TECHNICAL PERFORMANCE MEASURE (TPM)	APPROPRIATE GOAL	WHAT THIS TPM EVALUATES	WHAT THIS TPM MEASURES	IS THIS A CORE TPM?	AVAILABILTY OF THIS TPM	COST	STANDARIZATION OF THIS METHOD	ADDITIONAL INFORMATION
Acid Base Accounting	Evaluate soil health/ecosystem function for revitalization	Agronomic measures	Soil properties	No	Readily	$-$$	Med	*Neutralizing Amendments and Rates of Application*
Animal tissue residue (field)	Reduce bioavailability	Bioavailability to animals from soil	Animal bioaccumulation	No	Readily	$$	High	This method is used to determine the bioaccessible contaminant content in soil or contaminated geomedia, and the potential for accumulation in animals. Bioaccessible contaminant concentrations in animals are established via the collection and subsequent analysis of surrogate species from the test area to establish contaminant concentrations in the organisms. Either whole body or target tissues may be subject to analysis.
Blood test methods	Reduce bioavailability	Bioavailability to or bioaccumulation in humans from food chain	Blood level (child Pb)	No	Limited	$$	High	Concentration of lead in blood has been used as an indicator of recent exposure to lead (the half-life of lead in blood is approximately 36 days). The most common methods to analyze lead in blood are flame atomic absorption spectrometry (AAS), graphite furnace atomic absorption spectrometry (GFAAS), anode stripping voltametry (ASV), inductively coupled plasma-atomic emission spectroscopy (ICP/AES), and inductively coupled plasma mass spectrometry (ICP/MS). ATSDR has outlined several methodologies in table 7.1 of the Draft Toxicological Profile for Lead (2005). In addition, FDA has approved a cost-effective rapid blood lead screening test that is available at many hospitals and doctor's offices. More Information and References
Bulk density	Evaluate soil health/ecosystem function for revitalization	Agronomic measures	Soil properties	No	Readily	$	High	Bulk density is a measure of the ratio of the mass of dry soil to the volume of the soil. This provides a measure of the density of a volume of soil in the field. Therefore, it can be an indication of the degree of soil compaction and suitability for plant growth. According to Miller and Gardiner (1998) the average bulk density for a cultivated loam soil ranges from 1100 kg/m3 to 1400 kg/m3. For good plant growth, they recommend bulk densities < 1400 kg/m3 for clay soils and <1600 kg/m3 for sandy soils. References
CaCO3 equivalent	Evaluate soil health/ecosystem function for	Agronomic measures	Soil properties	No	Readily	$	High	Calcium Carbonate Equivalence (CCE) is a measure of the neutralizing value of liming materials that may be used to ameliorate low pH soils. References
Calibrated in vitro extraction	Reduce toxicity or bioavailability	Toxicity or bioavailability to plants or animals from soil	Soil extraction	No	Readily	$	High	Simple, inexpensive soil extractions can sometimes be used to augment more expensive bioassay data. By pairing in vivo with in vitro data a site specific calibrated in vitro method can be used as a site specific surrogate to predict contaminant bioavailability or to evaluate remedial success. A strong relationship between in vitro and in vivo data is a prerequisite for using this technique. A robust calibrated in vitro method may allow for a more thorough characterization of sites' contaminant bioavailability/toxicity than would be economically feasible with in vivo data only. More Information.
Cation exchange capacity	Evaluate soil health/ecosystem function for revitalization	Agronomic measures	Soil properties	No	Limited	$	High	Cation exchange capacity (CEC) is an important property of soil that affects biological availability of nutrients and contaminants (i.e., availability to plants, soil invertebrates, microorganisms). Soil CEC is the sum total of exchangeable cations a soil can hold. Exchangeable cations are held weakly by the surface negative charge sites of the soil. This weak bonding prevents/reduces leaching of cations from soil drainage from rainfall or irrigation. However, cations on the soil CEC are available to plants and other soil organisms. Soil CEC is an important source of nutrient cations including ammonium, calcium, magnesium, and potassium. Soil CEC can also be a source of metal cation contaminants including zinc, cadmium, lead, copper, and other positively charged ions. More Information
Dietary exposure model (food basket)	Reduce bioavailability	Bioavailability or toxicity to humans from soil through food	Dietary exposure to humans	No	Readily	$$	Med	Dietary exposure models are used to evaluate whether contaminant concentrations in food items available from the site may lead to toxicity to or bioaccumulation in humans.
