USDA Natural Resources Conservation Service
U.S. DEPARTMENT OF AGRICULTURE

Soil Screening for Soil Science and Urban Agriculture Portable X-Ray Fluorescence (pXRF) User Guide

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Overview

This user guide provides regional guidance for conducting soil screening of trace metals or other targeted elements using portable x-ray fluorescence (pXRF) equipment in support of technical assistance or conservation plan development. This guide is a reference document with a methodology and procedures for conducting pXRF screening analysis and provides currently available references and resources.

Guidance provided includes

- Evaluation methods for pre-site visit analysis
- Survey design strategies
- Onsite data collection methods
- Data evaluation
- Considerations for soil use and management

In accordance with "National Soil Survey Handbook" (NSSH) policy and guidance, soil scientists from the Natural Resources Conservation Service (NRCS) have been providing pXRF-level soil screening in support of conservation technical assistance and planning for many years. Section 655.1(3) of the NSSH outlines how

> Site-specific soil investigations, testing, interpretation, and evaluations are services that support the design and installation of works and structures or the implementation of agricultural practices. These technical soil services are part of NRCS technical assistance to individual cooperators or units of government that have signed agreements for specific services. The intention of services to individual cooperators is usually to help apply a conservation plan. These services are described in general terms in district agreements with NRCS. They are a very site specific and often result in design and practice specifications.

Section 603.00 in the "Technical Soil Services Handbook" (TSSH) describes how

> Soil scientists can assist in the in-field resource inventory, determining the soil-based resource concerns and making recommendations to the conservation planner as to the best conservation practices to apply to ameliorate degraded properties and behavior or other resource concerns.

Soil screening conducted with pXRF equipment conforms with this mandate to provide site-specific investigations and evaluations in support of technical assistance to cooperators and customers.

Scope

Procedures and guidance outlined in this user guide are not intended to replace or modify the requirements or safety information of any specific equipment used or any federal, State, or local regulations pertaining to operation of pXRF equipment.

Field-based pXRF screening is not as accurate as laboratory analysis and is not designed to identify sources of lead or any other trace metals or pollutant. This information may be interpreted by organizations, agencies, units of government, or others based on needs; however, they are responsible for the appropriate application. Federal, State, or local regulatory bodies are not to reassign to the NRCS any authority for the decisions they make. The NRCS will not perform any evaluations of these data for purposes related solely to any regulatory programs.

Data collected by NRCS staff is not designed for use as a primary regulatory tool in permitting or citing decisions but may be used as a reference source. If the landowner shares this information with a third party (e.g., organizations, agencies, units of government), the landowner in conjunction with the third party assumes the responsibility for its appropriate application.

Section 629.02 of the TSSH provides instruction for how site-specific investigations are completed where soil survey information is not adequate for site planning and design considerations. Point sampling must be done to collect data for a specific use at a specific location.

It is important to understand what data are needed to make the appropriate interpretations for the proposed use, such as soil survey mapping or conservation practice, before conducting a pXRF screening. This knowledge can guide sampling design and ensure the appropriate data are collected. For information on the characteristics that are important for a conservation practice, refer to the conservation practice standards in the NRCS Field Office Technical Guide.

Onsite screening is limited to the review of trace metals found within a specific sampled area. Data collected are for informational purposes and are not meant to encompass all potential contaminants that may or may not be present. This would include polychlorinated biphenyls (PCBs) or per- and polyfluoroalkyl substances (PFAS) among others that are beyond the scope of what NRCS can provide and the limit of detection of the equipment.

It is important to note that a landowner, participant, or cooperator will have certain legal responsibilities to report the conditions identified in the soil screening to the applicable regulatory agency as required by law. If the landowner, participant, or cooperator does not provide the required notice of disposal or release of contamination exceedances within the prescribed timeframe, that individual may be solely liable for failure to report. Pertinent federal regulations include: Resource Conservation and Recovery Act (RCRA), the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and the Federal Insecticide, Fungicide, and Rodenticide Act. NRCS staff should provide information to the landowner, participant, or cooperator regarding specific State laws as appropriate prior to site evaluation and screening.

NRCS policy prohibits assistance with removal of hazardous waste. Policies that provide guidance for technical assistance and hazardous waste are available and should be followed. According to Title 210, National Engineering Manual, Part 503 – Safety, Subpart E – Prohibited Technical Assistance

> 503.70 General
>
> NRCS is often asked to provide technical assistance in many areas. However, this assistance must not be provided for activities that are outside the normal area of expertise if these activities expose NRCS field employees to hazardous conditions or expose the agency to uncontrolled liability.
>
> 503.71 Prohibited Activities
>
> The following activities are prohibited:
>
> 1. Assistance with removal of underground storage tanks
> 2. Assistance with removal of hazardous waste
> 3. Assistance with removal of unidentifiable waste.

If a request for service is received that is beyond the scope of NRCS capabilities or it places staff or the agency at risk (safety or liability), the landowner, participant, or cooperator should be referred to other available resources for assistance, such as the Environmental Protect Agency's Land Revitalization Program and Agency for Toxic Substances and Disease Registry's (ATSDR) Land Reuse Health Program.

