IMPLEMENTATION GUIDE

Demonstration and Validation of Ex Situ Soil Washing to Remove PFAS Adsorbed to Soils from Source Zones

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This Implementation Guide has been prepared to describe how soil washing can be used to treat per- and poly-fluoroalkyl substances (PFAS) impacted soil. It will describe the basic principles and capabilities of soil washing and the applicability of soil washing for different sites. This Implementation Guide will then describe the steps required to implement soil washing: from the initial feasibility study and scaling up bench scale treatability studies to a full-scale treatment system. Soil washing can be used to treat a variety of chemicals of concern; however, this Implementation Guide will focus on the treatment of PFAS impacted soil and does not include discussion of treatment of other chemicals of concern.

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1.0 INTRODUCTION

This Implementation Guide has been prepared to describe how soil washing can be used to treat per- and poly-fluoroalkyl substances (PFAS) impacted soil. It will describe the basic principles and capabilities of soil washing and the applicability of soil washing for different sites. This Implementation Guide will then describe the steps required to implement soil washing: from the initial feasibility study and scaling up bench scale treatability studies to a full-scale treatment system. Soil washing can be used to treat a variety of chemicals of concern; however, this Implementation Guide will focus on the treatment of PFAS impacted soil and does not include discussion of treatment of other chemicals of concern.

Soil washing has been applied since the 1980s to treat a range of chemicals of concern and achieve volume reduction by treating the coarse-grained fraction and segregating the fine-grained fraction for secondary treatment. This guide references various soil washing guidance documents and provides practitioners with invaluable insights in planning and implementing soil washing to treat PFAS impacted soil.

2.0 PFAS SOIL WASHING

Soil washing is a physico-chemical mass removal and volume reduction technology that can be used to treat PFAS impacted soil from source zones and prevent groundwater impact. The primary soil washing mechanisms include dissolution/suspension into an aqueous solution, separation through physical differences, and/or desorption using non-hazardous solvents. Soil washing reduces the volume requiring expensive landfilling or thermal treatment by mechanical separation and focuses treatment on the coarse fraction of soil.

Treatment begins with the removal of debris, and soil subsequently enters the soil washing process, where it is subjected to size and, in some instances, density separation processes. Water-soluble chemicals of concern transferred into the aqueous phase are processed in a wastewater treatment circuit. Treated water is subsequently recycled back into the soil washing process for reuse and further treatment of soils. Following treatment, the fine fraction of soil is separated from the other soil fractions and sent for additional treatment or disposal. An extraction module is used to contact chemically amended process water with the fines to facilitate the transfer of PFAS from fine-grained soil into wash water before being dewatered. Treated soil is stockpiled and tested to validate that the post-treatment environmental soil quality objectives have been met. Concentrated chemicals of concern spent adsorbent media, and dewatered residuals can be disposed in a licensed landfill or treated using a destructive technology.

The challenge with implementing soil washing is that there is not a singular soil washing process that can be evaluated. Since the first soil washing efforts in the 1980s, there have been numerous soil washing flowsheets and equipment configurations applied at impacted sites. While many of the flowsheets have common treatment elements, the processes can vary from aggregate industry-based simple wet-screening systems to complex physical/chemical treatment circuits with custom-made equipment.

Figure 1 presents the three most common configurations ascribed to the soil washing technique. Option 1 is a basic size separation process that separates out the fine-grained soil from the coarser fractions using size and density separation techniques. The goal is to separate and concentrate the chemicals of concern into fine-grained soil fractions. Option 2 is a soil washing technique that treats the entire mass of the soil by contacting it with a chemical extraction fluid to solubilize the chemical of concern into the process water, while option 3 is a combined approach that treats soil using both physical and chemical extraction processes.

