

COST AND PERFORMANCE REPORT

Electrokinetics at Site 5, Naval Air Weapons Station
Point Mugu, California

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U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Technology Innovation Office

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Background Information

The U.S. Army Environmental Center (USAEC) and the Engineer Research and Development Center (ERDC) Waterways Experiment Station conducted a field demonstration of electrokinetics at a metals contaminated site at Naval Air Weapons Station (NAWS) Point Mugu, California. The demonstration was sponsored by the Environmental Security Technology Certification Program (ESTCP) and the Southwest Division, Naval Facilities Engineering Command. Lynntech, Inc. was the vendor for the demonstration.

Located in Ventura County, California, NAWS Point Mugu comprises approximately 4,500 acres in the western portion of the Ventura Basin. The installation is approximately 50 miles northwest of Los Angeles and borders the western slopes of the Santa Monica Mountains. The site at NAWS Point Mugu selected for the demonstration was Site 5, the Old Area 6 Shops. Site 5 is a large area where electroplating and metal finishing operations were conducted. The area of study was approximately ½ acre in and around two former waste lagoons located in the center of Site 5 (Figure 1). The lagoons are unlined and were used between 1947 and 1978 to receive wastewater discharge from electroplating and metal finishing activities. The largest waste generator was a plating shop that discharged approximately 95 million gallons of plating rinse solution into the lagoons. Additionally, up to 60,000 gallons of waste photographic fixer solution and small quantities of organic solvents and rocket fuel were disposed of in the lagoons (Fabian and Bricka, 1999). Following a 1994 emergency removal action, surface sampling within the lagoons indicated that levels of chromium and cadmium were up to 25,100 mg/kg and 1810 mg/kg, respectively [email], exceeding the allowable limits for California (2500 and 100 mg/kg, respectively [22 CCR 66261.24]).

The waste lagoons were adjacent to Mugu Lagoon, a natural wetland. Because of the potential for damage to the marsh area and the presence of state and federally listed endangered species in the area, a less invasive method of metals extraction was sought and electrokinetic remediation was selected as a potential solution.

Prior to the field demonstration, extensive laboratory testing was conducted to assess the potential effectiveness of electrokinetic extraction at NAWS Point Mugu. Testing included determining



