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SANDIA REPORT

Adaptive Sampling Approach to Environmental Site Characterization at Joliet Army Ammunition Plant: Phase II Demonstration

Grace E. Bujewski, Robert L. Johnson

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Adaptive Sampling Approach to Environmental Site Characterization at Joliet Army Ammunition Plant: Phase II Demonstration

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ABSTRACT

Adaptive sampling programs provide real opportunities to save considerable time and money when characterizing hazardous waste sites. This Strategic Environmental Research and Development Program (SERDP) project demonstrated two decision-support technologies, SitePlanner™ and Plume™, that can facilitate the design and deployment of an adaptive sampling program. A demonstration took place at Joliet Army Ammunition Plant (JAAP), and was unique in that it was tightly coupled with ongoing Army characterization work at the facility, with close scrutiny by both state and federal regulators. The demonstration was conducted in partnership with the Army Environmental Center's (AEC) Installation Restoration Program and AEC's Technology Development Program. AEC supported researchers from Tufts University who demonstrated innovative field analytical techniques for the analysis of TNT and DNT.

SitePlanner™ is an object-oriented database specifically designed for site characterization that provides an effective way to compile, integrate, manage and display site characterization data as it is being generated. Plume™ uses a combination of Bayesian analysis and geostatistics to provide technical staff with the ability to quantitatively merge soft and hard information for an estimate of the extent of contamination. Plume™ provides an estimate of contamination extent, measures the uncertainty associated with the estimate, determines the value of additional sampling, and locates additional samples so that their value is maximized.

The primary objectives identified for the demonstration were successfully accomplished. The SERDP research team was able to generate graphics on the fly; to develop a conceptual model for the site; to direct the sampling program; and to provide estimates of contamination for the JAAP remedial action plan. We successfully coupled the adaptive sampling approach with an ongoing characterization activity that had close regulatory oversight. We also identified key technical or logistical issues. The JAAP demonstration showed that the adaptive sampling approach, as well as the specific technological decision-support tools, are acceptable within the current regulatory framework.

ACKNOWLEDGMENTS

CONTENTS

Figures

ACRONYMS

AEC	Army Environmental Center
DOE	Department of Energy
DNT	Dinitrotoluene
USEPA	United States Environmental Protection Agency
ft	feet
FAMs	field analytical methods
GC/MS	Gas Chromatography/Mass Spectrometer
IEPA	Illinois Environmental Protection Agency
IRP	Installation Restoration Program
JAAP	Joliet Army Ammunition Plant
LAP	Load-Assembly-Package Area
m	meter
MFG	Manufacturing Area
MWLID	Mixed Waste Landfill Integrated Demonstration
NT	Nitrotoluene
OHM	OHM Remediation Services Corporation, Inc.
OTD	Office of Technology Development
ppm	parts per million
QA	Quality Assurance
QC	Quality Control
RCRA	Resource Conservation and Recovery Act
SERDP	Strategic Environmental Research and Development Program
SNL	Sandia National Laboratories
SVOCs	semi-volatile organic compounds
TDP	Technology Development Program
TNT	Trinitrotoluene
VOCs	volatile organic compounds
XRF	x-ray fluorescence
yrs	years

INTRODUCTION

Characterizing the nature and extent of contamination at hazardous waste sites is an expensive and time-consuming process that typically involves successive sampling programs. The total cost per sample collected can be prohibitive when sampling program mobilization costs, drilling or borehole expenses, and sample analysis costs are all included. Traditional characterization methodologies rely on pre-planned sampling grids, off-site sample analyses, and multiple sampling programs to determine contamination extent. Adaptive sampling programs present the potential for substantial savings in the time and cost associated with characterizing the extent of contamination. Adaptive sampling programs rely on recent advances in field analytical methods (FAMs) to generate real-time information on the extent and level of contamination. Adaptive sampling programs result in more cost-effective characterizations by reducing the analytical costs per sample collected, by strategically locating samples in response to field data so that no samples are wasted, and by bringing characterization to closure in the course of one sampling program.

A successful adaptive sampling program requires two components: (1) a field analytical method applicable to the contaminants and action levels of concern for the site, and (2) a means for rapidly making decisions in the field regarding the course of the sampling program. The general purpose of this project was to demonstrate decision support technologies applicable to adaptive sampling program design and execution. The two primary technologies that were demonstrated as part of this Strategic Environmental Research and Development Program project are SitePlanner™ and Plume™. Both were originally developed and field tested with funding from DOE's Office of Technology Development.

SitePlanner™ is an object-oriented database specifically designed for site characterization work. SitePlanner™ provides an efficient and effective way to compile, integrate, manage and display site characterization data as it is being generated. SitePlanner™'s graphics include traditional maps or plan views of sites, fence diagrams, vertical profile views, bore logs, and contaminant surfaces that can be built from sample results. In the context of an adaptive sampling program, SitePlanner™ allows field staff to maintain an accurate understanding of characterization data as it is being generated. This ability is particularly important at a site such as the one used for this demonstration, where sampling crews were able to collect more than one hundred samples per day.

Plume™ uses a combination of Bayesian analysis and geostatistics to provide quantitative support for adaptive sampling programs. Bayesian analysis is based on Bayes rule, which provides a way for statistically integrating different sources of information. Geostatistical analysis allows for the interpolation of results from locations where information is present (such as sampling points) to areas where it is not. Using Bayes rule and geostatistics, Plume™ provides technical staff with the ability to quantitatively merge soft and hard information for a site. Soft information includes historical records, aerial photographs, field observations, results from non-intrusive surveys, past experience with similar sites, etc. Hard information are the results obtained from collecting and analyzing samples. Based on the information available, Plume™ estimates the extent of contamination and provides a measure of the uncertainty associated with that estimate. Plume™ also suggests the next best set of locations for sampling to reduce contaminant extent uncertainty, and also indicates the value one might expect from sampling those locations.
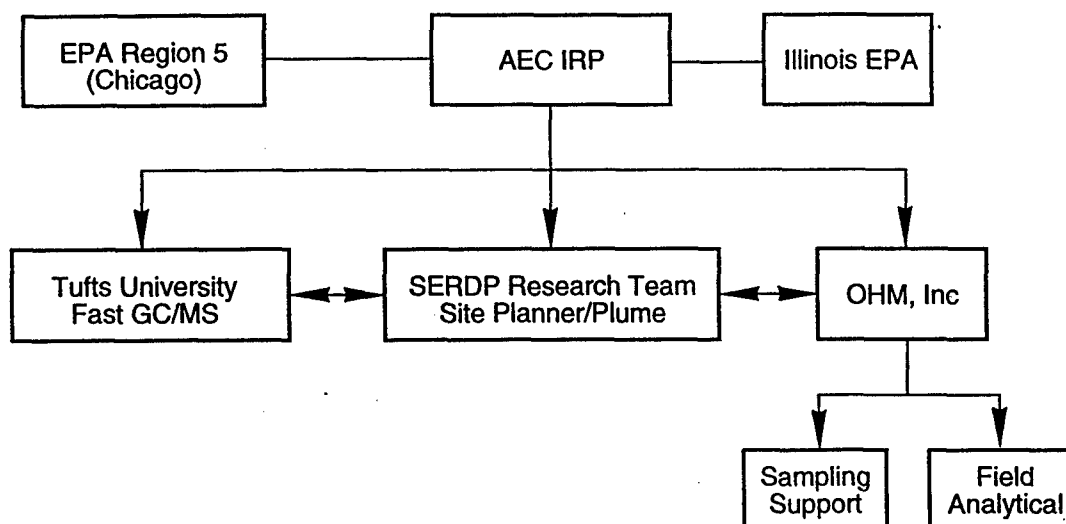
This work represents Phase II of a SERDP funded project to demonstrate the adaptive sampling methodology using SitePlanner™ and Plume™. The first phase took place in the summer of 1994 at the RB-11 site at Kirtland Air Force Base, Albuquerque, New Mexico. Details of that demonstration were reported in Floran et al., (1995). During that demonstration, the cost savings of using an adaptive sampling design were demonstrated to be significant over a conventional gridded sampling design for site characterization. For the Phase II demonstration, the SERDP research team wanted to focus on a more extensively contaminated site and further evaluate the capabilities and limitations of SitePlanner™ and Plume™, particularly exploring regulatory approval issues.