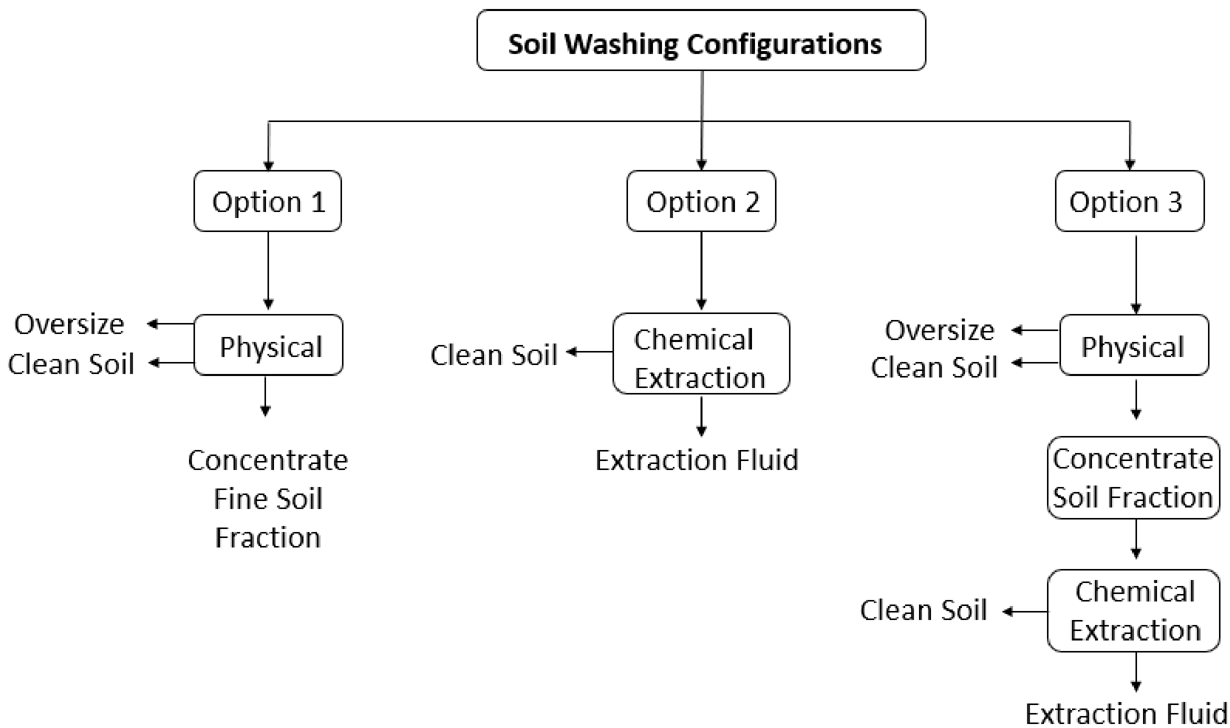

Figure 1. Soil Washing Configurations

Most of the soil washing processes that have been applied to PFAS sites fall into the description of Option 1. While the number of trials to date is limited, the results show that soil washing systems designed with a simple physical separation approach can treat the coarser soil fractions for PFAS into the low single-digit part per billion range. The separated fine-grained soil generally will not meet soil remedial objectives and will require further management.

As soil cleanup goals become more stringent, more advanced soil washing processes will be needed to consistently treat the coarse-grained soil fractions to a PFAS concentration less than 1 part per billion. Ongoing research has shown that optimization of the physical separation approach combined with chemical treatment has the potential to achieve these levels in this coarse-grained soil as well as a portion of the fine-grained soil fraction.

3.0 CAPABILITIES OF SOIL WASHING

The chemical properties of PFAS make it a good candidate chemical of concern for treatment via volume reduction by soil washing. Organic matter content, mineralogy, fine-grained soil percentage, and pH are all soil properties that interact with the chemical characteristics of PFAS to influence their retention on a given soil (Liu et al. 2020). In a soil washing process, the high aqueous solubility of PFAS (along with ability to control the pH of the process water, segregate the fine-grained fraction of the soil from the coarse-grained, and target the separation of organics or other soil minerals from the bulk soil) offer the ability to treat the coarse-grained soil and reduce the volume of impacted soil requiring further treatment or disposal.

The results of recent treatability and pilot tests on PFAS impacted soils have confirmed that soil washing treatment is highly effective for coarse-grained sand and gravel fractions of soil. The fine-grained soil fraction (clay and silt) and organic fractions typically require alternative treatment following soil washing.

The soil washing processes trialed to date on PFAS have consisted of relatively simple physical separation techniques designed to separate the fine-grained soil from the coarse-grained fraction, effectively reducing the volume of PFAS impacted soil requiring further management. The benefit of this volume reduction approach is that more cost-effective means can be applied to treat most of the impacted soil volume while limiting expensive residuals disposal or treatment. Treated soils can be beneficially re-used on site, and fines can be sent for off-site disposal, undergo thermal treatment or alternatively can be stabilized on-site to meet leaching-based standards. This flexible approach allows tailoring of the combined remedial strategy to meet clients' objectives and risk tolerance though a sustainable, least-cost remedial approach.

The volume reduction approach has demonstrated treatment of the sand and gravel soil fractions down to the low part per billion levels with PFAS removal efficiencies, but as soil cleanup goals become more stringent, it is anticipated that more advanced soil washing processes will be needed to consistently treat the coarse-grained soil fractions to a PFAS concentration less than 1 part per billion. In anticipation of these new cleanup goals, ongoing research has shown that optimization of the physical separation approach combined with chemical treatment has the potential to achieve these levels in the coarse-grained soil as well as a portion of the fine-grained soil fraction.