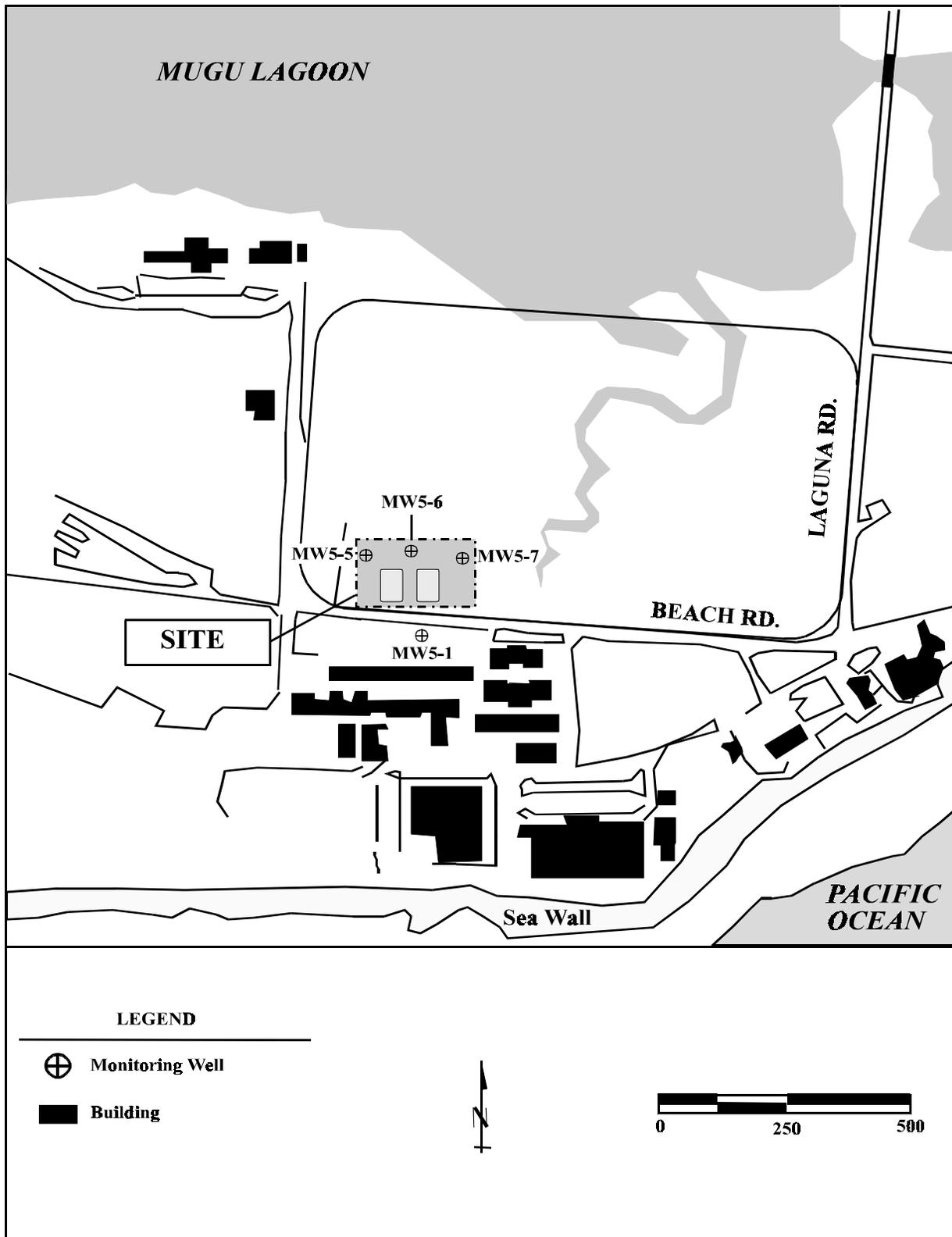


Figure 1. Location of Site 5 at NAWs Point Mugu (modified from Fabian and Bricka, 1999)

the contaminant and soil characteristics, such as contaminant types and concentrations, particle size assay, porosity, pH, total organic carbon (TOC), toxicity characteristic leaching procedure (TCLP), hydraulic conductivity, cation exchange capacity (CEC), and a total charge balance. The characteristics of the soil matrix are listed in Table 1. These analyses were followed with a series of treatability studies to determine electrolyte conditioning requirements, migration of contaminants and competing ions, electrode placement, time versus treatment analysis, removal efficiency, and process power/operating requirements. (Fabian and Bricka, 1999)

Table 1. Characteristics of the Soil Matrix at NAWS Point Mugu

Parameter	Value
Soil type	Sandy soil and sediment
Particle size distribution	85% sand, 7% gravel, 6% silt, 1% clay
pH	5.84
TOC	6390
TCLP	10.5 mg/L cadmium Nondetect levels of chromium
Hydraulic conductivity	0.045 cm/sec
CEC	3.9
Maximum or range of contaminant concentrations	Nondetectable to 1810 mg/kg cadmium Nondetectable to 25,100 mg/kg chromium

Source: Fabian and Bricka, 1999 and Fabian, 1999a

The laboratory studies indicated that electrokinetics could successfully be applied to the demonstration site at NAWS Point Mugu. The treatability studies indicated that the majority of the metal contaminants would be solubilized in the pore water as a result of the pH front generated by the application of electrokinetics. The major phenomena contributing to electrokinetic transport of the contaminants at NAWS Point Mugu was expected to be electromigration of these solubilized metals (Fabian and Bricka, 1999).

Technology Description and System Design

The objective of the field demonstration was to evaluate electrokinetic extraction of heavy metal contaminants from impacted soil and sediment. The demonstration was designed to identify, collect, and



verify the economic, operational, and performance data that would be used to validate and transfer this technology to potential users. The following evaluation points were to be addressed by the field demonstration:

- Validation of the treatability study predictions of electrokinetic extraction performance
- Assessment of the ability to control the effects of electrokinetic extraction in both an artificially confined and an unconfined treatment area
- Identification of off-gas emissions resulting from electrokinetic extraction
- Monitoring the effects of electrokinetic extraction on organic contaminants in the soil
- Identification of site-specific characteristics affecting the performance of electrokinetic extraction
- Identification of site-specific characteristics affecting electrokinetic extraction remediation costs
- Assessment of potential health hazards to site workers and the public resulting from fugitive emissions (i.e., H₂, O₂, and Cl₂) from electrokinetic extraction
- Quantification of the costs (capital costs and operation and maintenance costs) for performing electrokinetic extraction

Two 1/8-acre test cells (Figure 2) were constructed to assess the performance of electrokinetic extraction. Test cell #1 contained the two former waste lagoons and the surrounding berms (Figure 2). Contaminants were characterized to a depth of 11 feet. Test cell #1 was an artificially confined treatment area. An electrically nonconductive sheet pile barrier wall was installed to a depth of 20 feet around the perimeter of the cell to prevent uncontrolled movement of metal ions and contaminants outside the test cell and to mitigate the influences of groundwater flow and tidal effects on the electrokinetic extraction process. Test cell #2 was an unconfined treatment area that was open to groundwater and tidal effects.

As shown in Figure 2, three rows of anode wells and two rows of cathode wells were installed to a depth of 10 ft. (Fabian, 1999a). Initial operations were conducted in test cell #1; the treatment timeline for test cell #1 is outlined in Table 2. Operation and monitoring of test cell #1 was initiated in March 1998 and continued until October 1998 with a temporary shutdown for 6 weeks from the end of June through mid-August.



