# Programmatic Methods for Addressing Contaminated Volume Uncertainties

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## ABSTRACT

Accurate estimates of the volumes of contaminated soils or sediments are critical to effective program planning and to successfully designing and implementing remedial actions. Unfortunately, data available to support the preremedial design are often sparse and insufficient for accurately estimating contaminated soil volumes, resulting in significant uncertainty associated with these volume estimates. The uncertainty in the soil volume estimates significantly contributes to the uncertainty in the overall project cost estimates, especially since excavation and off-site disposal are the primary cost items in soil remedial action projects. The U.S. Army Corps of Engineers Buffalo District’s experience has been that historical contaminated soil volume estimates developed under the Formerly Utilized Sites Remedial Action Program (FUSRAP) often underestimated the actual volume of subsurface contaminated soils requiring excavation during the course of a remedial activity. In response, the Buffalo District has adopted a variety of programmatic methods for addressing contaminated volume uncertainties. These include developing final status survey protocols prior to remedial design, explicitly estimating the uncertainty associated with volume estimates, investing in predesign data collection to reduce volume uncertainties, and incorporating dynamic work strategies and real-time analytics in predesign characterization and remediation activities. This paper describes some of these experiences in greater detail, drawing from the knowledge gained at Ashland 1, Ashland 2, Linde, and Rattlesnake Creek. In the case of Rattlesnake Creek, these approaches provided the Buffalo District with an accurate predesign contaminated volume estimate and resulted in one of the first successful FUSRAP fixed-price remediation contracts for the Buffalo District.

## INTRODUCTION

Accurate estimates of the volumes of contaminated soils or sediments are critical for effective program planning and successfully designing and implementing remedial actions. The volume of contaminated soil or sediment identified for the remedial design is usually calculated on the basis of remedial investigation data. Unfortunately, the volume of contaminated soil or sediment ultimately removed from a site is usually greater than the preremedial estimate. Three recent examples at U.S. Department of Energy remediation sites in Ohio highlight this issue. In the case of the Fernald site, about 625,000 $m^3$ (817,500 $yd^3$) of additional contaminated soils were ultimately removed and disposed of. As part of the Columbus Closure Project, almost three times the amount of contaminated soil was removed from the West Jefferson site than originally expected. At the Mound site, the amount of contaminated soil removed was approximately double the original estimate [1].

A variety of factors contribute to inaccurate contaminated soil/sediment volume estimates. The primary factor is that remedial design needs are not typically identified as data quality objectives during the design and acquisition of site investigation data sets, which usually occur during the remedial investigation phase. This results in sparse data sets being used for volume estimation, combined with significant spatial heterogeneity in the underlying spatial distribution of contamination. Consequently, cleanup decision making, and more specifically contaminated volume estimation, is often conducted with undesirable uncertainty. The ramifications of uncertainty for projects include cost and schedule overruns, and inefficiencies in the remedial design. As an example, the additional contaminated soil volumes at the Fernald site required special off-site disposal at significant unexpected cost when the design capacity of the on-site disposal facility was exceeded [1].

The U.S. Army Corps of Engineers (USACE) Buffalo District has had similar experiences as part of the Formerly Utilized Sites Remedial Action Program (FUSRAP). The USACE Buffalo District has been attempting to implement fixed price contracts for remediation work when project conditions permit. Large volume uncertainties can play havoc in a fixed-price contract setting, and, consequently, the USACE Buffalo District has been aggressively pursuing strategies to improve contaminated media volume estimation. The Buffalo District has incrementally incorporated lessons learned from each FUSRAP remediation project that it has conducted. It has developed a programmatic and technical process that has led to increased success in developing contaminated volume estimates sufficiently accurate to support fixed-price remediation contracts. This process includes: (1) developing initial volume estimates from historical data sets that incorporate an assessment of volume uncertainty; (2) engaging in predesign data collection activities to further refine volume estimates when the uncertainties are unacceptable; (3) developing geographic information system (GIS) models that allow building real-time characterization approaches into remedial actions to ensure that the resulting removal is as precise as possible; and (4) structuring and sequencing Final Status Survey (FSS) plans and activities in a manner that is both consistent with contaminated soil volume estimation techniques, and that identifies FSS closure problems before remediation activities are complete.

