Comparison of Statistically Modeled Contaminated Soil Volume Estimates and Actual Excavation Volumes at the Maywood FUSRAP Site - 13555

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ABSTRACT

As part of the ongoing remediation process at the Maywood Formerly Utilized Sites Remedial Action Program (FUSRAP) properties, Argonne National Laboratory (Argonne) assisted the U.S. Army Corps of Engineers (USACE) New York District by providing contaminated soil volume estimates for the main site area, much of which is fully or partially remediated. As part of the volume estimation process, an initial conceptual site model (ICSM) was prepared for the entire site that captured existing information (with the exception of soil sampling results) pertinent to the possible location of surface and subsurface contamination above cleanup requirements. This ICSM was based on historical anecdotal information, aerial photographs, and the logs from several hundred soil cores that identified the depth of fill material and the depth to bedrock under the site. Specialized geostatistical software developed by Argonne was used to update the ICSM with historical sampling results and down-hole gamma survey information for hundreds of soil core locations. The updating process yielded both a best guess estimate of contamination volumes and a conservative upper bound on the volume estimate that reflected the estimate's uncertainty.

Comparison of model results to actual removed soil volumes was conducted on a parcel-by-parcel basis. Where sampling data density was adequate, the actual volume matched the model's average or best guess results. Where contamination was uncharacterized and unknown to the model, the actual volume exceeded the model's conservative estimate. Factors affecting volume estimation were identified to assist in planning further excavations.

INTRODUCTION

The Maywood Formerly Utilized Sites Remedial Action Program (FUSRAP) site is in a developed area of northeastern New Jersey, in the boroughs of Maywood, Rochelle Park, and Lodi. Contamination at the affected properties results from rare earth and thorium processing activities conducted from the early 1900s through 1959. The United States Army Corps of Engineers (USACE) New York District is currently responsible for remediating soil contamination associated with the Maywood site through FUSRAP. Soil is remediated by excavation and shipment to an off-site disposal facility. Remediation at much of the Maywood properties has already been completed. However, some of the most significant amounts of contamination—from a soil volume perspective—remain to be addressed. Figure 1 shows the locations of the Maywood properties addressed by this study (highlighted in red).

The primary purpose of the volume estimation analysis was to estimate the remaining in situ volume of accessible Th-232 contaminated soils. Argonne's Bayesian Approaches to Adaptive Spatial Sampling (BAASS) software [1, 2] was used to prepare the volume estimate. A secondary objective of the analysis was to prepare retrospective volume estimates for areas that have already been remediated, to indicate the likely accuracy of the estimate of remaining contaminated soil volume.

METHOD

The BAASS contaminated soil volume estimation process involves a series of steps that include the following:

- Assembling and evaluating all existing soft information (other than soil sampling and measurement results) pertinent to the potential contamination status of soils at the Maywood site. This includes descriptions of what occurred historically at the site, historical aerial photographs, maps, etc. The product of this evaluation is an initial conceptual site model (ICSM) that captures the probability of contamination being present above release criteria at various locations of the site.

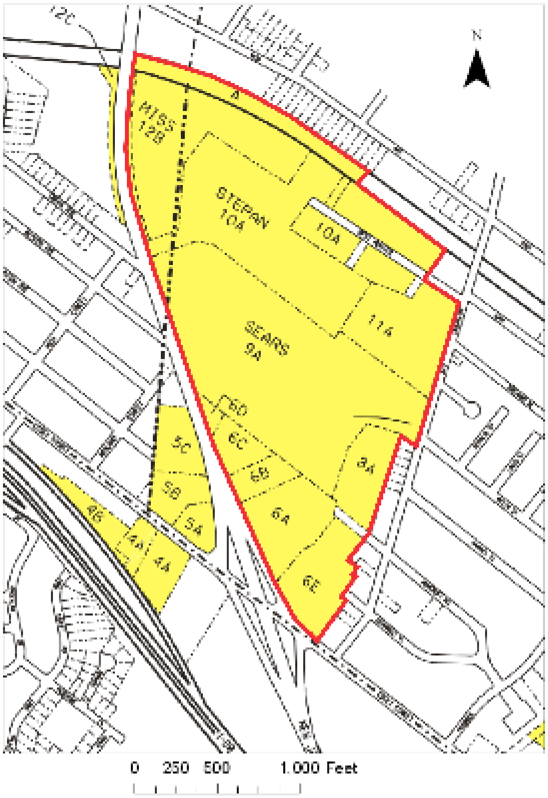

Fig. 1. Location of Maywood Properties.

- Reviewing existing soil sample and measurement information and codifying it as indicating that contamination is either above or below release levels. The available information for Maywood included soil sample results from soil cores and down-hole gross gamma measurements.