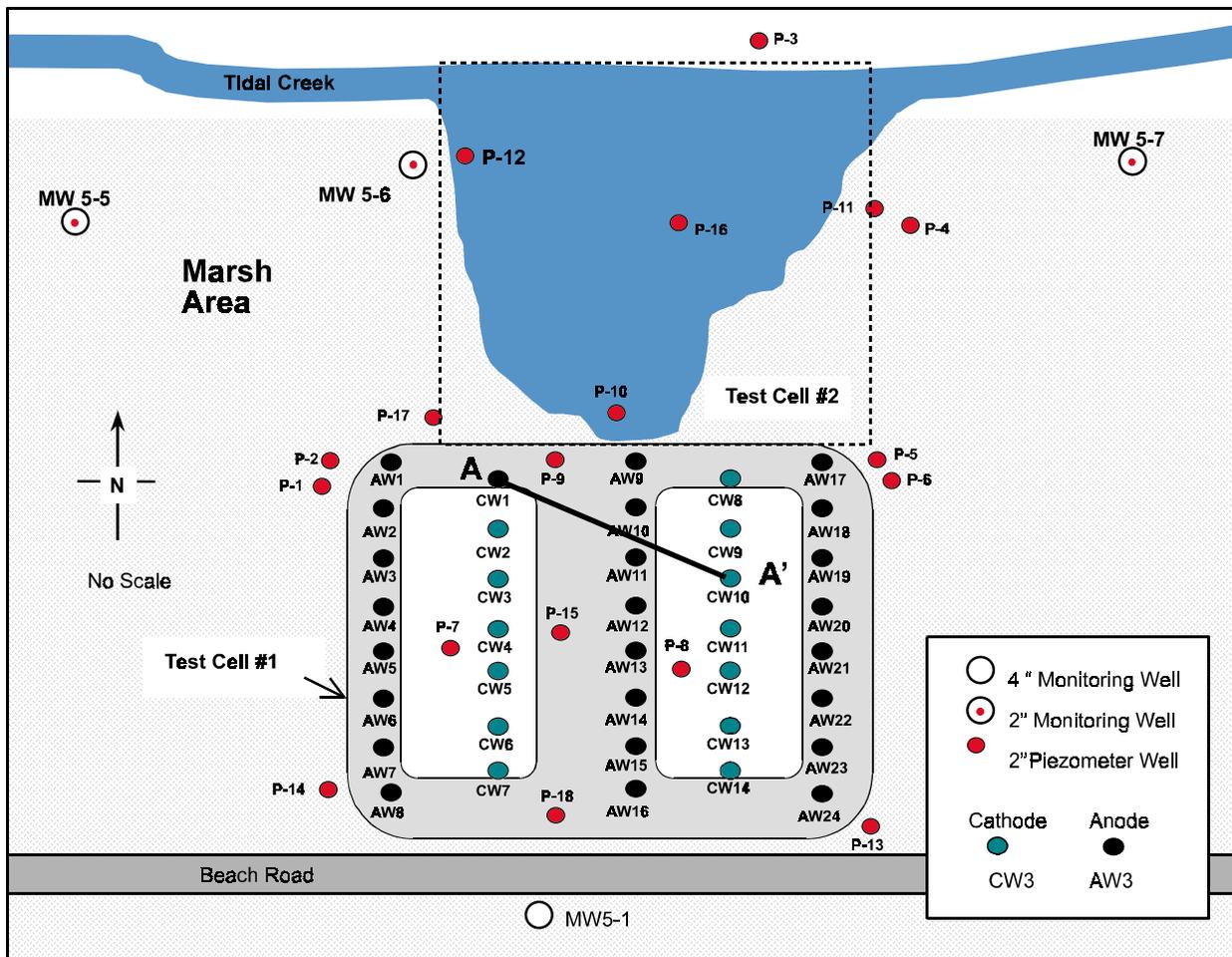


Figure 2. Layout of the test cells at Site 5 showing locations of electrode wells (modified from Fabian and Bricka, 1999)

In May 1998, a three-month progress review was held. It was determined that electrokinetic extraction was progressing much slower than originally expected. There was little contaminant movement, and the pH front in the soil had not developed.

Also, the current densities used in the bench scale studies (0.5 mA/cm^2 and 2.3 mA/cm^2) were much higher than those used in the field demonstration (initially 0.1 mA/cm^2 and increased to approximately 0.2 mA/cm^2). The current density was changed from 0.1 mA/cm^2 to 0.2 mA/cm^2 two weeks prior to the 3-month progress review. In an effort to increase the rate of contaminant movement, the current density applied to test cell #1 was increased further. To achieve a current density increase without having to purchase expensive power supplies, the treatment area within test cell #1 was reduced by approximately one half so that treatment was applied to only the east waste lagoon. The current

