Quantifying Contaminant Mass for the Feasibility Study of the DuPont Chambers Works FUSRAP Site – 13510

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ABSTRACT

The U.S. Army Corps of Engineers (USACE) - Philadelphia District is conducting an environmental restoration at the DuPont Chambers Works in Deepwater, New Jersey under the Formerly Utilized Sites Remedial Action Program (FUSRAP). Discrete locations are contaminated with natural uranium, thorium-230 and radium-226. The USACE is proposing a preferred remedial alternative consisting of excavation and offsite disposal to address soil contamination followed by monitored natural attenuation to address residual groundwater contamination. Methods were developed to quantify the error associated with contaminant volume estimates and use mass balance calculations of the uranium plume to estimate the removal efficiency of the proposed alternative.

During the remedial investigation, the USACE collected approximately 500 soil samples at various depths. As the first step of contaminant mass estimation, soil analytical data was segmented into several depth intervals. Second, using contouring software, analytical data for each depth interval was contoured to determine lateral extent of contamination. Six different contouring algorithms were used to generate alternative interpretations of the lateral extent of the soil contamination. Finally, geographical information system software was used to produce a three dimensional model in order to present both lateral and vertical extent of the soil contamination and to estimate the volume of impacted soil for each depth interval. The average soil volume from all six contouring methods was used to determine the estimated volume of impacted soil. This method also allowed an estimate of a standard deviation of the waste volume estimate. It was determined that the margin of error for the method was plus or minus 17% of the waste volume, which is within the acceptable construction contingency for cost estimation.

USACE collected approximately 190 groundwater samples from 40 monitor wells. It is expected that excavation and disposal of contaminated soil will remove the contaminant source zone and significantly reduce contaminant concentrations in groundwater. To test this assumption, a mass balance evaluation was performed to estimate the amount of dissolved uranium that would remain in the groundwater after completion of soil excavation. As part of this evaluation, average groundwater concentrations for the pre-excavation and post-excavation aquifer plume area were calculated to determine the percentage of plume removed during excavation activities. In addition, the volume of the plume removed during excavation dewatering was estimated. The

results of the evaluation show that approximately 98% of the aqueous uranium would be removed during the excavation phase. The USACE expects that residual levels of contamination will remain in groundwater after excavation of soil but at levels well suited for the selection of excavation combined with monitored natural attenuation as a preferred alternative.

INTRODUCTION

The U.S. Army Corps of Engineers (USACE) - Philadelphia District is performing environmental restoration at DuPont Chambers Works in Deepwater, New Jersey under the Formerly Utilized Sites Remedial Action Program (FUSRAP). USACE completed a remedial investigation / feasibility study (RI/FS) and identified natural uranium (U-nat), thorium-230 (Th-230), and radium-226 (Ra-226) as contaminants of concern.[1] The Proposed Plan has the preferred remedial alternatives of excavation and offsite disposal to address soil contamination followed by monitored natural attenuation to address residual groundwater contamination.[2] As part of the alternatives evaluation in the FS, a mass balance was performed to determine the volumes and ratios of the contaminants in solid and aqueous phases. Accurate estimation of the contaminant volume has a significant programmatic impact on project schedule, costs and remedial design. Industry-wide, heterogeneities in natural geosystems and in the spatial distribution of contaminants data contribute to significant errors in the estimation of contaminant volumes. Since transport and disposal of soil are major cost factors, the accurate estimation of soil volumes is critical for project budgeting and planning. For this project, efforts were made to estimate the uncertainty in the contaminant volume estimation methods. Calculating the mass balance helped to develop a qualitative understanding of the distribution of uranium in media both before and after excavation.

It is expected that excavation and disposal of contaminated soil will remove the contaminant source zone and significantly reduce contaminant concentrations in groundwater. To test this assumption, a mass balance evaluation was performed to estimate the amount of dissolved uranium that would remain in the groundwater after completion of soil excavation. The result of the evaluation showed that residual levels of contamination will remain in groundwater after excavation of soil but at levels well suited for the selection of excavation combined with monitored natural attenuation as a preferred alternative.