User Requirements[1]

For the USDA, the [Office of Homeland Security – Radiation Safety Division](#) (OHS-RSD) is the governing unit issuing Permits (valid for 5 years) for the use and possession of radioactive materials or x-ray producing equipment. The Permit enables the OHS-RSD to keep track of radioactive material and x-ray equipment, including acquisition, transfer, and disposal activities.

USDA employees who want to use radioactive material or x-ray producing equipment must have or request access to the RSD database. Prior to conducting a pXRF screening, NRCS staff must submit a request for an x-ray permit to the OHS-RSD through the database. An x-ray Permit lists approved x-ray equipment, actual equipment inventory, storage rooms, and associate users. Once approved, a Permit Holder has access to the Permit tracking data base known as Radiation Safety Management System.

Any USDA employee seeking to operate x-ray equipment must be listed on a Permit issued by the OHS-RSD either as the Permit Holder or an associate user. Only the Permit Holder and the associate users listed on the Permit are authorized to acquire, possess, store, or operate x-ray equipment.

An x-ray Permit Holder is a person whose training and experience have been reviewed and approved by the OHS-RSD. To become a Permit Holder, instruction and training in the principles and practices of radiation safety and in the performance and operation of the x-ray equipment is required.

The Permit Holder is the person who uses and directly supervises the use of x-ray equipment. The Permit Holder's primary responsibility is to ensure that x-ray equipment, as listed on the Permit, is used safely and according to USDA radiation safety requirements. The Permit Holder must also see that procedures and engineering controls are used to keep radiation doses as low as reasonably achievable.

An associate user is a person listed on the Permit who is authorized to work with the x-ray equipment under the Permit Holder's supervision. The Permit Holder must be the supervisor of the associate users listed on the Permit. The Permit Holder may delegate specific tasks to associate users (such as doing surveys or taking measurements), but the Permit Holder is responsible for the safety and security of the x-ray equipment.

All users must have specific training that is commensurate with the scope of assigned duties and proposed activities, so that they know how to operate analytical equipment

[1] Information in this section is from the Permit Program and Program Procedures X-Ray Producing Equipment information available on the OHS-RSD SharePoint. The intent is to inform the reader on the basic user requirements and mandatory safety precautions. It is not a substitute for the information and instruction provided on the OHS-RSD SharePoint site.

and understand the hazards. A competent training authority includes a college or university, a manufacturer’s training course, or some other professionally administered training organization.

Safety Precautions and Requirements

The equipment manufacturer provides radiation safety and user training on pXRF operation. After receiving equipment, NRCS staff should contact the manufacturer's regional representative. A representative will typically come to the office or site to provide training and a training certificate. The representative can troubleshoot and assist with any issues in loading or operating software.

Radiation levels must not exceed 0.5 milli-rem/hour when measured at a distance of 5 centimeters from any surface on the pXRF equipment. Radiation surveys are generally aimed at detecting areas where x-rays could be leaking through voids or breaks in the shielding. A standard Geiger-Mueller detector can be used to detect a problem. These surveys can be arranged in a maintenance contract with the manufacturer.

Dosimeter Badges

The Department of Homeland Security provides dosimeter badges upon request through Landauer (fig. 1). The badges are shipped out to the Permit Holder every 3 months with a return envelope to be processed. Badges include three area monitors and a control, with begin wear dates and change deadlines for all four the badges.

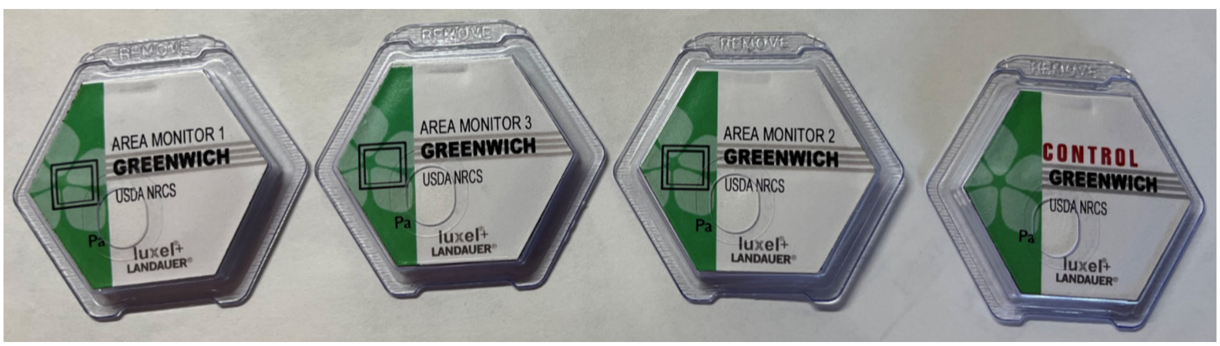

Figure 1. Landauer dosimeters for the control and the three monitors with plastic tab.

The OHS-RSD assigns three area monitors for each piece of x-ray equipment. An area monitor is like a personnel dosimeter except that it is not worn by individuals but placed nearby the x-ray equipment to detect any possible radiation leakage.

