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Economical Site Characterization Using High-Resolution Passive Soil Gas Sampling

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ABSTRACT: Solid waste management units (SWMUs) at Arnold Air Force Base (Base), Tennessee, are undergoing a RCRA Facility Investigation (RFI) to evaluate the nature and extent of soil and groundwater impacted by releases of volatile organic compounds (VOCs) and mercury. Base testing activities over the years have lead to potential releases of contaminants to the soil and groundwater, and these release areas were not clearly identified prior to the start of the RFIs. The SWMUs are located within the Base's heavily industrialized area, which includes numerous surface and subsurface structures and utilities. Due to site access limitations, the large size of the SWMUs (more than 50 acres), and associated high investigation costs, traditional soil and groundwater sampling methods were not utilized. Instead, passive soil gas (PSG) samplers (GORE^{TM} Modules) were deployed across each site to delineate source areas and approximate the extent of the contaminants in the subsurface. Beginning in July 2004 through March 2006, nearly 1,000 PSG samplers were deployed at the Engine Test Facility (ETF; SWMU 102) and the Propulsion Wind Tunnel (PWT; SWMU 102) areas. The PSG results were used to focus additional sampling in potentially impacted areas, while eliminating other areas of the SWMUs from further investigation. The PSG results revealed contaminated areas that were previously unsuspected at the site, and confirmed areas of known subsurface contamination identified during previous investigations. Subsequent sampling has confirmed the PSG results and identified areas with light- and dense nonaqueous-phase liquids (LNAPLs and DNAPLs) in the subsurface materials. The PSG approach provided an accurate, rapid, high resolution sampling method for characterizing large areas of the Base easily and economically, while optimizing remedial programs and long-term site monitoring.

INTRODUCTION

Arnold Air Force Base, a Department of Defense (DoD) facility in Tennessee, is undergoing a RCRA Facility Investigation (RFI) at two adjacent solid waste management units (SWMUs) - the Engine Test Facility (ETF; SWMU 101) and the Propulsion Wind Tunnel Area (PWT; SWMU 102). The SWMUs are located within the highly industrialized portion of the Arnold AFB Main Test Area (MTA). The investigations were aimed at identifying contaminant release areas and evaluating the extent of soil and groundwater contamination beneath the sites from volatile organic compounds (VOCs) and mercury.

Conventional soil and groundwater sampling and characterization techniques were deemed impractical. This conclusion was based on the large size of the area requiring assessment, access limitations due to current site use coupled with numerous surface and subsurface structures and utilities, and the prohibitive costs associated with large-scale conventional soil and groundwater sampling. A cost-effective yet accurate and robust site assessment tool was required to move the investigation forward. Passive soil gas sampling (PSG) was selected as an economical, easy-to-use, accurate means to develop a high resolution image of the soil and groundwater contamination beneath the site, and therefore focus the subsequent more invasive and expensive sampling in select target areas.

The soil gas data from the GORE™ Survey PSG technology (described below) do not provide actual concentrations in the soil or groundwater, but identify areas where elevated concentrations of contaminants are likely present in the subsurface. Thus, the PSG results are used to minimize additional site characterization sampling within focused areas of the site, while eliminating other areas from further investigation, and optimizing remediation and long-term monitoring goals.

The PSG technique utilized and the results of the PSG and subsequent investigations are presented below. The economical impact of the PSG approach, and the future remedial plans as a function of this investigative approach, are discussed in the conclusions.

SITE DESCRIPTIONS

SWMU 101 – Engine Test Facility. Completed in 1953, the 28 acre (11.3 hectares) ETF is used for development and evaluation testing of propulsion systems for advanced aircraft, missiles, satellites, and space vehicles. The SWMU is underlain by numerous underground pipes used for the transfer of fuel, gas, waste water, storm water, cooling water, and compressed air. Telephone, electrical, and data cable underground lines also traverse the site. Large diameter air transfer and other aboveground piping, associated with the ETF, are abundant within the central and northern portions of the site. Potential contaminant releases within the ETF area included: spills/leaks of chlorinated solvents and mercury; releases of rocket fuels, lube oils, freons, and hydrazine; leaks from underground jet fuel transfer lines; and releases to the ground surface from various liquid release pipes throughout the SWMU.

SWMU 102 – Propulsion Wind Tunnel. Completed in the late 1950s, the PWT area contains some of the most heavily used facilities at the Base, including the Supersonic and Transonic wind tunnel facilities and High Temperature Laboratories. The complex occupies approximately 26 acres (10.5 hectares) and shares components with other Arnold AFB test facilities. Like SWMU 101, this SWMU is underlain by numerous underground pipes used for the transfer of fuel, waste water, storm water, cooling water, and compressed air. Telephone, electrical, and data cable underground lines also traverse the site. Large-diameter air transfer and other aboveground piping associated the PWT test facilities are abundant within the northern and eastern portions of the site. Potential contaminant releases within the PWT area include spills/leaks of chlorinated solvents, fuels, lube oils, and releases to the ground surface from various liquid release pipes.