- Updating the ICSM by using BAASS and the sample/measurement data to produce a final conceptual site model (CSM). This final CSM is used to develop volume estimates that are tied to levels of certainty. Typically, a BAASS analysis will provide at least two points of information: the "most likely" volume estimate and a more conservative volume estimate that bounds the quantity of contamination present. The difference between the two volume estimates reflects uncertainty in the true volume of contaminated soil present at the site. In general, the more sample/measurement data available to support the volume estimate, the closer the upper bound will be to the most likely volume estimate.

RESULTS

Initial Conceptual Site Model

In the case of Maywood, three primary sources of information were available for constructing the ICSM. The first source was anecdotal information captured and described in various historical reports prepared for the site (see, for example, [3]). This reporting was particularly useful for identifying the potential presence of burial pits across the site. The second source was a series of historical aerial photographs that depicted site conditions from 1931 (the earliest photo available) to the present. Use of geographical information system (GIS) software for geo-referencing air photos allowed disturbed areas that indicated the presence of pits/lagoons or backfill activity to be identified and delineated. The third source was information from site bore logs that indicated the depth of fill and the depth to bedrock—critical pieces of information for volume estimation. Because the majority of the soil contamination at the site resulted from fill activities, the depth of fill provides an indication of the possible depth of contamination at locations where bore logs are available. Depth to bedrock provides a maximum estimate of vertical contamination extent.

Maywood Chemical Works (MCW) was constructed in 1895. In 1916, the plant began extracting thorium and rare earths from monazite sand for use in manufacturing industrial products such as mantles for gas lanterns. Thorium extraction ceased in 1956, but thorium processing of stockpiled material continued until 1959, when the property was sold to the Stepan Company. The Stepan Company never processed radioactive material. The primary radioactive contaminant at the Maywood site is Th-232 and its associated daughter products, with lesser amounts of radionuclides in the U-238 decay chain. Recoverable wastes from thorium processing operations were stored in an unsheltered phosphate pile between buildings in the main yard. Unrecoverable wastes from thorium processing operations (i.e., residues and tailings) were piped to a large pile on the perimeter of the MCW property. The pile, containing several tons of waste slurry, was surrounded by earthen dikes but remained exposed to weather.

In 1932, the disposal areas were separated from the plant and partially covered by the construction of New Jersey State Highway 17 (Route 17). Additional waste migrated off the property via natural drainage associated with the former Lodi Brook. Historical photographs and maps indicate that the former course of the brook, which originated on the MCW property, generally coincides with the distribution of contaminated properties in Lodi. Most of the open stream channel in Lodi has been replaced by a subsurface storm drain system.

Stepan began to clean up residual thorium wastes in 1963, partially stabilizing residues and tailings in place by covering them with clean soil. In 1966, 6,400 cubic meters (m^3) (8,400 cubic yards [yd^3]) of contaminated material was removed from the property west of Route 17, returned to the Stepan property, and buried in an area now covered with grass. In 1967, an additional 1,600 m^3 (2,100 yd^3) of material was removed from the same general area and buried on the Stepan property at another burial pit that is now a parking lot. In 1968, an additional 6,600 m^3 (8,600 yd^3) of waste from the area west of Route 17 was transferred and buried in a third burial pit in an area where a warehouse was later constructed.

Seventeen aerial photographs spanning an 80-year period were available for the area of interest. Once geo-referenced, these photographs were invaluable for identifying and delineating the locations of burial pits and areas of significant fill activities. On the basis of anecdotal information and the aerial photographs, a probability map was constructed representing the ICSM (Figure 2), color-coded by the likelihood that contamination might be present above release criteria. Because of the long duration of site activities and the degree of surface reworking over the years, almost the entire area of interest was identified as possibly having contamination present. The areas of highest likelihood corresponded to locations where burial pits were known to exist or significant fill activity took place. Because of the surface reworking, contamination overlain by relatively clean surface backfill or building footprints was assumed to occur in many instances across the site.

In addition to the ICSM presented in Figure 2, more than 500 soil core locations were scattered across the site, with core log information that could be potentially used to determine the depth of fill. Of these, more than 400 were completed to bedrock and so provided depth-to-bedrock data. By combining data gleaned from these soil core locations with the ICSM, preliminary contaminated soil volume estimates were calculated, assuming that contamination could extend either to the depth of fill or, most conservatively, to bedrock.