The dosimeter badges do not provide immediate results. Staff must return them to the company for data processing. After the badges are processed, the company creates a data report to send to the OHS-RSD, and the OHS-RSD shares the report with the Permit Holder.

NRCS staff must remove the plastic tab at the top of the dosimeter prior to use. If this tab is not removed, the company will consider the dosimeter unused and will not process the data. All badges must be returned for processing, or the OHS-RSD will be charged for each missing or lost badge.

Safety Signs

NRCS Staff must label all x-ray producing equipment or transportation cases with a sign stating "Caution: this equipment produces x-rays when energized" (fig. 2). Permit Holders can contact the OHS-RSD to request labels and signs.

Figure 2. OHS-RSD safety sign.

Soil Handling Safety

Mining, manufacturing, and the spreading or disposing of synthetic products (e.g., pesticides, paints, batteries, industrial waste, industrial sludge, and domestic biosolids) can result in metal contamination of urban and agricultural soils. Metals also occur naturally, but they rarely occur at toxic levels. Contaminants are generally not identified in soil survey reports. Soil survey reports can be helpful in locating land uses that may be associated with contaminants. The reports include aerial photographs or satellite imagery as base maps. Photo interpretation techniques can help to ascertain the extent and location of specific land uses, depending on what surface features or land uses were evident at the time of the photography (USDA, 2004).

Areas under the jurisdiction of the U.S. Environmental Protection Agency (EPA), such as superfunds (locations polluted with hazardous materials) or brownfields (properties that contain or may contain a hazardous substance, pollutant, or contaminant, complicating efforts to expand, redevelop or reuse them), must be avoided. These areas have the potential of containing hazardous substances or contaminants, and examples include sites contaminated by petroleum or petroleum products, by heavy industrial activities, or by mining operations.

When a potential for contamination is suspected, personal protective equipment (PPE) is highly recommended during the initial assessment of the area. Recommended PPE includes disposable gloves with appropriate polymer rating for chemical resistance, work gloves, and safety glasses (Soil Survey Staff, 2022).

pXRF Components

The pXRF equipment in NRCS at this moment consisted of the Delta equipment, which is the older model, and the Vanta equipment, which is the newest model. Both equipment models have a window screen (fig. 3) that the user needs to pay attention to during operation to avoid rupture and soil getting in contact with the inside components. This equipment also can be use with different accessories, such as a workstation, to ease the use in the field (fig. 4). In addition to accessories there are reference samples and blank samples that are recommended to measure equipment performance. More information on best operation practices is provided in appendix E.

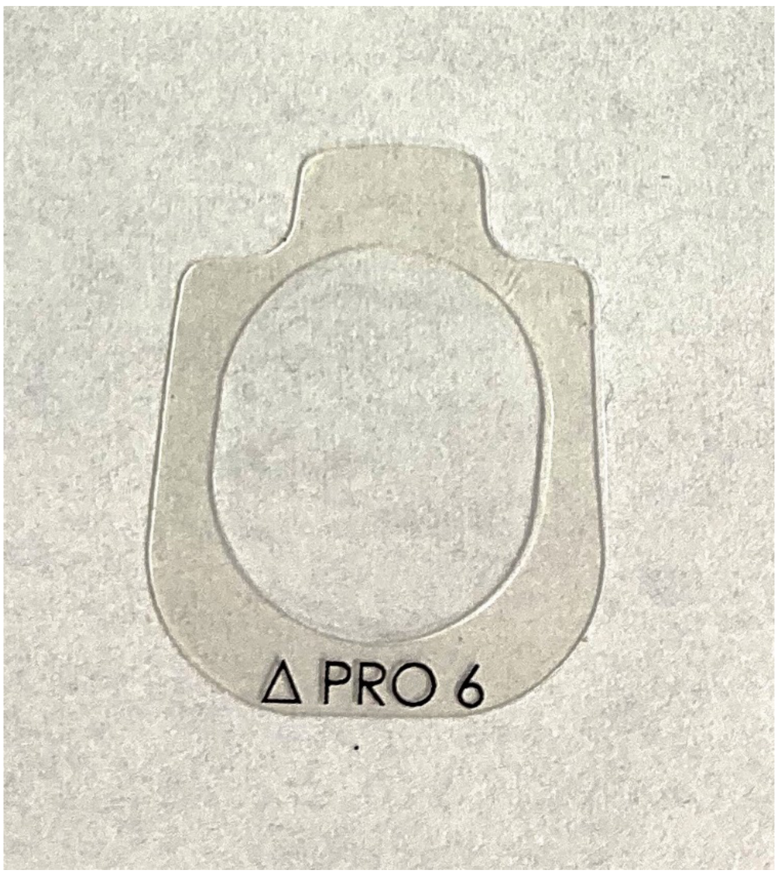

Figure 3. A propylene window screen.