Table 2. Treatment Timeline for Test Cell #1, NAWS Point Mugu

Activity	Time Period	Comment
Operations and maintenance begun	March 1998 to end-June 1998	Initial operations (1/8 acre, 0.1 - 0.2 mA/cm ²)
Three-month progress review	May 1998	Little contaminant movement and pH front had not developed Increased power and reduced treatment area (1/16 acre, 0.33 mA/cm ²)
Temporary shutdown	end-June 1998 to mid-August 1998	Shut down due to contractual issues with vendor, Lynntech, Inc.
Operations and maintenance resumed	mid-August 1998 to October 1998	pH front just beginning to develop
Progress review	October 1998	Unknown factors were retarding performance
Operations suspended	October 1998 to January 1999	Determined that technology required further investigation
Operations resumed	January 1999 through mid-June 1999	Attempted to identify factors that were retarding performance Reduced treatment area (approx. 500 ft ² , 1.0 mA/cm ²)

Source: Fabian and Bricka, 1999 and Fabian, 1999a

density was increased from 0.2 mA/cm² to more than 0.33 mA/cm² for the reduced test area. The reduced electrokinetic extraction system was operated for an additional 10 weeks.

During March 1998 to October 1998, the system operated for 22 weeks. At the end of this 22-week period, the pH front was just beginning to appear. Another progress review was conducted at this point, and it was determined that unknown factors (either system design or site soil characteristics, or both) were retarding the performance and that the technology required further investigation and development prior to full-scale implementation. On October 7, 1998, the field demonstration was suspended.



In January 1999, operation of the electrokinetic extraction system was resumed in test cell #1 to attempt to identify the factors that may be retarding the performance of the technology and to improve design and operational parameters. To reduce operational costs, the treatment area was again reduced (to approximately 500 ft²), consisting of six anode electrodes and three cathode electrodes. The electrokinetic extraction system was operated through mid-June 1999.

Operations within test cell #2 were never initiated due to the performance problems observed in test cell #1.

Technology Performance

The remediation goals for the field demonstration at NAWS Point Mugu were:

1. To reduce metal contaminant concentrations in soil to below federal regulatory action levels for metals concentrations and toxicity criteria as measured by TCLP, California state total threshold limit concentration (TTLC), and soluble threshold limit concentration (STLC) levels
2. To reduce contaminant concentrations to modified USEPA Region IX Preliminary Remediation Goals (PRGs) that are based on human health risk assessments and established site background levels.

According to the study sponsors, lowering the contaminant concentrations in the test cells to target levels protective of human health should result in ground water and surface water levels below current EPA Marine Ambient Water Quality Criteria (AWQC) (Fabian and Bricka, 1999).

The field demonstration was monitored to verify control and containment of the electric field effects and control of contaminant migration and emissions. Process dynamics were assessed using surface water, groundwater, and soil contaminant levels measured prior to, during, and after system operation.

Prior to the initiation of the electrokinetics system operations, process control zones were established between select pairs of electrode wells to monitor the progress of the metals movement. The area between AW-10 and CW-09 was used as a control zone (Figure 2). This pair of anode/cathode wells was selected because they were in the area of highest chromium concentrations. This zone was



baseline characterized by a soil sampling in February 1998. Bulk and core samples were taken at multiple locations within this zone (Figure 3). In addition to the February 1998 soil sampling, two other soil sampling events were conducted in October 1998 and June 1999. The results of the three sampling events are presented in the cadmium and chromium contaminant profiles presented in Figures 4 and 5, respectively.

To monitor pore fluid, piezometer wells were inserted into the control zone (e.g., P1, P2, etc., in Figure 3). The pore fluid was sampled monthly starting in January 1998 and was analyzed for pH, chloride, chromium, and cadmium. The analytical results of the multiple soil and pore fluid samples were used to track the movement of the heavy metals over time. Table 3 summarizes the monitoring results for the pH front and movement of cadmium and chromium.