The demonstration site was the Joliet Army Ammunition Plant (JAAP). The demonstration was conducted in partnership with the Army Environmental Center's (AEC) Installation Restoration Program (IRP) and AEC's Technology Development Program (TDP). AEC's TDP supported researchers from Tufts University who demonstrated innovative field analytical techniques for the analysis of soil samples for TNT, DNT and NT. OHM, Inc., contractors for AEC's IRP at JAAP, were responsible for collecting samples in the targeted production lines, as well as conducting a broader characterization program across the TNT production area at JAAP (Figure 1). The problem of soils contaminated with explosives is extremely important from the Army's perspective. The Army has 28 ordnance manufacturing facilities with soil contamination problems very similar to those found at JAAP. Any enhancement in the characterization and restoration process at these facilities could result in significant time and cost savings.

Contained within the general purpose of showing how decision support tools can be used to facilitate the design and implementation of an adaptive sampling program, the SERDP funded work at JAAP included three objectives. The first objective was to successfully demonstrate several specific capabilities. These included: (1) the ability to fuse soft data with any existing hard data into an initial conceptual model that would initially guide the course of the sampling program; (2) the ability to provide graphics in "real time" that synthesize characterization data available to date; (3) the ability to provide sampling recommendations on the fly to field sampling crews; and finally, (4) the ability to develop quantitative estimates of the area affected by contamination. The second objective was to include this demonstration in an ongoing characterization effort that would demonstrate its acceptability to the regulatory community. The third objective for the work was to identify technical or logistical issues that require resolution for adaptive sampling programs to be truly effective.

Site Background

JAAP is a U.S. Army ordnance depot located 10 miles south of Joliet, Illinois. The installation is divided into two separate areas, the Manufacturing Area (MFG), and the Load-Assembly-Package Area (LAP) (Figure 2). The installation was constructed in the early 1940's and operated at various levels of activity through 1977. The facility is now slated for complete closure and transfer to other uses. Based on an Installation Assessment, the site was placed on the National Priority List. One of the areas of primary concern in the MFG portion of the facility was the TNT production lines (Figure 3). Results from both

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│ EPA Region 5 │─────────│   AEC IRP    │─────────│ Illinois EPA │
│  (Chicago)   │         │              │         │              │
└──────────────┘         └──────────────┘         └──────────────┘
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Figure 1. Project Organization.

surface soil and sediment samples, as well as ground water samples, indicated contamination with TNT production derivatives. Based on these preliminary results, AEC's IRP proposed a more detailed and intensive sampling effort to determine the nature and extent of explosives contamination in surface soils within the lines (OHM, 1995). The conclusions drawn from this sampling program will directly support the design of a remedial action for the TNT production area.

The TNT production area consisted of 12 TNT production lines, organized into 6 pairs. Figure 4 shows the physical layout of Line #5. Each production line included a series of "houses" that performed a step in the production process, and that were connected to other houses by overhead pipe lines. Examples were the "Mono-", "Bi-", "Tri-nitration" houses, a wash house, and an acid and fume recovery house. Packing houses and transfer facilities were also part of the production areas. Each pair of production lines also included a smaller, independent DNT production line. During the production process, wash and waste waters were typically discharged via small surface drains to the TNT ditch. The TNT ditch traversed the area from the north to the south and emptied into Grant Creek. In 1965, a flume was constructed parallel to the ditch that captured the waste water and transported it to an incinerator complex located at the southern end of the production line complex.

The objective of the characterization work proposed by OHM for the TNT production lines was to determine the extent and level of explosives contamination in soil. The original OHM scope of work called for a combination of gridded and adaptive sampling, with field analysis performed using D TECH^{TM} TNT test kits, a gross field screening technique for TNT based on immunoassay technologies. Approximately 750 samples were to be collected in the TNT production area. These represented approximately 375 sampling locations, with two samples at different depths taken from each location. The gridded samples in the TNT production line were assigned to a very coarse grid (500 foot spacing between sampling locations). The adaptive samples were to be located based on visual inspection of the production lines and ditch areas. The original scope of work assumed that the judgmental samples would be distributed equally among the production lines.
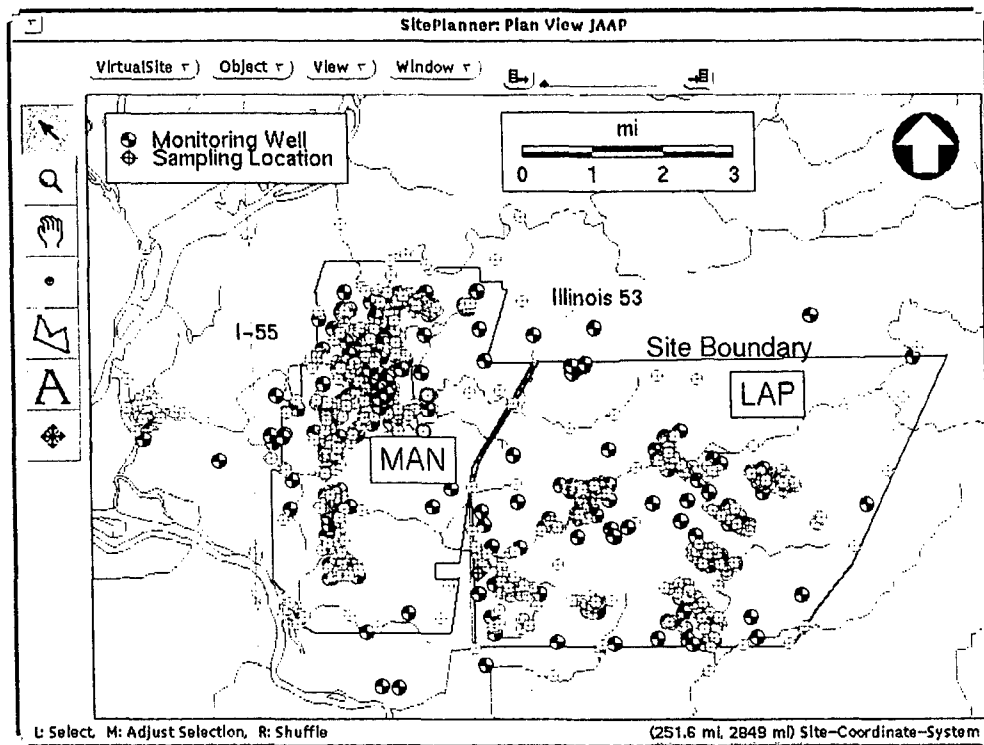
Figure 2. Joliet Army Ammunition Plant.

Figure 3. The TNT Production Area.