## MANAGING VOLUME UNCERTAINTIES

The first soil remediation action undertaken by the USACE Buffalo District was the Ashland 2 site. Ashland 2 remediation work began in 1998. The Remedial Investigation/Feasibility Study (RI/FS) included an estimate of the contaminated soil volume at Ashland 2 that was 11,000 $m^3$ (14,000 $yd^3$). The main objectives of the RI/FS data set were to identify the nature and extent of contamination and to develop comparative costs for feasible remedial action alternatives. With the assistance of Argonne National Laboratory (Argonne), the Buffalo District prepared its own volume estimate to support the remedial design with the RI/FS data. This volume estimate was based on 341 soil samples drawn from 116 soil cores (approximately 68 samples per acre). The volume estimation process made use of a joint Bayesian/geostatistical method developed by Argonne [2]. This method provides both a “best guess” of the contaminated soil volume and an upper and lower bound on the likely amount of contamination present. On the basis of this method, it was determined that the contaminated soil volume could range up to more than three times the RI/FS estimate [3].

As a result of the large range identified for the volume of contaminated material potentially present, the Buffalo District designed a conceptual site model and a GIS program that allowed real-time data acquisition techniques to be incorporated into the remediation process to keep the excavation work as precise as possible. One objective was to minimize the possibility of unnecessarily shipping clean material to an off-site disposal facility. The real-time technologies employed included on-site gamma spectroscopy capabilities for rapid sample turnaround, and a gamma walkover survey (GWS) combined with Global Positioning System (GPS) and data logger to provide real-time gamma surveys of exposed dig surfaces. Prior to excavation, correlation sampling was conducted to determine upper and lower field investigation levels for the proposed detector systems that could be used in conjunction with GPS data to guide the excavation activities. GWS results below the lower investigation level were assumed to be representative of exposed surfaces with contamination activity concentrations below Derived Concentration Guideline Levels (DCGLs). GWS results above the upper investigation level were assumed to be representative of exposed surfaces with contamination activity concentrations above DCGLs. Areas with GWS results between these investigation levels were candidates for soil sampling and gamma spectroscopy analysis to assist in clarifying their contamination status. The excavation work proceeded in approximately 2-ft lifts, with the exposed dig face reevaluated by GWS and soil sampling before further excavation continued.

Precise excavation work at the Ashland 2 site was completed as part of a cost-reimbursable contract. The precise excavation approach implemented at the Ashland 2 site in 1998 successfully segregated contaminated from clean soil; the excavation was guided by real-time GWS data, and only the contaminated soils were excavated and shipped off-site for disposal. Less than 3% of the waste profile shipment samples were below DCGL requirements for the site [4]. Only about 1% of the FSS samples collected when excavation was completed were individually above DCGL requirements. However, the final in situ surveyed volume of contaminated soil material that was excavated and shipped off-site for disposal was 27,000 $m^3$ (35,000 $yd^3$) [5]. While this volume was within the potential range identified for Ashland 2, it was still significantly greater than what had been expected by the Buffalo District on the basis of the RI/FS estimate.

The Ashland 1 site was the next FUSRAP Tonawanda site slated for soil remediation by excavation and off-site disposal. Like Ashland 2, the RI/FS included an estimate of contaminated soil volume at Ashland 1 that was 22,000 $m^2$ (29,000 $yd^3$). Using Argonne's statistical method, the USACE reevaluated existing RI/FS data, which included 548 soil samples from 138 soil cores (approximately 55 samples per acre), and determined that the volume could range up to 108,000 $m^3$ (141,000 $yd^3$), with a best guess estimate of 34,000 $m^3$ (44,500 $yd^3$) [3]. With the lessons learned from the volume increases of Ashland 2, the Buffalo District chose to invest a minimal amount of resources into predesign data collection. Argonne's method identified those areas where uncertainty about the presence or absence of contamination was greatest; the USACE dug test pits to look for contamination, and collected preremedial surficial GWS data. These data were used to refine the volume estimate, which yielded a best guess of 73,000 $m^3$ (95,000 $yd^3$).

As was done at Ashland 2, to keep the excavation as precise as possible, the dig was designed around real-time characterization techniques and lifts. Because the contaminants of concern were the same as Ashland 2, the same suite of real-time techniques was deployed at the site. When excavation work at the Ashland 1 site was completed in 2002, a final in situ surveyed volume of 78,000 $m^3$ (102,000 $yd^3$) of contaminated soil material had been removed [5]. This volume compared favorably with the best guess predesign estimate of 73,000 $m^3$ (95,000 $yd^3$). It was significantly greater, however, than the best guess based simply on the historical RI/FS data set, and underscored for the Buffalo District the value of targeted predesign sampling for improving volume estimates.