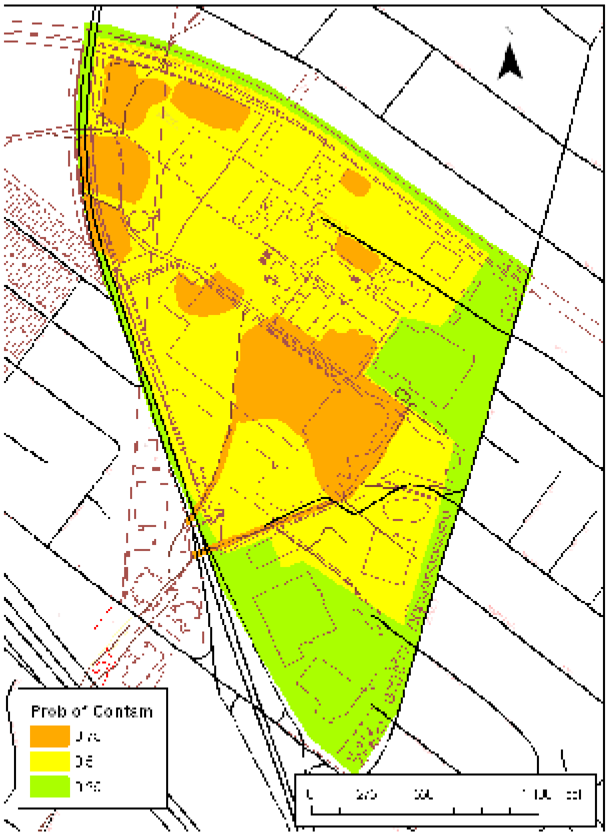

Fig. 2. ICSM for Maywood.

Soil Sample and Down-Hole Gamma Data

Historical data for the site consisted of soil samples retrieved from various depths and locations and analyzed in a laboratory for Th-232 activity, plus down-hole gamma (DHG) activity measurements performed for a subset of the available sampling stations and at independent stations. Much of the data was collected during a remedial investigation [3].

Analyzing the Maywood historical data was challenging. Some data existed in spreadsheet format, but much was only available as scanned reports. Location information existed as State Plane coordinates in some cases, while in other cases local coordinate systems were used, with location information only as demarcations on a scanned map. Significant effort was invested in developing datasets suitable for volume estimation, based on available historical data. This effort included capturing data contained in scanned reports in a suitable electronic format, as well as rectifying coordinate information for locations where data had been collected. In the latter case, GIS software was used to geo-reference scanned report figures so that approximate State Plane coordinates could be determined for each station.

Sample analytical results and the DHG data were contained in separate files. As part of the data evaluation process, where possible, the laboratory data and DHG data for the same station location were merged to provide the most accurate understanding possible regarding the presence and vertical depth of contamination. In some cases this was straightforward (e.g., both laboratory data and DHG data shared the same station name and mapped to approximately the same location). However, in many other instances station names were absent, and slight spatial errors were associated with geo-referencing. In general, when a sampled location mapped to within 3 meters (m) (10 feet [ft]) of a location with DHG information, the presumption was that the two together reflected the contamination status at that spot.

Additional data were collected in 2012 [4] in the northern portion of the site, including several locations selected by BAASS using its capability to choose new locations to reduce uncertainty in the estimate. Overall Th-232 data quantities assembled for this study (all locations within or alongside the Maywood main triangle) include 2,451 laboratory results for Th-232 at 1,045 stations and 13,338 DHG measurements at 724 stations. Through the data evaluation process, this was reduced to 755 stations with only laboratory sample results, 434 stations with only DHG results, and 290 stations with a combination of the two.

Sample/DHG results for individual locations were compared with the ICSM predictions, providing one measure of the quality of the ICSM (Figure 3). In general, the agreement between the ICSM and laboratory result/DHG data was good. Only 4% of stations within the area considered unlikely to be contaminated on the basis of the ICSM encountered contamination; 58% of those in the ICSM area deemed to have a 50% chance of being contaminated were contaminated; and 68% of those in the areas considered likely to be contaminated were contaminated.