4.0 APPLICABILITY OF SOIL WASHING

When evaluating soil washing as a treatment alternative, one should consider a systematic approach to feasibility assessment and predesign studies. Soil washing guidance developed in the 1990s provides a roadmap, whether the focus is simple volume reduction or enhanced treatment. The USEPA has published several step-by-step guides outlining a systematic approach to designing and implementing treatability studies (USEPA 1991; USEPA 1992) along with guidance on planning-level process feasibility evaluations specific to physical separation for volume reduction (USEPA 1999).

Section 5 will outline a systematic approach for assessing the applicability of soil washing and then implementing soil washing for PFAS treatment based on EPA guidance documents; however, several rules of thumb can be used as an initial screening step to evaluate whether soil washing would be a suitable treatment technology for a site:

- **Soil volume**—Treating 10,000 tons is generally considered the threshold for making soil washing a cost-effective treatment method for a full-sized soil washing process with a throughput of 20-50 tons per hour. Treatment of less than 10,000 tons can still be cost-effective, but it generally requires a smaller or mobile treatment system with lower throughput.
- **Site geology**—Soil is predominantly coarse grained with less than 40% fines.
- **Suitable area for onsite treatment**—A 50-meter x 50-meter flat area for process equipment and additional space for stockpiling untreated and treated soil would generally be required. A serviced site with access to water and power is also beneficial to a full-scale application, however equipment can be run with generators and water can be trucked in from nearby water sources for remote sites.
- **Climate**—Soil washing is a wet process and can only run during above freezing temperatures outside. The local seasonal temperatures will need to be considered in relation to the timelines to complete the treatment.
- **Disposition of treated soil**—This is site specific and dependent on stakeholder objectives and local regulations, but treated soil needs to be reused onsite and residuals (fines and organics) need to be managed for secondary treatment (e.g., stabilization, landfilling, or thermal treatment).
- **Budgetary Constraints**—Application of soil washing will be in the range of $100 to $200 /ton plus the cost to manage the fines.

5.0 IMPLEMENTING SOIL WASHING

This section summarizes the steps that should be followed when evaluating soil washing as a treatment alternative.

5.1 STEP 1: PRELIMINARY INFORMATION

Preliminary information is typically compiled through a desktop review of relevant reports available for the site and discussions with stakeholders. Reports typically reviewed include site investigation or remedial investigation reports, risk assessments, and any geotechnical investigations that may have been completed. Preliminary information generally includes:

- Sources of PFAS impact
- Presence of co-occurring chemicals
- Concentrations of PFAS and co-occurring chemicals
- Cleanup criteria
- Volume of material requiring treatment
- Site geology and soil properties (particle size distribution, percentage of organics, pH)
- Timelines for treatment
- Suitable on-site area for soil treatment (including water and power)
- Climate

- Disposition of treated material
- Budgetary constraints

The goal of this stage is to fully understand the impacted property with focus on remedial goals, soil types, variation of chemical of concern concentrations at the impacted property, form of the impact, and identification of any data gaps present within the environmental characterization available at the property. Particular attention should be given to the cleanup criteria and the average, minimum, and maximum concentrations of PFAS at the site. The current state of soil washing can treat the coarse-grained fractions to the single digit part per billion for perfluorooctane sulfonate (PFOS). The ability to consistently treat to that level will be influenced by the untreated concentrations and needs to be considered at this stage. Aqueous film-forming foam sources are typically in the single digit part per million range and are amenable to soil washing. Soil with higher concentrations could require more advanced applications of soil washing.

Following the completion of this stage, conclusions can be made regarding the potential applicability of remediation by soil washing at a particular site and the likelihood of achieving the remedial goals.

5.2 STEP 2: PRELIMINARY MATERIALS CHARACTERIZATION

The preliminary materials characterization builds upon the data collected in the first step and identifies data gaps specific to application of a soil washing system. Data needs to further evaluate soil washing include representative sampling of stockpiles and not just in situ soil samples. Analysis should include PFAS, grain size, cation exchange capacity, total organic carbon, and particle size including clay content. It is recommended that soil is sampled from stockpiles after it has been excavated, and excavators should be used to collect representative soil from throughout the stockpile. Collecting soil samples from a Geoprobe™ or hand auger could bias samples to collect soil with a higher fines percentage.

Data should be compiled in a way that will ultimately be useful to soil washing vendors when evaluating the actual untreated concentration of soil that will enter the soil washing plant. Using upper confidence limit calculations is useful from a risk assessment viewpoint but understanding the true range and mean concentrations of soil is necessary to determine the most cost-effective soil washing process.