TNT Line 5

DNT Production Line

Pipes

Drainage Feature

Tri-Nitration House

Mono-Nitration House

Wash House

Acid and Fume
Recovery House

Bi-Nitration House

Rail Tracks

TNT Ditch

Packing and Loading House

Conveyor

Red Earth Area

Roads

ft

0   100   200   300
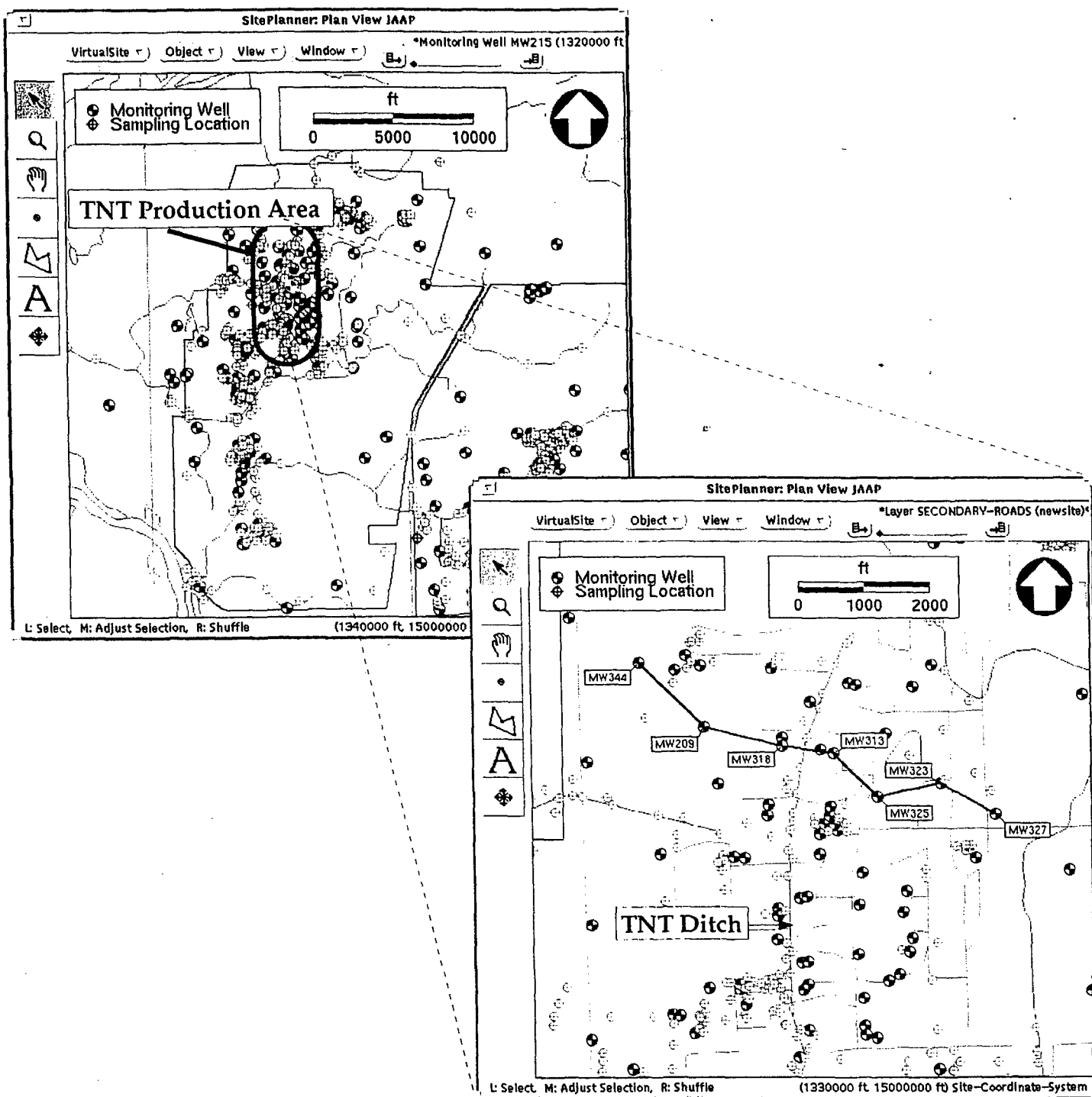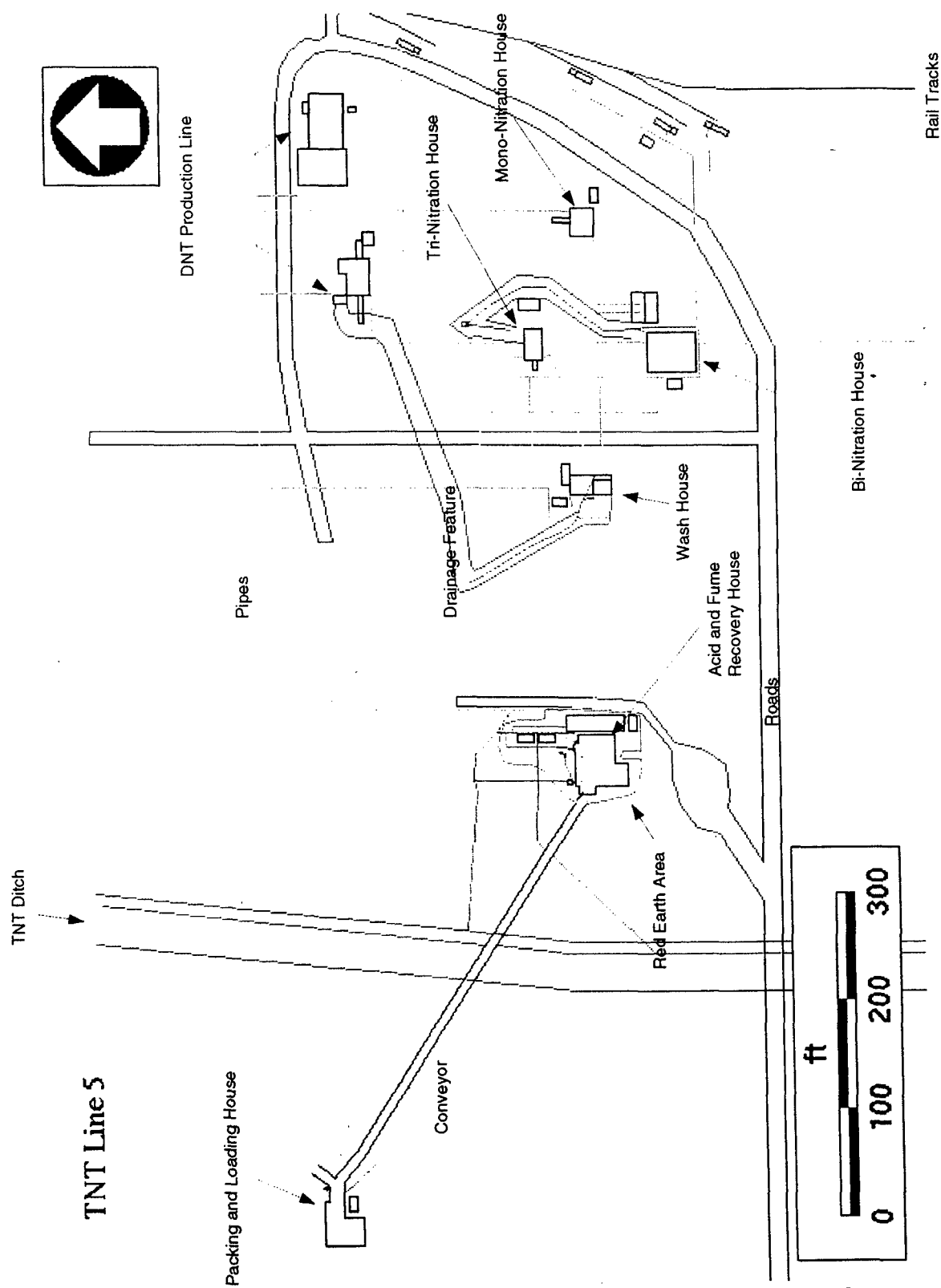
Figure 4. TNT Production Line #5.

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Figure 5. Dr. Bob Johnson, ANL, and Bob Bowden, U.S. EPA Region 5, in the TNT Manufacturing Area at JAAP.

