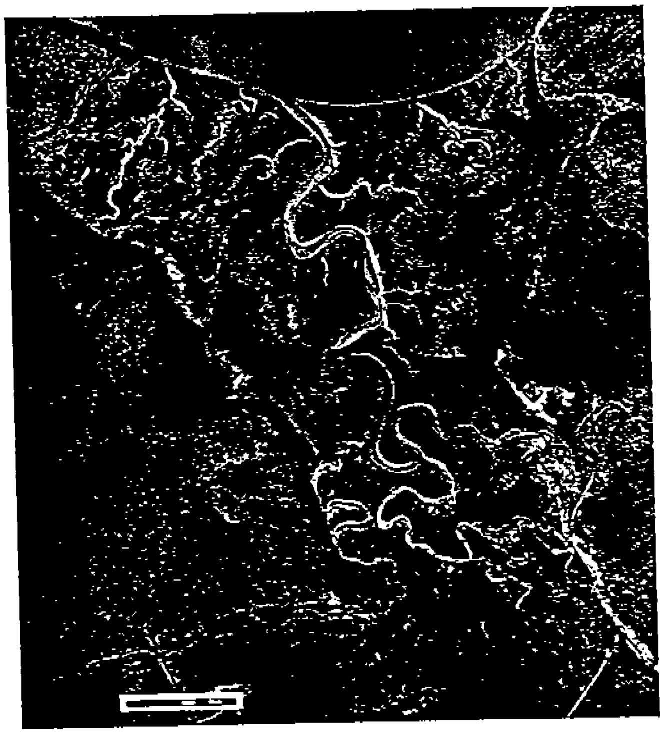
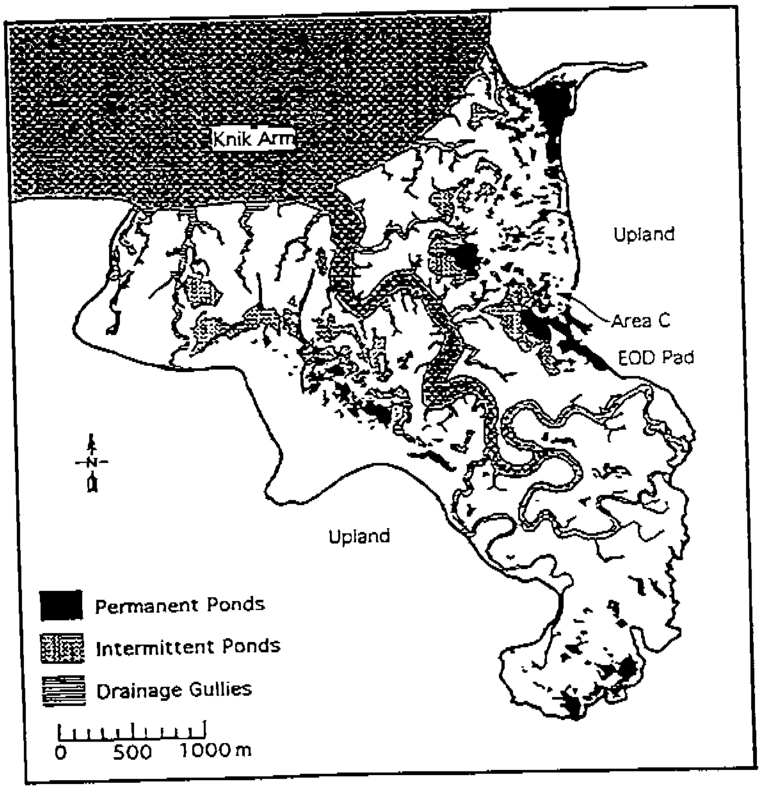
INTRODUCTION

Ongoing investigations into the waterfowl die-offs and the persistence of the causal agent, white phosphorus (WP), in Eagle River Flats (Fig. IV-6-1) indicate that any remediation strategy will have to include consideration of removal and controlled processing of contaminated sediments (Racine and Cate 1995). Contaminated areas which are constantly flooded, such as the deeper ponded areas, do not allow natural drying of the soil and subsequent sublimation of the residual white phosphorus particles. Some of these permanently flooded areas are interconnected over large areas and would be impractical to address through pumped pond draining. These areas, which are generally vegetated and heavily used by affected dabbling ducks and swans, have been found to be contaminated even after five years in which no WP rounds have been fired into the Flats. Although some areas of the Flats have shown evidence of natural remediation due to drying cycles in warm, dry years (Walsh 1995), the ponded areas still pose a substantial risk to waterfowl.

The objective of this project is to investigate the feasibility of using a small, remote-controlled dredge to remove sediments from contaminated ponded areas and treating the spoils in an open retention basin. The treatment method will be through unenhanced drying and sublimation of the contaminant white phosphorus in the basin.



a. Aerial photo.



b. Map of the Flats.

Figure IV-6-1. Eagle River Flats, Alaska (9 October 1995).

Dredging was chosen as a method of remediation because of the positive displacement of the contaminated material and the ability to treat the material in a controlled environment. Using a small dredge, limited areas can be addressed and transport of the contaminated material (spoils) to a retention basin for treatment can be quickly and efficiently conducted. Environmental impact, although not negligible, can be minimized through a careful dredging strategy.

BACKGROUND

This is the second year of the dredging program at Eagle River Flats. The first year primarily involved processing a contract for the dredge equipment, designing, constructing, and testing a spoils retention basin, integrating specialized equipment to the dredge, getting the leased equipment operational, and dredging a small area at the Flats (Racine and Cate 1995, Henry et al. 1996, Walsh et al. 1995). Due to the late arrival of the equipment because of contracting delays, very little actual dredging took place before the onset of winter and the cessation of dredging activities.

An overview of the area involved is shown in Figure IV-6-2. The area to be addressed this year is within the Clunie Creek inlet and along Clunie Point towards Canoe Point in Area C. These areas are permanently ponded areas, well characterized through surveys and sampling. Dredging in 1994 occurred only in a small area in Clunie Inlet.

RETENTION BASIN

Before dredging could begin in 1995, the Retention Basin was reexamined. The Retention Basin is located on the Explosive Ordnance Disposal (EOD) pad, which at the time of construction was a RCRA (Resource Conservation and Recovery Act) site. Due to the presence of contaminants (Holdsworth 1992), percola-

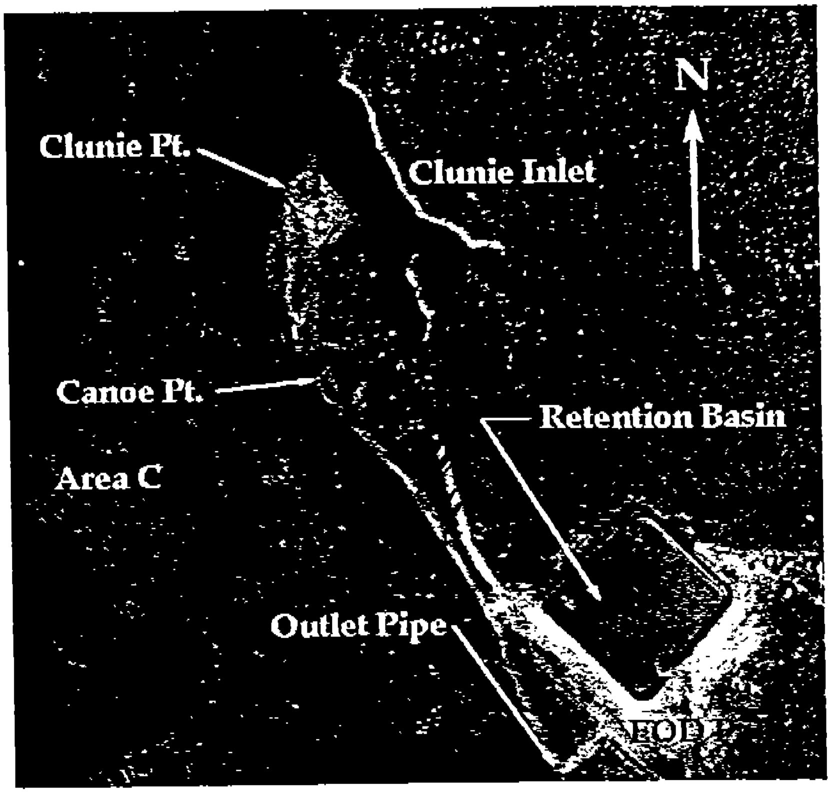


Figure IV-6-2. Area involved in work unit (October 1995).

tion of water from the spoils through the EOD pad needed to be held to that which would occur through a cap on a hazardous waste site (10^{-6} cm/s). Extensive testing in 1994 indicated that the Basin, consisting of a packed gravel base and berms with a packed peaty silt liner, would provide acceptable retention properties for the required infiltration rates. The addition of sludge from the sediments was shown to increase the hydraulic resistance of the system, thus providing a margin of safety for the Basin (Walsh 1995).

With the limited use of the Basin in 1994 and the subsequent drying and freeze/thaw cycling over winter, extensive cracking of the Basin floor occurred (Fig. IV-6-3). The presence of the liner cracks necessitated rerunning percolation tests on the liner to determine their effect on the system hydraulic conductivity. Seven percolation (perc) barrels were set in three different areas characterized by the liner crack density and apparent moisture content (Table IV-6-1). Tests were conducted using a constant head except for periods extending overnight. Liner depth and crack size were recorded prior to the initiation of tests.

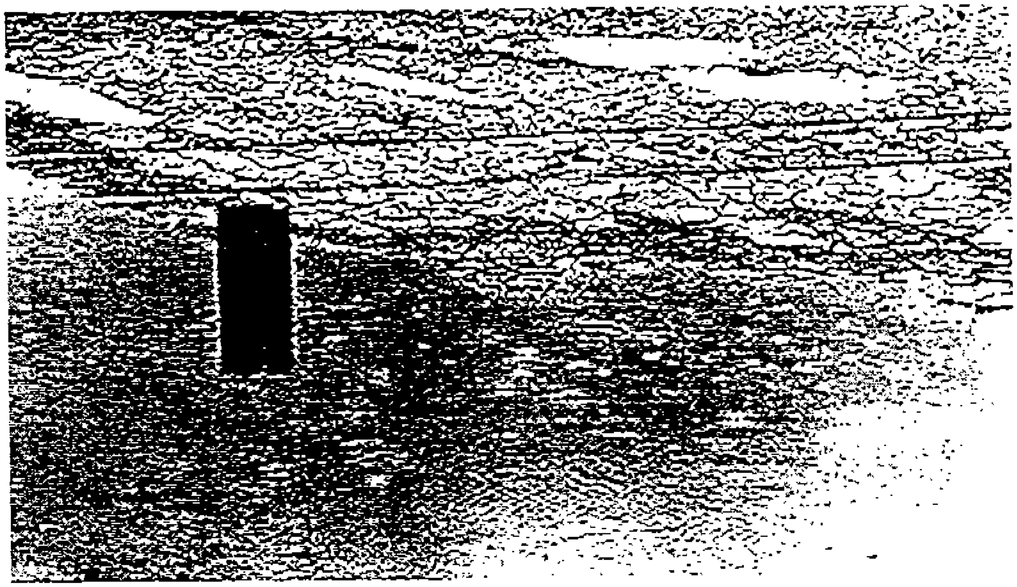


Figure IV-6-3. Perc barrel and cracked liner.

Table IV-6-1. Initial conditions at Basin percolation sites.

Site #	Liner depth (cm)	Max. head (cm)	Crack size (cm) Depth × width	Initial conditions
BP-1	15.2	35.6	3 × 1	Moderately cracked: Dry
BP-2	10.2	40.6	5 × 1.6	Moderately cracked: Moist
BP-3	6.4	40.6	None	No cracks: Wet and soft
BP-4	8.9	40.6	None	No cracks: Wet and gooey
BP-5	20.3	30.5	10.2 × 3	A few large cracks: Dry and stiff
BP-6	15.2	35.6	10.2 × 3	A few large cracks: Dry and stiff
Bbl. C	20.3	35.6	Not measured	Few cracks: Moist

The percolation tests were run over a period of up to nine days. While most tests indicated a percolation rate below the acceptable level of 10^{-6} cm/s, one test exceeded that level (Fig. IV-6-4). This was attributed to loose gravel beneath the liner. The cracks within the perc barrels healed as the testing progressed, indicative of swelling of the liner, most likely due to its high organic content. All but the one site equilibrated at or near the values found from last year's tests (2 to 6 × 10^{-6} cm/s). Overall performance of the liner was sufficient for us to judge it acceptable for use again this year.

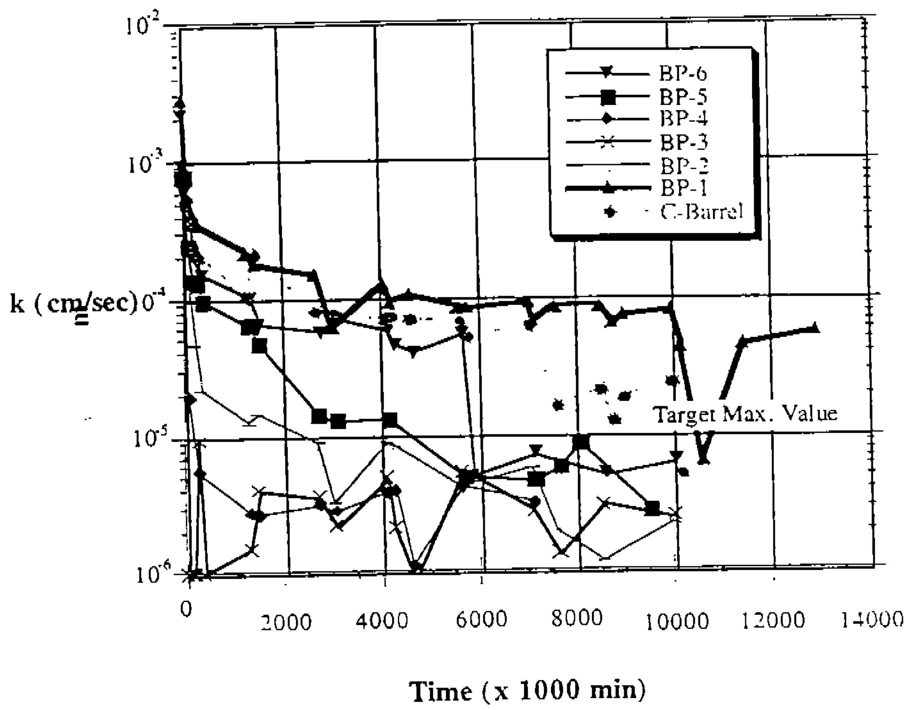


Figure IV-6-4. Percolation test results.

In addition to the perc tests, moisture content and densities were obtained for the material near the percolation tests to complete the recharacterization of the Retention Basin liner. Sand cone density measurements were taken at the perc barrel locations and the removed material brought back to base to run moisture content measurements (Table IV-6-2). Moisture contents ranged from around 30% to around 70%. Densities generally ran around 0.9 g/cc (55#/cubic ft). No density test was run on the perc barrel in the vicinity of C barrel.

The four instrumentation stations were once again assembled inside the Basin to monitor parameters essential to the remediation of WP (Table IV-6-3). A contracting action was initiated in February to have ground water level monitoring wells drilled and installed inside and around the Basin to assess the effect pumping spoils into the Basin would have on the hydrology of the EOD Pad. Due to protracted contracting delays, we were unable to drill the monitoring wells before the end of September. The well inside the Retention Basin was not placed due to the softness of the liner at that time.

Finally, damaged areas of the Basin were repaired. At the front of the spoils splash pad where there is no chain link fence, a wooden weir about 30 cm high

Table IV-6-2. Water content and densities of Basin liner samples taken adjacent to percolation test sites.

Sample #	Soil+tare Wet (g)	Soil+tare Dry (g)	Weight Water (g)	Tare (g)	Dry soil (g)	Water Content (%)
BP-1	2003	1539	464	48	1491	31.1
BP-2	2276	1348	928	48	1300	71.4
BP-3	2256	1293	963	48	1245	77.3
BP-4	2966	2367	599	48	2319	25.8
BP-5	2194	1599	595	48	1551	38.4
BP-6	2656	2004	652	48	1956	33.3

Sample #	Weight Soil+tare Wet (g)	Hole vol. (g)	Tare (g)	Wet soil (g)	Wet unit (g/cm³)	Dry unit (g/cm³)
BP-1	2003	1391.65	48	1955	1.4	1.07
BP-2	2276	1584.37	48	2228	1.41	0.82
BP-3	2256	1435.21	48	2208	1.54	0.87
BP-4	2966	1403.14	48	2918	2.08	1.65
BP-5	2194	1643.19	48	2146	1.31	0.94
BP-6	2656	1966.73	48	2608	1.33	0.99

Note: (Ref. DD Form 1215, 1 Aug. 57)

Table IV-6-3. Instrumentation configuration for Basin stations.

Sensor	Parameters	Station number 1	2	3	4
Station / location	Northing	6801054.17	6801090.75	6801109.88	6801106.35
	Easting	355613.50	355630.13	355599.97	355678.56
	Elevation (m)	9.5	9.48	9.45	9.58
	Heights				
Thermistors sensors	#1 (cm)	0	–5	0	0
	#2 (cm)	10	5	20	10
	#3 (cm)	25	15	40	25
	#4 (cm)	40	40	60	40
Watermark soil moisture blocks	#1 (cm)	0	0	0	0
	#2 (cm)	10	15	20	10
	#3 (cm)	25	30	40	25
	#4 (cm)	40	45	60	40
Air temp. sensor (cm)		260	–	–	–
Snow gauge height (cm)		320	–	–	–

Note: All sensor height measurements are referenced to surface of liner on 5/11/95. Locations surveyed by D. Lambert from TBM Berm.

was built to redirect the flow. In addition, riprap was placed at other areas where minor erosion had occurred. Damage caused by local fauna, such as deep moose and bear prints and locations where wolves and coyotes had dug, were also repaired.

Table IV-6-4. Boom box calculations.

Case	*Inlet diam. (in.)*	*Inlet length (in.)*	*Length factor (in.)*	*Box "diam." (in.)*	*Outlet diam. (in.)*	*K inlet*	*K outlet*	*K' factor*	*K total*	*Description* *Inlet*	*Outlet*
1	6			19	6	0.81	0.42		1.23	Sudden enlarge.	Sudden contract.
2	6			19	6	0.81	0.05		0.86	Sudden enlarge.	Rounded
3	6	12	0.54	19	6	0.87	0.05	1.07	0.92	Gradual enlarge.	Rounded
4	6	14	0.46	19	6	0.82	0.05	1.01	0.87	"	Rounded
5	6	16	0.41	19	6	0.78	0.05	0.96	0.83	"	Rounded
6	6	18	0.36	19	6	0.7	0.05	0.86	0.75	"	Rounded
7	6	24	0.27	19	6	0.49	0.05	0.61	0.54	"	Rounded
8	6	30	0.22	19	6	0.43	0.05	0.53	0.48	"	Rounded
9	6	12	0.54	19	6	0.87	0.05	1.07	0.92	"	Rounded
10	6	14	0.46	19	6	0.82	0.05	1.01	0.87	"	"
11	6	16	0.41	19	6	0.78	0.05	0.96	0.83	"	"
12	6	18	0.36	19	6	0.7	0.05	0.86	0.75	"	"
13	6	24	0.27	19	6	0.49	0.05	0.61	0.54	"	"
14	6	30	0.22	19	6	0.43	0.05	0.53	0.48	"	"
15	6			19	6	0.81	0.05		0.86	Sudden enlarge.	"

Ref: Avallone and Baumeister: Mark's Standard Handbook for Mechanical Engineers, 9th Ed. Page 3-58.
Note: Case 1 is present case.
K is used in head calculations (L/D=K/f)
Best case: #8

EQUIPMENT PREPARATION

Following on from last year's effort, work continued on dredge system modifications. A new ordnance collection box ("boom box") was designed using hydrodynamic principles (Table IV-6-4). It was then fabricated in Alaska and installed between the augerhead and the slurry pump. The new box is aluminum construction for ease of installation and to reduce system weight. It has a backflush trap door near the front and spring-loaded side doors to flush captured ordnance (Fig. IV-6-5). Initial tests indicated air leaks due to a deviation from the design drawings, so a modification was made (the hatch seen in Figure IV-6-5) and the box was reinstalled.