GEOLOGY/HYDROGEOLOGY

Much of the shallow soil within the SWMUs has been reworked due to site construction activities. These residual soils are derived from the weathering of the underlying limestone bedrock.

The groundwater system beneath the SWMUs can be divided into three primary aquifers: shallow, intermediate, and deep (limestone bedrock). The shallow aquifer consists of a silty sand/silty gravel layer encountered roughly 15 feet (4.5 m) below ground surface (bgs) and extends to approximately 30 feet bgs (9.1 m). The depth to the water table is found from approximately 15 to 20 feet bgs (4.5 to 6.0 m). The intermediate aquifer is the primary source of drinking water in the region and consists of well-graded clayey gravel with interbedded sand lenses. The gravel (chert) content increases with depth in the aquifer. The aquifer is present from approximately 40 to 45 feet bgs (12.0 to 13.7 m) and extends to the top of the limestone bedrock. Because the aquifers are generally not separated by confining units, water is able to migrate between the aquifers. The deep aquifer consists of interconnected fractures and bedding plane features of the Fort Payne Limestone formation. The top of this limestone unit is present roughly 70 to 90 feet bgs (21.3 to 27.4 m) and the formation is approximately 30 feet (9.1 m) thick beneath the sites. The Chattanooga Shale lies below this limestone unit. This shale unit is roughly 20 to 30 feet (6.1 to 9.1 m) thick within the region, is considered an aquitard, and defines the base of the regional aquifer system.

PASSIVE SOIL GAS SAMPLING

The PSG sampler selected for this investigation is the GORE™ Module (module; Figure 1). The patented module contains hydrophobic adsorbents enclosed in a waterproof, vapor-permeable GORE-TEX® membrane tube. The membrane prevents liquid water, soil and other materials from coming in contact with the adsorbent, while allowing vapors to diffuse freely to the adsorbent. The engineered hydrophobic adsorbents have minimal water vapor uptake, while having an affinity for a broad range of volatile and semi-volatile organic compounds (VOCs and SVOCs).

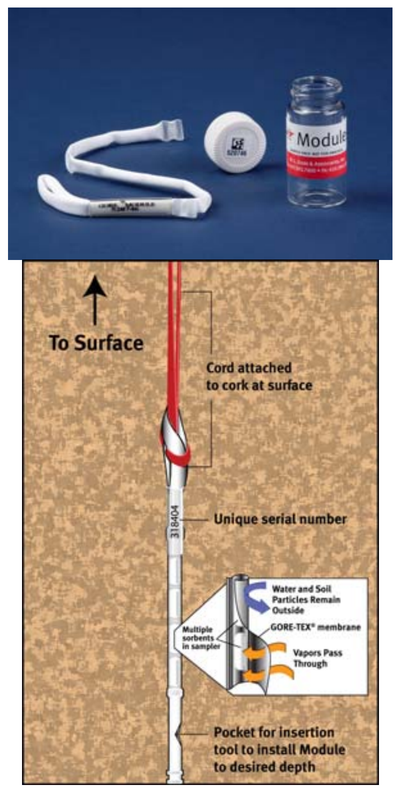

FIGURE 1. The GORE™ Module used in the Arnold AFB site investigations.

For soil gas and subslab soil gas sampling, the module is inserted into a narrow diameter hole, cased or uncased, advanced to the desired sampling depth. The modules can be deployed to any depth or placed on the soil surface (e.g., at sites with unexploded ordnance). In addition to soil gas sampling, the module can be deployed for air sampling (indoor, outdoor, crawlspace) for use in vapor intrusion investigations. The waterproof membrane also allows for deployment of the module directly in saturated soils, sediments, and surface and groundwater. No additional modification of the module is necessary.

Module analysis follows a modified US EPA 8260/8270 method (thermal desorption, gas chromatography, mass selective detection). Analysis of the modules for mercury follows a thermal desorption, gas chromatography, atomic emission detection method (TD/GC/AED). Data are reported in units of desorbed mass (micrograms, µg), which can be converted into units of concentration (air, soil gas and water), while mercury data are reported in a relative abundance unit.

For soil gas sampling, compounds partitioning to vapor from soil and groundwater contamination, migrate through the vadose zone, pass directly through the membrane, and are captured on the adsorbent. The technology provides, at a minimum, a semi-quantitative result, i.e., compound speciation and measured mass, but does not apply to the mercury reporting. The performance claims of the GORE™ Module have been verified on two occasions under the US EPA Environmental Technology Verification (ETV) program (USEPA, 1998; Einfeld and Koglin, 2000).