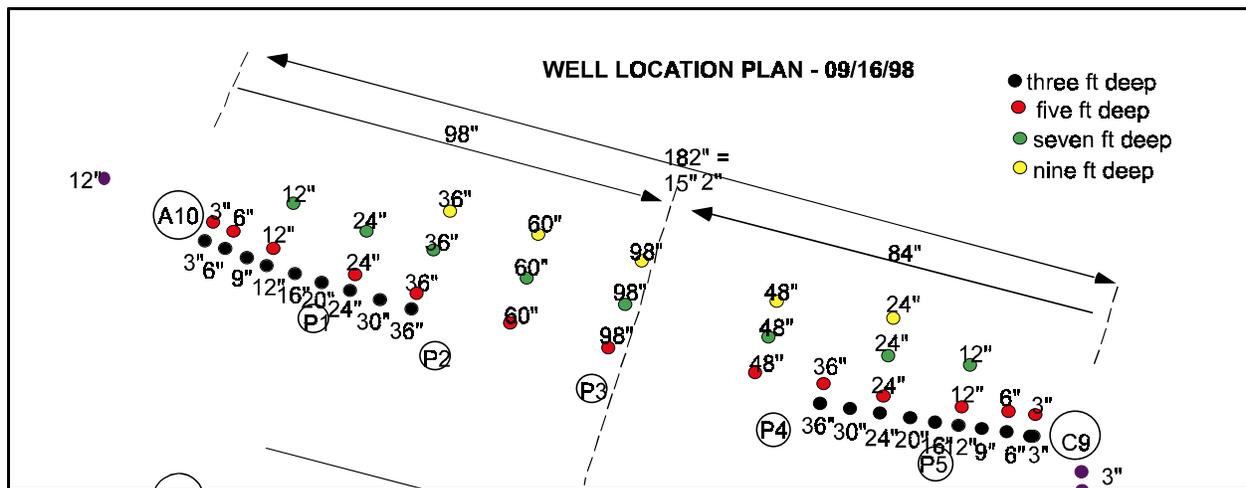
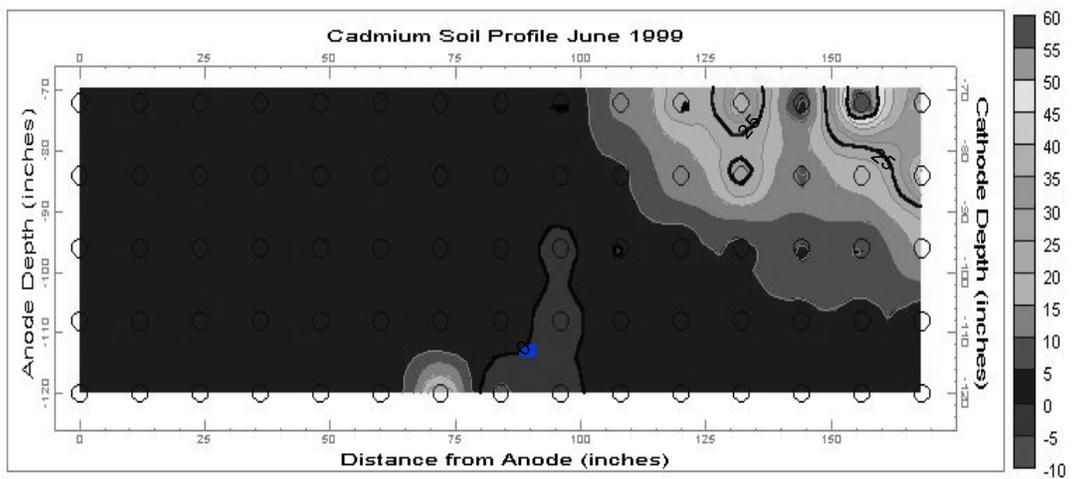
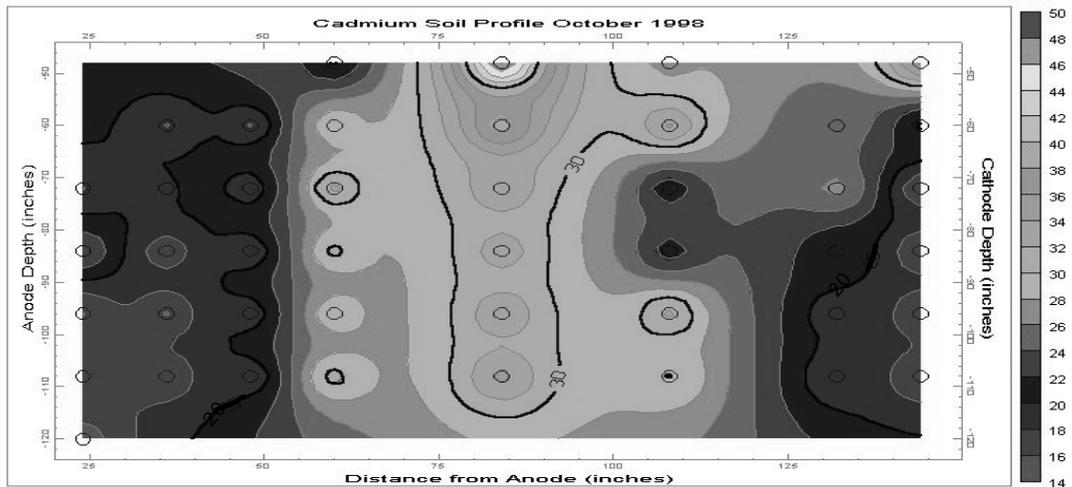
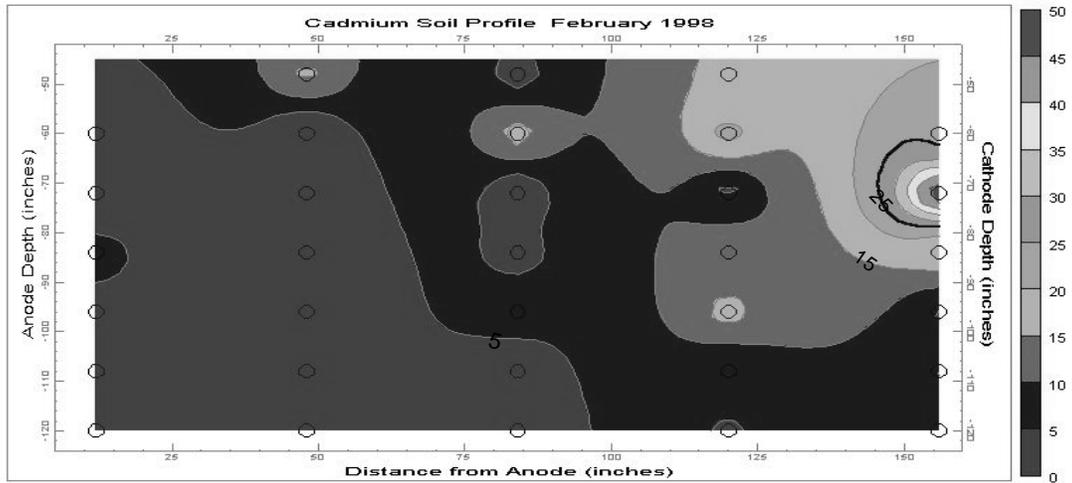