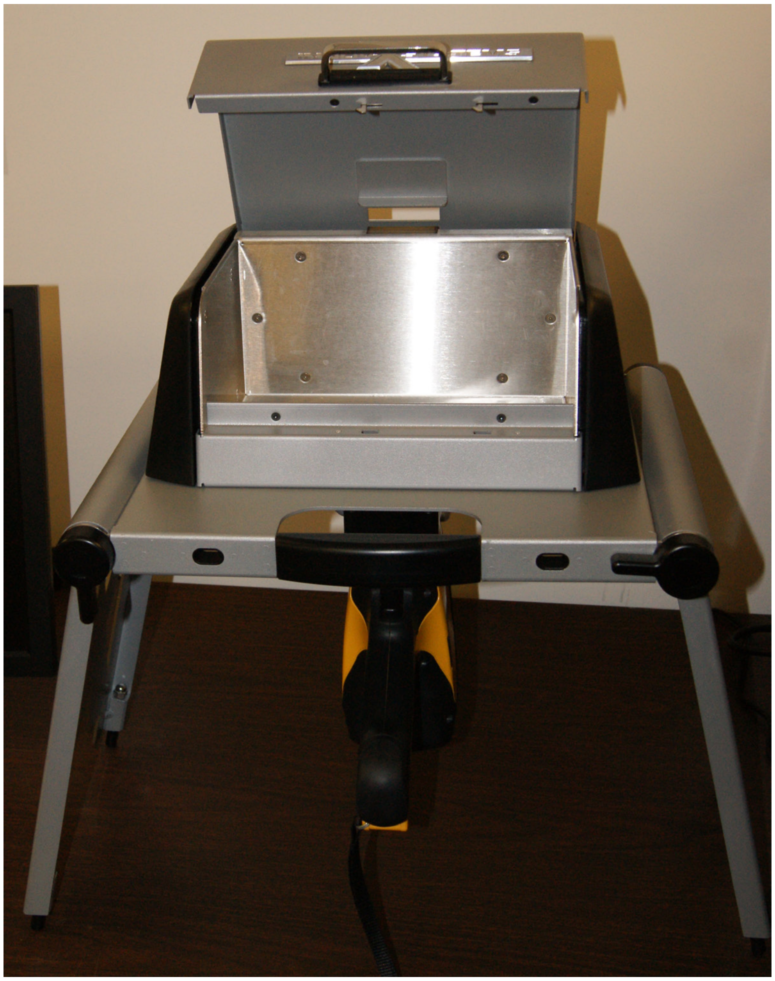

Figure 4. The workstation provides the capability of using the pXRF equipment in the office and functions as safety equipment shielding x-ray when equipment is energized.

Software Requirements

Remote viewing or operating software is necessary for using a workstation with the pXRF equipment. Only approved [Client Experience Center (CEC) Certified Software] should be used on government computers. CEC certified software can be requested by using an Office of the Chief Information Office (OCIO) help ticket.

Any free software provided with the equipment may **only** be used if it has been submitted and approved for certification by CEC. NRCS staff can submit a request through using the Certify Software option on the [CEC Digital Workspace].

The Bitlocker exemption for USB devices is essential for remote operation of pXRF equipment with the workstation, updating user templates, and exporting results to a CSV file.

Manufacturer Software

For government computers, the following software is currently approved CEC-certified software and can be requested for installation through OCIO help ticket request for support.

Delta equipment (older equipment)—Manufacturer: Olympus Imaging Corp
Delta Advance PC Software—2.5.21.945 PC SW English
Note: CEC approved Software by the manufacturer SOTI has been retired.

Vanta equipment: remote operating software with workstation
Search CEC approved Software by Manufacturer: Olympus Imaging Corp.
Title: Vanta
OlympusVanta3.22.40_WKS
Passed Certification—Limited use on July 16, 2020
Description: CEC has only tested installation of the application. If the application fails to function properly it is the initiator's responsibility to contact the software vendor for assistance.

The most updated software and user manuals are available on the USB drive of the pXRF equipment. NRCS staff will need to submit a ticket to OCIO to request CEC approval tickets of updated versions of software on a periodic basis.

Calibration

Calibration verification is conducted with labeled reference standards (i.e., National Institute of Standards and Technology (NIST) or OREAS certified reference materials (CRMs) (figs. 5 and 6). If conducting in situ sample, it is advisable to keep a copy of the reference certificate analysis with the pXRF equipment for comparison. The values of the standard's elements of interest (i.e., lead or arsenic) in a field book for reference should also be noted. This procedure works for both Delta and Vanta types of pXRF equipment.

Figure 5. NIST standards.

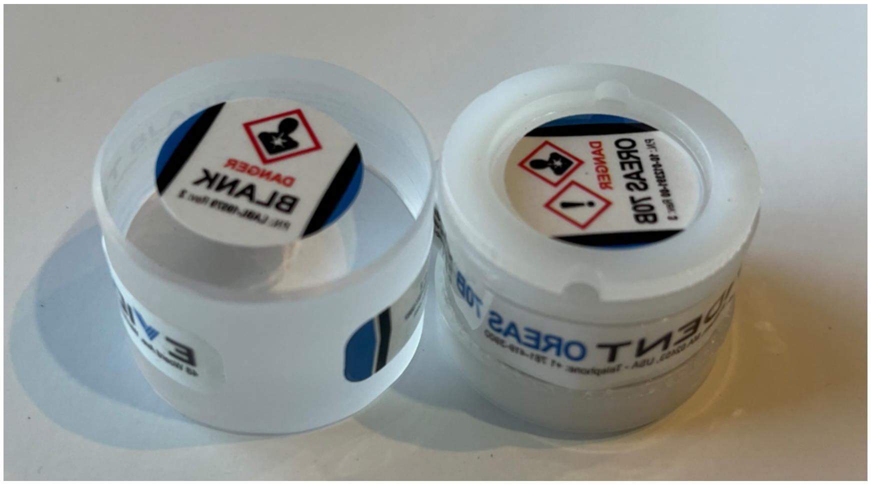

Figure 6. OREAS CRMs.