Passive Soil Gas Sampling at Arnold AFB. For the PSG investigations at Arnold AFB, the modules were installed in ¾-inch diameter uncased holes, drilled with a hand-held compression drill, to approximately two feet below grade (Figure 2). The installation holes were sealed with corks to prevent infiltration of ambient surface contamination. In all cases, the modules were exposed to the soil gas for approximately 12 to 14 days. The majority of the samplers were deployed in grid fashion with spacing ranging between 15 and 50 feet (4.5 to 15.2 m), allowing for high resolution spatial sampling and contaminant delineation beneath the site areas investigated.

FIGURE 2. Using a compression drill to create the installation hole for the GORE™ Modules.

The PSG technology facilitated sampling within limited access areas of the sites and showed elevated levels of chlorinated solvents, petroleum-related compounds, and mercury. Also, the module installation and retrieval required less labor, presented smaller risks associated with buried utilities, and allowed data to be collected in areas that could not otherwise be sampled. The PSG sampling results for mercury were summarized in Singer and Whetzel (2006) and Singer et al. (2006), and will not be discussed in detail here.

SWMU 101 – ETF – PASSIVE SOIL GAS SURVEY AND RESULTS

In July of 2004, a pilot survey, consisting of 75 GORE™ Modules, was conducted in a portion of the ETF site, where free mercury and other VOCs had been identified previously. The objectives of the study were to determine if the PSG method would be suitable to detect the compounds of concern in the given site geology, and if the sample spacing was sufficient to resolve the contaminant features of interest. The pilot study was successful in meeting the objectives, and the survey was expanded over the entire 28 acre site (Singer and Whetzel, 2006; Singer et al., 2006).

A total of 542 GORE™ Modules were deployed to sample the soil gas in the ETF area in the spring of 2005. The two datasets were combined onto one set of maps, providing a comprehensive subsurface image of the area sampled. Mercury and a range of VOCs, including fuels and chlorinated solvents, in significant mass levels, were detected and the spatial distribution determined (Figure 3).

FIGURE 3. ETF Area - PSG results (µg), total target VOCs (summation of individual target compounds) and groundwater concentrations.

The potential VOC release areas identified by the PSG data were investigated further, and the PSG results correlated well with soil and groundwater data. Concentrations of trichloroethene (TCE) and other chlorinated solvents were identified by the PSG study within three separate areas of the SWMU that previously had not been identified as potential contaminant release areas. Additional sampling within these areas revealed the likely presence of DNAPL in the subsurface material. In one of the areas, groundwater concentration equal to nearly 80% of the effective solubility of TCE were observed. Fuel related products (BTEX), coupled with chlorinated solvents, were also identified during the PSG study within two other areas of the site. Confirmation sampling within these two areas showed the presence of free-phase jet fuel (as LNAPL) and DNAPL within the shallow soil and groundwater.

SWMU 102 - PWT – PASSIVE SOIL GAS SURVEY AND RESULTS

In March of 2006, 358 GORE™ Modules were deployed over the 26 acre SWMU to assess the subsurface impact by releases of VOCs and mercury. Mercury was identified in the soil gas at only one location, while fuel-related and solvent-based compounds were observed in significant mass levels within several distinct areas of the site (Figure 4). Subsequent soil and groundwater sampling confirmed the PSG results. The PSG study identified a large area (roughly 0.5 acres; 2,000 m^2) that previously had not been identified as a potential contaminant release area within the SWMU. Shallow groundwater collected within this area contained elevated milligram per liter concentrations (mg/L; part per million levels, ppm) of 1,1,1-TCA and 1,1-DCE which exceed 1% of the compounds effective solubility, indicating the presence of DNAPL. The groundwater also contained mg/L (ppm) concentrations of 1,4-dioxane, a chlorinated solvent stabilizer.