Dietary exposure model (input accumulation data)	Reduce bioavailability	Bioavailability or toxicity to animals from soil through food chain	Dietary exposure to animals	No	Readily	$$	High	Dietary exposure models are used to evaluate whether contaminant concentrations in food items may lead to toxicity to or bioaccumulation (and biomagnification) in higher trophic level animals. More accurate exposure models can be developed when site-specific bioaccumulation data (i.e., onsite tissue concentrations of food items) are used.
Direct ingestion evaluation	Reduce bioavailability or toxicity	Bioavailability or toxicity to animals from soil	Animal bioaccumulation	No	Readily	$$	Med	This method is used to determine whether exposure to the bioaccessible contaminant content in soil or contaminated geomedia results in adverse biological effects. Bioaccessible contaminant concentrations are established via exposure of surrogate prey species to soil or geomedia.
Field organism monitoring (body burden)	Reduce bioavailability	Bioavailability to animals from soil	Animal bioaccumulation	No	Readily	$$	High	This method is used to determine the bioaccessible contaminant content in soil or contaminated geomedia, and the potential for accumulation in food items and prey species. Bioaccessible contaminant concentrations in prey species are established via the collection and subsequent analysis of surrogate prey species from the test area to establish contaminant concentrations in the organisms. Either whole body or target tissues may be subject to analysis.

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Field organism testing (histology, critical body burden)	Reduce bioavailability	Toxicity to animals from soil through food chain	Animal bioaccumulation	No	Readily	$$	High	This method is used to determine whether exposure to the bioaccessible contaminant content in soil or contaminated geomedia, and subsequently concentrations in food items / prey species, results in contaminant concentrations in biota capable of producing an adverse effect. Either whole body or target tissues of biota may be subject to histological analyses to directly observe changes related to exposure and/or impact. Similarly, either whole body or target tissues of biota may be subject to chemical analyses in order to compare site tissue concentrations with a concentration known to be associated with adverse effects.
In vitro GI test method	Reduce bioavailability	Bioavailability to humans from soil	In vitro GI (bioaccessible)	No	Readily	$	Med	The bioavailability of a limited number of inorganic contaminants (i.e., Pb, As, Cd) in soils can be assessed by conducting dosing trials using animal models. To overcome the difficulties and expenses associated with conducting such in vivo trials, researchers have developed in vitro gastrointestinal (IVG) methods to simulate the gastrointestinal environment. In choosing an appropriate IVG method, it is important to recognize that a strong correlation between in vitro and in vivo (e.g., an animal model accepted as a surrogate for humans) data is required, and gastric pH used for IVG methods can greatly affect the amount of bioaccessible Pb in soil treated with amendments (i.e., biosolids, phosphate materials, etc.). More Information
In vivo test method - swine	Reduce bioavailability	Bioavailability to humans from soil	Animal bioaccumulation	No	Rare	$$$$	High	The bioavailability of a limited number of inorganic contaminants (i.e., Pb, As, Cd) in soils can be assessed by conducting dosing trials using animal models in lieu of human testing, which is highly unlikely. Immature swine and primates have been used as acceptable human surrogate models for determination of bioavailability of lead and arsenic in contaminated soil. Other animal models may be acceptable if peer review research shows they can serve as acceptable surrogates for estimating human oral contaminant bioavailability from ingested soil. It should be noted that there are several disadvantages to conducting in vivo animal trials such as length of time it takes to conduct the trial, expense of conducting the trials, and dosing problems. To overcome the difficulties and expenses associated with conducting in vivo trials to assess bioavailability of Pb in soils, research efforts have been directed toward the development of chemical in vitro methods. *Estimating Contaminant Bioavailability Associated with Incidental Ingestion using In Vitro Gastrointestinal Methods: Determining Bioaccessible Contaminants in Treated Soil* More References
Infiltration/percolation	Evaluate soil health/ecosystem function for revitalization	Agronomic measures	Soil properties	No	Readily	$$	High	Establishing vegetation increases the infiltration of meteoric water and harvesting of water by plants reduces the amount deep percolation. Changes in water flux from pre-remediated conditions can be used to access risk mitigation within this contaminant movement pathway. There are many techniques that can be used from simply infiltration methods to complex sensors placed in the soils, and the extensive use of water balance models.