Electrical problems were addressed and safety modifications were completed on the system. The lateral winch motors, used to position the dredge perpendicular to the traverse direction, were not waterproof and had to be replaced by the contractor.

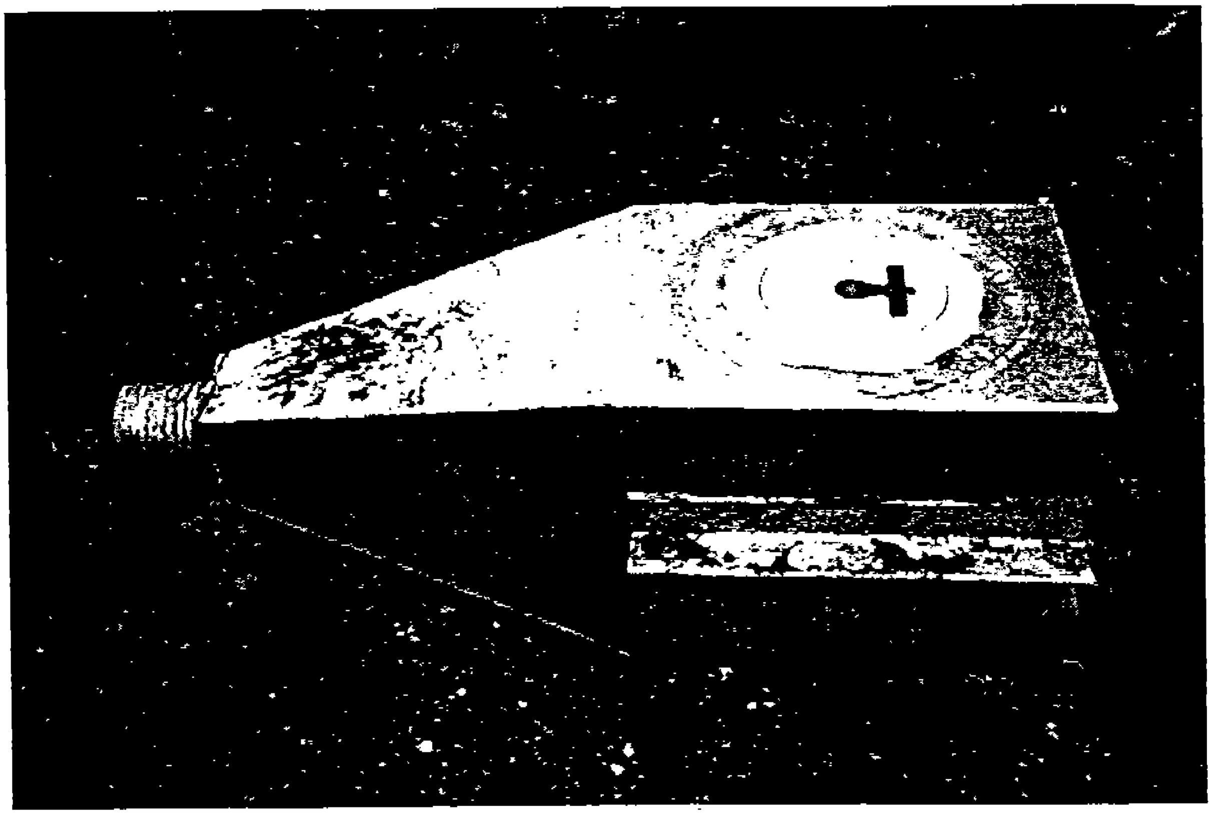


Figure IV-6-5. New boom box with hatch modification.

INITIAL DREDGING OPERATIONS

Initial dredging operations were quite discouraging, showing little improvement over the previous season. Output from the various dredge sensors was still unusable, and the pump did not seem to be operating correctly. Top speed was attained at about 50% of hydraulic throttle, and flows could not be maintained. In addition, the ø 25-cm flexible sections in the spoils line continued to blow fittings. Several calls to the equipment manufacturer were fruitless, as they insisted the equipment was operating according to specification. Even a representative from the Corps of Engineer's Waterways Engineering Station was at a loss for an explanation. We finally decided after an unsuccessful trip in June to start from scratch and troubleshoot every suspect component in the system.

Flexible sections

All the flexible sections in the spoils line were removed and replaced with short sections of rigid PVC pipe. After one section of PVC pipe blew an end fitting, the number of screws holding the fittings to the pipe ends were doubled from two to four. No further problems were encountered.

Sensors

Closer examination of the sensors indicated that the output signal was 1–6 V DC, not the 0–5 V DC specified. This resulted in miscalibration and filtering of the higher output signal (5–6 V). In addition, the sensors were wired to the wrong inputs to the video panel meter, which transforms the signals into output data for transmission over the video system. These were rewired to the correct inputs. A voltage reduction circuit using precision resistors was designed at CRREL and installed between the sensor output leads and the video panel meter (Fig. IV-6-6). This circuit attenuates the signal 20%, resulting in an input signal of 0.8 to 4.6 V DC to the panel meter. The panel meter was reprogrammed and pumping tests rerun to obtain data for pump evaluation.

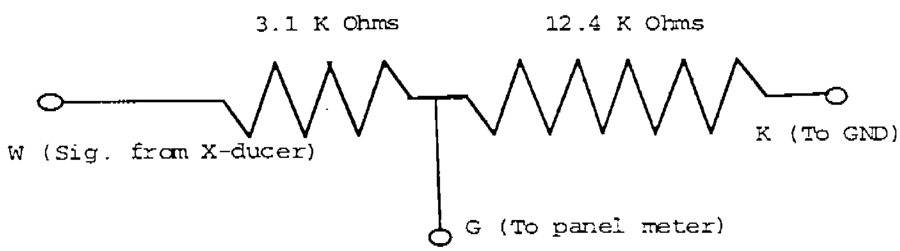


Figure IV-6-6. Sensor voltage divider (Typ. each sensor).

Pump

With the sensors wired correctly and recalibrated, a series of tests pumping clean water was conducted. In these tests, generator current; pump rpm; inlet, outlet, and hydraulic pressures; pump throttle setting; and outflow were monitored. Composite results are shown in Table IV-6-5.

Table IV-6-5. Pump performance test.

	Slurry pump					
	Outlet pressure					Output
Control setting (%)	Sensor (psi)	Gauge* (psi)	Shaft speed (RPM)	Hydraulic drive (psi)	Current draw (amps)	flow (visual)
100	15	17	1257	3345	50	Full
95	15	17	-	3345	-	Full
90	15	17	1269	3340	-	Full
85	15	17	-	3340	-	Full
80	15	17	1270	3340	50	Full
75	15	17	-	3340	-	Full
70	15	17	1275	3340	-	Full
65	15	17	-	3340	-	Full
60	15	17	1280	3340	50	Full
55	15	17	-	3335	-	Full
50	15	17	1282	3332	-	Full
45	15	17	-	3330	-	Full
40	13	15	1116	2615	25	≈3/4
35	11	13	-	1930	-	≈1/2
30	9	11	806	1455	-	≈3/8
25	8	10	-	950	-	≈1/4
20	6	8	492	500	≈7	0
15	4	7	-	580	-	0
10	-	-	135	-	-	0
5	-	-	-	-	-	0
0	-	-	0	-	≈5	0

* 200 psi gauge.

Static head calculations were then made to determine the theoretical head at full flow. Friction factors were derived from empirical data (O'Brien 1995). The following parameters were used:

- Flow: 113.5 L/s
- Friction factor - ø 25-cm polypipe: 1.69 m/ 100 m
- Friction factor - ø 20-cm rubber hose: 3.7 m / 100 m
- Height of top of berm from water level: 6.52 m
- Drop from berm to spoils line outlet: 0.81 m

Total head for the system:

- Static head: 6.52 – 0.81 = 5.71 m
- Friction head: Polypipe (335 m): 335 × 1.69/100 = 5.7 m
- Friction head: Hose (76 m): 76 × 3.7/100 = 2.81

Total head will be the sum of all three components above, or:

$$h = h_s + \Sigma h_f = 5.71 + 5.70 + 2.81 = 14.22 \text{ m.} \quad (1)$$

The head was also calculated using the Hazen–Williams formula:

$$h_f = 10.44\,(L)/(gpm)^{1.85} \,/\, [(C)^{1.85}\,(d_{inches})^{4.8655} \quad (2)$$

where:

- L is the length of pipe in feet (1000 ft)
- gpm is the flow through the pipe (1800 gpm)
- C is the Hazen–Williams constant (≈1.40 for PE)
- d is the pipe inside diameter in inches (≈10 in.).

Plugging in the values and constants above for PE pipe, we get (converted):

$$h_f = 1.61 \text{ m}/\ 100 \text{ m} \quad (3)$$

thus validating the value used in equation 1. Design pump flow is actually 106.3 L/s, so the total head we should see at the dredge should be approximately:

$$h_p = h_s + (V_1/V_2)2\ (\Sigma\ h_f) \quad (4)$$

$$h_p = 5.71 + (106.3/113.5)^2\ (5.7+2.81)$$

$$h_p = 13.2 \text{ m.} \quad (5)$$

Using 998 kg/m³ as the density of the pumped water, the actual power head is:

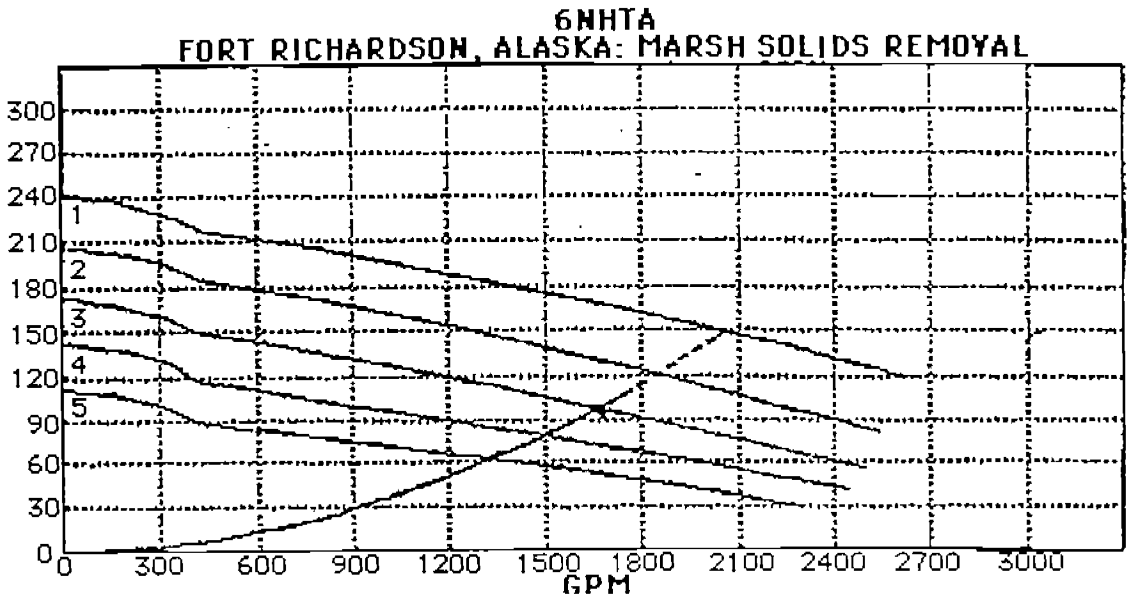
$$h_p = P_{out}/\ \rho \quad (6)$$

$$h_p = (103 \times 10^3)\ (10.2 \times 10^{-2})\ /\ 998$$

$$h_p = 10.5 \text{ m.} \quad (7)$$

This is about 30% less than what the system output should be if the equipment was operating properly. A call to the equipment manufacturer resulted in the discovery that the pump trim and pressure relief settings were not correct. The system was set up with a 14-in. (356-mm) impeller operating at 1250 rpm. It was designed to run with a 12-in. (300-mm) trim operating at an 1800 rpm impeller speed (Fig. IV-6-7).

Given this situation, there were three options available. The first was to leave the impeller as is and increase the hydraulic pressure to run the pump at a sufficient speed to attain the flow rates in the specifications. As can be seen in Figure

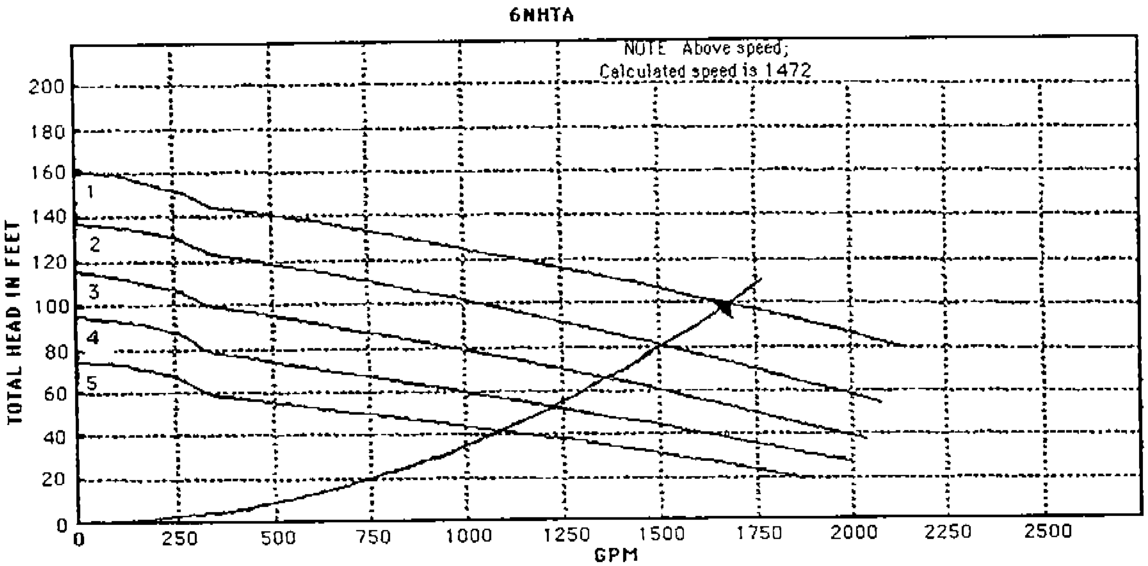


Design point	
Flow (US gpm)	1685
Head (ft)	100
Speed (rpm)	1800
Trim (in.)	12
Horsepower (hp)	50.5
Efficiency (%)	81.8
Static head (ft)	0.0

Curve	Trim	Max. HP @ 1.0 SG
1	14.00	97.70
2	13.00	68.78
3	12.00	51.08
4	11.00	38.23
5	10.00	27.75

Figure IV-6-7. Pump curves for 1800-rpm impeller. (Adapted from Cornell 1995.)

IV-6-8), that speed is 1470 rpm. Note that the power requirements are the same due to increased pump efficiency. The second option was to trim the impeller to 13 in. (330 mm) and increase the pressure to attain the correct flow. The third option was to trim the impeller to 12 in. (300 mm) and increase the impeller speed to make the pump operate as originally planned. The first option was the quickest method of obtaining the desired result, so that option was favored. However, before a decision could be made, other factors, such as computed head, available horsepower, and available suction need to be examined. A shortfall in any of these three parameters will dictate the consideration of an alternate strategy.



Design point	
Flow (US gpm)	1685
Head (ft)	100
Speed (rpm)	1470
Trim (in.)	14
Horsepower (hp)	50.5
Efficiency (%)	83.7
Static head (ft)	0.0

Curve	Trim	Max. HP @ 1.0 SG
1	14.00	53.21
2	13.00	37.46
3	12.00	27.82
4	11.00	20.82
5	10.00	15.12

Figure IV-6-8. Pump curves for 1470-rpm impeller. (Adapted from Cornell 1995.)

A system analysis was performed using the pump affinity laws. For the system as delivered, without the boom box, we have the following parameters:

- Trim: 14 in. (356 mm)
- Max. shaft speed: 1280 rpm
- Max. outlet pressure: 16 psi / 36.9-ft head (11.25 m).

The first calculations are for a 12-in. (300-mm) trim. Adjusting for trim using the head relationship:

$$\frac{h_2}{h_1} = \left(\frac{d_2}{d_1}\right)^2 \qquad (8)$$

where

h_1 is the current outlet head,

h_2 is the projected outlet head,

d_1 is the original impeller diameter, and

d_2 is the impeller diameter of interest.

$$\frac{h_2}{16} = \left(\frac{12}{14}\right)^2$$

∴ h2 = 11.76 psi @ 1280 rpm (81.1 kPa).

Adjusting for speed using the head / speed relationship:

$$\frac{h_2}{h_1} = \left(\frac{n_2}{n_1}\right)^2 \tag{9}$$

where

n_1 is the original impeller rotational rate, and

n_2 is the rate of interest.

$$\frac{h_2}{11.8} = \left(\frac{1800}{1280}\right)^2$$

∴ h_2 = 23.3 psi (53.8-ft head) @ 1800 rpm (160.6 kPa/16.4 m).

The next series of calculations are for a 13-in. (330-mm) trim. The equations used are the same:

$$\frac{h_2}{16} = \left(\frac{13}{14}\right)^2 \quad \text{(Ref. 8)}$$

h2 = 13.8 psi @ 1280 rpm (95.1 kPa)

$$\frac{h_2}{13.8} = \left(\frac{1800}{1280}\right)^2 \quad \text{(Ref. 9)}$$

∴ h2 = 27.3 psi (62.9′ head)@ 1800 rpm (188.2 kPa/19.2 m)

Finally, for the 14-in. trim, we need adjust for impeller speed only:

$$\frac{h_2}{16} = \left(\frac{1800}{1280}\right)^2 \quad \text{(Ref. 9)}$$

h_2 = 31.6 psi (73-ft head) @ 1800 rpm (188.2 kPa/22.3 m).

Referring to Figure IV-6-7, we should be capable of around 150 ft (45 m) of head. Lack of line resistance is the probable cause of this differential. Referring back to Figure IV-6-8, the outlet head is calculated for an impeller speed of 1500 rpm:

$$\frac{h_2}{16} = \left(\frac{1500}{1280}\right)^2 \quad \text{(Ref. 9)}$$

h_2 = 22 psi (51-ft head) @ 1500 rpm (188.2 kPa/ 15.6 m).