Background

From 1942 to 1947, the Manhattan Engineer District (MED) and Atomic Energy Commission contracted with DuPont to process uranium compounds and uranium metal scrap to produce uranium tetrafluoride, uranium hexafluoride and uranium metal.[3] More than half of the Chambers Works production was from the recycling of uranium-bearing dross and scrap from other MED facilities into uranium peroxide dihydrate as an intermediate product. [4] Uranium peroxide dihydrate ($UO_4 \bullet 2H_2O$), known as metastudtite, is a comparatively soluble hexavalent mineral species.[4] RI activities confirmed the presence of uranium in both soil and groundwater. Soil samples in Area of Concern (AOC) 1, a former uranium production area, had U-nat concentrations ranging up to 0.615 becquerels per kilogram (Bq/kg or 16,600 picocuries per gram (pCi/g)). Groundwater samples collected from this area had uranium concentrations as high as 748 becquerels per liter (Bq/L, or 29.6 milligrams per liter (mg/L)).

USACE conducted a baseline risk assessment to evaluate potential risks to both potential human and ecological receptors. The assessments determined an unacceptable level of dose and risk to potential human receptors at Areas of Concern (AOCs) 1, 2, and 6. The Feasibility Study established the remediation goal of 2.41×10^{-3} Bq/kg (65 pCi/g) uranium concentration.

Methods

Two different evaluations were performed to determine the areas and volume of the contaminated soil and to estimate the amount of dissolved uranium that would remain in groundwater after completion of a remedial action for soil, specifically an excavation alternative. Each of the evaluations is summarized below.

Estimation of In-Situ Waste Volumes

During the RI, approximately 500 soil samples were collected from six AOCs and one background reference area. The soil sampling results were compared to the remediation goal to determine the areas and volume of the contaminated soil. Initially, soil analytical data was segmented into several stacked depth intervals corresponding to excavation lifts of 1.2 meters (4 feet). Six interpolation methods included in the Surfer® contouring software [6] were used to calculate the contaminated soil contours in each lift:

- Kriging
- Minimum Curvature
- Modified Shepard's Method
- Natural Neighbor
- Nearest Neighbor
- Triangular with Linear Interpolation

The initial step of contouring is a data gridding process, where the sampling results are interpolated onto a regularly-spaced grid. The contouring program then uses the grid to generate the contour map. Each of the interpolation methods are summarized below.

Kriging is perhaps the most popular geostatistical gridding method.[7] It is an inverse-distance method that reduces the 'nugget effect' by handling clusters of biased data more like systematic, gridded data.

The Minimum Curvature method ‘smoothes’ the data to reduce the effects of high and low data outliers.

Modified Shepard’s method is an inverse-distance weighted-average interpolator that minimizes the ‘bull’s-eye’ effect, which is the tendency to create closed contours around data outliers.

The Natural Neighbor method uses a weighted average of the neighboring observations, where the weights are proportional to the ‘borrowed area’. It generates good contours from data sets containing dense data in some areas and sparse data in other areas.

The Nearest Neighbor method is compatible with regularly spaced systematic sampling grids. This method is useful for filling in ‘holes’ in a systematic sampling dataset.

The Triangulation interpolation is an exact interpolation of nearest data points. This method honors the values of the nearest data points very closely. [8]

The average from all six contouring methods was used to determine the estimated in-situ volume of soil exceeding remediation goal. This method also allowed an estimate of a standard deviation of the waste volume estimate. Table I presents the in-situ soil volume estimate for each interpolation method.

Groundwater Mass Balance Evaluations

Approximately 190 groundwater samples were collected from 40 monitor wells during the RI. Mass balance calculations were performed to estimate the amount of aqueous-phase uranium that would be removed during soil excavation and to develop an understanding of the efficiency of excavation in groundwater remediation. Mass Balance evaluations were performed in these areas by calculating pre and post excavation groundwater concentration contours, then determining the percentage of the groundwater plume removed during excavation. Additional estimates were made of the volumes of aqueous uranium recovered during construction dewatering.