Kd test method	Reduce bioavailability	Mobility and transport in ground or surface water	Partition coefficient	No	Readily	$$	Med	K_d is the partition (or distribution) coefficient between the pore water (ground water) and the soil solids. It is a measurement of how tightly a contaminant adheres to soil particles. More Information and References
Laboratory animal bioassay (ASTM 1976-97)	Reduce bioavailability	Bioavailability or toxicity to animals	Animal bioaccumulation	Yes	Readily	$$	High	Earthworm biological endpoints (mortality, tissue contaminant content, reproduction) are often used as indicators of soil contaminant bioavailability/toxicity. Estimates of the bioavailability or toxicity of soil contaminants are important for making remedial decisions and for evaluating remedial success. More Information and References
Laboratory plant bioassay (ASTM 1963-02)	Reduce toxicity or bioavailability	Toxicity and bioavailability to plants from soil	Phytotoxicity and plant bioaccumulation	Yes	Readily	$$	High	Plant biological endpoints (germination, tissue contaminant content, dry matter growth) are often used as indicators of soil phytotoxicity. Estimates of the bioavailability or toxicity of soil contaminants are important for making remedial decisions and for evaluating remedial success. Phytoaccumulation and phytotoxicity are often poorly related to total soil contaminant content. Contaminant bioavailability may be a better predictor. More Information and References
Measure percent vegetative cover	Reduce dust generation or bioavailability	Mobility in surface water or dust generation	% vegetative cover	Yes	Readily	$$	High	Cover of vegetation is the percentage of ground surface covered by vegetation material. It is a key measurement of revitalized landscapes. There are many techniques for determining vegetation cover ranging from field observations and measurements to emerging remote sensing methods. References
N mineralization	Evaluate soil health/ecosystem function for revitalization	Functional analysis of soil community	Soil function	No	Limited	$	High	Nitrogen mineralization is the primary process where nitrogen (N) is converted to plant-available inorganic forms (ammonium and nitrate). This process is completed by soil microbes and fauna as a by-product of organic matter decomposition. Measurement of N mineralization provides an indirect measure of the health and function of the soil ecosystem.
Neutron activation analysis (NAA)	Characterize soil	Contaminant concentration	Total contaminant	No	Limited	$	High	Neutron activation analysis (NAA) is a method used to determine a soil total elemental content. This technique is based on the interaction of radiations with matter. It is suitable for a wide range of elements and is sensitive. For more information, consult: Helmke, P.A. 1996. Neutron Activation Analysis. In Methods of Soil Analysis: Physical and Mineralogical Methods. Part 1. A. Klute, editor. Soil Sci. Soc. Of Am., Madison WI.
Particle size/contaminant test method	Reduce dust generation	Dust generation	Particle size distribution	No	Readily	$$	High	Large areas of land contaminated by metals and supporting little vegetation can be sources of metal –laden dusts. Air monitoring assessing respirable dusts (generally < 10 microns) and/or collection and analysis of transient dusts can be used to quantify effectiveness of mitigating movement of contaminants through the air pathway.

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Plant community structure (health indices, % cover)	Evaluate soil health/ecosystem function for revitalization	Structural analysis of soil community	Community structure	No	Readily	$$	High	Plant community can be described as the number (species richness) and relative abundance of species, and the physical structure of the community. Attributes that can be observed or measured include physiognomy, species composition, and species patterns. For contaminated areas that are treated using in situ methods, the establishment and persistence of the seeded or planted species and the evaluation of successional trend are important to ascertain long-term effectiveness and permanence. Attributes of cover, richness, density, and production (agronomic) can be measured by a variety of ecological methods.