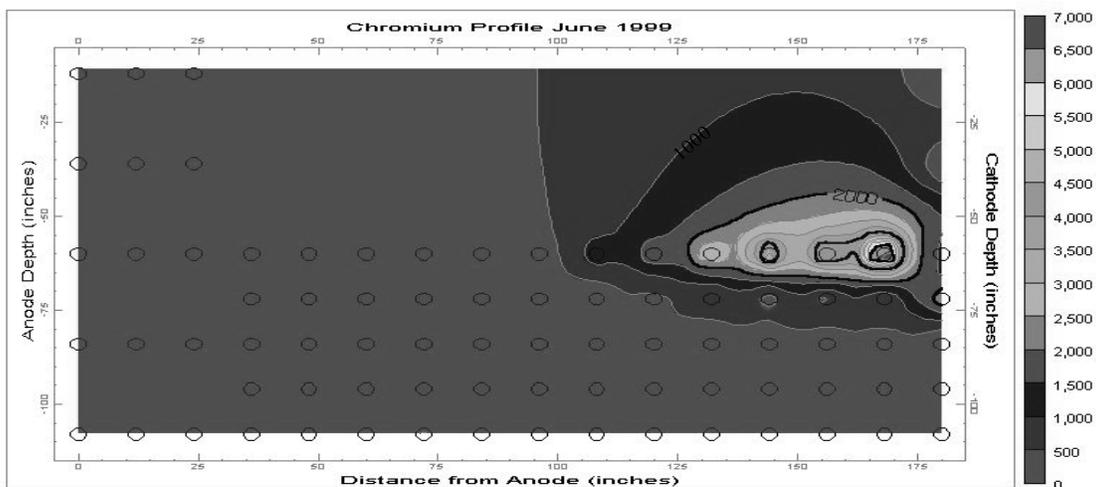
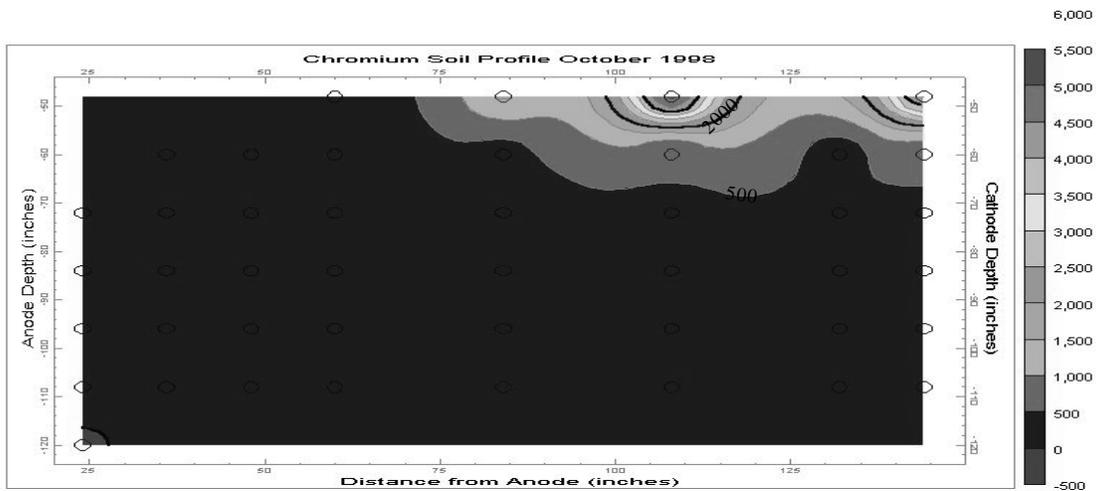
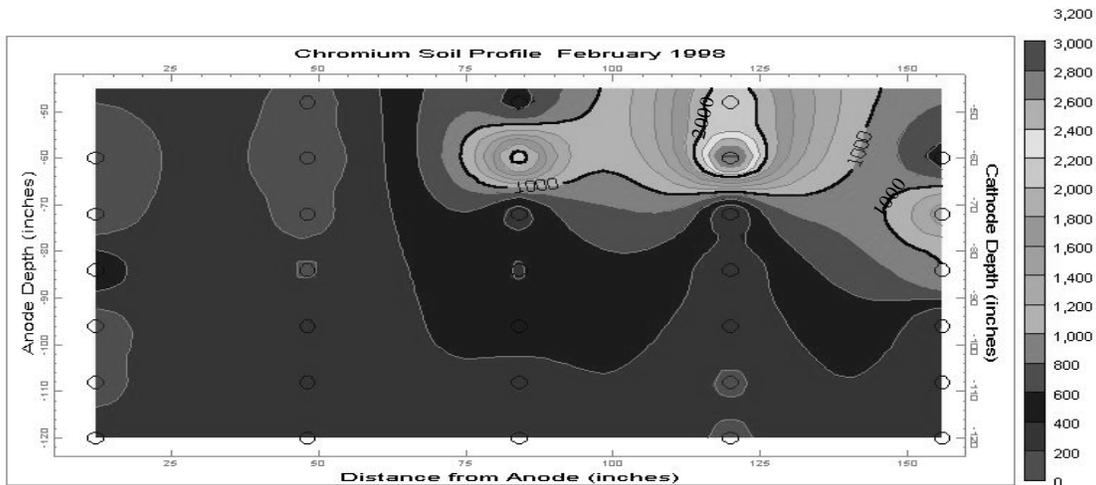


