APPENDIX A

In Situ Soil Flushing

1.0 Technology Background

In situ flushing of the vadose zone involves the addition of a flushing solution to affected soils to mobilize chemicals from soil to groundwater. The specific contaminants in soil determine the type of flushing solution that is used, which is typically (1) water only, or (2) water plus additives, such as acids, bases, or surfactants. Because other technologies evaluated and described in this study remediate vadose zone soils through the in situ action of water plus additives (specifically electron donors and nutrients to stimulate biodegradation), this discussion of in situ soil flushing will be limited to flushing with water only.

Water for soil flushing is typically applied via surface infiltration ponds, infiltration galleries, drip irrigation or sprinklers, or injected or tilled into surface soils as needed. The applied water then percolates through the soil column, leaching chemicals from the vadose zone. Once this leachate reaches the saturated zone, it mixes with groundwater, and chemicals that have been leached from the vadose zone are removed, either through a groundwater extraction and treatment system, or through use of an active or passive in situ groundwater remedy.

Soil flushing is most effective in relatively permeable soils, such as sands and gravels. Soils containing a large amount of clay and silt are generally less appropriate for remediation by soil flushing, both because of reduced percolation rates of water through these soils, and also because contaminants can be more tightly bound on soil particles or in interstitial pore spaces.

In situ soil flushing has been considered for use in the remediation of a wide variety of chemicals from soil, including metals, halogenated solvents, pesticides, and organics such as gasoline and fuel oils, though flushing with water alone is most effective in removing relatively soluble compounds, such as perchlorate. Mobilization of less hydrophilic compounds is often improved through the addition of amendments such as surfactants or acids.

In situ soil flushing can be effective at mobilizing chemicals located well below the ground surface, since it is an in situ method in which the applied water moves through the vadose zone under gravity. As well, it can be applied in some areas where access is limited such as under pavement or in areas with subsurface improvements and utilities, with some engineering controls and systems for the uniform application of water.

2.0 Technology Implementability

This Site has many characteristics required for the successful application of soil flushing. Site vadose-zone soils are generally permeable. The COCs that are targeted for remediation are either highly soluble (such as perchlorate) or present in lower concentrations or more localized areas of the Site. The ground surface of much of the Site is accessible and without obstructions such as buildings and utilities that require special techniques to flush, yet affected vadose zone soil extends up to 80 feet below the existing ground surface. Most importantly, there is an existing groundwater extraction and treatment system in operation. This system controls the migration of groundwater in the subsurface, and it can provide some capacity for both the hydraulic control and the treatment of leachate that will be generated by potential soil flushing operations.

The Site is located on Quaternary alluvial (Qal) deposits that are a heterogeneous mixture of sands and gravels with lesser amounts of silts, clays, and caliche. These alluvial deposits are generally highly permeable. Discontinuous caliche layers have been identified at the Site, though based on groundwater monitoring results, the caliche does not appear to have significantly impeded the downward migration of perchlorate to the saturated zone at the Site.

Perchlorate is highly soluble in water and is not readily adsorbed on the surface of unsaturated soils (Urbansky, 2003). Other COCs are less soluble, but considering that the potential remedial objectives for the vadose zone may be based on the leachability of these compounds from soil to water, soil flushing becomes a viable remedial technique to mitigate future groundwater impacts by definition. As well, the current distribution of these less soluble COCs is more limited than that of perchlorate.

Hydraulic control and treatment of groundwater and leachate is an essential element of soil flushing, and often can significantly affect the cost required to implement this technology. At this Site, there is an existing network of extraction wells and a subsurface slurry wall that capture groundwater downgradient of most potential soil flushing locations. As well, the existing groundwater treatment system has some existing capacity to accept higher flow rates for perchlorate treatment, and the capacity of the chromium removal system can be increased with a moderate capital investment.

Other compounds such as cobalt, manganese, and pesticides may also be flushed to groundwater as a result of soil flushing. The ability of the current treatment system to remove these compounds is being evaluated, and some process or operational modifications may be required to remove these compounds from extracted groundwater. Once again, though, it appears as if these modifications will be modest in scope, and the existing equipment will provide some treatment capacity for the removal of these other constituents should they appear in concentrations that require treatment.

3.0 Technology Performance

In situ soil flushing is a technology that has been widely used for a variety of contaminants. The most recent technology status report on in situ flushing listed 64 case studies in the United States and Canada in pilot scale or full scale application and another 20 studies that had progressed to laboratory scale (GWRTAC, 1998). Most of these were for the remediation of soils containing NAPL sources of VOCs, and many included the use of surfactants or cosolvents to increase the mobilization of these constituents. Projects targeting hydrophobic compounds have had mixed success with soil flushing, and complete mobilization and removal of NAPLs has not been observed in the field with chemical amendments (National Research Council, 1994).

However, more soluble compounds such as perchlorate are more likely to be effectively mobilized through soil flushing. The ITRC report on remediation techniques for perchlorate notes that “precipitation can act to disperse or flush the [perchlorate] source … to surface water or groundwater. In an arid environment, the dispersal may be limited” (IRTC, 2008). Soil flushing is essentially an acceleration of the natural process of precipitation and infiltration. This Site receives an average of approximately four inches of rainfall per year. A Site-specific infiltration rate has not been developed, though the USGS has estimated that approximately 2 percent of this precipitation eventually reaches the groundwater in undeveloped land in the region (USGS, 2007). Thus, it may be possible to generate the equivalent recharge (and leaching) of many years of normal precipitation through a moderate application of water at the ground surface.