Plant nutrients	Evaluate soil health/ecosystem function for revitalization	Agronomic measures	Soil fertility	Yes	Readily	$	High	Adequate soil fertility is necessary for soil health, ecosystem function and for successful revitalization and reuse. Plants need both macro and micro nutrients to grow. More Information and References
Plant tissue residue (field)	Reduce bioavailability	Bioavailability to plants from soil	Plant bioaccumulation	Yes	Readily	$$	High	Metal concentrations in aboveground portions of the established vegetation are an important consideration in the use of in situ technology. Plant species selected for revitalization depending on end land use, and may include native species, agronomic species, or pasture plants. In general practice, species that exclude metals are preferred to that that may accumulate metals for revitalization efforts. Aboveground portions of plants are collected by species, dried, and ground. Acid digestion of the plant tissue is followed by quantification of metals levels using standard techniques. Plants tissue metal concentrations may be compared to established scientific literature values and to maximum dietary levels provided in Mineral Tolerance of Animals (NRC 2005).References
Pore water or in vitro extraction	Characterize soil	Bioavailability to ecological receptors	Soil extraction	Yes	Readily	$	High	Soil water is naturally attracted to soil clay particles by its adhesive force and sticks to the surface of each particle and in the various sized capillary spaces or pores between the soil particles. When soil is drying, an increasing force is required to remove water from soil capillary pores. Soil pore water can be collected using a commercially available large volume soil/water sampler designed for near-surface installation at depths ranging from 15 centimeter (cm) to 1.8 meter (m) (ASTM Committee, 1992; Soil Moisture Equipment Corporation, 1999). The unit, sometimes called a “suction lysimeter”, consists of a 4.8 cm outside diameter polyvinyl chloride (PVC) tube, a porous ceramic cup, and a Santoprene stopper. The pore water sampler allows soil pore water to be removed from the soil by creating a vacuum (negative pressure or suction) inside the sampler greater than the soil suction holding the water in the capillary spaces. This establishes a hydraulic gradient for the water to flow through the porous ceramic cup and into the water sampler. This equipment is easy to operate, and can be used for soil pore water collection both in-situ and ex-situ. For in-situ operation, please see Operating Instructions for 1900 Soil Water Sampler (Soil Moisture Equipment Corporation, 1999). The soil water sampler also has been used to collect soil pore water for various projects in ex-situ conditions. Approximately 1,000 g of test soil is placed in a one-liter (L) plastic container and placed in the laboratory at room temperature (25 oC). The soil is kept at field capacity by adding water if it is needed. The soil moisture content at the field capacity is determined before the initiation of soil pore water extraction. The weight of each pot is recorded and maintained by adding deionized water as needed. The water sampler is installed into the center of the container. A vacuum inside the water sampler is created by withdraw air from the sampler using an attached syringe. It usually takes three to five withdrawals of the air from the sampler to produce a good vacuum for pore water collection. The soil pore water collection can be started a few hours after installing the pore water sampler by withdraw water from the sampler. After the water inside the sample is withdrawn, create the vacuum for the sample again for next pore water collection. The soil pore water is collected twice a day for three to five days. The water collected from each replicate pot during the three to five-day period is combined to yield a composite sample for each replicate of a treatment. The soil pore water is preserved at a pH of 2 and temperature of 4 oC. If more than one liter of soil is available for soil water collection in ex-situ, it is recommended to use large containers, such as two-liter plastic container or two-gallon plastic bucket. It is important to pack the soil sampler tight inside the test soil, and good vacuum is produced each time after the soil pore water is removed from the soil sampler. References ASTM Committee D18 on Soil and Rock. 1992. Standard Guide for Pore-Liquid Sampling from the Vadose Zone. ASTM, West Conshohocken, PA. Soilmoisture Equipment Corporation. 1999. Operating Instructions for 1900 Soil Water Sampler. Santa Barbara, CA.
Resuspension test method	Reduce bioavailability	Mobility in surface water	Resuspension	No	Limited	$$	Med	Resuspension is a liquid phase bioassay of aquatic organisms (e.g., flathead minnow) evaluating survival, growth, and reproduction. It is used to determine the exposure risk from soil erosion (i.e., its runoff and suspension in nearby surface water) to these organisms. It involves preparing an elutriate of the soil according to the Army Corps of Engineers guidance, Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S. - Testing Manual (EPA-823-B-98-004; also known as the Inland Testing Manual). Following the settlement of particles and removal of the overlying water, a short-term chronic toxicity test is then conducted using aquatic organisms. The recommended test should follow the EPA guidance Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms, Third Edition.