Figure 3. Sampling locations within the process control zone between anode well AW-10 and cathode well CW-09 (modified from Fabian and Bricka, 1999)



**Figure 4. Cadmium profiles from soil sampling (mg/kg)
(modified from Fabian and Bricka, 1999)**



**Figure 5. Chromium profiles from soil sampling (mg/kg)
(modified from Fabian and Bricka, 1999)**

Table 3. Monitoring Results of Control Zone Profile Between Wells AW-10 and CW-9^a

Sampling Event	pH Front	Cadmium Movement^b	Chromium Movement^c
February 1998	pH front had not developed	Peak Cd concentration (50 mg/kg) was 2 ft from cathode	Peak Cr concentration (3000 mg/kg) was approximately 5 ft from cathode
October 1998	pH front was just beginning to develop	Peak Cd concentration (50 mg/kg) was midway between anode and cathode, approximately 8 ft from cathode	Cr concentrations were increasing/migrating toward cathode Peak Cr concentrations (5000 - 5500 mg/kg) were 2 ft and 6 ft from cathode
June 1999	pH front had almost traversed control zone profile	Cd concentrations were increasing/migrating toward cathode Peak Cd concentrations (55 - 60 mg/kg) were 2 ft from cathode	Cr concentrations were increasing/migrating toward cathode Peak Cr concentration (6500 - 7000 mg/kg) was 1 ft from cathode

Source: Fabian and Bricka, 1999

- a. Refer to Figures 2 for the locations of wells AW-20 and CW-9 and Figure 3-9 for the location of soil samples in the control zone.
- b. Refer to Figure 4 for the cadmium profiles for each sampling event.
- c. Refer to Figure 5 for the chromium profiles for each sampling event.

pH Front Monitoring

The pore fluid sampling showed that the pH front was developing at the 7-ft depth of the control zone profile. At this depth the pH front was advancing more quickly than at the other depths monitored. As of June 1999 the pH front had almost traversed the control zone profile at the 7-ft depth. The saturation of the soil profile with the pH front was an important step in the electrokinetic extraction process because it enabled mobilization and subsequent transport of the metal contaminants.



Cadmium and Chromium Monitoring

The results of the baseline characterization in February 1998 showed that cadmium was seen throughout the control zone profile primarily in the upper layer of soil (0 to 5 ft deep) (Figure 4). The peak cadmium concentration was approximately 156 in. from anode, or approximately 2 feet from the cathode. The results of the October 1998 soil sampling showed that cadmium had been removed from both the anode and cathode regions and was predominantly in the center of the profile (Figure 4). The cadmium concentrations that built up midway between the anode and cathode resulted from cadmium moving away from the anode and concentrating at the midpoint. Contaminant ions do not move across the profile uniformly, resulting in this type of intermediate build up (Fabian, 1999a). The results of the June 1999 soil sampling implied that the cadmium was moving toward the surface and towards the cathode region, with concentrations increasing toward the cathode (Figure 4).