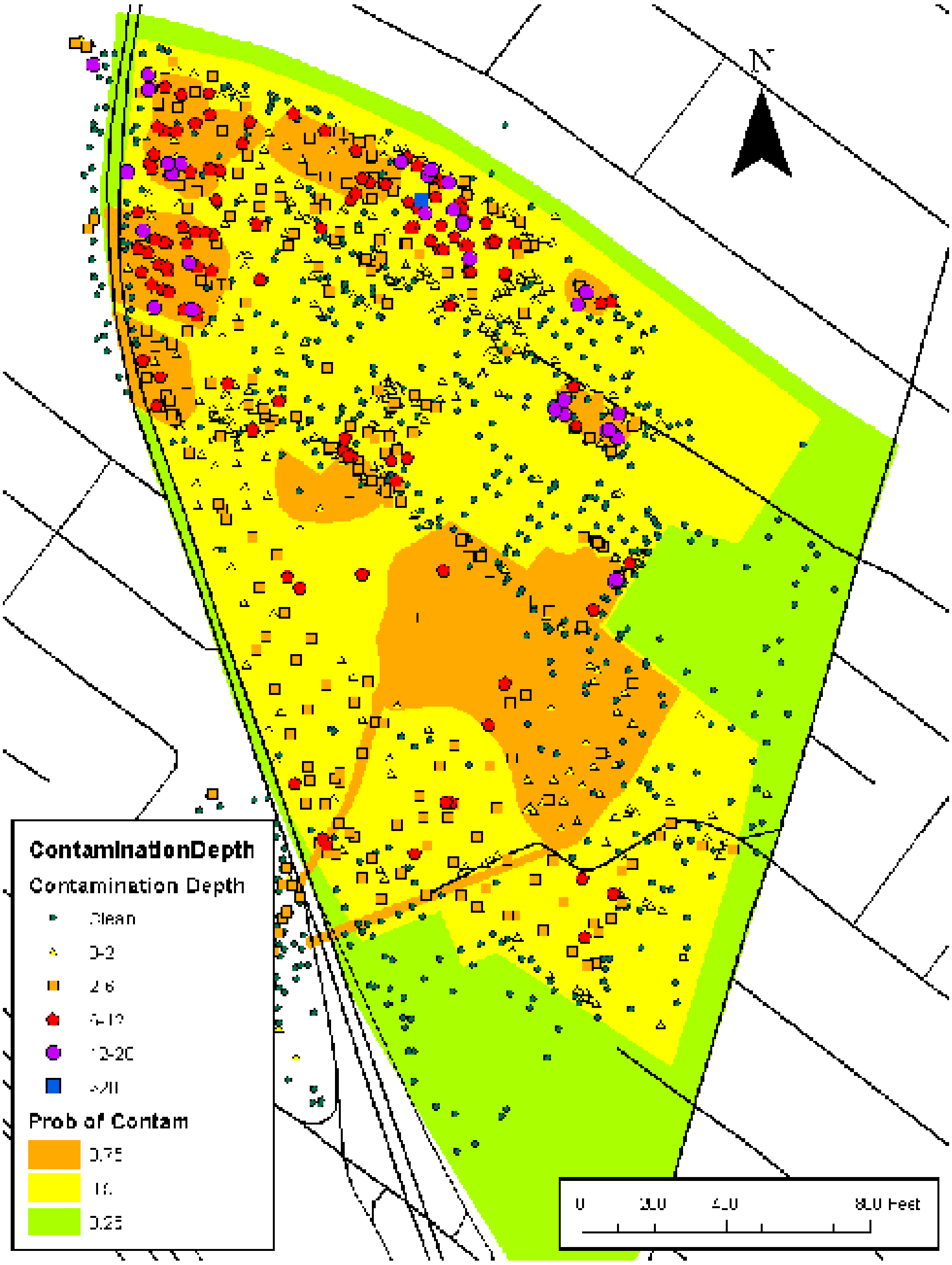

Fig. 3. Sample and DHG Results Color-Coded by Depth of Contamination Encountered, Overlain on the ICSM.

BAASS Volume Estimation

BAASS requires that soil sample laboratory results and DHG measurements be converted to indicator form (i.e., results either indicate the presence of contamination at levels of concern or they do not).

The Record of Decision (ROD) [5] calls for radiological cleanup criteria of an average of 5 pCi/g of Ra-226 and Th-232 combined (above background) at most of the site, and an average of 15 pCi/g of Ra-226 and Th-232 combined (above background) in subsoils at selected parcels. Including background values, these levels are 6.64 and 16.64 pCi/g, respectively. The ROD also calls for an average of 100 pCi/g of U-238 (above background). The driver for the Maywood site, however, is Th-232, and as implemented in the field, the goal is to clean up to 5 pCi/g Th-232. Final Status Survey (FSS) results indicate residual Th-232 of approximately 2-3 pCi/g including background at most FSS units.

Therefore, for laboratory data, any Th-232 result less than 5 pCi/g was considered clean and assigned a “0” value and results greater than 5 pCi/g were assigned a “1” value, indicating contamination at levels of concern. In the case of DHG measurements, any result less than 23,000 cpm was considered not affected at levels of concern and assigned a “0” value, any result between 22,000 and 33,000 cpm was assigned a 0.5 value, and any result greater than 33,000 cpm was considered indicative of contamination at levels of concern and assigned a “1” value. These cpm bins were determined on the basis of an analysis of the pre-2012 DHG and co-located Th-232 sample results.

Each station was then assigned a 0, 0.5, or 1 depending on the maximum indicator value observed from its DHG/lab sample results. For each station, the maximum depth at which either a 0.5 or a 1 value was observed was noted as well. Using the station data, and assuming an exponential variogram with a range of 50 ft and a search neighborhood of 50 ft, a BAASS update was performed on the ICSM. The BAASS grid resolution was set to 10 ft, resulting in approximately 45,000 BAASS grid nodes for the study area. The results were updated probabilities of contamination being present at each of the grid nodes.

The depth of contamination at each grid node was estimated using nearest neighbor interpolation and the maximum depth of contamination observed for each of the station locations. The remediation status across the main triangle as of August 2, 2012, was given in a Shaw drawing of irregularly shaped areas that are inaccessible, remediated (completed), or otherwise. Using GIS, the in situ contaminated soil volumes were estimated for each of the area types by parcel, including a “best guess” soil volume corresponding to all grid nodes that had a greater than 50% probability of contamination being present at levels of concern, and a conservative bounding volume corresponding to all grid nodes that had a greater than 20% probability of contamination being present. In the case of the “best guess,” the average maximum depth of contamination observed at the grid nodes was used for the volume calculation. In the case of the conservative bounding volume estimate, the 80th percentile of the depth of contamination observed at the grid nodes was used in the calculation.