Reference samples should include a silica (SiO_2) or other blank sample that should be run at the beginning of each site visit and twice daily, at a minimum, to verify that the window screen on the equipment remains clean and free of debris. This will also help to prevent false readings.

The difference between pXRF measurements and the certified values provided with the reference NIST or OREAS CRMs samples should be within a 20 percent threshold (EPA, 2007). If the results are not within the 20 percent threshold and taking in consideration sources of error discussed later in the Sources of Error section, NRCS staff should contact the company to discuss possible causes for the difference in readings, such as known interference by other elements, and potential actions improve pXRF equipment accuracy. Another option to improve pXRF equipment accuracy is by following the procedure in Appendix A Element Adjustment.

The percent difference can be calculated for each element using the following equation (EPA, 2007):

$$\%\mathrm{D} = ((C_s - C_k) / C_k) \mathrm{x}\, 100$$

where:
%D represents the percent difference
Ck represents the certified concentration of standard sample
Cs represents the measured concentration of standard sample

Note: Details on calibration verification checks can be found in SW-846 Test Method 6200: Field Portable X-Ray Fluorescence Spectrometry for the Determination of Elemental Concentrations in Soil and Sediment (EPA, 2007).

Calibration—Delta Equipment

For Delta equipment (fig. 7), it is recommended to run the energy calibration check twice daily, at a minimum, during data collection. The calibration (Cal) check is conducted using the 316 sample on dock base station (fig. 8) or with a 316 coin (fig. 9) in the field. Calibration verification with reference standards is also recommended.

Figure 7. Delta equipment with foot accessory for self-standing while conducting screening.

Figure 8. Delta equipment docking station with battery charger integrated calibration coin.

Figure 9. The 316 calibration coin. This coin is used for the Delta and Vanta equipment calibration in the field.

Calibration—Vanta Equipment

Vanta equipment (fig. 10) calibration check is done automatically but can also be done on a docking station (fig.11) or manually with a 316 coin (see fig. 9).

Figure 10. Vanta equipment handheld unit.

Figure 11. Vanta equipment docking station with battery charger integrated calibration coin.

Onsite Evaluation[2]

Survey Scope and Producer Goals

NRCS staff should define the survey scope and producer goals to identify the type and level of survey needed. For example, the scope for an inventory survey during pre-construction for practice design or site selection purposes (i.e., an empty lot) will be different from the scope of a support survey to evaluate practices already installed (i.e., raised beds of an established community garden). Clearly defining and documenting the need will facilitate efficient survey design and onsite data collection methods. Discussion between NRCS staff and the producer or cooperator will also provide an opportunity to clearly communicate the type and level of information that can be delivered.

Initial Onsite Evaluation

The initial onsite evaluation consists of a walk around the site to observe the surface soil condition, possible resource concerns, and evidence of past and present site management. Items to record during an onsite evaluation as part of a detailed inventory include

- Presence and amount of anthropogenic soil material including human artifacts.
- Water discharge from adjacent properties.
- Areas with evidence of ponding or flooding.
- Presence of non-native or invasive plants.

In addition to recording observations, a brief soil description of the dominant soil condition with enough information to possibly assign a series name should be included in the prepared report if soil survey information is not available or if the available information is too general. The brief soil description should include

- A maximum rooting depth or depth to a root restrictive limiting layer, whichever is shallower.
- Soil color.
- Redoximorphic features.
- Soil texture.
- Percent and source of the coarse material (e.g., rock fragment and human artifacts).
- Soil structure.
- Depth to seasonal high-water table.

[2] Information in this section is from NRCS-NJ Soil Screening Procedure Using pXRF.

Soil pH should be taken into consideration and measured as part of the brief soil description. Soil chemistry dictates the fate and transport of different elements in the soil.

Additionally, during the initial evaluation, recording of soil condition like soil moisture content and estimation of soil organic matter are important since those could be possible sources of error, reducing the equipment measurement accuracy. The Sources of Error section provides a list of possible sources of error and how to avoid them.

Soil moisture content and organic matter are two soil properties with the potential to influence the accuracy of the pXRF results. Even though soil moisture is not generally considered a limiting factor (Li et al., 2022), the pXRF manufacturer recommends analyzing samples with moisture content less than 20 percent. The pXRF analyses have been shown to decrease in accuracy and precision by 15 to 20 percent for samples with a moisture content of higher than 30 percent (Nakano, 2022). The pXRF analyses of saturated samples can significantly underestimate the results (Sahraoui and Hachicha, 2017).