If the 14-in. impeller option is chosen, the outlet pressure should be about 22 psi for the same configuration as the original. This allows much greater flexibility in operations due to the greater available pressure range for dredging.

The next factor to be examined is the power requirement. For this, the classic fluid power equation is used:

$$P = \left(\frac{pQ}{1714}\right)(0.7457) \qquad (10)$$

where

P is required power (kW),

p is system pressure (psi), and

Q is fluid flow rate (gallons per minute).

The impeller drive motor requires 0.017 gallons per revolution. Table IV-6-6 illustrates the various power requirements for different system configurations. Units have been converted to metric.

A total of 74.5 kW of power is available at the electric motor, driving the hydraulic pumps. Two other systems are driven off the auxiliary hydraulic pump. The auger motor requires about 8.9 kW at full power, 80% efficiency, and the traverse drive requires about 0.4 kW at the same conditions.

Table IV-6-6. Slurry pump power requirements.

Impeller speed (rpm)	*Pressure (Mpa)*	*Flow (L/s)*	*Power (kW)*
1280	24.1	1.4	32.9
1280	31.0	1.4	42.3
1500	24.1	1.6	38.6
1500	31.0	1.6	49.6
1800	24.1	1.9	46.3
1800	31.0	1.9	59.5

Using these numbers, a total of 65.2 kW is available to drive the slurry pump. Using an efficiency factor of around 80%, the greatest power utilization comes at an impeller speed of just below 1500 rpm with line pressure at 31 MPa (4500 psi). These are the conditions for which the 14-in. impeller works best.

Finally, the net positive suction head available (NPSHA) needs to be examined to ensure cavitation does not occur. In this analysis, absolute engineering (English) units are used. The equation normally used is:

$$NPSHA = h_a + h_s - h_{fs} - h_{vp} \qquad (11)$$

where

h_a is atmospheric head,

h_s is static suction head,

h_{fs} is the friction loss in the suction line, and

h_{vp} is the vapor pressure head.

Atmospheric pressure is taken as 33.9 ft. For static suction head, the intake for the pump is 1.6 ft below water level. Friction head loss is calculated on the basis of pipe diameter, fluid speed and roughness.

Pipe diameter:	0.505 ft (6-in. Sched. 40 pipe)
Pipe area (Use 0.5 ft ø):	0.2 ft^2

$$v = \text{fluid speed} = Q/A \qquad (12)$$

Q = 1685 gpm (system requirement)

$= 1685\,(2.228 \times 10^{-3})$

$= 3.75\ \text{ft}^3/\text{s}$

$\therefore\ v = 3.75/0.2 = 18.8$ fps.

Entrance loss is calculated on the basis of fluid velocity and an entrance loss coefficient, K_e. In this case, K_e is 0.5, based on a flush, square-edged entrance (Lindeburg 1984, p. 3–24).

$$h_e = K_e\left(\frac{v^2}{2g_c}\right) \qquad (13)$$

$$h_e = 0.5\left(\frac{(18.8/1.56)^2}{2(32.2)}\right)$$ (Opening is 1.56 times larger than hose)

$$h_e = 1$$

Equivalent lengths of the various components are taken from standard tables:

- Short 90° (Eye inlet): 9 ft.
- Intake hose (6 in.): 8 ft.
- Entrance loss (see above): 1 ft.

Total equivalent length is therefore 18 ft. To calculate the suction friction loss, the Darcy equation is used:

$$h_f = \frac{f(L)(v)^2}{2Dg_c}. \quad (14)$$

Using cold, clear water,

$$\nu = 1.22 \times 10^{-5} \ (\approx 16°C).$$

Plugging into the formula for Reynolds number:

$$N_{Re} = \frac{D_e v}{\nu} \quad (15)$$

results in a Reynolds number of

$$N_{Re} = \frac{(0.5)(18.8)}{1.22x10^{-5}}$$

$$N_{Re} = 7.8x10^5$$

which is in the turbulent region. To determine the Darcy friction factor f, the relative roughness ratio, ε/D, must be estimated. Using 0.5 ft for the hose diameter and a specific roughness $\varepsilon = 1 \times 10^{-5}$ (Lindeburg 1984),

$$\varepsilon/D = 2 \times 10^{-5}.$$

Using the relative roughness and Reynolds number to find the Darcy friction factor from a Moody friction factor chart, we find that

$$f \approx 0.014.$$

Plugging these values into equation (14) results in a head of

$$h_f = \frac{0.014(18)(18.8)^2}{2(0.5)(32.2)}$$

$$h_f = 2.8 \text{ ft}.$$

Finally, the vapor pressure head at 16°C is 0.6 ft. Filling in the values derived for Equation (11), we get:

$$NPSHA = 33.9 + 1.6 - 2.8 - 0.6$$

$$NPSHA = 32 \text{ ft } (9.75 \text{ m}).$$

Using a set of pump curves from the manufacturer (not shown), a net positive suction head required of approximately 15 ft is required at 1685 gpm (4.6 m at 106 L/s). For higher flow rates, which occur with lower outlet line resistances (shorter lines), the NPSHR rises quickly. At 142 L/s, the NPSHR becomes 7.3 m, and at 190 L/s, which we were approaching with only 76 m of hose attached to the dredge, we are at or slightly above the NPSHA. However, for our operations, the 14-in. (356-mm) impeller operating near 1500 rpm should work well.

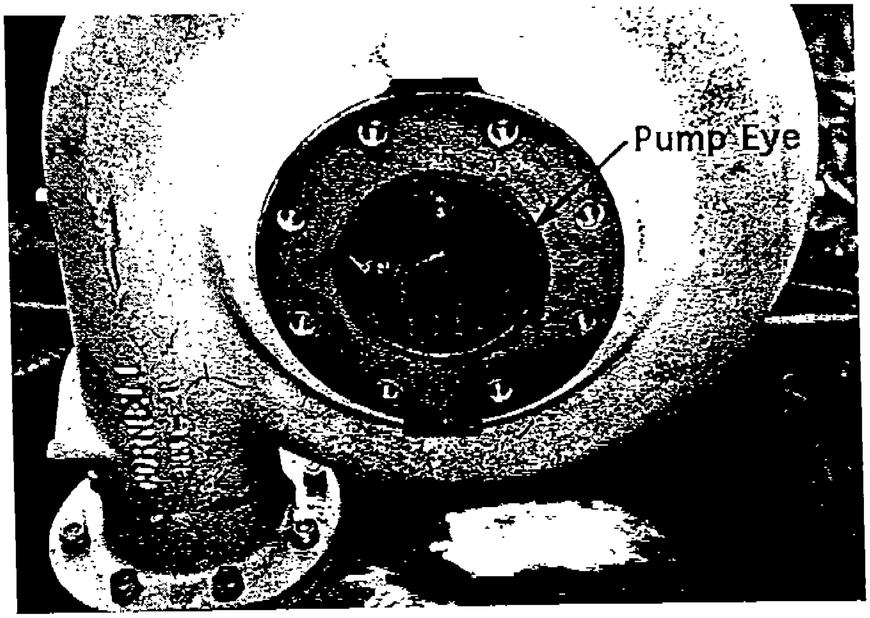
Table IV-6-7. Final pump performance test results.

Control setting (%)	*Slurry pump* Outlet (kPa)	*Slurry pump* Hyd. (MPa)	*Outlet flow (visual)*
100	108.9	33	Full pipe
95	108.9	33	Full pipe
90	108.9	33	Full pipe
85	108.9	33	Full pipe
80	108.9	33	Full pipe
75	108.9	33	Full pipe
70	108.9	33	Full pipe
65	104.8	31	Full pipe
60	95.1	27	Near full pipe
55	85.5	23	Near full pipe
50	75.8	20	Near full pipe
45	64.1	16	≈7/8 pipe
40	54.5	12	≈3/4 pipe
35	47.6	10	≈5/8 pipe
30	42.7	6.2	1/3 to 1/2 pipe
25	37.9	4.8	Trickle

With the slurry pump hydraulic system pressure relief valve set to 4800 psi (33 MPa), the pump tests were rerun. In this case, the boom box was removed and a new grate system, described later, was installed at the dredge head intake. The data, as shown in Table IV-6-7, is as expected from the calculations above.

Grates

With a handle on the pump performance problem, a closer look was taken at the debris ingestion problem. Although the system is supposed to be able to tackle vegetation, the presence of the boardwalk and other wood debris is problematic for the pump. Chunks of wood will become lodged in the eye of the pump, quickly accumulating other debris in a process called "beaver-damming" (Fig. IV-6-9). Evidence of this phenomenon first surfaced during pumping tests, when cyclic surging, the period of which was related to impeller speed, occurred for no apparent reason. Pump blockage was suspected. When the dredge was pulled from the water and the pump eye examined, it was found to be clogged with debris. The instigator in all three occurrences was a section of boardwalk approximately 7 mm wide by 2 mm thick by 15–20 mm long. Because the wood was of near-neutral buoyancy, it did not drop out in the boom box. We also found that aluminum objects did not drop out either.

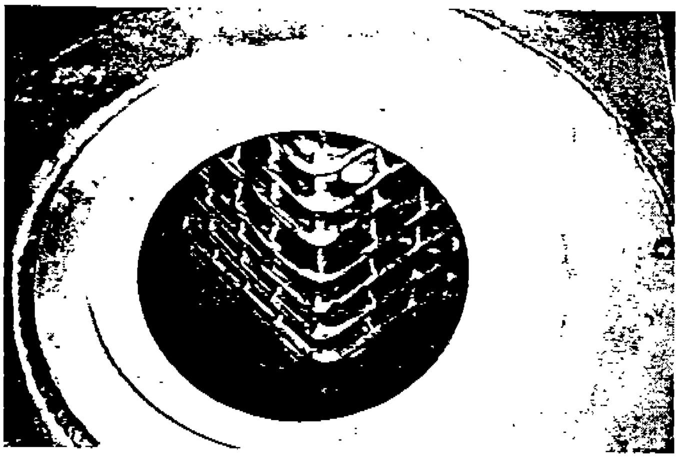


a. Debris in pump eye.

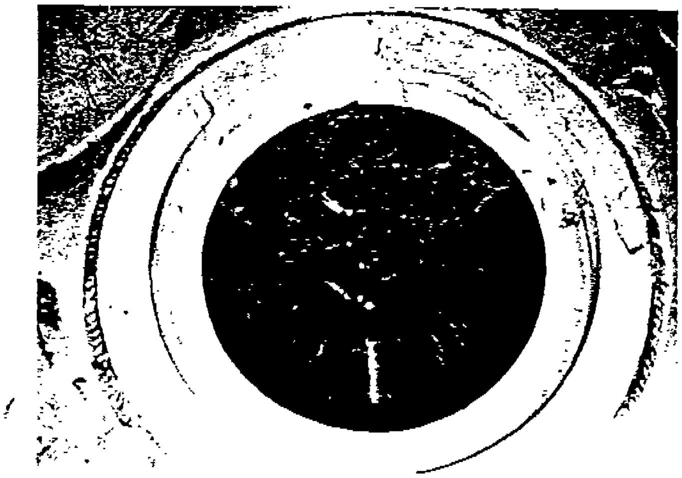
b. Extracted debris. Note aluminum illumination round section.

Figure IV-6-9. Slurry pump eye clogging.

Although the boom box was working well keeping out heavy steel debris, it was not functioning when confronted with lighter materials. A coarse screen system was installed in the boom box, but that quickly plugged, crippling the dredge within minutes (Fig. IV-6-10). A new approach was needed that would exclude debris from the pump, but not clog with the ubiquitous vegetation.



a. Clean screen.



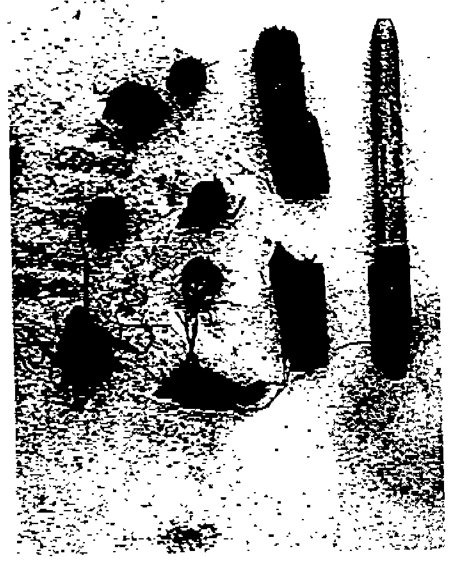
b. After about 20 minutes of operation.

Figure IV-6-10. Coarse screen inside boom box.

The solution is a cutter and grate system for the auger head. The vertical grates are attached to the front of the dredge head where the intake is located. A cutter bar, attached to the center of the auger, keeps the grates clear of vegetation by sweeping debris up the grates and cutting it at the top. A tapered transition section behind the grates smoothes the flow of water from a rectangular cross-sectional opening to a ø 15-cm hose adapter. Stiff tines are attached to the auger flights to augment maceration of vegetation prior to ingestion.

The original system was designed to function as a bolt-on system (Fig. IV-6-11). Operational usage of the system indicated that extended run-time was possible with the grates installed. However, some plugging of the grates was

a. Side view of grates with cutter.



b. Debris extracted from grates.

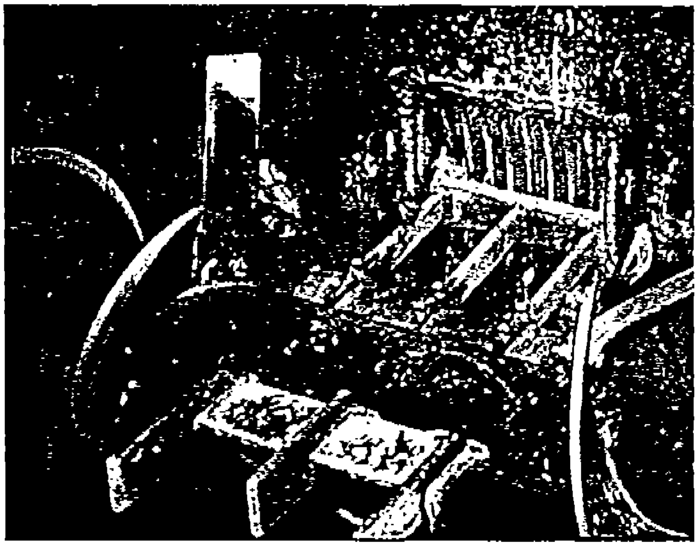
Figure IV-6-11. Original (Mk. I) cutter/grate system.

experienced. For the most part, the debris was confined to upper and lower 5 cm of the grates. The material lodging in the grates, shown in Figure IV-6-11b, consisted of small chunks of wood (boardwalk), hard vegetative nodules, and root masses. Some modification of the grates was done to reduce entrapment, but the cause of the plugging was the deflection of the grates.

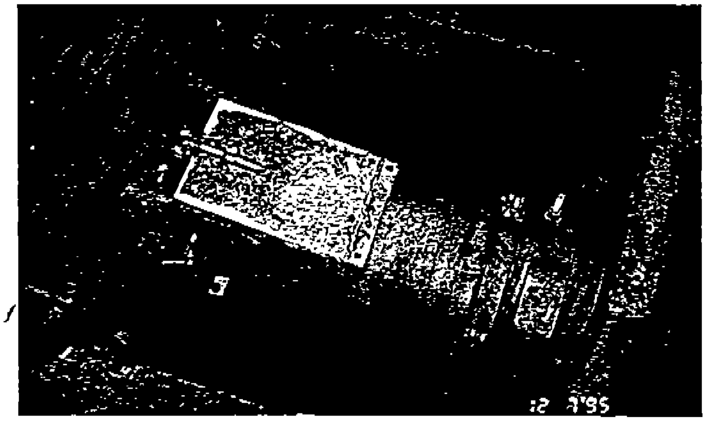
During the interval between the July and September deployments, an improved system was designed and fabricated. The grates were stiffened by using thicker stock for fabrication, 9.5 mm rather than 4.75 mm. The grates were machined in a T shape to allow slightly oversized debris to pass through the grates without jamming. An improved transition box was also designed to allow backflushing and manual cleaning of the rear of the grates. Finally, the grates were designed to fit flush with the front of the auger head shroud (Fig. IV-6-12).

Auger drive motor

With the stiff tines and cutter adding to the torsional resistance of the auger, a new, higher-torque motor was needed. A new hydraulic drive motor with twice



a. Cutter and grates. Note vertical stiff tine.



b. Top view of transition box showing manual cleanout.

Figure IV-6-12. Mk. II Cutter/grate system.

the torque and half the speed of the original was installed. In the process, the hoses had to be replaced due to abrasive wear. During dredging operations, the drive motor is forced through consolidated material as it extends beyond the augerhead shroud. This causes wear on the component as well as resistance to motion. It is recommended that, if possible, the drive motor be located behind the shroud and the auger driven with a chain link.

Deadmen

One problem we were not able to solve completely was the stabilization of the deadmen. Problems with the deadmen were discovered almost immediately last year during the initial work with the dredge. A second 2-ton block was placed next to the originals and cabled together in an unsuccessful attempt to stabilize the blocks. This spring, Danforth anchors were deployed to try to alleviate the problem. Initial deployments were unsuccessful, as the anchors did not bite deep enough into the vegetative root mat to hold. The flukes of the anchors were extended to increase the purchase, but they still performed inadequately. What was needed was an anchoring system that could extend below the root mat into consolidated material.

The initial solution was to employ screw anchors, similar to those used to tie down dogs. Screw anchors, 6 cm in diameter and modified to a length of 1.3 m, were installed after screening the area for UXOs with a magnetometer. The deadmen were then guyed to the anchors and dredging reinitiated. The anchors held but not satisfactorily. They were slowly pulled over or out, so another method was required. Several guy wire anchors, used in bracing telephone poles, were purchased. These have a 15-cm split-auger disk at the base, an eye at the top, and are 1.6 m long. Using the magnetometer, these were installed in place of the screw anchors. These proved more rugged, although some block movement still occurred, due to the stems of the anchors bending over towards the blocks. Although the system needs to be tuned, it should prove to be a viable solution.

DREDGING OPERATIONS

With the bugs finally worked out of the system, continuous dredging was now possible. Due to the large amount of trapped debris and the extensive root mats, vegetated areas were avoided and only open channels were addressed. The mouth of Clunie Creek and the area around Clunie Point were dredged to a depth of 0.8–1.0 m. Two channels were dredged into Area C adjacent to Canoe Point (Fig. IV-6-13). A total of 366 m of 20-cm hose and 340 m of 25-cm pipe were deployed during dredging operations. At the greatest extent of line, the dredge had no problems pumping the spoils into the Retention Basin.