Table I: Estimated In-Situ Soil Volumes Exceeding the Remediation Goal

AOC	Contouring Method	Volume Estimates [m^3]	Mean Estimate [m^3]	Standard Deviation [m^3]
AOC 1	Kriging	1757	1500	200
	Minimum Curvature	1512		
	Modified Shepard's Method	1678		
	Natural Neighbor	1604		
	Nearest Neighbor	1119		
	Triangulation with Linear Interpolation	1518		
AOC 2	Kriging	4889	4400	700
	Minimum Curvature	4089		
	Modified Shepard's Method	4032		
	Natural Neighbor	5236		
	Nearest Neighbor	3103		
	Triangulation with Linear Interpolation	4840		
AOC 6	Kriging	2598	2600	300
	Minimum Curvature	2811		
	Modified Shepard's Method	3125		
	Natural Neighbor	2198		
	Nearest Neighbor	2514		
	Triangulation with Linear Interpolation	2424		
Total Estimated Volume:			**8500**	**800**

Determination of Pre- and Post- Excavation Groundwater Concentrations

The pre-excavation groundwater concentrations were calculated as follows:

1. GIS mapping was used to draw the areas of impacted groundwater between the 1, 30, 100, and 1000 microgram per liter (µg/L) aqueous uranium isopleths.

2. Areas within the uranium isopleths were calculated between the areas (1 to 30) µg/L, (30 to 100) µg/L, and (100 to 1,000) µg/L, and inside of 1,000 µg/L.

3. The area-weighted average uranium concentration in groundwater was calculated using the following equation:

$$= \frac{\Sigma(\qquad)}{} \qquad \text{(Eq. 1)}$$

4. The volumes of the plumes were calculated by multiplying the plume areas by total porosity and aquifer thicknesses.
5. The area-weighted average groundwater concentration was then multiplied by the plume volumes to calculate the contaminant masses.

The post-excavation groundwater concentrations were calculated using the same methods as described above. However, the area-weighted average uranium concentration in groundwater was calculated using the concentrations and the area of impacted groundwater in the residual plume.

Table II presents the results of percentage of total uranium removal during the excavation process for AOC 1, AOC 2 and AOC 6. The soil excavation cut lines and plumes in AOC 1 are shown in Figure 2.

Table II: Estimated Removal of Uranium Mass from Groundwater by Excavation

	AOC 1	**AOC 2**	**AOC 6**	**Totals**
Pre-Excavation Uranium Mass in groundwater [kg]	0.6	5.1	0.07	**5.8**
Post-Excavation Uranium Mass in groundwater [kg]	0.02	0.11	0.013	**0.14**
Percent Removal of Aqueous Uranium	**97%**	**98%**	**81%**	**98%**

RESULTS

Of the waste volume estimates, none of the six contouring methods consistently gave the highest estimate, and none consistently generated results closest to the mean estimate. The Natural-Neighbor and Nearest-Neighbor methods tended to give the lowest estimates. The highest estimates were consistently 60% to 70% greater than the lowest estimates. Standard deviations were between 11% and 16% of the means.

As seen in Figure 1, only 65% of the AOC 1 plume area would be excavated. However, approximately 97% of the aqueous uranium mass will be removed. Similar results are estimated for the other AOCs: although only about 62% of the volume of the plumes will be removed, approximately 98% of the aqueous uranium mass will be removed. The average of the aqueous uranium concentrations would be reduced by 83%.