The Linde site, next on the Buffalo District's remediation schedule, posed special problems. As with the Ashland 1 and 2 sites, the Buffalo District had to base the initial contaminated soil volume estimate primarily on RI/FS data; the estimated contaminated soil volume estimate for Linde was 14,000 $m^3$ (18,000 $yd^3$). Although there was a significant amount of preremedial sample data for the Linde site (1,074 samples from 328 cores) the samples tended to be clustered in areas of known contamination, leaving the rest of the site insufficiently characterized (i.e., on average, only 8 samples per acre). In addition, radiologically contaminated materials have been discovered around buried infrastructure, including utility tunnels, sanitary and storm sewer lines, water lines, and electrical/communication lines. Radiologically contaminated materials were apparently used as backfill or landscaping around subsurface infrastructures during installation by various site owners. Finally, unlike the contamination at Ashland 1 and Ashland 2, the mixture of contaminants of concern varied depending on location. At some areas of the site, uranium contamination dominated; at other areas, Th-230 was of primary concern.

All of this uncertainty was reflected in the revised volume estimate prepared for the USACE, with a best guess contaminated soil volume of 36,000 $m^3$ (47,000 $yd^3$), and the plausible volume ranging up to 180,000 $m^3$ (235,000 $yd^3$). In the case of Linde, the USACE developed a more flexible FSS strategy than had been used at the Ashland 1 or 2 sites. In the case of both Ashland 1 and 2, all FSS activities had waited until excavation work was complete. Using guidance from the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM), the Linde site was divided into Class 1, 2, and 3 areas, with the classification of these areas based primarily on RI data. The USACE recognized that there was significant risk in postponing the FSS data collection work until excavations were complete at Linde, since the FSS sampling process in Class 2 and 3 areas might uncover contamination not known previously to have existed. Consequently, the FSS process was designed and implemented so that FSS activities in Class 2 and 3 areas started immediately, with the intent of reducing the risk of discovering unknown contamination as soon as possible.

As with Ashland 1 and 2, remediation work at Linde was handled through a cost-reimbursable contract. Also, as with Ashland 1 and Ashland 2, the remediation was designed to include real-time characterization tools. In addition to GWS and on-site gamma spectroscopy capabilities, Linde also implemented a subsurface core scanner. The primary purpose of the core scanner was to quickly identify subsurface contamination by scanning subsurface soil cores. As part of the FSS activities alone, more than 1,600 subsurface soil cores were collected sitewide from Class 2 areas.

The Linde remediation work began in 2000 and is still underway. As work progressed, the FSS and remediation activities identified extensive subsurface contamination that had previously been unknown; consequently, the volume of contaminated soil has increased. To date, more than 134,000 $m^3$ (175,000 $yd^3$) of contaminated soils have been shipped off-site for disposal, with a current remaining volume estimate of 28,000 $m^3$ (37,000 $yd^3$). The Linde remediation underscored for the Buffalo District the programmatic importance of developing sufficiently accurate volume estimates to support confident project and program planning.

The latest Buffalo District FUSRAP site to undergo remedial activities was the Rattlesnake Creek (RSC) portion of the Ashland sites. RSC is an intermittent stream with a broad floodplain that drains the Ashland 1 and Ashland 2 areas. The RI sampling activities conducted for the Ashland sites failed to identify any significant contamination concerns in creek sediments. However, the Ashland 2 remedial excavation activities pursued contaminated soil lenses into the creek floodplain. At the time, addressing contaminated creek sediments was beyond the scope of planned activities for Ashland 2. In addition, the encountered contamination was believed to be limited in its spatial extent within the creek. Plans were made to revisit the creek with FSS sampling to demonstrate that the bulk of the creek did not require remedial attention.

However, during the attempted RSC FSS activities in 2000 and 2001, evidence was found of a buried contaminated sediment layer that appeared to be pervasive for a significant distance down the creek. Using the sampling datasets generated by 2000 and 2001 data collection activities and volume estimation methods developed by Argonne, the Buffalo District estimated that the contaminated volumes could range between 11,500 $m^3$ (15,000 $yd^3$) and 25,000 $m^3$ (33,000 $yd^3$), with a best guess estimate of 17,000 $m^3$ (22,000 $yd^3$) [6]. At the time the Buffalo District had a goal of transitioning FUSRAP remedial contracts from cost-reimbursable to fixed-price contracts. The RSC remedial action was selected as the first to use a fixed-price contract. However, to award this type of contract for the soil remediation activities at RSC required a much more accurate and defensible volume estimate than the historical data would support. Consequently, the Buffalo District decided to invest in predesign data collection to reduce the uncertainty in the contaminated soil volume estimate. The goal was to produce a volume estimate that was within 5% of the actual contaminated volume.