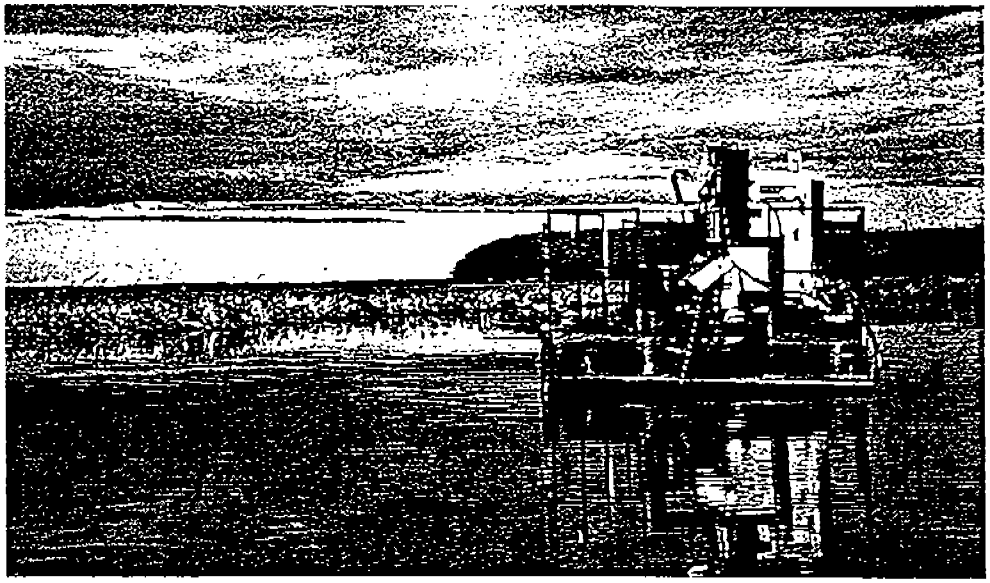


Figure IV-6-13. Dredging off Canoe Point.

During dredging operations, both sediment and water were sampled for analysis of white phosphorous. Sediment samples were taken from the spoils line near the berm. Consolidated composite sampling was used. Every 15 minutes, 4.2 L of spoils were directed into a 17-L bucket via a pitless adapter connection to the spoils,line. After four subsamples were obtained, the bucket was set aside to allow settling of the sediment. When the sediment had sufficiently settled, anywhere from two hours to two days, the supernatant was decanted. The sediments were then stirred and deposited in one or more 500-mL glass widemouth jars with a polyethylene 250-mL ladle. The sample was then labeled, sealed, stored in a cooler, and recorded in a field data book. The empty barrel was then rinsed and dried for later use. When necessary, samples were stored overnight in a locked refrigerator in a locked building on a locked, restricted compound on base. Samples were delivered to a local analysis laboratory under custody for analysis of white phosphorus.

Water samples were taken from the outlet pipe from the Basin drop inlet structure. One-liter grab samples were obtained at the end of each day that dredging and draining of the Basin occurred. Sampling handling and storage is the same for the water as the sediment, with the exception that water samples were analyzed as soon as possible.

The 1995 field season was a very wet one, especially later in the season. Many prolonged flooding tides, much rain, and flooding of the Eagle River resulted in a large influx of fresh water into the area being dredged. Salinities, historically in the 5- to 8-ppt range in Area C, were from 0.3 to 1.1 ppt this year. This resulted in a drastic decrease in settlement rates for the suspended solids in the Retention Basin. For flocculation to occur, salinities in the 3- to 5-ppt range are necessary. Attempts to decant water over the weir of the drop inlet structure resulted in the clogging of the silt fence and further accumulation of supernatant. To continue dredging, a limited amount of supernatant was allowed to pass beneath the fence. Samples were quickly analyzed to determine if the water was contaminated with WP. When no positive results were found among the first eight samples, the Basin was allowed to drain in the planned manner.

After several weeks of dredging, one contaminated water sample was found. To ensure that the white phosphorus was of a form that would not adversely affect the environment, total suspended solids (TSS) samples were taken for analysis for TSS and grain size. Further sampling of the decanted supernatant turned up no hits, so Basin draining was resumed.

RESULTS

During dredging operations, a total of 137 sediment samples, 23 water samples, four TSS samples, and one spoils line solids content and grain size analysis sample were taken and analyzed. Each of these data categories will be discussed below, as well as an analysis of the results, an estimate of material removed, and a cost estimate for removal.

Sample analysis for white phosphorus

The large number of sediment and water samples should give a reasonable indication of the contamination of each material. Table IV-6-8 is a summary of the data in Appendix IV-6-A on the sample analyses done for the dredging project. As can be seen from the table, about 19% of the sediment samples were hits. This is constant with the results of random sampling done by other researchers at the Flats. The range of concentrations for the sediment hits is low, indicative of non-particle hits. This may be due to the sampling technique. The sample port is perpendicular to the flow of the spoils, and thus larger grains and particles may not be drawn through the port. Grinding and mixing of the particles over the 720-m length of the spoils line may also have an effect.

Table IV-6-8. Results of dredge sample chemical analyses.

	Soil (spoils)	*Water (supernatant)*	*Total*
Number of samples	137	23	160
WP hits	26	1	27
% hits	19%	4%	17%
Range (μg/kg)	0.22–66.00	-	-
Average (μg/kg)	6.16	4	-

The water hit is somewhat suspect, although the lab spokesman said that when they got the hit, they reran the sample with the same results. He also stated that the calibration curve done that morning was not atypical. The hit may be attributable to sediments in the Basin stirred up during lowering of the weir. In any case, it is a singular hit that is not of great magnitude.

Total suspended solids

Due to the slow settling of the solids suspended in the water column, supernatant decanted over the weir and out the Basin was not of the quality originally anticipated. For this reason, four samples were taken from the Basin outlet pipe for TSS analysis. Table IV-6-9 shows the results of these analyses. For comparison, normal TSS at ERF is 10–20 mg/L, and TSS during flooding events is 1000–3000 mg/L (Bigl 1995).

Table IV-6-9. Total suspended solids analysis.

Sample	*TSS (mg/L)*
15 Sept. 1995	215
16 Sept. 1995	1595
19 Sept. 1995	611
20 Sept.1995	850

From these data, it is clear that the supernatant exiting into Area C is not degrading the water quality of the Flats. It should also be noted that the area in which the Basin is draining is heavily vegetated, and thus the solids should drop out more efficiently due to slower moving water. More importantly, any trace WP in the stream should quickly sorb to the organic matter in the area.

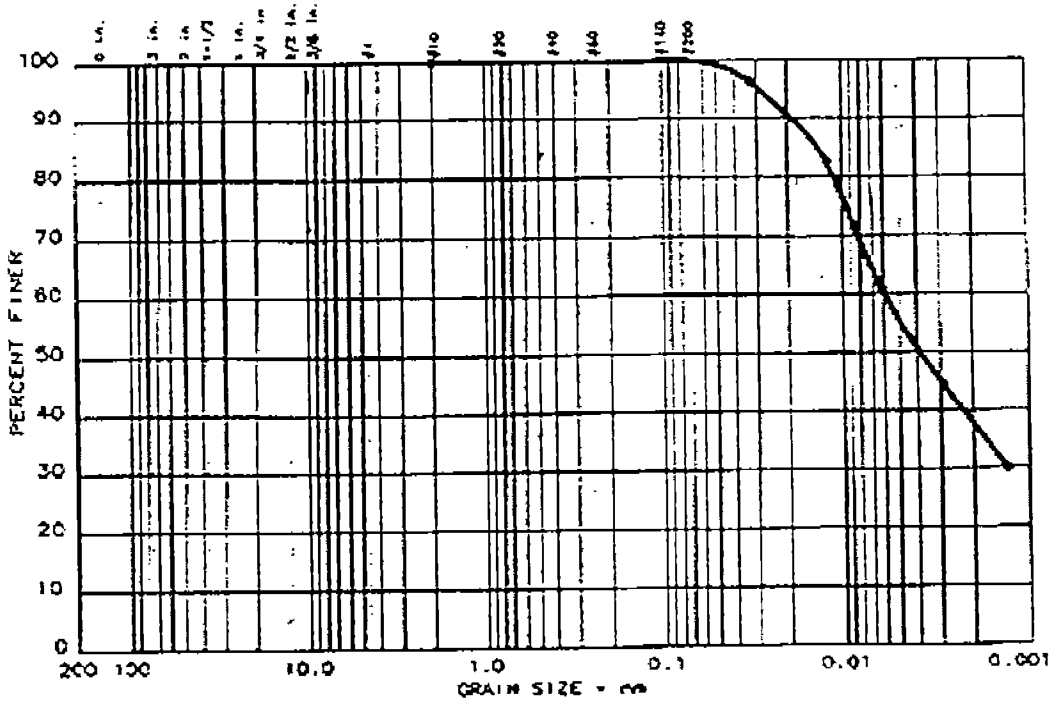


Figure IV-6-14. Graph of grain size analysis for spoils sample.

Grain size analyses

Grain size analyses were done on two samples. The first was a spoils sample taken directly from the sampling port of the spoils line. The second was taken from a TSS sample of the Basin outlet runoff. Results of the analysis of the spoils line sample are shown in Table IV-6-10. These results include percent solids and salinity. Grain size is also graphed in Figure IV-6-14.

Table IV-6-10. Grain size analysis: Spoils sample.

Diameter (mm)	*Percent finer*
0.0327	96.3
0.0208	90.9
0.0122	82.6
0.0087	71.8
0.0061	60.9
0.0029	44.3
0.0013	30

The spoils sample was taken from the spoils line on 27 July 1995. Volume was 500 mL, and total weight, including the container, was 769.321 g. The weight of the dry soil and container was 319.42 g, and the weight of the container is 301.03 g, leaving a weight for the soil of 18.2 g and a weight of the soil and water of 468.01 g. The percent solids is 3.8 %, and salinity was 1.1 ppt.

The one TSS sample that was examined for grain size was check against only the #200 sieve (0.075 mm particle diameter). Only 1% of the sample was retained.

Other sieve sizes were not checked due to the small volume of the sample and the small particle sizes. We were most concerned with particles greater than 0.1 mm diameter, as those are most lethal to some waterfowl at ERF (Walsh 1994).

Estimated contaminant removal

The volume of material removed from ERF is difficult to estimate due to the disturbance of UXOs in the dredged area. An estimate can be made by surveying the dried sediment in the Retention Basin, but the material was saturated at the time we departed. A rough estimate can be obtained from observations of the quantity of sediment in the Basin. At the cessation of dredging activities in late September, the quantity of material in the Basin would fill about one third of the area to the 60-cm level. This is equivalent to about 1650 m^3. Material was removed to a depth of 75–100 cm from the water level at the time of dredging.

From this quantity and the results of the sediment sampling analysis, a rough estimate of the WP mass transfer can be made. Calculations follow:

Total solids removed:	1650 m^3
Avg. sample (hit) concentration:	6.16 µg/kg (6.16 ppb)
Percent spoils hits:	19%
Possible quantity of contaminated spoils:	$0.19 \times 1650 = 313.5$ m^3
Mass transfer of WP:	$= 313.5 \times 6.16 \times 10^{-6} = 2$ cm^3
	$2 \times 1.82 \times 10^3 = 3600$ mg.

To put this number in perspective, it should be considered in terms of lethal doses. Using estimates based on Reitsma and Steele (1995) and toxic dose levels based on Sparling et al. (1995), Table IV-6-11 was constructed.

Table IV-6-11. Contaminant removed as a function of lethal doses.

Species	*Lethal dose (mg)**	*Single species mortality*	*Mortality observed (%)*	*Multi-species mortality*
Teal	1.5	2400	26	624
Mallard	4	900	37	333
Pintail	3	1200	37	444
Total		900–2400	100	1401

The quantity of white phosphorous transferred from the Flats to the Basin given here is conservative due to the sampling apparatus. The pitless adapter used to sample the spoils stream was located near the wall of the line and sampled perpendicular to the flow. Next year, an elbow will be installed to better sample from the middle of the spoils line.

Economic analysis

An accurate estimate of cost per cubic meter of removal is still not possible. However, a rough estimate will be attempted based on experience gained with the system over the last year. Set-up requires about five days with a crew of four and some heavy equipment, such as a crane (≈8 hours at $130/hr), a fork lift (two days at $85/hr), and a flat-bed truck (2 days at $65/hr). Retrograde would require about half the effort. A helicopter (UH-1H "Huey") is also needed for about four hours to deploy and retrograde the lateral winches. If deadmen need to be set, helicopter time (UH-60 Blackhawk) must be scheduled. Current helicopter costs are $600 hr for the Huey and $2600/hr for the Blackhawk. A minimum of four people are required/for operations due to sampling and safety considerations.

A rough, maximum sustainable production rate based on our experience at the end of the 1995 season would be 500 square meters per day at a depth of 1 m (water and sediment), based on a 10-hour day and about 60% run time. Actual transfer of sediment would be much lower, on the order of about 50% of this volume (due to "overburden" of water and overlap of dredging passes). Dredging would occur four days per week, and one day per week would be devoted to maintenance and positioning of the dredge. Drainage of the Retention Basin would occur on off days. Estimated dredging time for a 0.4-ha site would be about 10 days. Table IV-6-12 gives a breakdown of estimated costs for a 0.4-ha (1-acre) area cleaned to a depth of about 1 m. Around two weeks will be required for actual dredging operations for this area. Labor costs are based on 10-hour days and six-day weeks. A 30% pay premium is added for Alaska employees, and a 25% hazardous duty premium is added to that for working in an active artillery impact area. An estimate of the cost of an additional 0.4 ha is included in the table.

Table IV-6-12. Economic analysis of a 0.4-ha dredging operation.

	Cost ($)						
		Heavy equipment			*Helicopter support*		*Sample*
Operation	*Labor*	*Crane*	*Forks*	*Flatbed*	*Huey*	*Blackhawk*	*analysis*
Set-up	6,485	1,040	1,360	1,040	2,400	-	-
Dredging*	10,514	-	-	-	2,400	-	-
Sampling†	11,774	-	-	-	-	-	5,805
Retrograde	3,242	1,040	1,360	1,040	2,400	-	-
Deadmen**	1,857	-	-	-	-	10,400	-
Subtotals	33,873	2,080	2,720	2,080	7,200	10,400	5,805
Total per 0.4 ha, one deadmen set-up:			64,158				
Additional 0.4 ha:			30,494				

*Labor rate based on a WG-11/5 with a 30% AK differential and a 25% haz. duty premium.
†Labor rate based on a GS-13/5 with a 30% AK differential and a 25% haz. duty premium.
**Crew of four, 4 hours.

Other factors or scenarios not presented here will affect the economics of this strategy. The greatest is the lease cost of the dredge. This currently stands at $180,000 per year (1 August to 31 July). Whether the work is done by CRREL or an outside contractor, this cost will have to be factored in. Heavy equipment support may not be factored in if it is done by the Ft. Richardson DPW. The number of deadmen required will also greatly affect cost due to the expense of the Blackhawks. For a 0.8-ha area, the cost can vary from $215,000 to $240,000, depending on the need of helicopter time, personnel and heavy equipment.

If the equipment is to be used much further from the Retention Basin, provision must be made for booster pumps. If a different area needs to be dredged, helicopter transport of the equipment must be investigated, as well as the possibility of constructing an additional retention basin.

DISCUSSION

With the correction of the equipment problems and the addition of some specialized components, the dredge proved a capable remediation tool. Removal rates were not as high as originally anticipated due to the inability of the equipment to cope with the very tough vegetation found in the area dredged. Once operational experience was gained, consistent dredging action was achievable (Fig. IV-6-15).

Figure IV-6-15. Pumping mud into the retention basin.

The removal of white phosphorus from Eagle River Flats through dredging is an expensive, time-consuming proposition but is quite effective in areas that cannot be treated otherwise. The pathway to ingestion is broken in two ways through dredging. First, contaminated material is being removed and treated away from normal feeding areas. Second, the distance between the water surface and the pond bottom is increased so that most waterfowl cannot reach bottom. The only species that may be problematic as dabblers are the swans. Some waterfowl (widgeon) and shorebird (yellowlegs) use of the Retention Basin occurred during dredging operations, but no mortality was observed or recorded. Indicators of other nonavian species, such as bear, coyote and moose, also were observed within the bounds of the Basin with no adverse effects.

Further work needs to be done on groundwater effects of the Basin on the EOD Pad. Wells are in place for this. The natural remediation aspect of the Basin system also needs to be completed. This was started this fall, but too late to get any meaningful data.

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IV-7. DEVELOPMENT OF A REMOTELY CONTROLLED DRILLING AND SAMPLING SYSTEM FOR REMEDIATION PROGRAM AT EAGLE RIVER FLATS

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INTRODUCTION

Continuing investigations into the fate and persistence of white phosphorus (WP) at Eagle River Flats indicate that although some natural attenuation is occurring in areas where intermittent drying takes place, areas where insufficient drying or warming occur continue to contain lethal quantities of readily available WP (Walsh 1995). Several remediation strategies for these persistent areas were initiated in the 1994 and 1995 field seasons, covering a range of methodologies, including covering contaminated areas (Pochop), designing equipment for the draining of large contiguous ponds (Collins), enhancing natural attenuation (M.E. Walsh) and dredging (M.R. Walsh) (Racine and Cate 1995).

The goal of this project was to develop, build, test and deploy a remotely operated drilling/coring platform for use in the Flats to assist in the study of efficiencies for the remediation investigations scheduled for FY 95 at the Flats. In addition, installation of water-level monitoring wells in the Explosive Ordnance Disposal (EOD) Pad was lumped into this work unit. The development of the piezometer well-drilling platform will be covered first, followed by discussion of the EOD Pad well installation and progress on the coring drill platform.

BACKGROUND

A market survey, including visits to manufacturers, was conducted and capabilities of various equipment configurations discussed. Additional discussions were held with drilling experts at the US Army Corps of Engineer's Cold Regions Research and Engineering Laboratory (CRREL) in NH and Alaska. From these discussions, a set of specifications was developed (Appendix IV-7-A) and bid requests sent out through the Ft. Richardson contracting office for a small, lightweight mobile drill.

Concurrent with this contracting effort, the U.S. Army Tank-Automotive Research Development and Engineering Center (TARDERC), located at the same facility as the Tank-Automotive and Armaments Command (TACOM) in Warren, MI, was tasked to develop, build and test a remote-control system for a vehicle similar to the carriers used with the drilling systems reviewed. A 6×6 vehicle was available for this purpose and sent to TARDEC as a test bed. Specifications for a remote camera system were also developed and a system ordered.

Contracting delays resulted in the awarding of the contract for the drill equipment on 22 July, with an early September delivery date. This precluded any meaningful work at the Flats for the 1995 season, but through a superb effort by TARDEC, we were able to deliver a working, tested system to the Flats on the 28th of September.

EQUIPMENT

Drill unit

The drill unit chosen for modification and use at the Flats is a Checkwell Model M660 vibratory drilling machine (Checkpoint Environmental, Inc., Hudson, MA). This unit is based on a Polaris 400 6 × 6 all-terrain vehicle, with low-ground-pressure tires (Fig. IV-7-1). This unit is capable of driving 6-m sections of

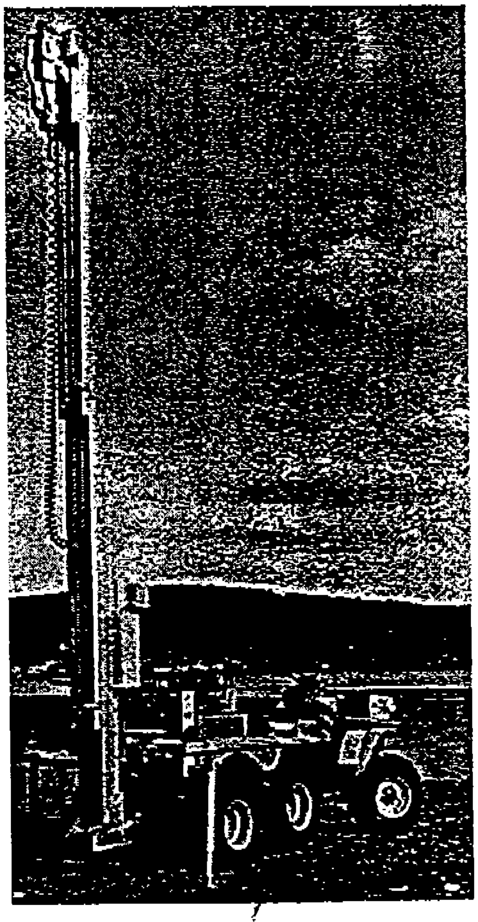

Figure IV-7-1. Checkwell Explorer II mobile drill.