METHODOLOGY

The demonstration work funded by SERDP was designed to both demonstrate enhancements to the proposed OHM work plan and to complement OHM's planned activities in the areas of decision support. Supporting all of OHM's planned sample collection and analysis activities was beyond the scope of work for this SERDP project. Instead, the attention of SERDP researchers focused on four of the 12 TNT production lines. The SERDP team also worked closely with Tufts University researchers. The original objective of the Tufts effort was to demonstrate several different field analytical methods for determining levels of TNT, DNT and NT in soils, and to compare these different techniques on the basis of their accuracy, adaptability to field conditions, completeness of analyses, and cost of implementation. In addition, for the samples collected from the four selected production lines, Tufts provided rapid turn-around of sample analyses to support the SERDP sampling program design process. All data presented in this report are based on Tufts "fast GC/MS[†]" analyses.

There was relatively tight coordination between SERDP researchers, Tufts University research staff, OHM's project personnel, AEC's IRP officer, USEPA Region V and the Illinois EPA. This coordination was essential to guaranteeing regulatory acceptance of the technologies and their results in the context of the work at JAAP, and to ensuring that the results from the use of the technologies did provide value to OHM's overall scope of work.

After consultation between SERDP researchers, EPA, and AEC, the adaptive sampling portion of OHM's original work plan (OHM, 1995) was revised to accommodate the inclusion and demonstration of SitePlanner[TM] and Plume[TM]. Recognizing that the number of samples available to characterize the production lines was insufficient to determine the extent of contamination at each and every line, a decision was made to follow a three-phase approach. This approach was based on the belief that, because the lines shared a common design and involved identical production processes, the patterns of contamination in each line should mirror the rest of the lines.

The first phase consisted of selecting two lines from the TNT production line area, Lines #2 and #5. A detailed conceptual model was developed for these two lines (Figure 6) (Bujewski, 1995). The conceptual model for each line attempted to delineate areas of high and low contamination probability, based on the information available for each line. Sampling began with these lines, with approximately 90 locations allocated per line (Figure 7). These 90 sampling locations were broken into three sequential groups. The first 30 were placed to verify that areas that were thought to be contaminated actually were. After the first 30 had been sampled, a second set of 30 were selected to delineate the extent of contamination where it was found. The final 30 sampling locations, selected after the second set of 30 had been sampled, were used both to finalize the delineation of contamination, and to verify that areas where contamination was thought

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[†] There are two primary differences between the GC/MS methodology employed by Tufts researchers and standard GC/MS techniques for explosives. The first is the use of thermal desorption. More importantly, however, is the use of ion fingerprint detection software (patent pending) that is capable of providing compound spectrum detection in the presence of multiple coeluting organics. This capability allows analysis cycle time that is less than three minutes per sample, as compared to traditional GC/MS techniques which, in the case of explosives, require 20 minutes or more per sample.
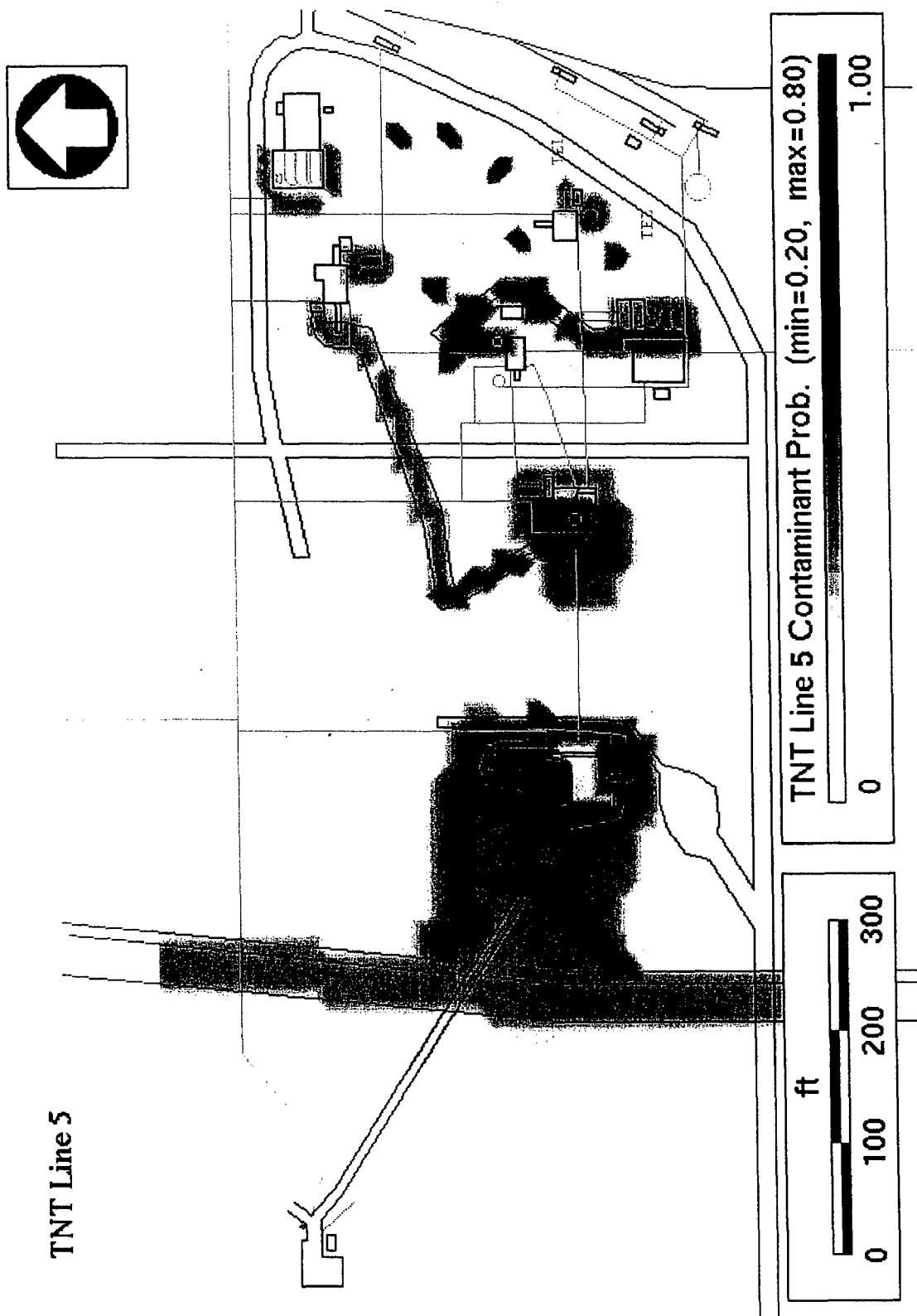
Figure 6. Initial Conceptual Model for TNT Production Line #5.

Figure 7. OHM Sampling Crew Member collects soil samples by hand auger adjacent to the flume in the TNT Manufacturing Area.

unlikely were indeed clean. Sample groups were broken into sets of 30 for two reasons. First, this was the approximate number of samples that one crew could collect in one day. Secondly, for the initial round of sampling when areas believed to be contaminated were targeted, 30 samples allowed coverage of the main areas of concern in the production line.