The lesson carried forward from Linde was that there was significant value in developing FSS plans early and proactively implementing FSS data collection prior to the completion of remediation. The RSC FSS plan was developed before any additional predesign data collection took place. The predesign data collection was consistent with the FSS plan. The intent was to use the predesign data for closure purposes in those areas where no contamination was found above DCGL requirements, and for volume estimation purposes where contamination was encountered.

RSC posed special characterization problems. Much of the area of concern was seasonally saturated or covered with standing water, thereby limiting the effectiveness of GWS. In addition, the mix of contaminants along with their DCGL requirements meant that action levels were close to the detection limits of surficial gamma scans, further limiting their utility. Finally, in many areas of the creek the contaminated sediment layer of concern was buried by more recent clean sediments. The primary contaminant of concern from a risk perspective was Th-230, which does not lend itself to accurate quantification with on-site gamma spectroscopy.

The real-time measurement option selected by the Buffalo District for RSC was X-Ray Fluorescence (XRF). XRF is traditionally used for heavy metal measurements such as lead. However, XRF also is an excellent method for quantifying total uranium in soils. A review of historical data showed that, in general, Th-230 at RSC was co-located with uranium, although the uranium was not at levels that would pose health concerns. The XRF could provide real-time results for total uranium in soils, and these data in turn could be used as a proxy or surrogate for the presence or absence of Th-230 above DCGL requirements. Upper and lower investigation levels were derived for the XRF based on historical results and XRF tests with archived samples. These upper and lower investigation levels were used to identify soil core intervals that required alpha spectroscopy results to be more definitive about the presence or absence of Th-230 above DCGL requirements.

The real-time characterization work at RSC made use of GeoProbe cores and ex situ screens of those cores using XRF. Approximately 3,000 XRF analyses were performed during the combined FSS/predesign data collection effort. These data, combined with a much smaller number of alpha spectroscopy analyses, allowed significant portions of the RSC floodplain to be cleared of contamination concerns and provided the basis for revised volume estimation and excavation footprint derivation for those areas where contamination was a concern. These, in turn, became the basis for awarding a fixed-price contract for remediation work at RSC.

The remedial excavation work at RSC was conducted in 2005. Fortunately, the summer of that year was relatively dry, thus minimizing water management issues in the creek as excavation work progressed. Despite the large amount of data supporting the design excavation footprint, some additional contamination was encountered during the remedial action that resulted in a 10% increase in the total excavated volume, which was 18,700 $m^3$ (24,500 $yd^3$) [5]. The increase in the contaminated soil volume was primarily due to the discovery of contamination adjacent to the creek buried by a “push-out” pile of soil. The increase in soil volumes was balanced by soils that, on average, were drier than expected. Consequently, the mass of contaminated material (i.e., total tonnage) disposed of was less than that projected, and this resulted in the project being completed on time and within budget.

## CONCLUSIONS

As the FUSRAP work has progressed, the USACE Buffalo District has steadily refined and improved the processes and methods it uses for project planning. One of these improvements is in the way the Buffalo District manages the inherent uncertainty associated with contaminated soil volume estimates. Over the years, the Buffalo District has developed a four-pronged approach that combines volume derivation with built-in uncertainty estimates, preremedial design data collection targeting volume uncertainties, real-time characterization techniques embedded in remedial designs, and proactive FSS planning/implementation. The RSC remediation provides an excellent example of how combining these four approaches can dramatically improve project and program planning outcomes. Managing contaminated volume uncertainties becomes particularly important in the context of a fixed-price contract, such as that used for RSC. Minimizing contaminated volume uncertainties allows for remedial action scopes of work that include firm fixed-price strategies.

The RSC remediation project, however, also highlights the fact that although strategies can be used to minimize volume uncertainty, uncertainty can never be completely removed. The best that can be achieved is effective risk management. Surprises during actual remedial activities are inevitable, and planning has to take their potential impacts into account regardless of the contracting vehicle employed.

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