1.5-cm ø steel piezometer tubing in fine gravel and compacted soil. It is not designed for nor intended for use on the unsorted gravel of the EOD Pad.

The drill unit was tested at both the manufacturer's facility prior to acceptance and at TARDEC after integration of the remote-control package. In both cases, the drill performed well, demonstrating sufficient capacity for operations at the Flats. In both cases, piezometer tubes were driven into the ground. The soil at the manufacturer's facility consisted of fine sand and clay, whereas at TARDEC, the soil was compacted clay only. No testing was done with the 47-mm coring drills at this time, due to the differences in soils.

Delivery of the drill to CRREL was made on 30 August. On 1 September, it was shipped to TACOM for remote control and remote camera integration. On 13 September, the integrated unit was shipped to Ft. Richardson. The drill unit arrived at Elmendorf AFB on 25 September and was delivered to Ft. Richardson. A two-day delay was caused by the crash of the AWACS plane on 22 September. The drill was fully operational by 27 September. Due to the closure of the 1995 field season and safety issues related to the destruction of the Rt. Bravo access bridge on the 21st, the drill was not deployed into the Flats for further testing.

Camera system

The camera system purchased for the drill rig is a radio-frequency remote control-camera system from EMCO INTERTEST, Inc., of Flanders, MA. Major components include a high-resolution zoom black-and-white camera mounted in an environmental housing attached to a pan and tilt unit (Fig. IV-7-2), a heads-up display unit for the operator, and a hand-held radio transmitter for the camera controls. These units are powered by 12 V DC from the vehicle auxiliary plug on board the drill as well as a battery pack for the operator's vision system.

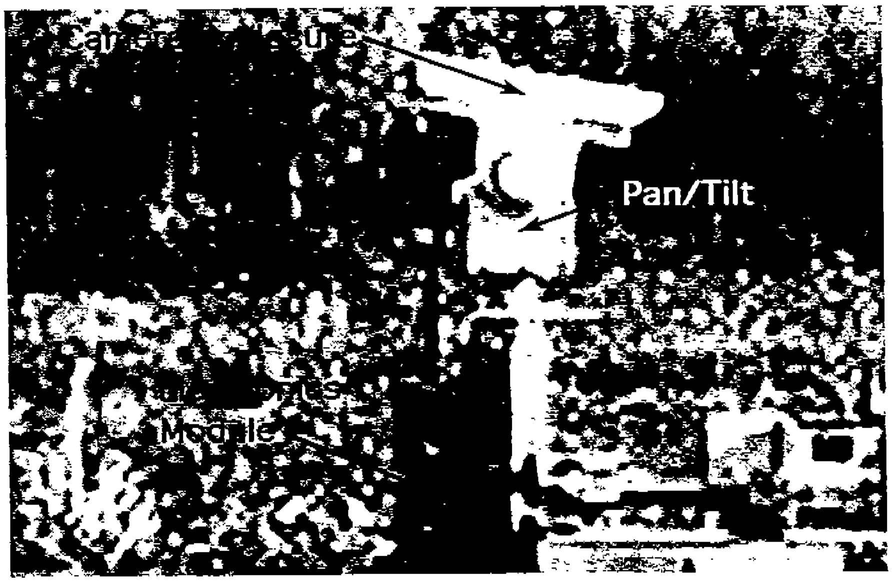

Figure IV-7-2. Remote camera mounted on drill.

The image is quite sharp and very clear, but the controls will need some practice. There are some problems with the frequencies the equipment operates on. The video link, at 2460.0 MHz, had to be verified for bandwidth and field strength, both of which were acceptable. The 150-MHz frequency of the pan-tilt-zoom control link was not cleared and could not be at the Flats. This frequency was changed to 162.8125 MHz at CRREL prior to shipment to TACOM. Paperwork is currently in process to obtain approval for this frequency from Ft. Richardson.

There are two other minor problems with the equipment which can be easily solved. The first occurred at the Flats during testing on the EOD Pad. The video signal began cutting in and out after about a half hour of testing, finally stopping altogether. This was traced to the keyed power switch. Replacing this switch should solve the immediate problem. A better vibration mount system for the camera system electronics will remedy the cause of the problem, excessive shaking of the electronics module. The second problem is accessibility to the frequency tuning controls for the pan-tilt-zoom controller, which is nothing more than a hand-held amateur radio. The radio is easily reprogrammed through the keypad. This requires resetting the receiver inside the electronics module, which is a simple task. To circumvent this problem, the transmitter can be programmed to operate on a single frequency. When approval for the 162.8125 MHz frequency is granted, it will be program in as the sole accessible frequency.

The camera system is designed to be portable, in case other uses should arise. Current plans include use on a converted M501-E3 Hawk missile transporter, which is in the process of being retrofitted as a remote-control drilling platform. The ability to operate on 12 V DC power enables this system to be used as a remote surveillance device as well, such as in the case of observing and recording scavenging activity at the Flats. The zoom and pan and tilt features are especially useful in this respect.

Remote control

The remote-control package was designed and built by TARDEC to CRREL specifications. This equipment is designed such that the drill can be driven either remotely or manually. Conversion is through the removal of three pins. Removing the entire remote-control package for use on a second drill requires less than two hours, and fitting to another unit about the same after initial installation modifications have been incorporated.

To better balance the drill during remote traverses, the 120 V AC generator on the drill unit has been moved from the midsection of the vehicle to an overhanging shelf on the front. This helps compensate for the absence of a driver as well. Removal of the generator and remounting to the original position again requires the removal and insertion of a few pins. Power for the actuators and receiver are taken from the vehicle's 12-V battery. This is somewhat problematic at present due to the low charging rate of the battery at low vehicle speeds. We are currently considering mounting a battery charger on the vehicle which would utilize the 120 V AC generator for charging the battery.

Control of the remote mobility package is affected through a multi-function hand-held model-airplane remote controller (Fig. IV-7-3). This is an off-the-shelf controller which interfaces with the TACOM-designed receiver package mounted on the front of the drill vehicle. In addition to driving the mobility package, the controller activates some of the drilling functions, enabling un-tethered remote operation of those functions. Servos within the receiver package drive the actuators and activate the switches which enable the functions listed in Table IV-7-1. The controller is battery powered and requires no external power supply.

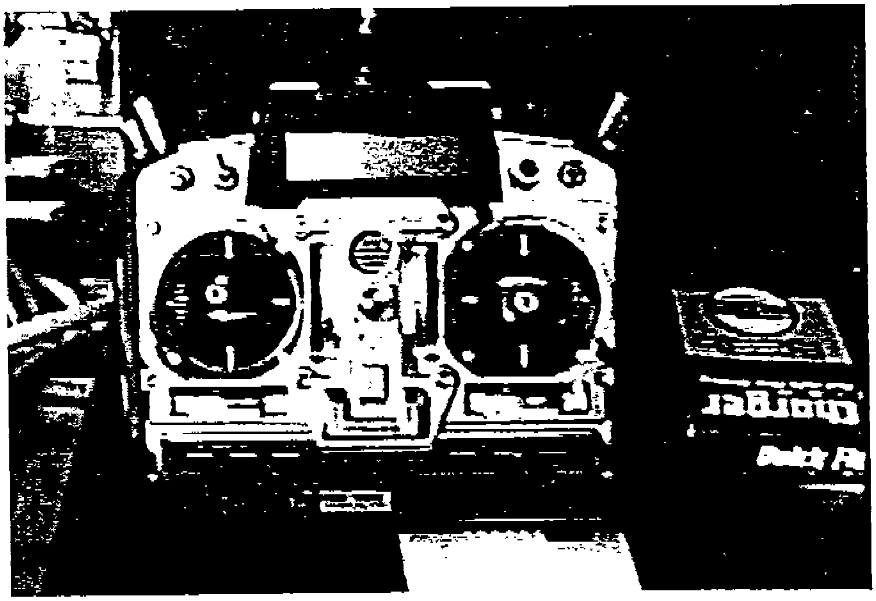

Figure IV-7-3. Drill mobility package remote controller.

Table IV-7-1. Remote control functions.

Equipment attribute	*Actuator type*	*Actuator function*	*Null (center) position*
Engine	Switch/solenoid	Engine on / off	Actuator off
Throttle	Rotary actuator	Engine speed control	Idle
Brake	Linear actuator	Activate/release brake	Parking brake
Steering	Linear actuator	Left / right steering	Straight
Shifting	Linear actuator	Forward (High) / reverse	Hold position
Mast Ass'y	Switch	Shuttle actuator left / right	Hold position
Mast / Drill	Switch	Up / down (Speed preset)	Hold position
Drill	Switch	On / off	Actuator off

SYSTEM CAPABILITIES

The remote-control drill is intended primarily for use in placing piezometer tubes at test sites. These tubes are 15.77-mm ID steel or aluminum tubes with well screens at the base. Lengths of the aluminum well tubes fabricated at CRREL vary from an overall length of 1.8 to 2.2 m, with subsurface lengths of 0.8–1.2 m. Druck PDCR 35/D depth transducers will easily fit inside. Wells can actually be any length up to 38 m, in 6-m sections. Placement of the wells in fine gravel or clay was quick, with a 6-m well installed in sand in less than 5 minutes. Placement of the wells in the fine, unconsolidated sediments of the Flats should be quite fast.

The static downforce of the drill is 3.4 KN. With the rotary hammer running, the drill is capable of much higher forces. A hydraulic puller capable of 16 KN pulling force is available with the drill, but it is not recommended that it be used due to the presence of UXOs. The drills capacity for coring is unknown at this time, although 50-cm cores have been obtained at the Flats using about 800 N of force. Before any coring or drilling is conducted, a sweep of the area with a magnetometer is recommended.

The vehicle is mounted on low-ground-pressure tires (34.5 kPa/5 psi) and has a 30-cm operating depth (Fig. IV-7-4). It should be capable of going most anywhere needed, within reason. Due to uneven weight distribution and hard rear axles, steering on the vehicle is not very responsive, so mapping out a route with the least amount of sharp corners is recommended. Climbing ability is good on dry

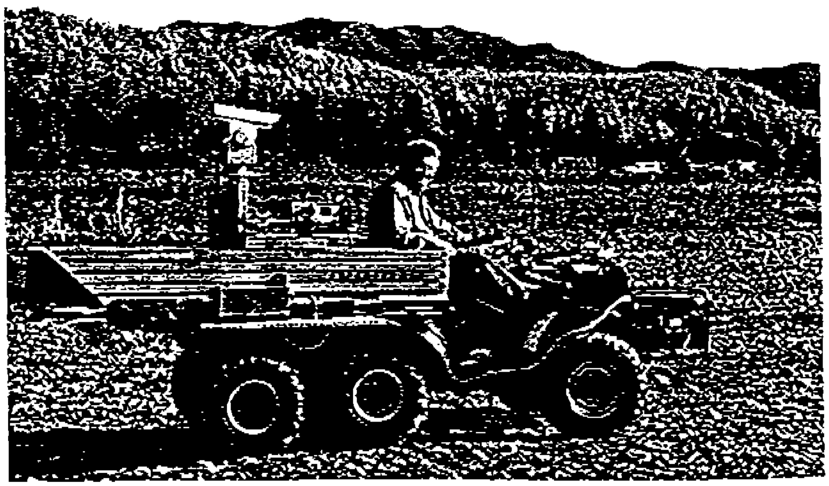

Figure IV-7-4. Drill unit on EOD Pad.

land but may be a problem in wet Flats sediments, especially near gullies. A winch has been purchased for the vehicle but has yet to be installed. Remote operation has been tested out to 350 m without any degradation of the video image or the response of the vehicle to remote-control commands.

DOCUMENTATION

All documentation for the drill and its components has been delivered to the Ft. Richardson Directorate of Public Works-Environmental. In addition, a short tape has been produced by TARDEC on the operation of the remote mobility/drill package. A more consolidated comprehensive operator's manual is being assembled at CRREL.

RELATED PROJECTS

Two additional projects were grouped with the piezometer drill. These were drilling of depth transducer wells on the EOD Pad and investigations of possible alternative platforms for winter sediment coring. These projects will be discussed separately below.

EOD Pad wells

To determine the effect of utilizing the dredge spoils Retention Basin on the hydrology of the EOD Pad, a series of drilled wells were planned for installation prior to commencement of dredging in May. Due to the extremely coarse nature of the unsorted gravel of the EOD Pad, we determined that the piezometer tube drill would not be appropriate for the task and that contracting out the drilling of the wells would be the most economical strategy. To expedite the contract, the number of wells were reduced from 10–12 to seven. Contracting delays of many months resulted in the award of the drilling contract in late September. The well planned for the center of the Retention Basin had to be scratched due to the presence of spoils and water in the Basin.

The wells were drilled from the 26th to the 29th of September by Denali Drilling of Anchorage, a subcontractor for ChemTrack Services Group, also of Anchorage (Fig. IV-7-5). The wells were drilled using a 6-in. (152-mm) auger with a 3.25-in. (83-mm) hollow stem. The monitoring wells consist of 1.5 m of 20-slot ISO 9002 52.3-mm (2-in.) PVC pipe with 4.5 ms of PVC riser pipe above. Screen slot width is 0.5 mm. Open area per meter is 118.5 cm^2 (5.6 $in^2/ft.$). Joints are composed of ASTM F480 well thread and Buna-N O-rings. Pipe sections are cleaned to remove grease, oils and other contaminating substances and are individually shrink wrapped and sealed at the factory. The pipe is manufactured by Johnson Screens, a division of Wheelabrator Engineered Systems, Inc. All drilling took place from the armored control cab used in the dredging program to ensure operator safety. The buddy system and radio communications were also in effect. More information can be found in Appendix IV-7-B.

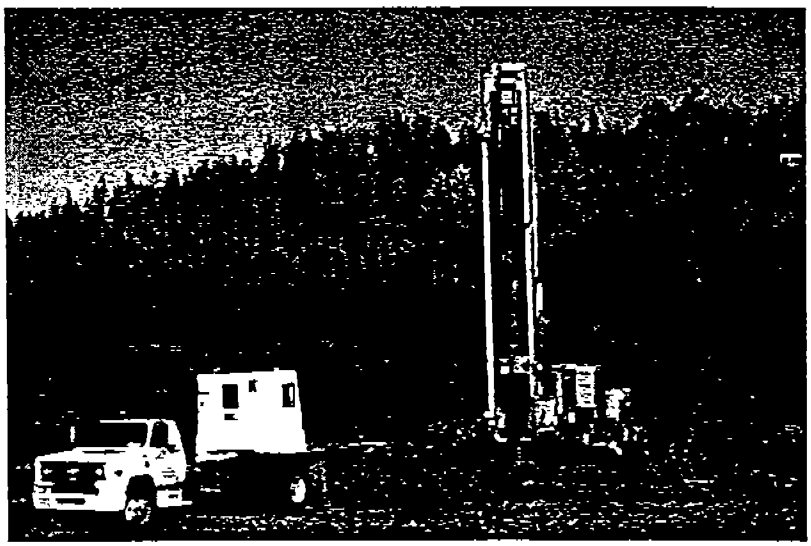

Figure IV-7-5. Drilling on EOD Pad. Note armored control cab.

All but one well penetrated to water according to the drillers. A typical well log is shown in Table IV-7-2. The wells are packed in 8/12 mesh (2.3/1.7 mm) sand. The well screens are completely within the clay layer. Complete sandpacks

Table IV-7-2. Typical drill log.

Depth (m)	Material
0 to 1.8	Sand and unsorted gravel
1.8 to 3.4	Hard, dry clay with fine gravel mix
3.4 to 4.3	Silty clay with sand
4.3 to 6.1	Wet gray clay

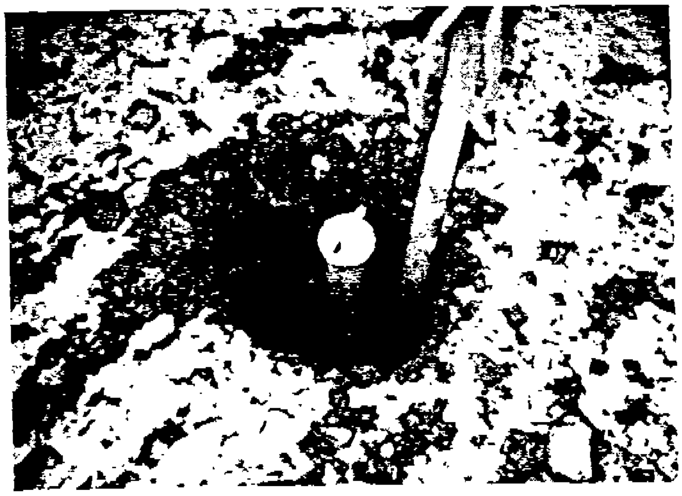

Figure IV-7-6. EOD Pad well - 12/95 (center of pad).

and seals were not installed on the wells at the time of drilling or pulling of the auger due to the danger posed by buried UXOs. Natural (in-situ) materials were used. A concrete annular seal is planned for the spring. The well tops have locking caps but don't extend above grade and are unprotected (Fig. IV-7-6). This will be rectified in the spring when the weather warms. Surveys of the well locations will also be done at that time.

Dataloggers and depth sensors are already in hand for monitoring the water level in each of the wells. If sampling is to take place with these wells, some sampling equipment is currently in hand, but most equipment will need to be borrowed or purchased. As there are many other sampling wells in place at Ft. Richardson, it is suggested that these wells be included as part of the regular sampling routine for the base. Before any samples are taken, however, the well will need to be developed.

Coring platform

Discussions on the feasibility of coring in areas where dredging has occurred indicate that, due to water depth in dredged areas, sampling will have to be conducted during winter when the water above the dredged areas is frozen sufficiently to support the weight of the drilling equipment. Sampling in other areas inaccessible to the current drill platform can also be conducted during that time. The problem lies in the ability of the piezometer drill to penetrate ice and frozen soil to obtain core samples. Some coring was budgeted for this winter, but inspection of the Flats in areas to be sampled indicated thick (≈ 1 m) ice. The fall and early winter were cold with very little snow cover, resulting in a hard freeze. At the end of January, over 3 m of frost penetration was reported in parts of the Anchorage region.