Likewise, organic matter has the potential to cause the pXRF to underestimate the concentration of some trace metals. Even though a calibration will improve the accuracy of measurement, this does not account for the possible dilution by the organic matter (Ravansari and Lemke, 2018). Additional validation using organic rich soils could be needed to improve manufacturer calibration (Shand and Wendler, 2014).

Sources of Error

- Soil moisture content has a dilution effect.
  - When possible, the samples should be air-dried.
- Non-homogenous samples increase variability in the results.
  - The sample should be ground with a mortar and pestle to decrease variability in the results.
  - Sample cups can be used as part of sample preparation as explained in EPA method 6200 Sections 11.5 and 11.6 (EPA, 2007). The homogenized sample is placed in the cup, and readings are taken from the cup opening. This same procedure can be used to prepare local reference samples where lab data is available.
- The window screen of the pXRF equipment or the blank sample is contaminated, or particles are adhered to it.
  - The screen should be replaced (replacement window screens are included with the pXRF equipment or can be purchased).

- It is a good practice to cover the window screen with a thin plastic bag (not a freezer bag) while in the field to keep pXRF equipment window screen clean.
- The blank should be verified periodically or at the beginning and end of sampling at a minimum.

Soil Screening

The soil screening must consider possible lateral and vertical movement of the targeted elements, the cropping system, and the crops. Two intervals are recommended according to the type of crop and the depth of the crop root systems. A typical approach would be to screen soils at depths of 0 to 8 inches from the soil surface with a second screening from 8 to 18 inches in depth. While most leafy vegetable root systems concentrate within 18 inches, fruits and vegetables could root deeper (between 24 to 36 inches), and screening depths may need to be adjusted accordingly.

For crops grown in raised beds where roots extend below the bed material into the soil underlying the bed, soil screening must be conducted in both growing media. This serves two purposes. First, it allows NRCS staff to compare the condition of the onsite soil material spatial distribution and the material used in the raised bed. Second, it helps determine if there is any upward movement of the targeted elements into the raised bed growing material. In areas without raised beds, the soil screening is conducted at two depths to provide information about potential vertical distribution. This information can be used to develop conclusions about how the targeted elements were deposited in the study area.

At the end of the soil screening, NRCS staff should meet with the customer to discuss the data collection report and, if necessary, assist with planning a strategy for soil sample collection and analysis by a certified soil lab. Another possible outcome of this meeting could include be a recommendation for CEMA 207 (Site Assessment and Soil Testing for Contaminants Activity).

Sampling Methodologies

The sampling methodology in this guide consists of four methods typically used in soil science to answer a question. Some of the methods could consist of one sample for a specific question, random sampling collection to obtain generalized information, or a structure sampling collection for a detailed data collection.

Grab Sampling

Grab sampling is a method of soil sample collection with the intent of limited analysis to answer a specific question (Schoeneberger et al., 2012). The grab sample could be used to answer questions, such as source and amount of coarse fragments or moisture content, or it could be used as a reference sample for laboratory analysis. As mentioned in the Sources of Error section, moisture content will cause a dilution effect, and by using a gravimetric test method, a correction factor could be defined and applied to the collected readings. As for the pXRF, the grab sampling could be used as a method to provide generalized information from specific land use or to compare different land uses.

Reconnaissance

Two survey types, zigzag survey and random survey, can be used to get a general idea of the soil condition, to develop a detailed screening plan, or for very small study areas. For a zigzag survey, the NRCS staff member walks in a zigzag pattern across the site to perform soil screenings. For a random survey, the NRCS staff member performs soil screenings at random locations throughout the site.

Transect

For sites where screening is conducted as part of a pre-installation inventory, a transect method might be preferred. The linear transect or modified linear transect are systematic methods implemented for detailed screening plans used to identify potential hot spots of targeted elements being evaluated. This information can be used to generate spatial distribution maps representative of the soil condition in the study area. The linear transect is a typical linear screening plan that consists of data collection in a linear direction at an established interval. The modified linear transect is like the linear transect method, but when significant differences in elemental concentrations are identified between two consecutive points, an additional data point is added mid-distance to locate a potential boundary.

A grid layout using a linear or modified linear transect must consist of a minimum of three transects equally spaced. This layout will provide a better distribution of sampling points and generate a more comprehensive representation of the soil condition when spatial analysis is used with the collected data.

Composite Sampling

Composite sampling methods are typically used for soil nutrient analysis in rural agricultural fields. The methods include the mixing of samples from different spatial locations. Composite sampling methods are not typically used for soil screening in urban areas due to the need to identify potential hot spots of certain elements.

Site Layout

Site screening layouts can vary depending on the land's present use, obstructions (e.g., existing structures), or customer land use plans. The process starts by listing the different land uses, such as cropping in natural ground or raised beds, followed by developing a data collection plan for each of the land uses. Data collection plans should include enough data points to avoid any unpredictability in data interpretations. For example, if there are two land uses with two different soil types, points should be collected in both soil types for both land uses.

Sample Size

Sample size can differ by the sampling method, size of the study area, consistency of the soil material, and the confidence level of the data collected. It is reasonable to follow similar data collection rules used for map unit requirements in soil survey. Typically, a soil survey will use a minimum of 30 recorded points for each map unit to document the composition for map units that are less than 2,000 acres (Section 627.8 of the NSSH). However, the sample size must take into consideration consistency in data collected, and the sample size must be increased as data variability increases.