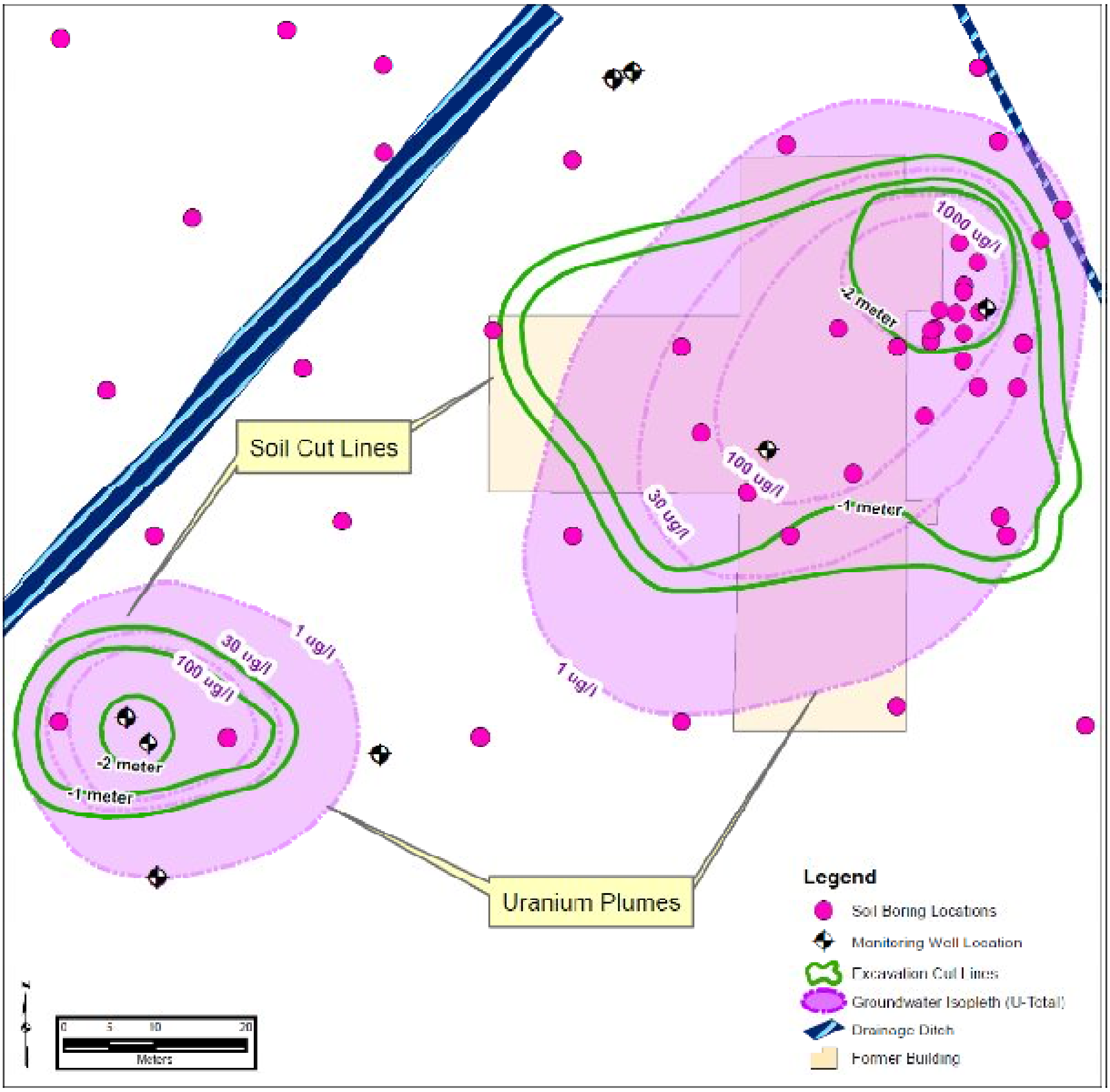

Figure 1: AOC 1 Soil Cut Lines and Uranium Plume

CONCLUSIONS

Six contouring methods were compared to develop an understanding of the error inherent with their use. An uncertainty in the contaminant volume estimate of plus or minus 10% was calculated simply by the selection of contouring method.

The mass balance of the uranium plumes that was developed to estimate the removal efficiency of the excavation alternative showed that aqueous uranium levels would be reduced sufficiently to allow for monitored natural attenuation to proceed thereafter. It was estimated that by excavating the source zones to meet the soil remediation goal, while 62% of the area of the plume would be removed, approximately 98% of the mass of aqueous uranium would be recovered. The average aqueous uranium concentration would be reduced by 83%.

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