A much heavier and more stable platform is obviously needed for winter coring operations. In discussing this matter with the TARDEC team working on the remote control package for the piezometer drill, they volunteered to check the Army tracked-vehicle excess inventory to see what was available. The vehicle in inventory that best fits our needs is the M501-E3 HAWK Guided Missile Loader-Transporter (Fig. IV-7-7). The excessed M501-E3s are available without charge from the Letterkenny Army Depot in Chambersburg, PA. A representative from TARDEC (John Schmidt) and CRREL (M.R. Walsh) visited the depot in November and selected eight vehicles for use with the project. Of these eight, three are in reasonable condition and will be brought up to operating condition. The remainder are to be used for parts. New power packs were located in inventory, and the vehicles and powerpacks shipped to TACOM for the initial work under a MIPR order from CRREL. Total cost for these vehicles, including power packs, was $2000.

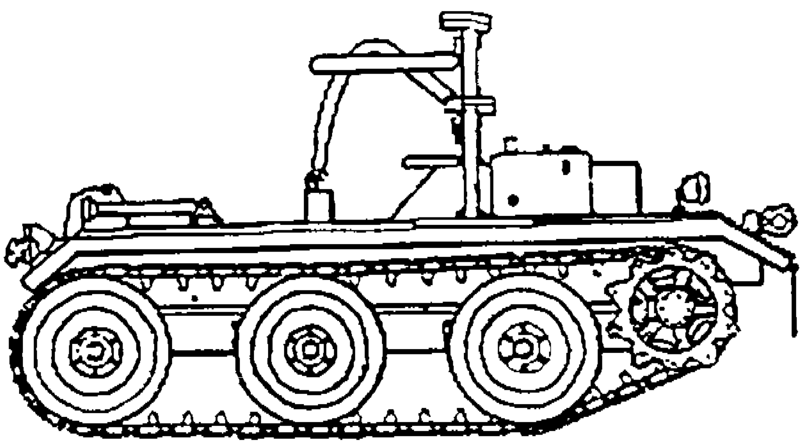

Figure IV-7-7. M501E3 without missile loader.

The weight of the vehicle with the remote control package and drill assembly is predicted to be around 2300 kg. At that weight, the ground pressure will be 34.2 kPa (5 psi). For reference, the average person exerts about 25 kPa (3.5 psi) of ground force. Cleats are available for the track links, and modified cleats may be installed. An additional 2.5-cm overhang on both sides of each link would lower ground pressure to a little over 25 kPa. The vehicle is powered by a gasoline engine and contains a 20-MPa (3000-psi) hydraulic system. Top speed is 20 kph (12.7 mph).

The current plan is to use two of the operational units as testbeds, one at TARDEC and one at CRREL. These units will also be used as backup vehicles for the third operational unit, which will be the deployment vehicle on which all the retrofit systems will be mounted. At the time of this report, two units are operational and design work has begun on the remote mobility package. When the mobility package is completed, the remote-control vehicle as well as a second operational unit will be shipped to CRREL for design and integration of the coring assembly. Funding expires at the end of June, by which time the vehicle should be close to complete. Deployment is not scheduled until next fiscal year due to a funding shortage for remediation work at the Flats.

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APPENDIX IV-7-A. DRAFT TECHNICAL SPECIFICATIONS FOR WELL DRILLING EQUIPMENT

I. Mobile drill rig (External vendor)

Carrier

- Weight: Less than 680 kg (1500 lb).
- On-board power: 12 V DC and 120 V AC power available from on-board generator.
- Automatic transmission (forward / reverse).
- Lifting points for crane or helicopter.
- Weight should be as evenly distributed on each axle as possible in the overland driving mode.
- LGP tires (35 kPa / 5 psi).
- 4- or 6-wheel drive.

Drill rig

- Self-contained unit:
  - Able to remove from carrier without major disassembly;
  - Power sources to be easily disconnected through plugs/quick disconnects.
- Lateral mast shuttle (≈ 1 m total. Left/right shuttle).
- Remote control drill and shuttle:
  - Emergency stop;
  - Drill down/up;
  - Drill head start/stop;
  - Pipe grip/ungrip (if used);
  - Mast shuttle right/left (set up on center position manually);
  - Operate from a distance of 50 m (150 ft):
    - Remote control can be via telemetry or tethered controls;
    - Functions may be programmed (except E-stop);
- Removable drilling head unit.

Vibratory drilling unit.

Drill pipe driver down force:

3.34 kN max. (750 lbf);

Adjustable.

No pulling capability required.

Environment

Will be operating in an estuarine salt marsh.

Vegetation will be present: grasses /bulrushes.

Must be capable of operations in up to 0.3 m (1 foot) of water.

Must be mobile in muddy terrain.

Must be all-wheel drive, preferably based on a small 6x6 vehicle.

Operating temperatures: -2° to 27°C (28° to 80°F).

<u>II. Wells</u> (CRREL)

Well size: 5/8 in. ID.

Well depths: 0.8–2 m.

Well freeboard: 1 m.

Total well pipe length: 3 m max. (one piece).

Screen length: 10 cm.

Placement: three-well side-by-side arrays.

Pipe size: 1/2-in. or 3/4-in. Sched. 40 pipe.

No welded or crimped pipe joints.

Options for pipe materials:

Stainless steel

Aluminum

Iron/steel

Number of wells and lengths

(20) 0.8-m wells (71 in. total length, 32 in. below grade)

(20) 1.0-m wells (78 in. total length, 39 in. below grade)

(20) 1.2-m wells (86 in. total length, 47 in. below grade)

III. Camera system (Outside vendor)

All systems 12 V DC.

Black-and-white 1/2-in. CCD system w/remote zoom capability and controls.

Distance of focus: 8 ft to infinity.

Camera system weatherproof.

3-ft tripod for camera / pan and tilt unit.

Remote 12 V DC pan and tilt head w/ controls.

Telemetry controlled. Max. distance: 1200 ft (line of sight).

Monitor or LED-type screen.

Environment: This equipment is to be used in the field to assist in several functions, including observing water sampling well installation, coring operations, and remote operation of a vehicle in an active firing range in Alaska. It needs to be small, portable and easily adapted to several configurations.

IV. Remote mobility package (TACOM)

Line-of-sight operation

12 V DC operation

Mobility

Automation of the automatic shift (Forward/Neutral/Reverse) lever

Throttle automation

Braking automation

Steering automation

E-stop automation

Drill

Mast shuttle left/right

Drill up/down

Drill on/off.

APPENDIX IV-7-B. EOD PAD MONITORING WELLS

The EOD Pad monitoring wells were installed under contract at the end of September. Due to the lateness of the season, the installation of these seven wells was not complete. In addition, safety regulations prohibited normal drilling procedures to be carried out, and thus the wells are not installed in the strict manner normally required for sampling wells. The presence of buried unexploded ordnance required that the drill operators be a minimum of 30 m from the drill rig during drilling and pulling operations. Therefore, well logging is approximate and packing of the well is not typical. The wells were installed as closely to the suggestions of EMCON (1993) as practical.

The following pages contain information derived during the process of installing the wells as well as comparative information from Smith (1980). The first table (Table IV-7-B1) contains general information about the wells, while Table IV-7-B2 is the well stratigraphy information, including a typical log from Smith. Two figures from Smith are also included for reference. The first, Figure IV-7-B1, is a typical grain size analysis performed on the top 2 m of the borings done at that time. The second, Figure IV-7-B-2, is a graph of moisture contents of complete borings (≈ 3m). These moisture profiles were done in both the winter and summer. It is interesting to note that at a depth of about 1 m, soil moisture drops to less than 4%. This is indicative of low percolation to groundwater, located at a depth of approximately 4.5 m.

When funding becomes available, the installed wells will be surveyed, a surface seal and steel monument installed, and water depths measured. Instrumentation will then be installed to measure water level fluctuations. Well development and sampling can also be initiated at this time. These wells can either be used in a preliminary evaluation of the EOD Pad groundwater contamination profile or as part of a more expanded effort.

Table IV-7-B1. Monitoring well general information.

Date drilled: 9/26-9/28/95	Drilled for: ERF Project
Name of driller: Joe Wininger	PI: M.R. Walsh
Company: Denali Drilling, Anchorage, AK	
Type of drill:	Hollow stem auger (150 mm OD/83 mm ID)
Wells	
Well material:	Riser: 2" Sched. 40 Polyvinyl Chloride (PVC) Slotted pipe: 2" Sched. 40 PVC 20-Slot
Well material treatment:	Factory degreased, cleaned, and shrink-wrapped
Well O.D.:	60.5 mm (2.38")
Well I.D.:	52.3 mm (2.06")
Joint type:	ASTM F480 w/ Buna-N O-Ring seals
Riser length:	1.52 m
Slot size:	20 Slot (0.5 mm)
Open area:	118 cm^2/m
Manufacturer:	Johnson Screens/Wheelabrator Engineered Systems, Inc.
Well construction	
Riser length:	4.6 m (Typ.)
Slotted length:	1.5 m (Typ.)
Caps:	Locking caps installed
Well backfill:	Native material (Sandy gravel/Silty sandy gravel)
Classification:	GM/GP (From Smith, 1980)
Sandpack:	8/12 mesh sand
Seal:	None at present
Monument:	None at present
Well development:	Not done
Observations:	No discolored ejecta No unusual odors No visible sheen on water Few metal fragments No detonations Stratigraphy similar on all wells
Well locations	
Well 1:	Center of Pad
Well 2:	Northeast corner of Pad
Well 3:	North edge of Pad at midpoint
Well 4:	Northwest corner of Pad behind basin berm
Well 5:	Southwest corner of Pad across road from basin berm
Well 6:	South edge of Pad at midpoint between road and edge of Pad
Well 7:	Northeast corner near entrance between road and edge of Pad

year during the initial work with the dredge. A second 2-ton block was placed next to the originals and cabled together in an unsuccessful attempt to stabilize the blocks. This spring, Danforth anchors were deployed to try to alleviate the problem. Initial deployments were unsuccessful, as the anchors did not bite deep enough into the vegetative root mat to hold. The flukes of the anchors were extended to increase the purchase, but they still performed inadequately. What was needed was an anchoring system that could extend below the root mat into consolidated material.

The initial solution was to employ screw anchors, similar to those used to tie down dogs. Screw anchors, 6 cm in diameter and modified to a length of 1.3 m, were installed after screening the area for UXOs with a magnetometer. The deadmen were then guyed to the anchors and dredging reinitiated. The anchors held but not satisfactorily. They were slowly pulled over or out, so another method was required. Several guy wire anchors, used in bracing telephone poles, were purchased. These have a 15-cm split-auger disk at the base, an eye at the top, and are 1.6 m long. Using the magnetometer, these were installed in place of the screw anchors. These proved more rugged, although some block movement still occurred, due to the stems of the anchors bending over towards the blocks. Although the system needs to be tuned, it should prove to be a viable solution.

DREDGING OPERATIONS

With the bugs finally worked out of the system, continuous dredging was now possible. Due to the large amount of trapped debris and the extensive root mats, vegetated areas were avoided and only open channels were addressed. The mouth of Clunie Creek and the area around Clunie Point were dredged to a depth of 0.8–1.0 m. Two channels were dredged into Area C adjacent to Canoe Point (Fig. IV-6-13). A total of 366 m of 20-cm hose and 340 m of 25-cm pipe were deployed during dredging operations. At the greatest extent of line, the dredge had no problems pumping the spoils into the Retention Basin.

Table IV-7-B2. Well stratigraphy.

Borehole Stratigraphy

Depth	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Smith*	Legend*
0 m-	Filled gravel:	Filled gravel:	Filled gravel:	Filled gravel:	Gravel:	Gravel:	Gravel:	Silty sandy gravel	GM
	Small gravel and	Small gravel and	Small gravel and	Small gravel and	Small gravel and	Small gravel and	Small gravel and	Silty sandy gravel	GM/GP
	sand. Some large	sand. Some large	sand. Some large	sand. Some large	sand. Some large	sand. Some large	sand. Some large		
1 m-	inclusions:	inclusions:	inclusions:	inclusions:	inclusions:	inclusions:	inclusions:	Sandy gravel	GP
	(20 cm)	(20 cm)	(20 cm)	(20 cm)	(20 cm)	(20 cm)	(20 cm)		
2 m-									
								Sandy gravel (D)	GP
		Silty sand	Silty sand	Silty sand				(20 cm max.)	
3 m-	Silty sand				Silty sand	Silty sand	Silty sand	Sandy gravel (D)	GP
								(60 cm max.)	
								Silty sandy gravel	GP/GM
4 m-								(M)	
	Sand (W)	Sand (W)	Sand (W)	Sand	Gravel and sand	Gravel and sand	Gravel and sand		
		Clay:	Clay:	Clay:	(M)	(M)	(M)		
5 m-	Clay:	Probably glacial	Probably glacial	Probably glacial	Clay:	Clay:	Clay:		
	Probably glacial	sediment (W)	sediment (W)	sediment (D)	Probably glacial	Probably glacial	Probably glacial		
	sediment (W)				sediment (W)	sediment (W)	sediment (W)		
6 m-									
(20 ft.)	Water in well	Water in well	Water in well	Dry hole	Water in well	Water in well	Water in well		
*	From Smith (1980): Typical well log data								
(D)	Damp								
(M)	Moist								
(W)	Wet								

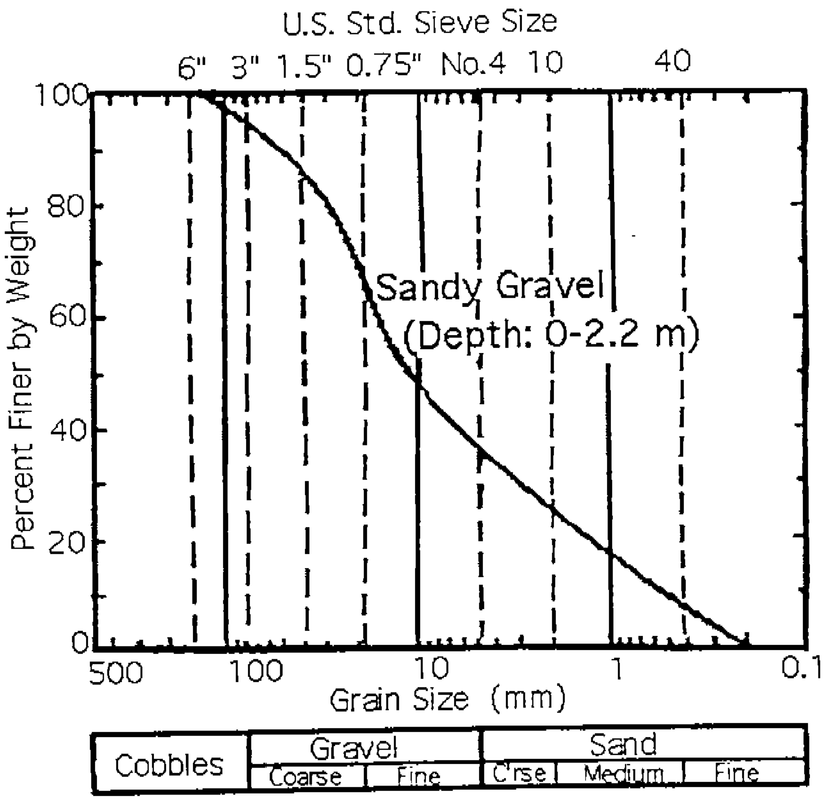

Figure IV-7-B1. Typical grain size analysis (Smith 1980).

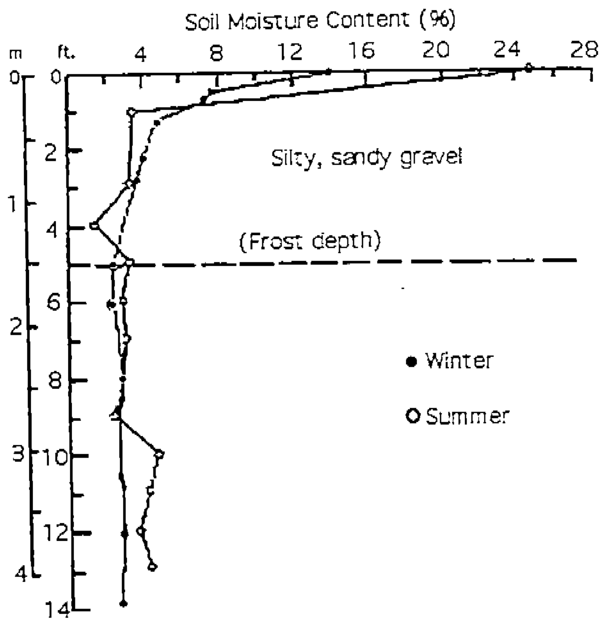

Figure IV-7-B2. Soil moisture profile (Smith 1980)

V-1. THE EAGLE RIVER FLATS SPATIAL DATABASE

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INTRODUCTION

Eagle River Flats (ERF) is an 865-ha subarctic coastal salt marsh on Cook Inlet, Ft. Richardson, Alaska. The area has been used by the U.S. Army as an artillery training range since 1945. ERF is also a migratory waterfowl staging area heavily used in the spring and fall. Mortality of waterfowl in ERF was discovered in 1981; in 1990 it was determined that particles of white phosphorus from smoke munitions were the cause of this mortality (Racine et al. 1992). Dabbling ducks and feeding swans ingest these particles from the pond bottom.

During the past five years (1991–1995) extensive studies of the distribution of white phosphorus and its effects on the biota (mainly waterbirds and eagles) have been conducted at ERF. Because WP contamination is a relatively unknown problem, a broad range of topics have been investigated including the chemistry (Walsh 1993) and toxicology of WP (Roebuck et al. 1993), environmental fate (Walsh et al. 1996), food chain effects and waterfowl use and mortality. In addition at least five different remediation techniques have been investigated, including pond drainage, pond bottom barriers, dredging, natural attenuation and hazing (Fig. V-1-1).

To remediate the WP problem in ERF, three basic questions need to be asked:

- What areas in ERF need to be treated (i.e. hot-spot identification)?
- What technology or method should be used to treat a particular WP-contaminated area?
- Did the remediation technique work?