At this stage, a laboratory-scale feasibility study could be conducted. The feasibility studies are limited in size and scope, and it is recommended to get a professional opinion on commissioning the study at this stage of the process. Indicator chemicals of concern, such as PFOS, and other regulated PFAS compounds, are evaluated to determine if a reduction in toxicity, mobility, or volume is occurring and if the technology can meet the site cleanup goals. USEPA guidance on this process can be found in Guide for Conducting Treatability Studies Under CERCLA (USEPA 1992) and Physical Separation (Soil Washing) for Volume Reduction of Contaminated Soils and Sediments - Processes and Equipment (USEPA 1999).

5.3 STEP 3: PRELIMINARY TECHNICAL AND BUDGETARY FEASIBILITY EVALUATION

The third step in the process evaluates the data collected to date to make a preliminary technical and budgetary feasibility evaluation. If treatment of the soil to the site cleanup criteria is amenable to volume reduction and further management of the fines, then the process is evaluated from a budgetary standpoint.

If the answer to the technical or budgetary questions are negative, then alternative technologies, approaches or disposal options must be considered. If the technical and budgetary questions are positive, then the next step is to assess the degree of certainty with that determination.

5.4 STEP 4: CONFIDENCE IN THE POSITIVE TECHNICAL AND BUDGETARY FEASIBILITY EVALUATION

In this step, the confidence of the positive assessment in step 3 is evaluated. This will include a review of the site characterization data, site data specific to the assessment of soil washing and, if conducted, the results of a laboratory-scale feasibility test.

Given that PFAS is a complex chemical of concern with few soil washing studies to date, in most instances, it would be recommended to proceed to step 5 until a larger dataset of laboratory and pilot-scale projects have been completed to base feasibility decisions.

5.5 GATHERING ADDITIONAL DATA

Step 5 involves gathering additional data upon which to base the feasibility decision. For example, this could include addressing data gaps in the site characterization analysis for hot spots or recommending additional samples for grain size in different soil units present at a site. More commonly, this step involves conducting a more detailed treatability test at the laboratory pilot or field pilot scales. Guidance on this process at the field scale is provided in the Guide for Conducting Treatability Studies Under CERCLA (USEPA 1992) and the Guide for Conducting Treatability Studies Under CERCLA: Soil Washing Interim Guidance (USEPA 1991).

If additional treatability testing is conducted, vendors with the capability and experience to conduct laboratory, pilot, and full-scale soil washing processes should be engaged. One of the uncertainties that can be addressed through treatability testing at this stage is the issue of scale-up. Vendors with experience scaling up soil washing processes from laboratory or pilot-scale to full scale should be able to demonstrate an understanding of how size changes will impact the physical treatment conditions created at the laboratory scale and how they will be duplicated or reasonably simulated at the larger scale. This necessity for an understanding of scale-up by the soil washing vendors will become more magnified as the soil washing process innovates to include chemical or other innovative treatment equipment to achieve more stringent cleanup standards.

5.6 STEP 6: FINAL TECHNICAL AND BUDGETARY FEASIBILITY EVALUATION

Step 6 is a repetition of step 3, but further evaluated with the additional information obtained in step 5. At this stage, the technical feasibility of applying soil washing as a volume reduction technique and managing the fines using a complimentary process should be fully evaluated.

If the conclusion on the technical feasibility is positive, then the question of the process meeting budgetary constraints is reexamined. If the answer to this question is also positive, then the project can move to the next steps, which may include the issuance of a request for proposal or the design of a full-scale system.

5.7 BENEFITS OF SOIL WASHING

Soil washing is a cost-effective volume reduction technology that can successfully treat the bulk of the soil matrix to achieve remedial goals. After separating the fine-grained soil, the fines can be disposed of at a licensed landfill or undergo more expensive treatment methods (e.g., thermal desorption or incineration).

Arcadis and Clean Earth (2022) indicates that soil washing (including secondary treatment of the fines) is more cost-effective than landfilling or thermal desorption for soil with up to 30 percent fines, and costs are comparable to these technologies, even with 50 percent fines.

Soil washing can be tailored to each site depending on soil characteristics, regulatory requirements, and stakeholder objectives. As soil cleanup goals get lower and lower, more advanced soil processes will be needed. As shown in the Final Report, basic soil washing processes can be employed to treat soil with low PFAS concentrations; however, to treat source soil or to achieve concentrations in the sub-part per billion range, chemical treatment and advanced physical optimization processes are needed.

Generally, the fine-grained soil fraction will not meet soil cleanup standards in soil washing. Ongoing research indicates that PFAS removal efficiencies can be improved for the fine-grained fraction with advanced treatment processes, which will reduce the volume of soil that needs to undergo secondary treatment. This ongoing research is needed to continue to make soil washing cost competitive with landfilling and thermal desorption.

6.0 REFERENCES

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