One of the advantages that Plume™ brings to adaptive sampling program design is its ability to fuse soft information into an initial conceptual model for a site, and then to base the selection of sampling locations on that initial conceptual model. The availability of a good initial conceptual model is crucial for the efficient design of the adaptive sampling program. It is one of the primary reasons that adaptive sampling programs often significantly out-perform gridded or random sampling program designs. The development of conceptual models for the two selected lines was based primarily on careful surveying conducted as part of this SERDP-funded project. The surveying targeted features in each of the lines that would have been expected to have an impact on contamination distribution. The locations of overhead pipe lines, storage tanks, buildings, drainage ditches, and natural topographic depressions were all carefully mapped. These data were then incorporated into a SitePlanner™ virtual site for the production lines. Figure 4 shows the results for Production Line #5 in the TNT production area. Based on these maps, each of the two lines was broken into four areas, areas where contamination was highly likely, areas where contamination possibly existed, areas where contamination probably did not exist, and finally areas where contamination was highly unlikely. These areas were used to create a Plume™ initial conceptual model for each of the two lines. Figure 6 shows the Plume™ conceptual model for TNT Production Line #5.

After Lines #2 and #5 had been completely sampled, the second phase of sampling began. In the second phase an additional two production lines were selected from the TNT production area, lines #4 and #9, and sampling was designed to verify that the patterns of contamination observed in the initial set of heavily studied lines was also present in those lines. Approximately 30 sampling locations were allocated per line for the second phase. The third phase consisted of cursory sampling in the balance of the lines, looking for anomalies that might make those lines different from the first few lines that were heavily sampled. The involvement of SERDP researchers ended with the completion of the second phase of the work. OHM completed the remaining third phase.

One of the primary challenges in successfully staging and completing an adaptive sampling program is logistics. Adaptive sampling program costs are usually measured on a per day basis, rather than a per sample basis, since sampling crews and field laboratories are billed on a daily basis. Total sample collection and analysis costs are determined by the productivity of the sample collection crews and the field laboratories. To keep per sample costs to a minimum, the output rate of sample collection crews and the throughput rate of field laboratories must be matched. This was a particular challenge in the case of JAAP, since OHM deployed three sample collection crews capable of generating more than 100 samples per day. Underutilized labs result in idle lab time. The effects of underutilized sampling crews (i.e., over booked field labs) can be even worse, since the pressure in that case is to continue sampling without the benefit of the results from previously sampled locations. In this case one of the primary benefits of adaptive sampling programs, smart sampling location selection predicated on previous sample results, is lost.

At JAAP, the SERDP team selected, flagged and surveyed locations to be sampled in the production line areas. OHM sampling crews sampled these locations, and split the samples. One set of the split went to the OHM field chemists who analyzed the samples with D TECH™ TNT field test kits. D TECH™ kits and DTECHTOR Analysis Meters are capable, over a limited dynamic range, of quantifying total explosive contamination within soil samples. The second set of the split went to field chemists from Tufts University who primarily used "fast GC/MS" technology to provide a more detailed analysis of the samples. Based on the Tufts sample results, the SERDP team selected the next batch of sampling locations.

OHM's field chemists were deployed in a trailer at the TNT production lines. Tufts University staff members were housed with their equipment a few miles away from the production lines in a secured building that had commercial, permanent power supplies. SERDP staff members worked out of a field trailer adjacent to the OHM trailer and relied on OHM's diesel generator for power. The data management and analysis for the SERDP portion of the project used both a workstation deployed in the trailer on site, and workstations at Argonne National Laboratory, approximately thirty miles from the site.

SERDP team members participated in briefings held for USEPA Region V, IEPA and AEC staff during the course of the sampling work in the TNT area. SERDP team members also worked closely with both OHM field team members, OHM project members, and Tufts University researchers through field consultations and conference calls. SERDP team members were responsible for selecting the sampling locations in the first two phases of the production line sampling work, and provided graphics used during the USEPA/IEPA/AEC briefings.

RESULTS

Sampling Results

The discussion in this section focuses on the results observed from sampling Line #5. Although the results from lines #2, #4 and #9 are not included, they mirrored the results obtained from Line #5.

Figure 4 shows the results from the initial surveying for TNT Production Line #5, while Figure 6 shows the resulting Plume™ conceptual model. Areas of high contamination probability found in the initial conceptual model were typically associated with surface soils that were stained red (a common artifact of soils contaminated with high levels of TNT). Areas of above average contamination probability corresponded to areas such as surface drainage lines, areas of stressed vegetation, and areas immediately adjacent to production line features that put them at risk for contamination. Areas where contamination probably did not exist were areas that lacked visual evidence of contamination, and that were not adjacent to any high risk buildings or drains. Areas that were classified as having a low probability of contamination were areas that showed no visible signs of contamination and that were physically removed from the production process.

Using Plume™'s probability map for the lines, one can set certainty levels and estimate the lateral extent of soils that would be classified as contaminated at that probability level. At the outset, when hard data is lacking, the probability map captured by the initial conceptual model is based on best judgment, using whatever soft information is available. As samples are collected and the initial conceptual model updated with hard data, the probabilities eventually reflect primarily the hard results. For example, with the initial conceptual model in TNT Production Line #5, if one identified all soils with greater than 0.7 chance of being contaminated and neglects soils immediately adjacent to the TNT ditch, the contaminated surface area would be 6,400 square feet. If one identified all soils with greater than a 0.5 chance of being contaminated, the area grows to 27,800 square feet (Figure 8).

Figure 9 identifies the initial round of 30 sampling locations selected for line #5, with the locations overlying the initial conceptual model for the site. These locations were selected to maximize the chance of encountering contamination based on Plume™'s initial conceptual model developed for this line. Two samples were collected from each sampling location, one at the surface, and a second at a depth of one to two feet. Figure 9 also shows the maximum contamination value encountered at each location using analytical data from Tufts "fast GC/MS" analysis that represents the summation of TNT, DNT and NT concentrations found in the samples. A similar set of 30 sampling locations was selected for Line #2.

After OHM had sampled the initial set of locations in Lines #2 and #5, a second set of approximately 30 locations were selected from each of these two lines. These were selected to delineate contamination that was encountered in the first round of sampling. Figure 10 shows the locations of these new sampling points for Line #5 and the maximum concentration observed at each location, along with "hits" from the first round (a "hit" was defined as TNT values greater than 200 ppm, or DNT values greater than 10 ppm).