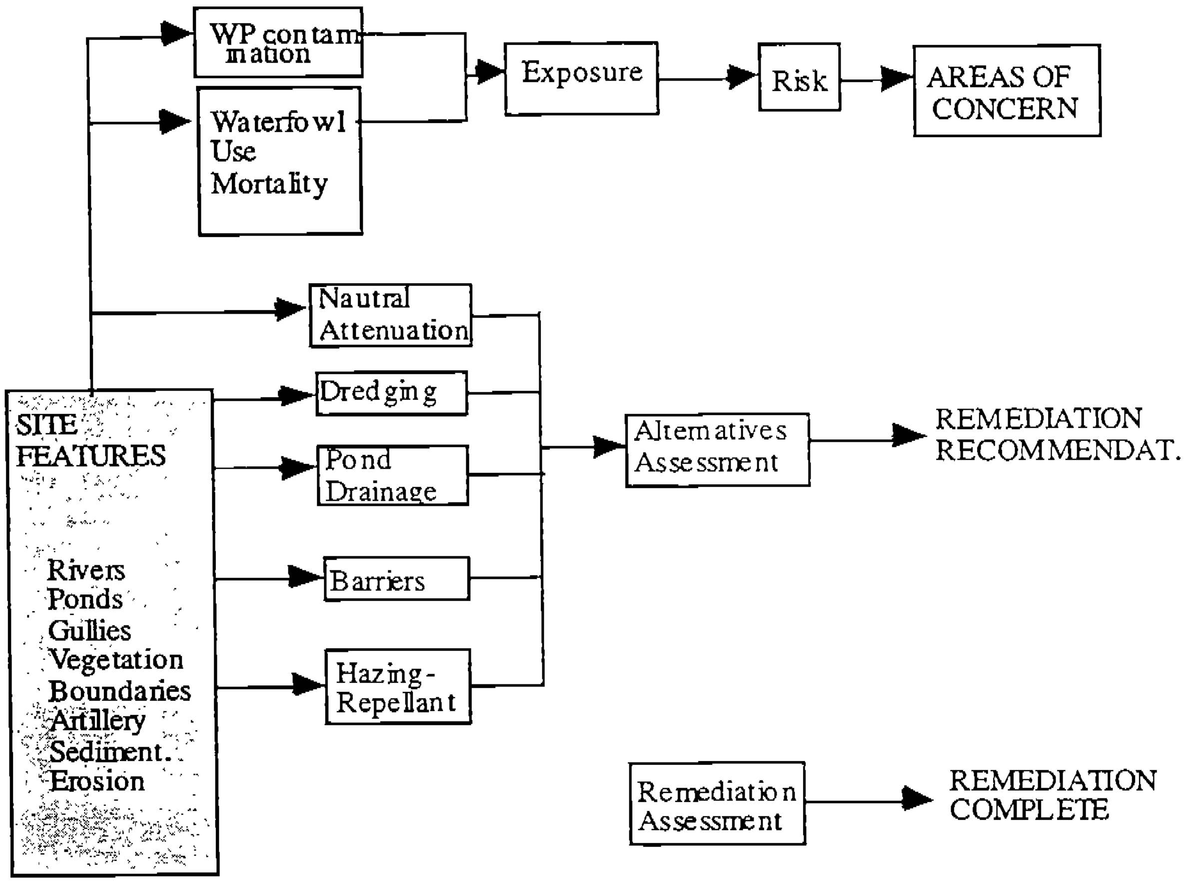

Figure V-1-1. Application of the database to decisions concerning areas to clean-up, method to be used and evaluation of success.

The data collected by the various projects could be used to answer some of these questions is shown in Figure V-1-1. At present the database is designed mainly to help make decisions concerning the first question (i.e. hot-spot identification) using the basic site features, waterfowl use, mortality and sampling data for WP. This risk assessment approach is based on identifying areas with high levels of waterfowl exposure to WP. These are defined as areas having significant amounts of WP (based on sediment sampling data) which also receive high usage by waterfowl. The mortality monitoring of carcass locations will hopefully support this exposure model. However, it is recognized that waterfowl can be poisoned in one area and fly to another before death occurs.

EARLY DATABASE DEVELOPMENT

In 1991 the need to build a spatial database (GIS) for Eagle River Flats was recognized based on:

- The absence of detailed maps of ERF showing the physical and biological features of ERF including habitat-vegetation, ponds, gullies and other natural and artillery features; and
- The need to document the location of large numbers of sediment samples being collected by C.H. Racine and C.M. Collins and being analyzed for WP by M.E. Walsh.

At that time, the location of each sample was determined by surveying by C.M. Collins; a spreadsheet of all samples analyzed with their UTM coordinates and concentration was maintained by M.E. Walsh. It was also recognized at this time that WP particle distribution was extremely non-random or heterogeneous and localized with very large differences or even presence-absence within a short distance of 1 m or less (Walsh and Collins 1993). Therefore, it was apparent that a spatial database or GIS of WP concentration data would help locate these extremely localized "hot spots" for future remediation.

Locational survey data was maintained from the outset of our study of the waterfowl mortality problem in ERF. In 1990 a surveying group from the COE Alaska District surveyed the location of all samples. Then following the determination that WP particles were the cause of waterfowl mortality in ERF in 1990, C.M. Collins used an HP Total Station to survey the location of all samples collected for analysis. Therefore, the precise locations and elevations of all samples were known. Later in 1993, two GPS units were purchased and have been used in real-time differential correction mode to monitor locations with submeter accuracy.

The major focus of this early effort was therefore the construction of a spatial database for all WP sediment and water samples collected and analyzed and the mapping of natural and artillery-related features in ERF. In September 1993, large-format (1:2400) black-and-white orthophotos of ERF (obtained on July 8, 1993) were produced by Aeromap Inc. (Anchorage), which permitted accurate mapping and digitizing of many features visible on these photos into a GIS system. In 1994, we obtained the necessary computer hardware and technical assistance to build data layers using ARC/INFO. M.C. Brouillette, the ARC/INFO technician hired at this time, did much of the digitizing and coverage preparation for these physical and natural features of ERF. The 1994 ERF report contained a map atlas showing over 50 coverages from the ERF spatial database.

1995 ADDITIONS TO ERF DATABASE

In 1995 the need to add additional data sets to the GIS database was recognized, particularly in relation to the identification of areas where waterfowl mortality and population use is high (Fig. V-1-1) and where toxic levels of WP are present. The major sources of waterfowl population-use information includes the radio-telemetry work conducted by Denver Wildlife Research Center (DWRC) during 1993, 1994 and 1995, and the aerial and ground-based censuses by U.S. Fish and Wildlife Service (USFWS) and the New England Institute of Landscape Ecology (NEILE), respectively. Aerial waterfowl census data for ERF areas have been collected by W. Eldridge (USFWS) since 1988, and various ground-based censuses of waterfowl numbers in different areas of ERF have been conducted by NEILE from 1992 to the present. This latter census was used to calculate the mortality, counted along permanent transects in various areas of ERF, to the numbers of waterfowl using that same area. In addition, NEILE began monitoring WP-poisoned carcasses along permanent transects in spring 1992, and these studies have been continued up to and including the present (fall 1995). Much of the ERF GIS database effort during 1995 centered on the entry of the census, telemetry and mortality data.

In 1993 remediation-feasibility studies of various technologies for removing or covering WP were also initiated. In addition extensive studies of WP fate and transport in ERF have involved "in-situ" particle attenuation due to the natural drying of sediments, and processes such as sedimentation and erosion to help quantify burial or transport of WP. The need to enter these results into the database was recognized, and test locations were entered into the GIS. However, further use of the GIS to help select appropriate technologies will depend on development of criteria for the types of conditions (i.e. pond depth, vegetation cover, access etc.) under which the method will work. In addition, success criteria need to be developed for each technology before the database can be used to evaluate remediation methods. Therefore, the data from these remediation studies presently reside as *secondary* coverages in the ERF GIS database.

ENVIRONMENTAL DATABASE DESIGN

Organization

The ERF GIS database consists of both primary and secondary coverages organized into workspaces or directories as shown in Figures V-1-2 and V-1-3. A coverage is a digital version of a map representing a single theme of data (for example, ponds). Primary coverages support decisions concerning hot spot identification (Fig. V-1-2). Secondary coverages are not presently useful for decision making concerning appropriate clean-up technologies or evaluating the success of this effort (Fig. V-1-3). They also include some of the ground

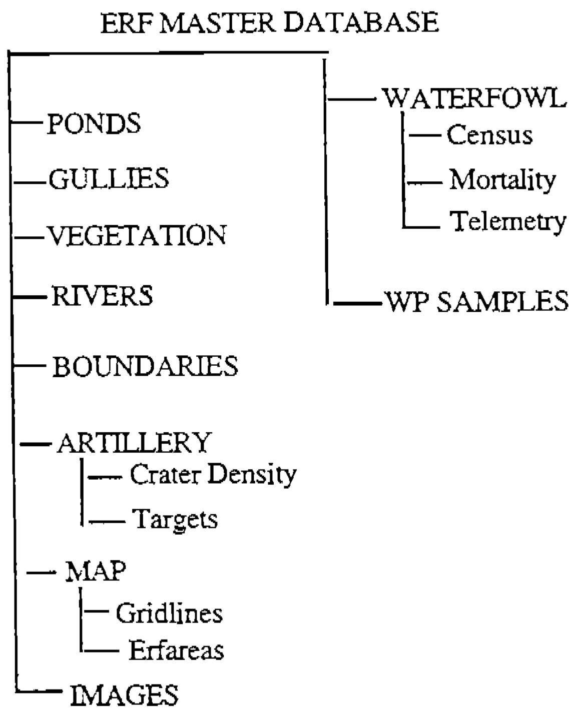

Figure V-1-2. Basic directory structure and general content of the ERF master spatial database containing primary coverages.

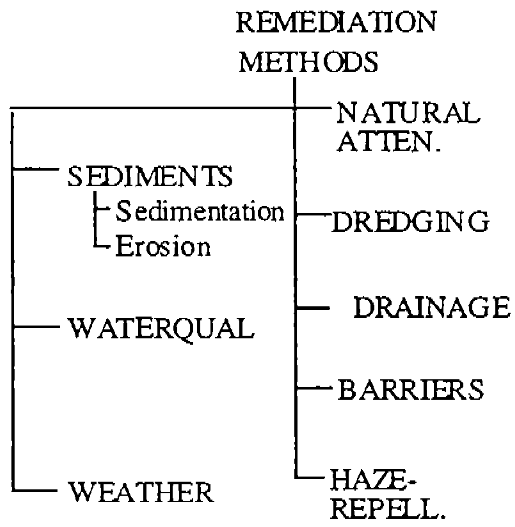

Figure V-1-3. Directory structure for secondary coverages.

truthing using a GPS (geopositioning system) unit to validate the photointerpretations conducted for some of the primary coverages. The database presently consists of 39 primary coverages in ARC/INFO. In addition the database consists of ARCVIEW translations of the ARC/INFO coverages and the tabular data (in spreadsheets) used to build these coverages. The two major branches of the data primary structure in Figure V-1-2 are:

- Coverages of natural-artillery ERF features and images; and
- Waterfowl studies and WP concentrations.

This directory structure is repeated in all three ARC/INFO, ARCVIEW and tabular data set storage.

Hardware, software and personnel

The ERF GIS database is stored on a Sun Sparcstation 20 workstation (known as GISSUN) connected to the local area Ethernet TCP/IP network at CRREL in Hanover, New Hampshire. The GISSUN is configured with 64-megabyte random access memory (RAM), a 64-megabyte SIMM memory expansion chip, 1.05-gigabyte internal drive, a 9-gigabyte SCSI hard disc, a CD-ROM and a ZX 24-bit three-dimensional graphics card.

This server is accessed by a networked Sparcstation 20 located in the ERF GIS laboratory which serves as an X-terminal to the GISSUN. This terminal has 24-bit graphics, a 1.2-gigabyte internal drive, a 20-inch high-resolution monitor and a 5-gigabyte, 8-mm tape drive. Hardware accessible over the network includes scanners, printers, an Altek A31 digitizer and an HP650C E-size plotter.

The software includes a three-node ARC/INFO license from Environmental Systems Research Institute (ESRI). Other software includes ARCVIEW (ESRI) on PC-DOS workstations, Microsoft Excel for constructing spreadsheets, Trimble PFinder Version 3.0 for collecting and processing geo-based data, Trimble Quick-Plan Version 1.2 (for forecasting the availability of satellites for geopositioning) and Clark University's IDRISI Windows Version 4.1 for handling raster-based image data.

Personnel currently working on the ERF GIS include an ARC/INFO software technician (J. Mullen who recently replaced M. Brouillette), a technician to digitize and produce spreadsheets of data and conduct error-checking (P. Robinson), and an ERF-GIS data manager, photointerpreter and director (C.H. Racine).

DATA FLOW

Overview

Two major sources of data for the ERF GIS include that interpreted from aerial photos on site features (Fig. V-1-4) and the data obtained from researchers and laboratories (Fig. V-1-5 and V-1-6). In both cases these data had to be translated and imported into ARC/INFO coverages. The first type of data includes site features interpreted from orthophotos (geocorrected and georeferenced aerial photos), including information on land cover types, drainage features, upland boundaries, rivers and artillery targets and craters. The

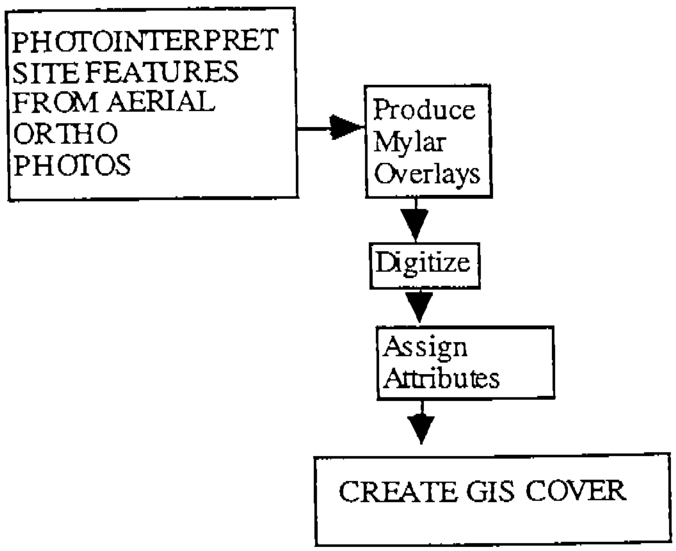

Figure V-1-4. Flow of data on physical and biological features of ERF into the GIS database.

second type of data includes information obtained from researchers and/or laboratories, including sample collections, WP analyses and waterfowl data on population censuses, telemetry and carcasses (Fig. V-1-5 and V-1-6). While some of these data were received from the researchers with sample locations plotted on a map (Fig. V-1-5), other data were received from the researchers with the locational information provided (Fig. V-1-6).

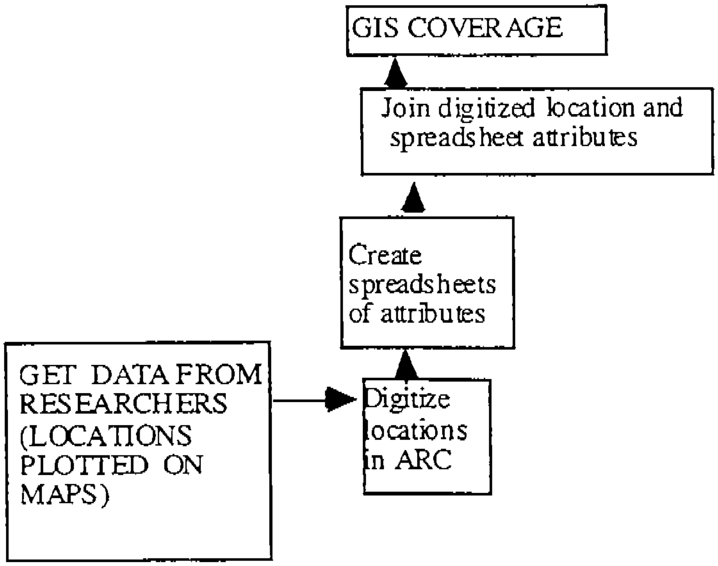

Figure V-1-5. Flow of data from researchers who provide locations of work on corrected maps or orthophotos.

Roles and responsibilities

C.H. Racine decides what coverages to create and requests data from researchers or the laboratory. In most cases the researchers provide the data. However, the researchers have never been obligated by a specific task in their work plans to provide data to the GIS team. CH2MHILL recommended that more formal mechanisms for the transfer of data from field personnel to researcher to GIS should be imple-

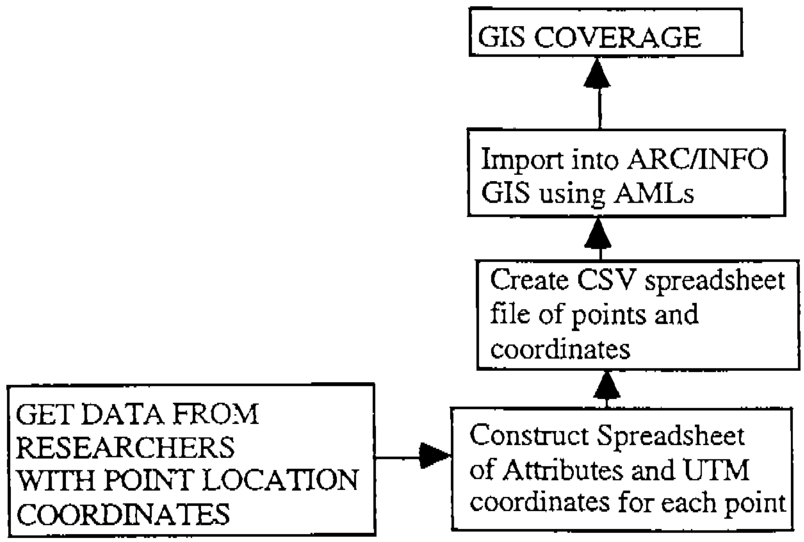

Figure V-1-6. Flow of data from researchers into the ERF GIS database beginning with researcher-supplied locational data.

mented. This recommendation will only be accomplished once the researchers' work plans include the specific data transfer task.

The roles and responsibilities of the three people presently working on the database have been defined (C.H. Racine, database manager, director, J. Mullen ARC/INFO technician; P. Robinson, data spreadsheet producer and QA/QC officer.

Once the GIS team receives data from the researchers, it is built into a spreadsheet of GIS attributes by Peggy Robinson. If digitizing is necessary, this is accomplished by John Mullen and P. Robinson. Then the ARC/INFO technician (J. Mullen) joins the digitized data with the comma-delimited spreadsheet in ARC/INFO.

Photointerpretation and digitizing of natural features

In 1994 large-format (80 × 100 cm) orthophotos of ERF obtained by aerial photography on 8 July 1993 (scale = 1:2400) were obtained and the major physical and biological features interpreted on mylar overlays (Fig. V-1-4). The outlines of features including ponds, rivers, tidal gullies, vegetation, mudbanks etc. were traced with a pen on a separate mylar sheet for each feature. M.C. Brouillette then digitized these features into ARC/INFO using an ALTEC digitizing board. These digitized features were then joined with attribute tables describing characteristics of the digitized points, lines or polygons.

Format of data from researchers

Researchers supplied data with and without locational coordinates (Fig. V-1-5 and V-1-6). WP sample and concentration data were entered into a large spreadsheet containing UTM location coordinates for each sample. These coordinates were obtained by various means:

- Surveying with an HP Total Station (providing the most accurate locations and also giving elevation of the sample site);
- Extrapolation from a location marked on the orthophoto maps with a grid overlay; and

- GPS of stakes placed in the field by the sample collector and entered electronically from the GPS software.

Waterfowl data on mortality, population census and telemetry were received from researchers as spreadsheets either in electronic or hard-copy format. Much of these data involved digitizing locations placed on maps by the researchers and then matching these locations with a spreadsheet of attribute data. Where the locations of their samples or studies have been surveyed, we imported the data directly into a GIS coverage (Fig. V-1-6). In other instances it was necessary to plot locations onto an orthophoto or map and digitize these locations or determine locations using a grid placed over the orthophotos (Fig. V-1-5). Assignment of attributes was also made based on the data set.

A set of notebooks (one for each research group) is kept in the ERF GIS lab containing the original data sets supplied by the research group along with the final spreadsheet and copies of maps displaying their data.

AMLs (ARCINFO macro language) were created in order to create a systematic process and provide documentation of actions involving the import of data into GIS coverages.