The results of the February 1998 soil sampling showed that chromium, like cadmium, was initially in the upper soil layer, approximately in the middle of the control zone profile, with concentrations up to 3,000 mg/kg (Figure 5). The results of the October 1998 soil sampling indicated that chromium was migrating towards the cathode (Figure 5). The results of the June 1999 soil sampling showed a definite trend of chromium movement toward the cathode region, with concentrations increasing toward the cathode (Figure 5).

While confirmation sampling is still required, it appears that electrokinetic remediation treatment has moved significant concentrations of chromium and cadmium toward the cathode. It is expected that continued operation of the system will transport the contaminants the remainder of the distance to the cathode well where they can be extracted.

Volatile Organics Monitoring

Monitoring was conducted during February to June 1999 to track remediation effects on existing volatile organic compounds (VOCs). Routine sampling began showing trihalomethane accumulation in the shallow piezometer wells inside and outside the defined treatment area. Subsequent sampling revealed that trihalomethanes were accumulating in the shallow breakout wells outside the barrier wall of test cell #1. Chloroform was the primary trihalomethane constituent, with concentrations in piezometer



well P-6 (refer to Figure 2 for location) ranging from 7500 $\mu\text{g/L}$ to 27,000 $\mu\text{g/L}$. Sampling of the electrode wells within the treatment area of test cell #1 showed elevated levels of trihalomethanes and free chlorine in the electrolyte solution, indicating that the electrokinetic remediation system was the source of the trihalomethanes. The maximum concentrations of the primary trihalomethane constituents in anode well AW-19 (refer to Figure 2 for location) were 165,000 $\mu\text{g/L}$ chloroform, 200,000 $\mu\text{g/L}$ acetone, and 8500 $\mu\text{g/L}$ bromodichloromethane. (Fabian and Bricka, 1999)

The conclusion that the electrokinetic remediation system was the source of the trihalomethanes was verified in a laboratory treatability test cell. The naturally occurring chlorides at the site were being electrochemically transformed into free chlorine at the anode well electrodes. The chlorine was saturating the pore fluid and reacting with the naturally occurring organic material in the shallow soil layer, which was believed to be forming the trihalomethane compounds. (Fabian and Bricka, 1999)

During May 1999 corrective actions were taken to control the trihalomethane releases. Corrective actions included periodically pumping down the electrode wells and improving anode well air sparging to remove the free chlorine generated on the electrode. The June 1999 monitoring results showed that chloroform levels decreased (from 165,000 to 9600 $\mu\text{g/L}$) as a result of these actions.

The monitoring results for chloride in the control zone profile indicated that the application of the electric field over time was drawing the mobile chloride ions from beneath the defined treatment zone into the treatment area. The concentration of the chloride ions was higher in the anode region during system operation. When the electrokinetic extraction system was turned off, the chloride ions dispersed. (Fabian and Bricka, 1999)

Technology Cost

Although one of the main factors that was to be addressed in the field demonstration was quantification of the costs associated with electrokinetic extraction, costs have not been quantified to date (Fabian, 1999b).



Summary of Observations and Lessons Learned

Based on the data collected, the electrokinetics technology only had a limited effect in the field. The assessment of the electrokinetic remediation's performance revealed many data gaps, and there is limited understanding of the factors that control performance. While positive results appear to be developing with the mobility of cadmium and chromium, many issues remain to be resolved prior to full-scale commercialization of electrokinetic extraction remediation. U.S. AEC and ERDC (Fabian and Bricka, 1999) recommended conducting further research in the following areas to understand the *in situ* dynamics of the technology:

- A better understanding of the technology's effects on naturally occurring ions and how these effects impact mobilization and removal of the target contaminants is needed. Many discrepancies between the laboratory tests and the field demonstration were identified. The retarding effects created by the naturally occurring ions can not be accurately quantified, and their effects on the type of metal species formed under the electric field influence cannot be accurately predicted. The metal species and corresponding ionic charges observed in the laboratory were different from those observed in the field. In addition, potentially hazardous by-products (i.e. chlorine, trihalomethanes, acetone, etc.) generated by applying an electric field on a soil containing these ions and means of inhibiting by-product generation requires further investigation.
- The limitation of electrokinetic remediation needs to be clearly identified. Laboratory testing may give a false indication of the applicability of electrokinetic remediation to a specific site. A means of identifying site-specific factors that limit performance needs to be developed.
- An improved methodology for predicting treatment performance needs to be developed.
- A better understanding of the electrode design and its effects on electric field shape and intensity is needed.
- An improved methodology for determining the configuration of the electrodes in field conditions is needed.

Operation of the electrokinetic extraction system at the NAWS Point Mugu site continues in order to identify and further assess the factors that retard the performance of the technology. Laboratory and pilot scale studies currently are being conducted to resolve the research needs identified above. USAEC stated that at its current stage of development, this technology is not considered to be sufficiently developed to be considered as a commercially available technology, and full-scale application is limited at best until the issues stated above can be resolved. (Fabian and Bricka, 1999)



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