TNT Line 5

▨ Probability of Contamination > 0.5

■ Probability of Contamination > 0.7

ft
0   100   200   300
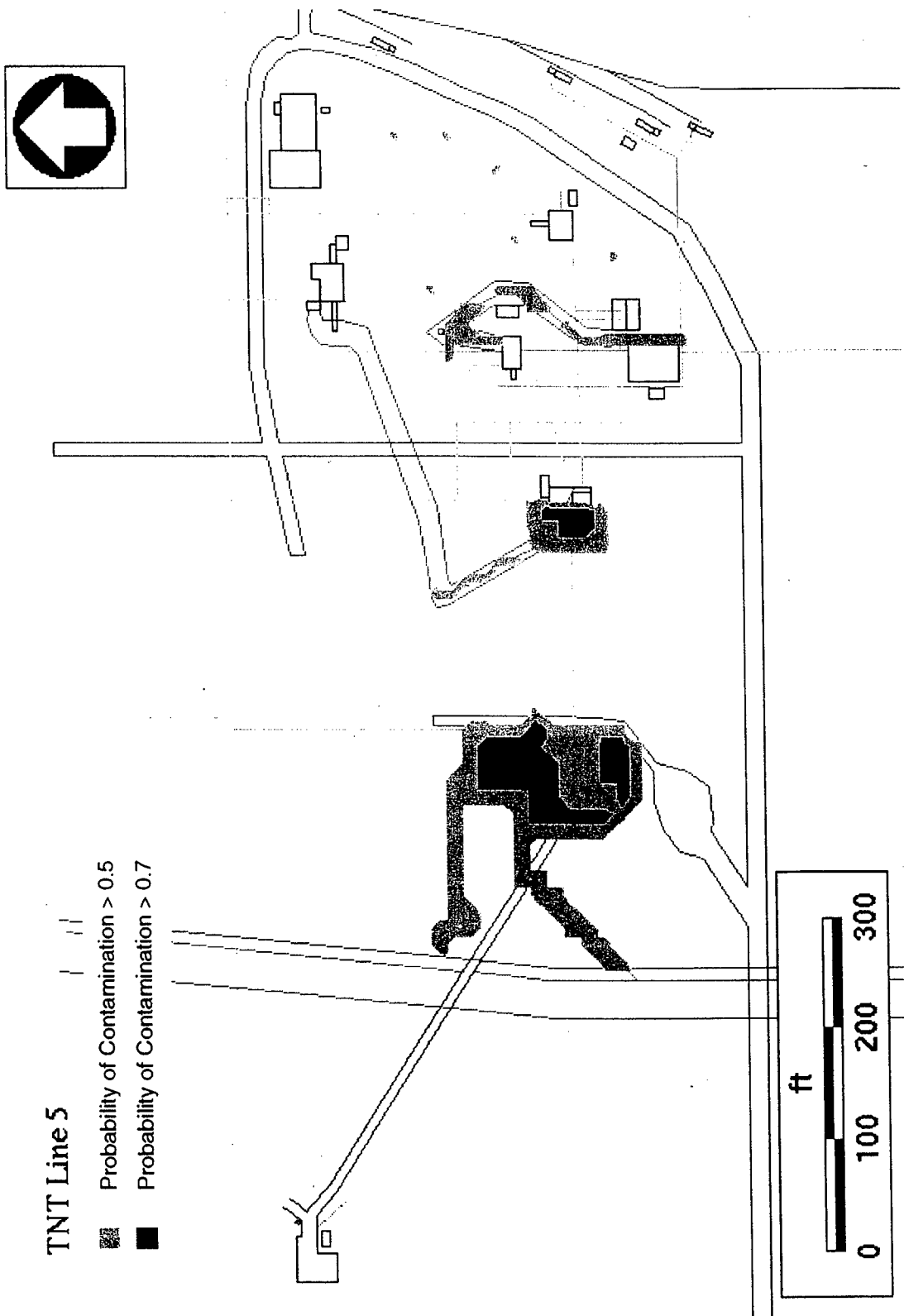
Figure 8. Presumed Contamination Extent.

14

Figure 9. First Round Sampling Results.

TNT Line 5

ND, 10.0 mg/kg, 47 mg/kg, 630 mg/kg, 2000 mg/kg, 79 mg/kg

ft
0   100   200   300
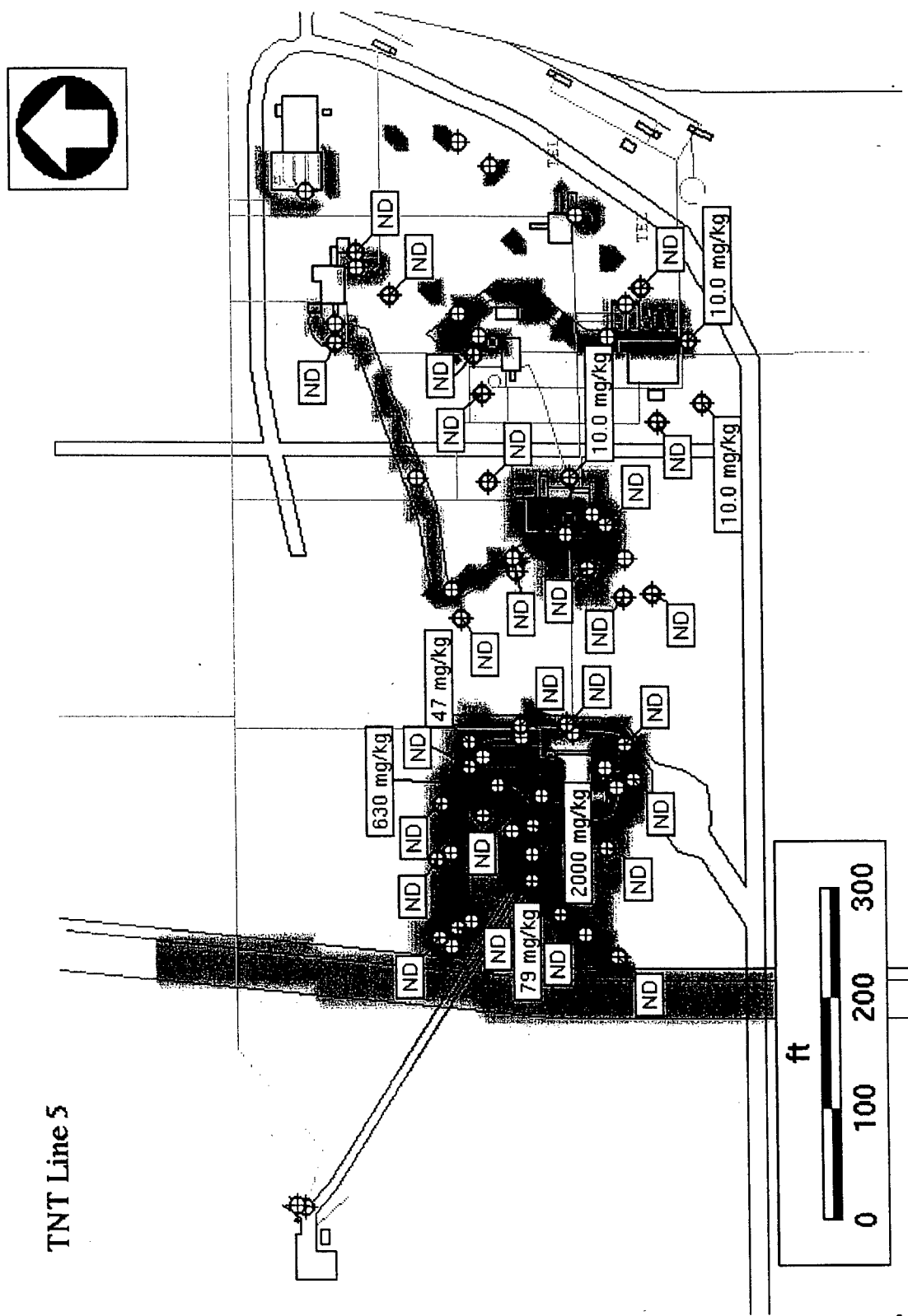
Figure 10. Second Round Sampling Results.

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These samples should have been either paired with "hits" from the first round of sampling, or otherwise located to bound the lateral extent of contamination. The inavailability of a complete data set at the time of new sampling location selection forced selection of some points without the benefit of earlier sampling results. Figure 11 shows the final selection set of 30 points for Line #5, their results, along with the "hits" encountered in the first two rounds of sampling.

Several items of interest arise from these data. First of all, because of logistical problems, complete data sets for the first set of samples collected from Lines #2 and #5 were not available for one week from the start of sampling. Consequently, the second round of samples had to be selected before all of the first round results came back. Of the thirty samples located in Line #5 in the second round, at least 8 samples were "wasted" in the sense that they were paired with previously sampled locations whose results were still unknown at the time the second round was selected, but that later turned out to be uncontaminated. By the time the third round of sampling locations was selected, coordination between OHM staff, Tufts researchers, and the SERDP team had improved to the point that the final set of samples could be based on the locations sampled up to that time.

Secondly, the soil contamination associated with the lines is predominately associated with the acid and fume recovery houses and the wash-out houses. These are also the areas that show the greatest signs of red earth staining. Apart from these two areas, contamination appears to be spotty and localized, predominately associated with man-made drainage ditches that would have carried overflow, waste and wash-out water away from line houses. In fact, of the 24 hits in Line #5, all but two were associated with either the acid recovery/washout houses or drainage features. TNT contamination can lead to stressed vegetation. While there were clearly areas of stressed vegetation in these two lines, none of the samples collected from these areas indicated elevated levels of explosives in the soils.