Format of WP concentration data from laboratories

The laboratory analysis results for WP concentrations were transferred to the CRREL GIS group in various ways depending on which lab performed the analyses. In 1991, 1992 and 1993 M.E. Walsh (CRREL) performed the laboratory analyses for WP and entered the concentration data and UTM coordinates directly into a spreadsheet in the laboratory. In 1994 WP analyses were performed by AEHA (Army Environmental Health Agency) laboratory (mainly on samples collected by C. Bouwkamp) and by WES (Waterways Experiment Station) on all other samples. During 1994 the resulting concentration data were provided to CRREL for the most part electronically via modem to the ERF GIS lab; a hard copy of the data was also mailed to C.H. Racine by WES. In 1995 Chemtrak (Anchorage, Alaska) performed most of the analyses and sent a hard copy of the lab results to

C.H. Racine at CRREL. This hard copy required keying the concentration data into the database spreadsheet. The lab results were matched to the collector-assigned id and then assigned a new CRREL id in the spreadsheet. Original data sheets are maintained in the ERF GIS lab.

In 1993 chain of custody forms were filed with M.E. Walsh. In 1994 and 1995 copies were furnished to the ERF GIS lab.

Quality control

The researchers are responsible for the accuracy of the original data. Data from researchers were built into spreadsheets with the attributes appropriate to each coverage (Fig. V-1-5 and V-1-6). These spreadsheets were then imported into ARC/INFO to be matched with digitized information via AMLs to produce GIS coverages (Fig. V-1-7). Then ARCVIEW shape files were produced in ARC/INFO and transferred to the PC where P. Robinson produced maps and attribute spreadsheets. These (spreadsheets and maps) were given to each of the researchers who contributed the data. The researchers checked map locations and attribute values and returned both the spreadsheet and maps to the GIS lab for corrections. P. Robinson then made corrections in the original spreadsheet and this was again built into a new and corrected GIS coverage (Fig. V-1-7). The use of ARCVIEW has greatly facilitated the error checking but it also made it necessary to make corrections in all three databases (ARC/INFO, spreadsheets and ARCVIEW) as the quality control procedures progressed.

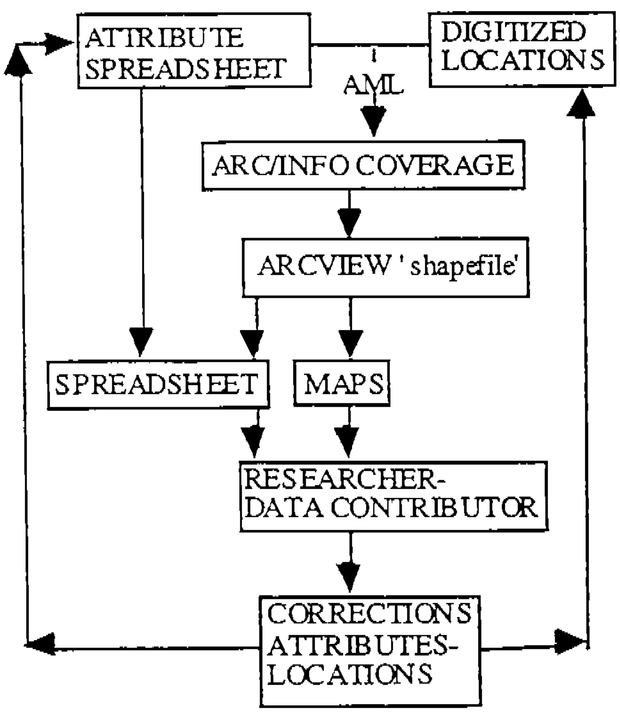

Figure V-1-7. Error checking procedure for ERF database.

GIS standards

The GIS application here to the white phosphorus problem in ERF involves the creation of a special-purpose GIS that is not being produced for general public distribution. Therefore, detailed GIS standards are not addressed in this report. In addition too many researchers generating spatial data of differing qualities were involved to complete this objective at this time. However, the catalogs in Appendices V-1-A and V-1-B describe how the coverages were produced.

Transfer of data to others

By performing our own analyses and sharing the database with other groups (Ft. Richardson, CH2MHILL and others), decisions concerning the selection of areas to clean up and methods to do it could be made. CH2MHILL visited the ERF GIS laboratory twice (August 1995 and January 1996) to review and use the database to determine its usefulness in making decisions both now and in the future concerning hot spot identification and clean-up technologies. Final coverages have been sent to other groups via FTP and 8-mm tape. This process has been slowed by the need to finalize the accuracy of the data by each contributing researcher. Changes are still being made (Feb. 1996) in some of the coverages.

The ERF spatial database is designed for use by other groups and researchers to produce maps and conduct analyses. To this end we have instituted the use of ARCVIEW on PCs to view final coverages and conduct analyses. The final ARC/INFO coverages are converted into the ARCVIEW native format (shape file) and placed on a public server for access. In addition Ft. Richardson and others (CH2MHILL) will receive ARC/INFO export files via FTP or 8-mm tape.

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APPENDIX V-1-A. DATABASE CATALOG: PRIMARY COVERAGES

IMAGES

1. **Orthophoto_rec.tif** (B and W, July 8, 1993) 0.6096-m pixel size-resolution (100 megabyte file). Produced by AEROMAP Inc. Anchorage, AK in 1994, scanned from B and W orthophotos.
2. **Eagle River. lan** (Color IR, Aug 30, 1994) 0.6096-m pixel size; mosaic of 1 in. = 600 ft and 1 in. = 500 ft color IR photos of ERF, scanned and georeferenced. Produced by Sewall Co., Old Town, ME, in 1995.

MAPPING

1. **G100** m line grid for overlaying on layers. Produced by M.C. Brouillette.
2. **G500** m grid.
3. **G1000** m grid.
4. **Erfareas** Polygons screen digitized from Orthophoto_rec.tif showing standardized area designations for ERF as assigned and determined by C.H. Racine in winter 1994 These areas are to be used by all researchers to designate study areas in ERF to provide a standard terminology.

BOUNDARIES

1. **Erfbnd.** Polygon of entire Eagle River Flats interpreted by C.H. Racine from USGS 1:24,000 quad of Anchorage. Digitized by M.C. Brouillette.
2. **Bound.** Line showing edge of ERF where upland forests and estuarine salt marsh meet, interpreted from USGS 1:24,000 quad and digitized by M.C. Brouillette.

3. **Roads.** Road network on Ft. Richardson surrounding ERF obtained from USGS DLG of roads for 1:24,000 Anchorage Quad which covers ERF. Attributes include surface type length and road id.
4. **Knikarm.** Polygon showing open water extent of Knik Arm from Knik River to Anchorage.

RIVER

1. **Ottercp** Polygon for Otter Creek produced by photo interpretation of 1993 B and W orthophotos by C.H. Racine. Digitized by M. Brouillette in 1994.
2. **Otterln** Line file for Otter Creek.
3. **Rivply** Polygon of Eagle River into and through ERF produced by photo interpretation of 1993 B-W orthophotos by C.H. Racine. Interpreted as top to levee bank of Eagle River channel. Digitized by M. Brouillette in 1994. Problem in that includes Racine Island because river rejoins itself.
4. **River** Line file for Eagle River including the river into and through ERF produced by photo interpretation of 1993 B-W orthophotos by C.H. Racine. Interpreted as top of levee bank of Eagle River.
5. **Mudbanks.** Polygons of exposed mudbanks and river water level at the time B and W orthophotos were obtained on July 8, 1983. Interpreted by C.H. Racine and digitized by M.C. Brouillette.
6. **Lowtide.** Line of tide water level in Eagle River and gully distributaries at the time B and W photo was obtained on July 8, 1993. Interpreted by C.H. Racine and digitized by M.C. Brouillette.

PONDS

Ponds were interpreted and mapped from the 8 July 1993 orthophotos (aerial photos) and were defined as areas with open water containing less than 50%

emergent vegetation cover. Where the vegetation cover in a pond was greater than 50% emergent vegetation, it was mapped in the vegetation coverage as sedge marsh. This approach was taken because the waterfowl victims of WP poisoning are generally known to feed in open water areas of various sizes. A total of 336 ponds covering about 100 ha were mapped on ERF

1. **Permponds.** Polygons of deeper permanent ponds which do not dry up during some summers with skipped spring tides and hot dry weather. Photo interpreted onto mylar over B-W orthophotos (July 8, 1983) by C.H. Racine in 1994 and digitized into ARC/INFO by M. Brouillette in 1994.
2. **Intponds.** Polygons of intermittent ponds which are shallower than permanent ponds and dry up during some summers. Interpreted by C.H. Racine in 1994 onto mylars over B-W orthophotos (July 8,1993) using sets of photos from other years. Digitized into ARC/INFO by M. Brouillette.
3. **Allponds.** Polygons combining both permanent and intermittent ponds with the division between the two types represented by a line.
5. **Wetswales.** Polygons of small ponds which form near river levees usually associated with meanders and riverbends. Interpreted on mylars over B-W orthophotos by C.H. Racine and digitized into ARC/INFO by M. Brouillette.

GULLIES

1. **Gull.** Polygons showing eroded distributary gullies from bank to bank as interpreted by C.H. Racine from July 8, 1993 orthophotos. Digitized by M.C. Brouillette in 1994.

LAND COVER / VEGETATION

1. **Vegclasses.** Polygons of vegetation types named using Viereck et al. (1993) (where appropriate) based on (ground truth) field sampling of vegetation along

transects (SEDTRAN) and photo interpretation on large-format mylar overlays of July 8, 1993, B and W aerial photos. Using color IR photos to supplement interpretation. Mylar overlays digitized into ARC/INFO by M. Brouillette in 1994. Some ground truthing using GPS to trace borders of types on the ground.

2. **Mudbanks.** Polygons showing barren banks of Eagle River, Otter Creek and distributary gullies exposed at low tide mapped from large-format aerial photos on mylar and digitized into ARC/INFO by M.C. Brouillette in 1994.

ARTILLERY **(Features related to the use of ERF as an artillery training area)**

1. **Craters.** Polygons 1 ha (100 × 100 m) covering all of ERF with number of craters photo interpreted (as one of the attributes of each cell) by C.H. Racine by overlaying a 100- × 100-m-scale mylar grid over high-resolution (1 in. = 500 ft) 9- × 9-in color IR aerial photos and using a 10× magnifier to count all visible crater holes. The purpose of this coverage is to help identify areas that have received high levels of high-explosive artillery bombardment. The assumption is made that these same areas have also received smoke munitions (WP) inputs in the past. Interpretation and recognition of craters is difficult in permanently flooded marsh and deeper open water pond areas and in areas of dense vegetation. However, all grid cells were assigned a value according to how many craters could be interpreted. Sun angle on this photo was low so that craters were easily seen on the mudflats.

2. **Targets.** Points representing 42 artillery targets placed in ERF over the past 50 years including trucks, cars, signs etc. The locations of some of these were determined by surveying, while others were located by real-time differential GPS.

WHITE PHOSPHORUS SAMPLES

1. **WPSAMP6.** (12/19/95) Point locations for 2548 sediment, water or slurry samples collected in ERF between 1990 and 1995 for WP analysis by GC, field screening and SPME. Various research teams have collected samples of sediments and water for WP analysis, About 2550 samples have been collected and analyzed for WP by four different laboratories (CRREL, AEHA, WES and Chemtrak) between 1990 and 1995. The collectors of samples provided the ERF Database manager with a list of their samples together with the locations (UTM coordinates) and with copies of the chain-of-custody sheets. Attributes for each sample include CRREL-id, collector name, collection date, site type, ERF region, basis for sample collection i.e. WP previously known to be present at that site, elevation (only for sites surveyed with total station), method used to determine UTM coordinates of sample location, sample material, sample depth, collection method, sample type, sample treatment, analysis method, laboratory, field screened?, WP concentration in µg/g wet wt for sediments or µg/L for water samples.

Data were built on Excel spreadsheets initially by M.E. Walsh 1990–1993 and later by receiving results directly (to C.H. Racine) from analysis laboratory (WES in 1994 and Chemtrak in 1995). Many of the research groups made little or no effort to have collection sites surveyed so that it was necessary to GPS staked sites or locate on orthophotos later and estimate UTM coordinates in that way. Therefore, there is an inconsistent degree of accuracy in terms of exact x-y coordinate values.

WATERFOWL

Census

1. **S94CP (Spring 94 Cole Point).** Polygons representing 15 areas of ERF in which waterfowl numbers were censused daily from the observation tower at Cole Point (CP) each morning (0700) by NEILE during a period of 39 days in spring

1994 (May 10–June 15). The values for each polygon are based on the average number of ducks per day by area in spring 1994. The areas (polygons) censused each morning from Cole Point were drawn onto a D-size map of ERF and then screen digitized in ARC/INFO. A spreadsheet table of attributes for each polygon or area was constructed to include the polygon area by name, total number of ducks for the season in that area and the average number of ducks per day. This was joined to the digitized area using an AML.

2. **F94CP (Fall 94 Cole Point).** Polygons in which waterfowl numbers were censused daily from the observation tower at Cole Point each morning (0700) by NEILE during a period of 20 days in fall 1994 (Aug 10-Oct 14). The attributes for each polygon include number of days censused, total numbers for season and average number of ducks per day

3. **S95CP (Spring 95 Cole Point).** Polygons representing areas in ERF where ducks were censused each morning over a period of 25 days during spring 1995 (April 28–May 30) from an observation tower at Cole Point.

4. **F95CP (Fall 95 Cole Point).** Polygons representing areas in ERF where waterfowl were censused each morning during 59 days (Aug 17–Oct 20) in the fall of 1995 by NEILE from the Cole Point observation tower. Attributes include average number of ducks per day and totals for the entire season.

5. **S94WSDBS (Spring 94 Waterfowl.** Polygon hectares (100 × 100 m) in which waterfowl were counted each day for 15 days during spring 1994 from April 18 to May 3 from the various observation towers in or near each of the hectare areas censused. Waterfowl were censused daily by NEILE from observation towers in 10 to 30 1-ha plots in Area A, Area B, Area C, Bread Truck Pond and C/D. The value for each 1-ha polygon or square is the average number of mallards, pintail, green-winged teal and total ducks observed in that square during the census period. The 1-ha polygons were obtained from the CRATER coverage above. The census data were input from the data contained in the FY 94 Waterfowl Mortality Report.

6. **F94WSDBS.** Polygon hectares (100 × 100 m) in which waterfowl were counted during 24 days in fall 1994 (Aug 12 to Sept 5) by NEILE. Waterfowl were censused daily from the various observation towers in 10 to 30 1-ha plots in Area A, Area B, Area C, Bread Truck Pond and C/D. The value for each 1-ha polygon or square is the average number of ducks observed in that square during the fall season.

MORTALITY

1. **Carctot.** (1/10/96-only available in ARCVIEW) (point locations for 1254 carcasses together with species, dates, finder, site, condition) inventoried along permanent transects and quadrats (shown in the coverages **morttran**, **woodtran** and **woodquad** described below) as well as some collected randomly from spring 1992 to and including the present (fall 1995). This database was generated during 1995 when Ben Steele (NEILE) went through field notebooks and marked carcass locations (estimated position along transects) and assigned an id number to each on large D-size plots of ERF. Dr. Steele then constructed a spreadsheet for this data with the id number of each carcass, the date found, species, finder and other information such as sex, condition etc. The location of each carcass was then digitized in ARC/INFO from these maps. This digitized file was then joined with a new spreadsheet containing the attributes for each carcass. The new carcass coverage was printed with the id number beside each location and the data checked by Ben Steele in Dec 1995. A number of errors and omitted carcasses were found, and these were corrected and the new carcasses digitized into the coverage below in January 1996. Hence the present coverage has been accuracy checked. However, a network problem in October caused the loss of the original mortality ARC/INFO coverage and our inability to rebuild or connect all of the digitized points with the attributes.

2. **Morttran.** Lines, showing the locations of mortality transects monitored by NEILE for carcasses during each migration period. The locations of these tran-

sects were determined by surveying or by GPS and imported into ARC/INFO from spreadsheets. Attributes for these line features include the type of transect (belts, edge random), date of establishment.

3. **Woodtran.** Line transects perpendicular to the edge of ERF which were originally established in 1993 to monitor the number and locations of carcasses carried out of ERF by eagles and brought into the adjacent woodland for consumption. The variation in numbers from year to year is a function of eagle numbers and waterfowl mortality rates.

4. **Woodquad.** Polygon (Woodland quadrat) along the east edge of ERF in the spruce–birch forest established in 1993 to monitor the number of carcasses scavenged by eagles and brought into this area for consumption.

TELEMETRY

Work done by DWRC (Denver Wildlife Research Center) involving radio-transmitter installation on wild birds in spring or fall followed by tracking their movements throughout the summer on ERF.

1. **Telemetry93.** Digitized points of daily observation position for 39 ducks radio-collared during 1993 (8 died on and 3 ducks died off ERF). Point locations for each bird were plotted on 48- × 36-in. mylar overlays placed over a large color IR aerial photo of ERF and the intersections of telemetry lines plotted as point locations. These points were then digitized in ARC/INFO on a large digitizing board by C. Yoder (DWRC) and joined with an attribute table at CRREL in January 1996. Attributes for each point include species, leg band number, sex, date captured, area in which bird was captured, whether or not bird died during the fall observation period.

2. **Telemetry94.** Point and line locations (Telemetryp94, Telemetryl94) for all birds with transmitters in 1994. Includes daily locations for 10 eagles, 20 shorebirds-(dowitchers) and 34 ducks. Produced in 1994 by M. Brouillette and C. Yoder

(DWRC) who manually determined point UTM locations from a gridded aerial photo. Includes attributes for each point such as id, species, sex, age, date captured.

3. **Telemetry95.** Point locations based on daily (or more often) telemetry for 54 ducks and 14 eagles during summer 1995. Points placed on large mylar overlays of a color IR aerial photo of ERF with monitoring radio receiver locations (control points) by C. Yoder digitized points at CRREL between Jan 3–10, 1996 and attribute tables showing species, observation number, band number and location trapped, found dead?, were linked.

APPENDIX B. DATABASE CATALOG: SECONDARY COVERAGES

EROSION

1. **Hub.** (Point locations of hub stakes for monitoring erosion) includes attribute date when hub was established determined by surveying with total station by D.E. Lawson and group. imported into ARC/INFO by spreadsheet.

SEDIMENTATION

1. **Pondsed.** (Locations of pond sedimentation stations, date established)
2. **Sedtran.** (Point locations of over 400 sedimentation traps along DEL transects with elevations, values for 1994 included) and date each station was established.

FEATURES

1. **Pondexts.** GPS lines representing extent of intermittent ponds during various time periods as drying occurred in summer 1994. Real time GPS by M. Brouillette who walked edge of ponds at different times during the summer of 1994.

OTHER

2. **Thalwegs.** Surveyed lines and elevations up the bottoms of several gullies by D.E. Lawson in 1993.

3. **Cra95gps.** Point locations of several hundred craters in several different 1-ha grid squares as determined with real time differential GPS in spring 1995 by M.C. Brouillette. Imported into ARC/INFO from a Trimble Pathfinder software. Work done to ground truth photo interpreted craters above. Comparison shows that crater coverage underestimates the actual numbers of craters, particularly where there is tall sedge cover but that relative counts are accurate.