Table 1 summarizes the volume estimation results but does not account for potential layback or constructability soil removal requirements or ex situ bulking.

Table 1. Maywood Contaminated In Situ Soil Volume Estimate Summary Based on BAASS Results and August 2, 2012, Site Status

Status	Best Guess	Conservative
Already Remediated	41,000 m^3 (54,000 yd^3)	86,000 m^3 (112,000 yd^3)
Remaining Accessible	71,000 m^3 (93,000 yd^3)	140,000 m^3 (183,000 yd^3)
Remaining Inaccessible	32,000 m^3 (42,000 yd^3)	73,000 m^3 (96,000 yd^3)
Total	145,000 m^3 (189,000 yd^3)	300,000 m^3 (392,000 yd^3)

Figure 4 accompanies Table 1 and illustrates the relationship between volume and probability for each case of land status and each approach for the estimation. The information in Table 1 and Figure 4 can be used with actual post-audit data from completed excavations to examine the relationship between the estimates provided in this report and the actual excavated volumes (including constructability volume) in portions of the Maywood site. Appropriate scaling may then be used to refine the estimate for remaining volumes in each parcel. This is discussed in the next section.

DISCUSSION

To assess the usefulness of the BAASS model, its results were compared to actual remediated volumes from the in-progress remediation.

Volumes tabulated by Shaw provided a snapshot of the volumes removed from the site as of July 25, 2012. This information is essentially the same date as an August 2, 2012, remedial status map provided by Shaw. The Shaw volumes are ex-situ cubic yards estimated based on truck counts. To relate the BAASS estimates of in-situ cubic yards to ex-situ cubic yards, Shaw suggests multiplying by a conversion factor of 1.3. The Shaw actual volumes associated with specific parcels and excavation phases were compiled; these 19 excavation phases are illustrated in a 2003 map provided by Shaw (Figure 5). In many cases, an excavation phase extends over more than one parcel, and the larger parcels have many different phases.