Sampling Naming Convention

NRCS staff should assign a unique identification (ID) code for the spatial point data and the pXRF tabular data. This unique ID code will be used to join the points data collected at sampling locations to the pXRF results table.

How to Use pXRF Equipment in the Field

Prior going to the field, NRCS staff who use multiple monitors in the office to view the pXRF workstation software should make sure to move software window back onto the laptop screen and set the laptop monitor as main display in settings. If the software window is not moved, the window may not be available next time the laptop is used in the field because the laptop will still attempt to display the software on the second monitor—even when the second monitor is not detected. To ensure the software window set to the laptop monitor, NRCS staff should

1. Click on task view icon on taskbar to verify that the software is up and running.
2. Go to display settings for laptop.
3. Choose the laptop monitor.
4. Make sure to check the box to "Make this my main display."

Note: During field investigations, it is advisable to bring a power extension cable and power strip along with the pXRF equipment's base to charge batteries or operate the workstation and laptop.

In the field, NRCS staff record information about site layout and determine the appropriate sampling size and sampling method. Optionally, using the selected sampling method, NRCS staff can locate data collection points using flags (fig. 12). Bore holes are opened with a soil auger laying out the soil material (fig. 13) for 0 to 8 inches and 8 to 18 inches (fig.14) as explained in the soil screening section. Another option is using a GPS unit in combination with the pXRF equipment to georeference the location of the data collection (appendix F). NRCS staff can use the combination of GPS and pXRF to locate the soil screening location precisely on a map and produce spatial analysis showing trace metal distribution in the study area as explained in the Spatial Analysis section.

Figure 12. Flags identify the data collection pattern based on the sampling method (flag colors are not relevant to the method).

Figure 13. NRCS staff using soil auger to layout soil material prior to pXRF soil screening.

Figure 14. NRCS staff taking apXRF reading. The pXRF equipment is linked to a GPS unit to georeferenced data collection points.

Data Processing and Management

As mentioned in the Software Management section, pXRF data can be downloaded in a .csv format. This data is then imported to a spreadsheet by means of using a customized template or alternatively opened directly in a spreadsheet as a raw dataset. To open the .csv directly in a spreadsheet as a raw dataset

1. Browse to the .csv file location and select the file. This will open the .csv in a spreadsheet.
2. Modify the spreadsheet by deleting empty columns and data that is not intended to be provided to the customer.

To import the pXRF data into a spreadsheet template, a template first needs to be created by editing the format or conditional formatting and then adding a title and the official USDA NRCS logo and agency name. Conditional formatting can be used to highlight values greater than the local soil clean-up standard or any other important condition.

How to Create a Spreadsheet Template for Data Processing and Data Analysis

A spreadsheet template makes information delivery convenient and streamlines repetitive processes. The spreadsheet discussed in this section creates a product containing agency logo and name, trace elements of interest, highlighted elements with elevated concentrations, maximum allowable concentration or soil clean-up standard, a disclaimer, and the agency's shortened nondiscrimination statement. NRCS staff use the template to provide information to customers about concentrations found during the soil screening and what those concentrations mean based on the maximum allowable concentrations of trace metals.

Basic Template Requirements

1. Open .csv in a spreadsheet
2. Edit the spreadsheet.
    a. Add USDA official logo and agency name (fig. 15-1).
    b. Add title and project name (fig. 15-2).
3. Add element name to correspond to the element symbols (fig. 15-3).
4. Add instrument information as part of the report header (fig. 15-4).
5. Add a disclaimer. A disclaimer is to provide information about the limitation or proper use of the data (fig. 15-5).
    a. Disclaimer example

Disclaimer

The data collected and reported as part of this procedure is not designed for use as a primary regulatory tool in permitting or citing decisions but may be used as a reference source. If the landowner shares this information with a third party (e.g., organizations, agencies, or units of government), they assume the responsibility for its appropriate application. Federal, State, or local regulatory bodies are not to reassign to the Natural Resources Conservation Service any authority for the decisions they make. The Natural Resources Conservation Service will not perform any evaluations of these data for purposes related solely to any regulatory programs.