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Salinity/sodicity	Evaluate soil health/ecosystem function for revitalization	Agronomic measures	Soil properties	Yes	Readily	$	High	Salinity measurements provide information about the ability of a site to support plant growth as well as some information regarding potential leaching and drainage problems. Excessive levels of sodium (Na) in soil can destroy soil structure and reduce water infiltration and soil permeability. More Information and References
Scanning electron microscopy (SEM) microprobe test, Extended X-ray absorption fine structure (EXAFS), X-Ray absorption near edge structure (XANES)	Characterize soil	Contaminant speciation	Metal speciation	No	Rare	$$$	Med	*Spectroscopic Speciation to Understand Bioavailability and Remediation*
Soil C	Evaluate soil health/ecosystem function for revitalization	Agronomic measures	Soil properties	No	Readily	$	High	For the purpose of determining appropriate TPMs for a site, it may be important to distinguish between soil organic carbon (OC) and inorganic carbon (IC). Each has important but different roles in soil remediation and as a component of soil quality as a growing media. More Information
Soil community structure (health indices)	Evaluate soil health/ecosystem function for revitalization	Structural analysis of soil community	Community structure	No	Rare	$$	High	The structure of biological community (e.g., fungal and bacterial biomass, faunal number and diversity, etc.) of the soil can serve as a prime indicator of the health of the soil ecosystem.
Soil pH	Evaluate soil health/ecosystem function for revitalization	Agronomic measures	Soil properties	Yes	Readily	$	High	Soil pH is often called the “master variable” it has the potential to modify metal (contaminant) solubility/availability in several ways. It controls dissolution/precipitation and therefore influences contaminant speciation. It regulates the ionization of pH dependent ion exchange sites affecting contaminant as well as nutrient availability. More Information and References
Soil respiration	Evaluate soil health/ecosystem function for revitalization	Functional analysis of soil community	Soil function	No	Limited	$	High	This measurement of soil respiration provides a measure of CO2 efflux at the soil surface of which rhizosphere (root and root exudates), microbial, and faunal respiration are components. Soil respiration provides a functional analysis and an indirect measure of the health of the soil community.
Synthetic precipitation leaching procedure (SPLP)	Characterize soil or reduce bioavailability	Availability to ground water or mobility in ground and surface water and	Leachability	Yes	Readily	$$	High	EPA Method 1312, the Synthetic Precipitation Leaching Procedure (SPLP) is used to evaluate the potential for leaching metals into ground and surface waters. This method provides a realistic assessment of metal mobility under actual field conditions, i.e. what happens when it rains (or snows). The extraction fluid is intended to simulate precipitation. East of the Mississippi River the fluid is slightly more acidic at pH 4.20 reflecting the air pollution impacts of heavy industrialization and coal utilization. A pH of 5.00 is used west of the Mississippi reflecting less industrialization and smaller population densities. More Information
Texture	Evaluate soil health/ecosystem	Agronomic measures	Soil properties	No	Readily	$	High	Soil texture is determined by measuring a soil’s particle size distribution. More Information
Urine test methods	Reduce bioavailability	Bioavailability to or bioaccumulation in humans from food chain	Urine (As)	No	Limited	$$	High	Several sensitive and specific tests that can measure arsenic (As) in humans are described in the Agency for Toxic Substances and Disease Registry’s (ATSDR) “Toxicological Profile for Arsenic, ”Draft for Public Comment” (September, 2005). These tests often are helpful in determining exposure to above-average levels of arsenic in the past. More Information and References
USEPA 3050/3051	Characterize soil	Contaminant concentration	Total contaminant	No	Readily	$$	High	See U.S. EPA Method 3050: Acid Digestion of Sediments, Sludges, and Soils and U.S. EPA Method 3051: Microwave Assisted Acid Digestion of Sediments, Sludges, Soils, and Oils
Water holding capacity	Evaluate soil health/ecosystem function for revitalization	Agronomic measures	Soil properties	No	Readily	$	High	In soils, the percent water content of a drained soil can be determined gravimetrically and is often expressed as the ratio of the mass of water in a soil per mass of soil (after it has been dried), as shown in the following: [(mass wet soil – mass dry soil)/mass of dry soil] x 100 = % water. References
X-ray fluorescence (XRF)	Characterize soil	Contaminant concentration	Total contaminant	No	Readily	$	High	X-Ray fluorescence (XRF) spectroscopy is a method to determine a soil total elemental content. In this technique, the soil sample is excited using an x-ray source and determination of the concentration of sample elements is then accomplished by measuring characteristic secondary radiation emitted from the excited sample. It is a reliable method and is useful for a wide range of soil elements. See the following: Karthanasis, A.D., and B.F. Hajek. 1996. Elemental Analysis by X-Ray Fluorescence Spectroscopy. In Methods of Soil Analysis: Physical and Mineralogical Methods. Part 1. A. Klute, editor. Soil Sci. Soc. of Am., Madison WI.