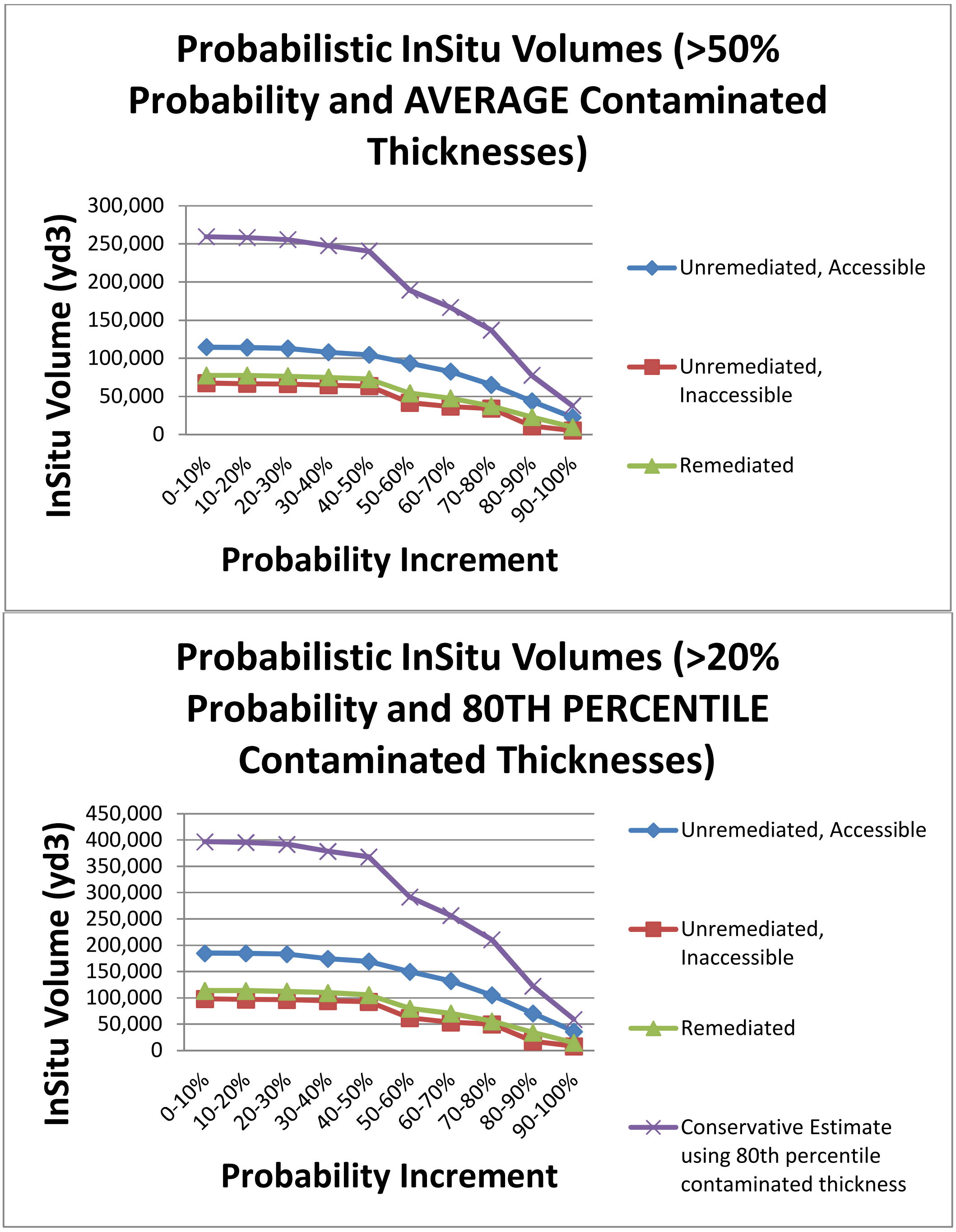

Fig. 4. Cumulative Volumes vs. Probability.

The named parcels were assigned to excavation phases either in their entirety (e.g., 06A, 06B, 06C, 06D, 11A, 11B, 11C) or were subdivided (e.g., MISS, Sears, Stepan) and grouped to form the excavation phases. Most of the excavation phases are incomplete as of July 25, 2012. Four of the excavation phases are noted by Shaw as being completed (Phases 5, 11, 13, and part of Phase 12). This comparison focuses on the accessible portions of the following:

- Phase 5 (06C, 06D, a portion of Sears);
- Phase 11 (11A, 11C, a portion of Stepan);
- Phase 13 (a portion of Sears, a portion of Stepan); and
- Phase 12 (a portion of Sears).

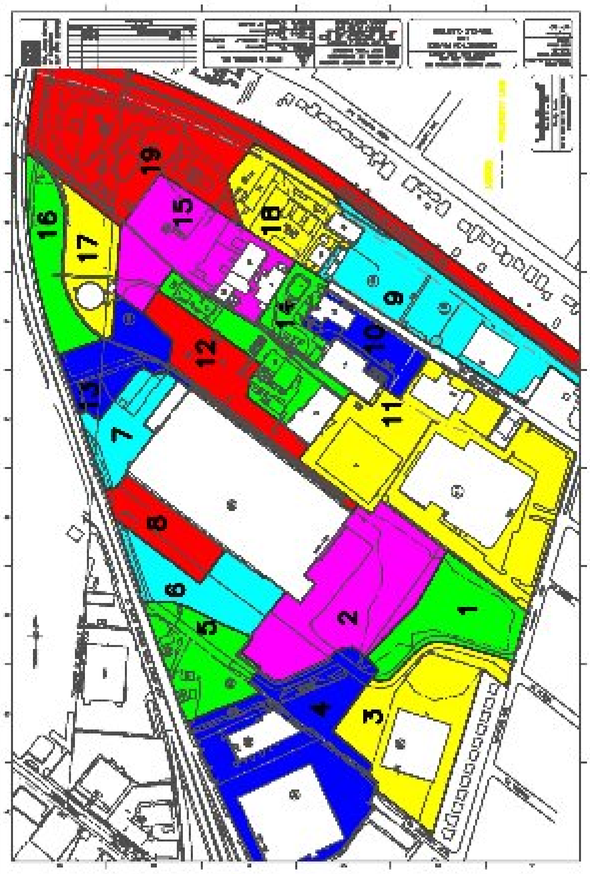

Figure 5. Maywood Main Triangle Excavation Phases

Another completed phase, Phase 4, was ignored in the analysis, because it apparently involved a great deal of excavation in Lodi Brook near the border of parcels 06B and 06C. Data provided to Argonne have not included any characterization data for the brook, so no soil contamination has been estimated in that location. An excavation took place there (visual evidence in GoogleEarth suggests around 2006), causing an exceedence of the estimate associated with that portion of the site.

The BAASS results along with Argonne-generated estimates for contaminated thicknesses were used to arrive at probability curves for the completed phases. The analysis is focused on the volumes removed from completed phases (converted into in-situ volumes) compared to the BAASS estimates (both average and conservative) for accessible areas only (inaccessible volumes are not compared to the actual removed volumes). Results for Phases 5, 11, 12, and 13 are summarized in Table 2.

For Phase 5, the estimated actual excavated volume (three phases totaling 7,531 m^3 or 9,851 yd^3) is very close to the best estimate using BAASS (Table 2 and Figure 6). It is between the best estimate and the conservative estimate, which is an expected outcome based on past experiences at other sites. This excavation phase took place in an area with adequate site characterization data and no large buildings.