A bench scale test using soil samples collected from the Site and flushed with stabilized Lake Mead water taken from the Site demonstrated that perchlorate can be readily transferred from soil into leachate. In these bench scale tests, three soil columns (each 6 inches in diameter by 6 feet long) were prepared and Lake Mead water was uniformly applied to the top of the column at a rate of 2mL per minute. It was found that the application of 2 pore volumes of water to the top of the column reduced the concentration of perchlorate in soil by more than 99% (PRIMA, 2010), which suggests that perchlorate concentrations in the vadose zone may be substantially reduced with the application of a practical volume of water. Field-scale pilot testing is necessary to determine whether these results are translatable to the field and what effects heterogeneity and contaminant depth will have on effectiveness and water volume requirements.

4.0 Case Study

One particularly relevant project involving in situ soil flushing was recently conducted at Edwards Air Force Base. In this demonstration project, perchlorate was mobilized to groundwater through a 129 foot-thick vadose zone by infiltration from near the ground surface.

Soil at this site was classified as clayey sand. An infiltration gallery of slotted PVC pipes within a permeable bed of washed gravel was constructed to introduce water at a sustainable rate of 2.3 gallons per minute near the ground surface. Water was amended with a potassium bromide tracer. A downhole neutron probe was used to track the movement of the wetting front downward and outward from the gallery. 14 weeks after water was introduced to the gallery, it was detected at the bottom of a 125-foot deep access tube. One week later, bromide tracer was detected in groundwater samples taken from directly below the infiltration gallery.

Eighteen weeks after the start of infiltration, groundwater samples collected from beneath the infiltration gallery contained 72,400 ug/L of perchlorate. This compared with a perchlorate concentration of 4,500 ug/L in groundwater samples collected before infiltration was started. This provided evidence of mobilization of perchlorate from the vadose zone to the groundwater.

This groundwater was captured by an adjacent groundwater extraction well, treated to remove the perchlorate, and recycled back into the infiltration gallery. Continued flushing of the vadose zone resulted in a rapid decrease in perchlorate concentrations with continued soil flushing.

The authors report that the this test indicated that this infiltration trench could provide a cost-effective alternative to injection wells for the reintroduction of treated groundwater to the aquifer, and that it could provide an effective mechanism for the delivery of amendments to the vadose zone and aquifer for promoting the biodegradation of perchlorate in soil and groundwater (Battey et al., 2007).

5.0 Regulatory Acceptance

In situ soil flushing has been selected as part of the source control remedy at over a dozen of Superfund sites (USEPA, 1991). The NDEP has reviewed and approved plans to conduct a pilot test of this technology at the Site. It is believed that with data from a pilot study, and establishment that leachate generated from a soil flushing operation can be contained and appropriately treated, that this technology may be approved for full scale implementation.

6.0 Costs

The primary cost drivers of soil flushing are dictated by site conditions, such as soil permeability, depth to groundwater, and solubility of COCs. The Remediation Technologies Screening Matrix and Reference Guide presented an analysis using the 2006 version of Remedial Action Cost Engineering and Requirements (RACER) software and concluded that costs for soil flushing range from $18 to $27 per cubic yard, though the scale of these projects was much smaller than those contemplated at this Site (a "large site" was 5,550 cubic yards) and the flushing system included surfactant-amended water (FRTR, 2006).

Preliminary cost estimates for full scale implementation at this Site suggest that costs for flushing may be lower, because of favorable site conditions and the ability to utilize existing systems for some or all of the capture and treatment of groundwater and leachate.

7.0 References

Battey, T.F., Shepard, A. J., and Tait, R. J., 2007, Soil Flushing Through a Thick Vadose Zone: Perchlorate Removal Documented at Edwards AFB, California, Abstract #H33E-1685, American Geophysical Union, Fall.

Ground-Water Remediation Technology Analysis Center, 1998, Technology Status Report In Situ Flushing, TS-98-01, November. Available online at http://clu-in.org/download/toolkit/isf_1117.pdf.

Interstate Technology and Regulatory Council (ITRC). 2008. Remedial Technologies for perchlorate contamination in water and soil. PERC-2. Washington, D.C.: Interstate Technology & Regulatory Council, Perchlorate Team, March. Available online at http://www.itrcweb.com

Federal Remediation Technologies Roundtable, Remediation Technologies Screening Matrix and Reference Guide, Version 4.0, Soil, Sediment, Bedrock and Sludge, In-Situ Physical/Chemical Treatment, Soil Flushing, 2006. Available online at http://www.frtr.gov/matrix2/section4/4-6.html

National Research Council, 1994, Alternatives for Ground Water Cleanup.

PRIMA Environmental, 2010, Column Tests to Evaluation In-Situ Flushing of Perchlorate on Soil and Groundwater, October.

Urbansky, Edward Todd and Brown, Stephanie K., 2003, Perchlorate Retention and Mobility in Soils, Journal of Environmental Monitoring, No. 5, pg 455-462.

U. S. EPA, 1991, Engineering Bulletin *InSitu* Soil Flushing, EPA/540/2-91/021, October.

U.S. Geological Survey, 2007, Ground Water Recharge in the Arid and Semiarid Southwestern United States, Professional Paper 1703, Ground Water Resources Program, July.