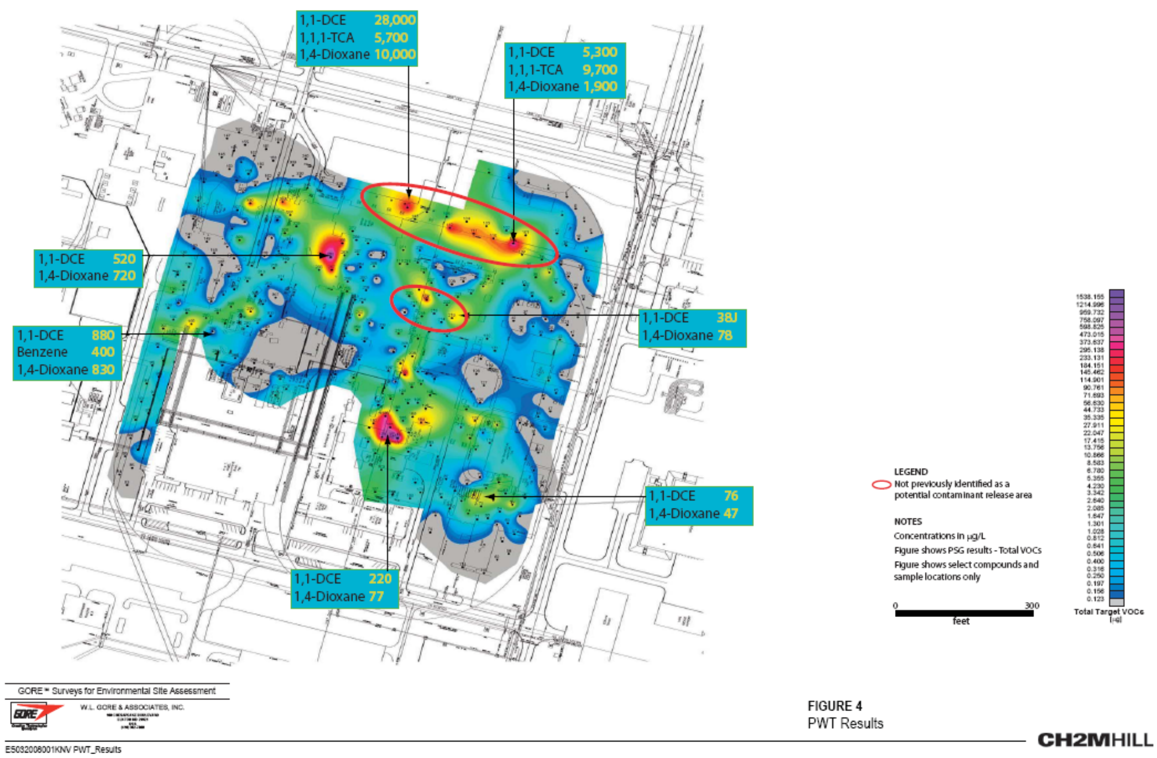

FIGURE 4. PWT Area - PSG results (µg), total target VOCs (summation of individual target compounds) and groundwater concentrations.

CONCLUSION

Over a multi-year period, passive soil gas sampling using the GORE™ Module was conducted at two large industrialized SWMUs at Arnold AFB, Tennessee (over 25 acres each; 20 hectares). The deployment of approximately 1,000 PSG samplers allowed for a rapid, cost-effective assessment of the spatial distribution of contaminants released into the subsurface soils and groundwater over the years of operation. Site access limitations, the large size of the SWMUs, and associated high investigation costs precluded a comprehensive site assessment using conventional soil and groundwater sampling. The PSG surveys identified previously unknown contaminant release areas and focused subsequent RFI soil and groundwater sampling, thus greatly reducing the number of required soil borings and monitoring wells. The results of the subsequent sampling also confirmed the PSG results. Corrective measure studies, focused on reducing source area contaminant mass identified through the PSG study and subsequent sampling, are currently being prepared for the two sites. These potential measures include in-situ enhanced biodegradation, chemical oxidation, dual-phase extraction, and emulsified zero-valent iron injection. In summary, the high resolution soil gas sampling using the GORE™ Survey economically identified previously unknown DNAPL source areas within the large industrial area of Arnold AFB.

Cost Savings. The costs to collect a passive soil gas sample were estimated to be 75% less than the costs associated with collecting a soil and/or groundwater sample using conventional techniques. The comparative costs included sample equipment, subcontractor charges, laboratory analysis, and associated labor. The original scope of work for characterizing the subsurface source and extent of organic compound impact consisted of conventional drilling and sampling at more than 300 locations in each SWMU. The results of the PSG curtailed the conventional sampling program significantly, reducing the sample locations to 20 in SWMU-101 and 18 in SMWU-102. The combined monetary savings in sampling costs alone easily exceeded $1 million dollars.

The PSG study also greatly reduced the time required to complete the RFI for both SWMUs by focusing the subsequent investigation in select target areas. Though not quantified, the cost savings in terms of shortening the RFI timeline are significant and cannot be ignored. The conventional drilling and sampling programs in each SWMU would have taken several months to complete, when compared to the few short weeks of passive soil gas sampling and focused conventional drilling and sampling.

The results of the PSG, which identified previously unknown source areas discussed above, will allow for remedial optimization, as the contaminant mass present in the subsurface can be estimated more accurately and with a higher degree of confidence. Subsequent long-term monitoring programs will also be optimized as a result of the PSG investigation (e.g., fewer groundwater monitoring well installations requiring periodic sampling).

Finally, the potential health and accident risk posed to the environmental consultants and base personnel involved in the site investigation within the industrialized area of the Base was greatly reduced by implementing the GORE™ Survey. The PSG technique allowed for minimally intrusive and safer sampling in areas which were access limited due to surface and subsurface utilities at Arnold AFB.

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