Table 2. Summary of Actual Excavated Volumes, Best Statistically Estimated Volumes, and Conservative Statistically Estimated Volumes for the Four Completed Phases

Phase	Actual Excavated Volume (converted to in situ)	BAASS Volume Estimate (in situ)
Phase 5	1,018 m^3 (1,332 yd^3) at 06A 1,142 m^3 (1,494 yd^3) at 06B 5,370 m^3 (7,025 yd^3) at part of Sears 7,532 m^3 (9,851 yd^3) total	7,023 m^3 (9,186 yd^3) best estimate 11,395 m^3 (14,904 yd^3) conservative estimate
Phase 11	18284 m^3 (23,915 yd^3) at part of Stepan 19 m^3 (25 yd^3) at 11C 233 m^3 (305 yd^3) at 11A 18,536 m^3 (24,245 yd^3) total	4,674 m^3 (6,114 yd^3) best estimate 7,113 m^3 (9,303 yd^3) conservative estimate
Phase 12	2,919 m^3 (3,819 yd^3) at part of Sears	1,192 m^3 (1,559 yd^3) best estimate 2,414 m^3 (3,158 yd^3) conservative estimate
Phase 13	4,289 m^3 (5,610 yd^3) at part of Stepan 3,920 m^3 (5,127 yd^3) at part of Sears 8,209 m^3 (10,737 yd^3) total	2,809 m^3 (3,674 yd^3) best estimate 5,181 m^3 (6,776 yd^3) conservative estimate

For Phase 11, the amount removed far exceeds the conservative BAASS estimate (Table 2). In this phase, the main excavation area was in a part of Stepan. Site characterization data were absent in a large area. This area was covered by a building, which was later removed down to its slab, then the slab was removed and excavation took place. Excavation in this portion of Phase 11 certainly exceeded the volume estimate due to incomplete information (especially regarding depth of contamination in the pit area) available at the time of the volume estimation, resulting in an increased removal volume.

For the completed portion of Phase 12 (a sliver of the Sears property), the excavated volume is slightly larger than the conservative estimate (Table 2). This may be due to a lack of sample data along a utility corridor, which was later allowed to be accessed by the remediation-phase excavation equipment. For Phase 13, the excavated volume is much larger than the conservative estimate (Table 2).

Because FSS results have been approximately 2 to 3 pCi/g in completed units, the laboratory data used as BAASS input in Phases 5, 11, 12, and 13 were inspected for stations with a highest Th-232 activity concentration in the range of 2.5 to 5 pCi/g. Phases 11, 12, and 13 had such stations (10, 2, and 8 stations, respectively), while Phase 5 had none. Although this finding does not focus on the residual concentrations at the completed excavations, it does give some support to the idea that excavated volumes may have been increased above the conservative estimate because of excavation to a lower residual concentration than 5 pCi/g.

Comparison of the overall results from the ongoing excavation in the Maywood main triangle include a total removed volume of 209,000 m^3 (273,000 yd^3) (converted to in situ) as of July 25, 2012, compared to BAASS totals (accessible areas only) of 112,000 m^3 (147,000 yd^3) (average approach) or 226,000 m^3 (296,000 yd^3) (conservative approach). The actual removed volume is therefore approaching the conservative BAASS estimate, and many of the phases are not completed. Possible reasons for the actual volume exceeding the conservative estimate are discussed below.