Thirdly, the data that was collected provided a good estimate of contamination extent in Line #5. Based on the initial conceptual model and the data collected for Line #5, a best guess estimate of the area contaminated but not associated with surface drains is 14,600 square feet. If one assumes a six foot width of contamination associated with the drains, this figure grows to 21,200 square feet. This does not include contamination associated with the TNT ditch, or areas west of the ditch.

Fourthly, and perhaps most importantly, the initial conceptual models for both lines #2 and #5 were an excellent predictor of the presence or absence of contamination. Figure 12 summarizes the data collected for line #5, with the results superimposed over the initial conceptual model. In line #5 there were 92 samples taken within the conceptual model's domain. Of the 10 samples taken within red earth areas (the areas in the initial conceptual model that were believed to be most likely contaminated with a probability of contamination 0.8), 8 (80%) produced TNT results greater than 200 ppm. Of the 36 samples collected from areas thought to have a probability of contamination equal to 0.6, 14 (36%) produced hits. Of the 31 samples taken from areas less likely to have contamination (probability of contamination 0.4), none encountered contamination at levels of concern. Finally, of the 15 samples taken from areas thought to have a low probability of contamination (0.2), only one (7%) encountered TNT contamination above 200 ppm.

TNT Line 5

Figure 11. Third Round Sampling Results.

TNT Line 5

⊕ Samples with TNT values < 200 ppm

⊕ Samples with TNT values > 200 ppm
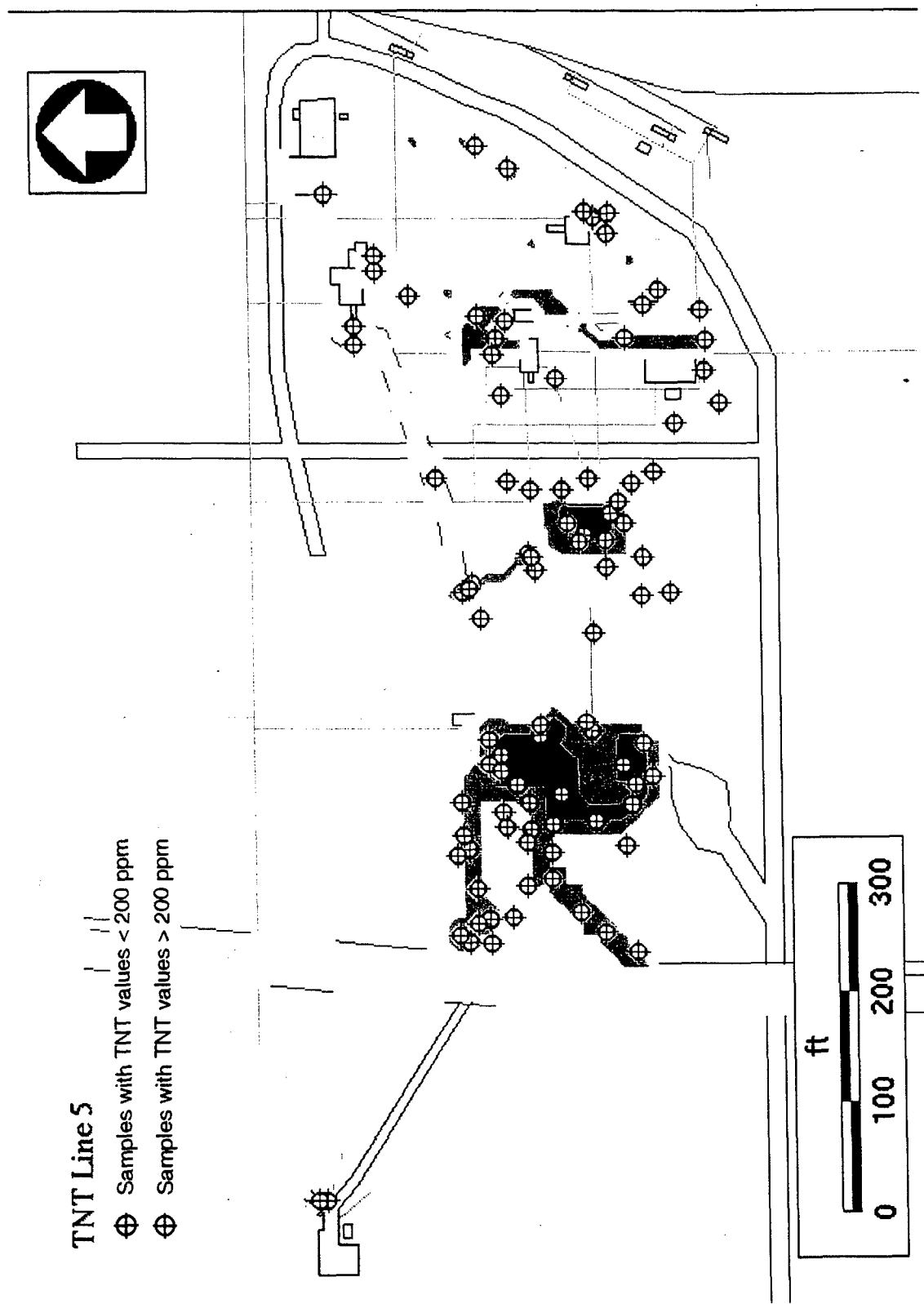
ft

0   100   200   300

Figure 12. Summary of Sampling Program Results for Line #5.

In general, this underscores the absolute importance of basing sampling decisions on whatever soft information is available for a site. In the case of JAAP and its TNT production lines, this finding is even more significant since it suggests that one may begin delineating TNT contamination by initially focusing on visible red earth areas and surface drainage ditches. If one had used only the red earth areas and known ditches for line #5 without any sampling, the estimate of contaminated areas would have been 16,000 square feet, which is 75% of the surface area identified by sampling. Two areas that produced samples with TNT hits would have been missed, but these two areas represented a minimal surface area.

Technology Demonstration Results

The demonstration was a success from the standpoint of the technologies and methodologies brought to the project with SERDP funding. There were three objectives for the SERDP work. The first objective was to demonstrate four decision-support technical capabilities that are important to the success of an adaptive sampling program. The first was the capability to produce graphics in "real-time" that synthesized sampling program data. Graphics from SitePlanner™ were generated as data from the field became available. These graphics assisted in the selection of new sampling locations, served as field maps for survey crews required to locate the new sampling points in the field, and ultimately became the basis for periodic discussions with AEC staff, IEPA and USEPA regulators, Tufts researchers and OHM field staff about the results that were returning and their significance. Although there was the capability in the field for generating graphics, because of the number of copies required most of the hardcopy graphics were produced at ANL and distributed at the site as the work progressed.

One example illustrates how important good graphics are for the success of an adaptive sampling program such as the one at JAAP. The initial assumption was that TNT contamination would be primarily surficial. A second sample was taken at a depth of one to two feet to estimate depth of penetration. Throughout the course of initial sampling, however, some locations yielded surface samples that were clean, and samples at depth that were highly contaminated. This troublesome finding was a topic of a joint meeting with the USEPA, IEPA, AEC and OHM staff, Tufts and SERDP researchers. A quick review of maps generated for the meeting showed that most such anomalous locations were immediately adjacent to surface drainage features. While the exact mechanism that resulted in this contamination pattern is not clear, the fact that it was confined to drainage lines allowed sampling away from drainage features to focus on surface samples.

The second was the capability to quantitatively incorporate soft information into the sampling program. Detailed conceptual models based on production line surveys were developed for two TNT production lines. These initial conceptual models were the basis for the initial set of sampling locations that were selected. As discussed earlier, these initial conceptual models successfully located the bulk of surficial soil contamination. This, in turn, dramatically changed the emphasis of additional sampling from determining the extent of contamination to confirming what had already been deduced from soft information.