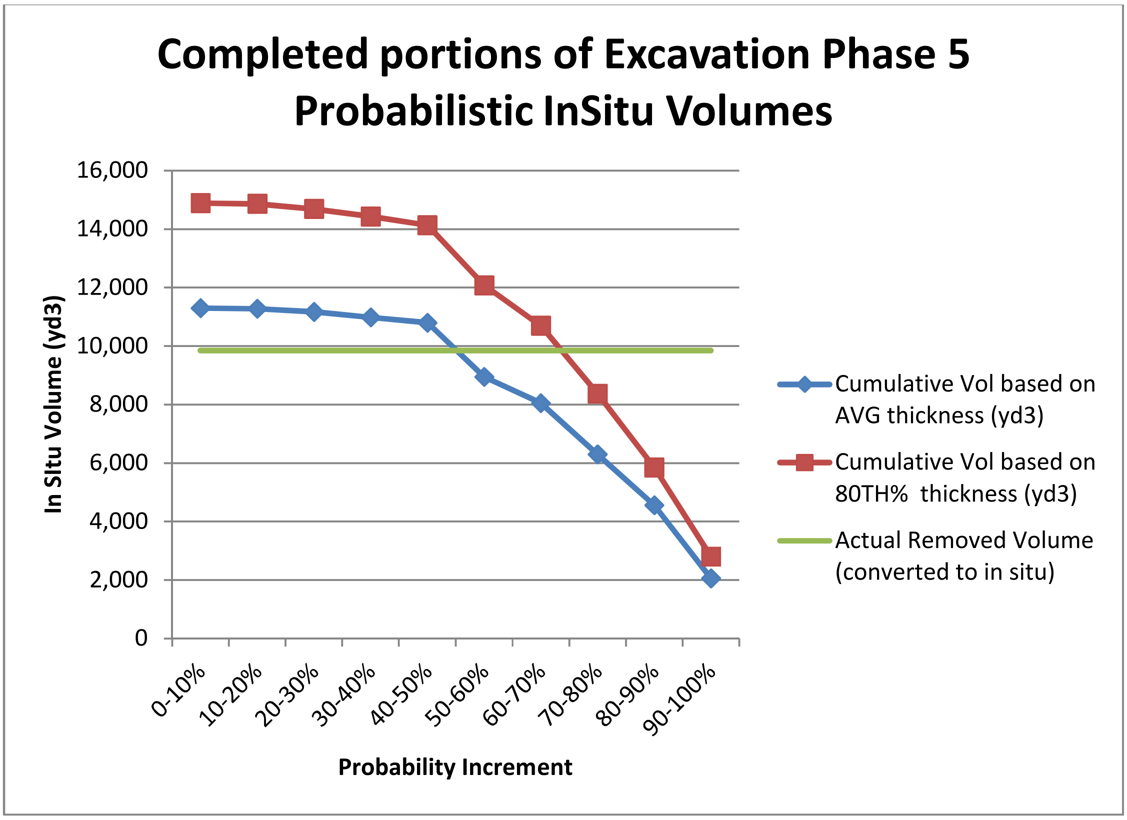

Figure 6. Cumulative Volumes vs. Probability for Excavation Phase 5.

CONCLUSIONS AND LESSONS LEARNED

For an analysis focused on a portion of the site with adequate characterization data and no apparent surprises (Excavation Phase 5), the BAASS average estimate matched the removed volume very closely. In another area (Phase 12), the removed volume matched the conservative BAASS estimate closely. Past experiences with FUSRAP site data and BAASS analyses have suggested that the ultimate removal volume is more adequately matched by a conservative BAASS approach rather than an average (or best) estimate approach.

In Excavation Phase 11, the actual removed volume was far larger than the conservative BAASS estimate for reasons dealing with an uncharacterized sub-slab area. Another area (Phase 13) was also somewhat higher than the conservative estimate for reasons that are not apparent. As discussed above, Phase 4 results could not be fairly compared to the removed volume because a large amount of material was apparently excavated from Lodi Brook, and no characterization data were available as input to BAASS.

The overall results suggest that the removed volume will exceed the conservative BAASS volume of in situ contaminated soil. Reasons for the discrepancies, where present, between completed phases' actual excavated volume (converted to in situ volumes) and the BAASS-estimated volumes for accessible areas (remediated and unremediated combined) include the following:

- Potentially, characterization data were not transmitted to Argonne for the analysis. Clearly, data had been collected along Lodi Brook, and an excavation took place there that could not have been included in the BAASS analysis.
- Actual field implementation of a cleanup goal of 5 pCi/g Th-232 may have been performed to a more conservative level of 2 to 3 pCi/g in many survey units. This level, which is generally consistent with what a gamma meter would indicate as a background reading, would result in a larger excavation volume relative to the BAASS criterion of 5 pCi/g. This finding would relate to large excavation volumes for particular excavation phases (complete or incomplete) as well as for the overall main triangle at Maywood.
- Overexcavation for constructability is commonly required, resulting in increased disposal volume compared to in situ volume estimates.
- Contamination is commonly observed in excavation walls, resulting in an expanded excavation that was unanticipated on the basis of the borehole data locations. In the same way, contamination may extend deeper than expected on the basis of borehole data. Both lateral and vertical dimensions of excavation depth can be increased due to the observations made using field scanning measurements.
- Errors in the estimation of actual volumes (truck counting, load estimates, conversion factor).
- Possible changes in the excavation phase boundaries since creation of the 2003 map.

As-built CAD files would help in identifying the contribution of several of the possible reasons for the discrepancy. The depth issue could be further explored by comparing as-built depths or elevations to Argonne estimates for the depths of contamination, fill, and bedrock. These were determined through inspection of hundreds of drilling logs for the site.

REFERENCES

1. Johnson, R., D. LePoire, A. Huttenga, and J. Quinn, 2005*, Bayesian Approaches for Adaptive Spatial Sampling: An Example Application*, ANL/EAD/TM/05-01, Argonne National Laboratory, April.

2. Johnson, R., D. LePoire, T. Klett, A. Huttenga, and J. Quinn, 2005, *Bayesian Approaches for Adaptive Spatial Sampling (BAASS) Version 1.0: Users' Guide*, Argonne National Laboratory, September.

3. Bechtel National, Inc., 1992, *Remedial Investigation Report for the Maywood Site New Jersey*, Volume I, December.

4. Shaw, 2012, *Geoprobe Investigation Report Re: Argonne – Shaw Geoprobe Investigation for Determination of Residual Soil Contamination Volumes*, prepared by B. Miller, October 3.

5. U.S. Army Corps of Engineers, 2003, *Record of Decision for Soils and Buildings at the FUSRAP Maywood Superfund Site*, Maywood, New Jersey, August.

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