The third was the capability to provide "on-the-fly" additional sampling locations based on previous sampling results. Logistical problems at times forced sampling decisions to be made without the benefit of

all of the results from previous rounds of sampling. Of the three rounds of sampling conducted at Lines #2 and #5, the first set of sampling locations and the last set were grounded in good prior data. The second set had to be selected based on spotty results from the first round, and this fact was reflected in inappropriate locations for some of the round two samples. Eight of the 30 second round samples from Line #5 were collected in areas that were later established as clean by first round results.

The final capability to be demonstrated was the ability to provide quantitative measures of contamination extent as the sampling program progressed. The use of Plume™ in developing a spatially accurate initial conceptual model allowed for initial contamination extent estimates that in retrospect were remarkably good. The data collected as part of the sampling work in line #5, along with the initial conceptual model, allowed an accurate estimation of contamination extent for that line.

The second objective of the SERDP work was to conduct the demonstration within the framework of an actual characterization program so that its acceptability to regulators could be evaluated. The SERDP effort was tightly woven into the overall characterization effort at JAAP. When initially proposed to AEC, the SERDP-funded work was designed simply as an add-on piece of work that was relatively independent of OHM's scope of work. However, by the time the field work started, with USEPA's encouragement SERDP-funded technologies were integral to the overall effort. For example, initial sampling in the TNT production lines was based on the initial conceptual models developed by SERDP researchers. Subsequent rounds of sampling in those lines also were based on recommendations developed by SERDP researchers. Graphics that were generated with SitePlanner™ were used extensively in the field to site new sampling locations, and were used as supporting evidence for data discussions that involved state and federal regulators. The final characterization report planned by OHM will include an appendix that summarizes the SERDP effort and its conclusions. The progressively more active role of SERDP researchers was encouraged by both the state and federal regulators involved with the site, primarily because of the perceived benefits of the technologies made available with SERDP funding.

The third objective of the SERDP work was to identify areas that are of special concern for the success of adaptive sampling programs. Three issues arose during the course of the demonstration. The first was the ability to quickly and accurately map key site features, including existing and proposed sampling locations. SERDP team members at JAAP used state-of-the-art surveying equipment to accomplish this. At JAAP, two-man survey crews were able to locate more than 300 points per working day, a capacity that was more than sufficient for the needs of the sampling work.

The second issue was proper matching of sampling crew production rates with field laboratory throughput. In the case of JAAP, partly because of the involvement of SERDP researchers which simplified the selection and identification of new sampling locations in the field, OHM sampling crews were able to generate more than 100 samples per day. At the outset, this far exceeded the analytical ability of OHM's field laboratory. Towards the end of the sampling work, the throughput rates for OHM's field lab finally approached the sampling crews' production rates. The effects of too little laboratory capacity are more problematic than that of unused laboratory capacity. Overbooked field laboratories (i.e., underutilized field crews) result in pressure to select new sampling locations before data from previously sampled locations are available.

The third issue was the importance of a tight, well-defined data management process that governs the flow of data from field crews through field laboratories and finally into data management and decision support systems such as SitePlanner™ and Plume™. In the case of JAAP, data passed hands several times before reaching SERDP researchers. These data included chain-of-custody records that were necessary to match sample identifiers with sampling locations already existing in SitePlanner™, survey information that correctly located those sampling locations, and GC/MS results. Problems and delays in coordinating this data flow, while inconsequential in a traditional sampling program where nothing immediate depends on sample results, proved critical when attempting to select new sampling locations for the production lines. In the case of JAAP, logistical problems forced the selection of second round sampling points before a complete data set was available from the first round. Consequently, some of the second round sampling points were "wasted" in the sense that their locations were incorrect. Again, by the end of the sampling work, most of the kinks had been worked out so that data moved quickly and smoothly.

POTENTIAL COST SAVINGS

There are principally four ways adaptive sampling programs such as the JAAP program can save money. The first is in reducing the cost per sample analyzed by making use of field analytical methods. The second is in reducing the number of samples collected by focusing sampling on areas that merit attention based on the field analytical results. The third is by eliminating return trips to the field. The last is by producing a better characterization. The last becomes particularly important when restoration moves into remedial action design and execution. Better characterizations in this context mean ensuring that only soils that are truly contaminated are targeted for remediation—i.e., not remediating clean soils inadvertently, and not leaving contaminated soils behind.

In the case of Joliet, a couple of different field analytical techniques were used for quantifying TNT contamination. Assuming a through-put rate of 100 samples per day, the DTECH kits cost approximately $50 per sample analyzed when staff time and kit costs are included. Tufts "fast" GC/MS technologies cost approximately $25 per sample analyzed when staff time and equipment costs are included. In contrast, off site analyses are on the order of $225 per sample.

The number of samples collected at Joliet was not changed from the original work plan, so there were no savings in total sample numbers. What did change was the way in which those samples were placed, which in turn resulted in a better characterization. As an example, if in Line #5, 96 sampling locations had been placed in a regular grid over the area of concern, the spacing between sampling locations would have been on the order of 75 feet. Of these 96 samples, only 3 would have encountered contamination. All three of these would have been in the Acid and Fume Recovery House area. Five other areas where contamination was encountered in the course of the adaptive sampling program would have been missed completely. The three samples that would have encountered contamination would have provided little information on the actual extent.

COMMERCIALIZATION STATUS OF PLUME/SITE PLANNER

SitePlanner[TM] and Plume[TM] are available for purchase from ConSolve, Inc., and can be run on a PC running SCO Unix or a Sun workstation running Open Windows. ConSolve holds the license and copyright for SitePlanner[TM]. The University of Chicago holds the copyright to Plume[TM], and ConSolve has a limited license to market Plume[TM].

Dr. Johnson developed Plume[TM] using Department of Energy Office of Technology Development funding over the past several years. Dr. Johnson was able to beta test Plume[TM] using characterization data from a SNL demonstration site and from the SERDP-funded demonstration in 1994 at the Kirtland Air Force Base RB-11 site.

CONCLUSIONS

Adaptive sampling programs provide real opportunities to save considerable time and money when characterizing hazardous waste sites. This SERDP project demonstrated two decision-support technologies, SitePlanner™ and Plume™, that can facilitate the design and deployment of an adaptive sampling program. The actual demonstration took place at Joliet Army Ammunition Plant, and was unique in that it was tightly coupled with on-going Army characterization work at the facility, with close scrutiny by both state and federal regulators.

Three primary objectives were identified for the demonstration, and all three were successfully accomplished during the course of the field work. SERDP researchers demonstrated key decision-support capabilities at JAAP. These included the ability to generate graphics necessary for the sampling program on-the-fly; the ability to quantitatively develop an initial conceptual model for the site based on soft information; the ability to provide direction to the sampling program as it progressed; and the ability to provide good estimates of contamination extent that will be used during the design of a remedial action at the TNT production lines.

The SERDP demonstration identified key issues that are important to successfully mounting an adaptive sampling program. These included the ability to quickly and accurately locate points in space, correctly matching sampling crew production rates with field laboratory analysis capabilities, and finally efficient data management protocols that quickly and smoothly move data from sampling crews through laboratories until it is finally integrated with software packages such as SitePlanner™.

Finally, and perhaps most importantly, the work at JAAP demonstrated that the general approach of adaptive sampling programs, as well as the specific technological decision-support tools contributed with SERDP funding, is acceptable within the regulatory framework. In the case of the work at JAAP, the SERDP funded technologies had the support of the state and federal regulators involved, and became crucial components in the design and execution of the field work.

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