6. Add the agency's shortened nondiscrimination statement: USDA is an equal opportunity provider, employer, and lender.

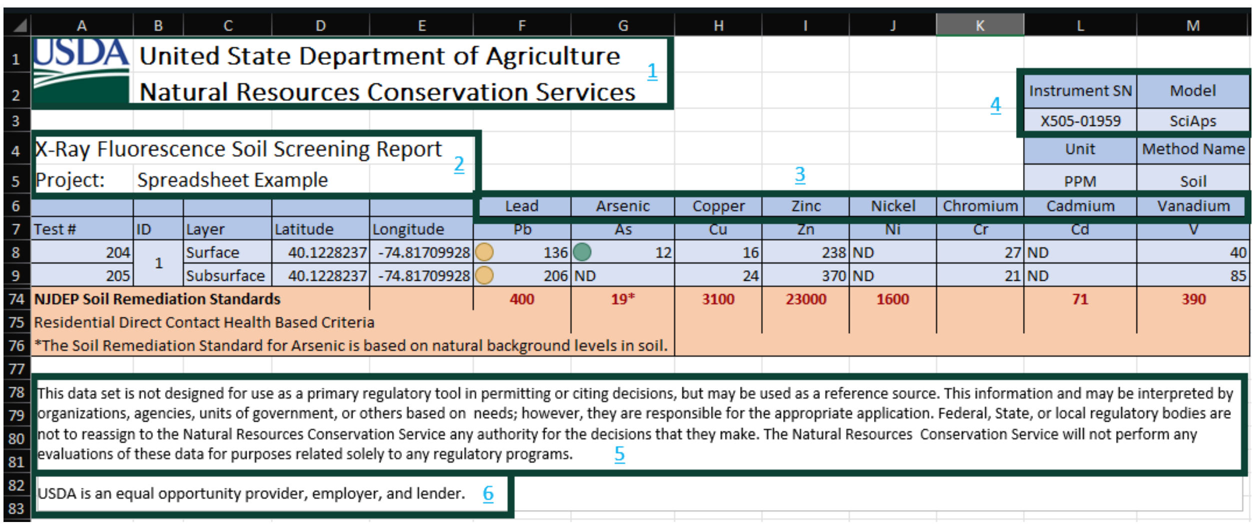

Figure 15. Example of spreadsheet showing the basic requirements: 1) USDA official logo and agency name; 2) title and project name; 3) element name to correspond to the element symbols; 4) instrument information; 5) disclaimer; and 6) shortened nondiscrimination statement.

7. Auto prompt location for .csv file import

   a. Select the **Data** tab.

   b. In the Get & Transform Data menu pane, select **Existing Connections** (fig. 16).

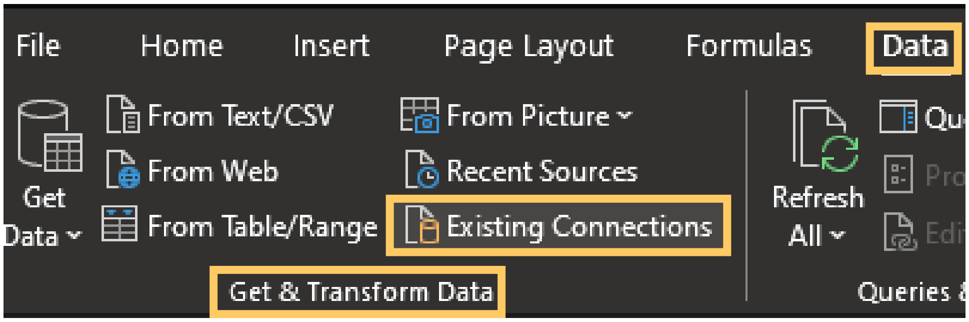

Figure 16. Screenshot of the menu showing the location of the tool to connect the workbook to .csv.

c. Click **Browse for More…** in the lower left corner of the window (fig. 17).

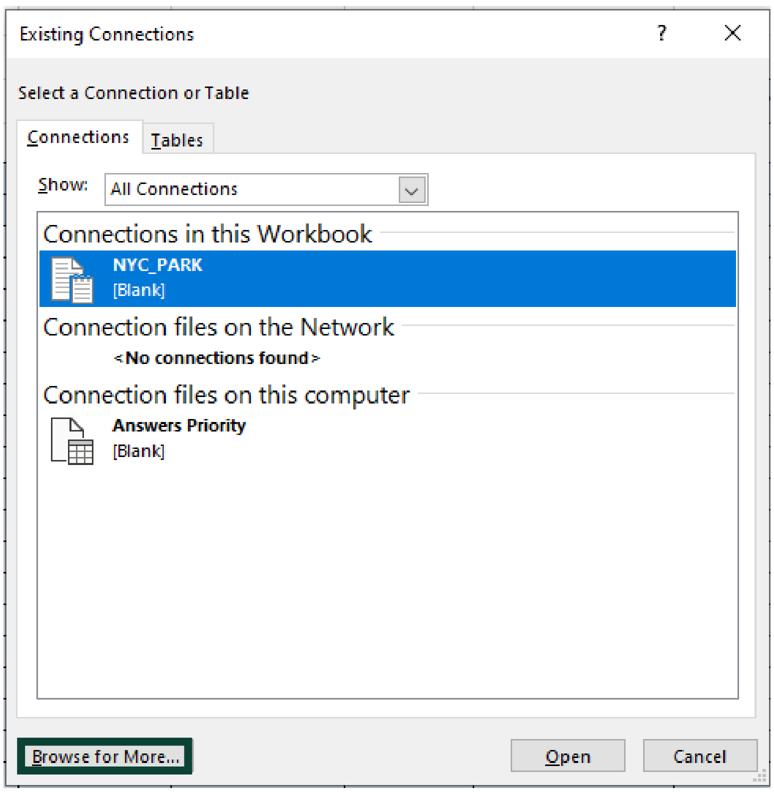

Figure 17. The Existing Connection tool showing the location for the Browse for More button.

d. Change file format to text file (fig. 18).

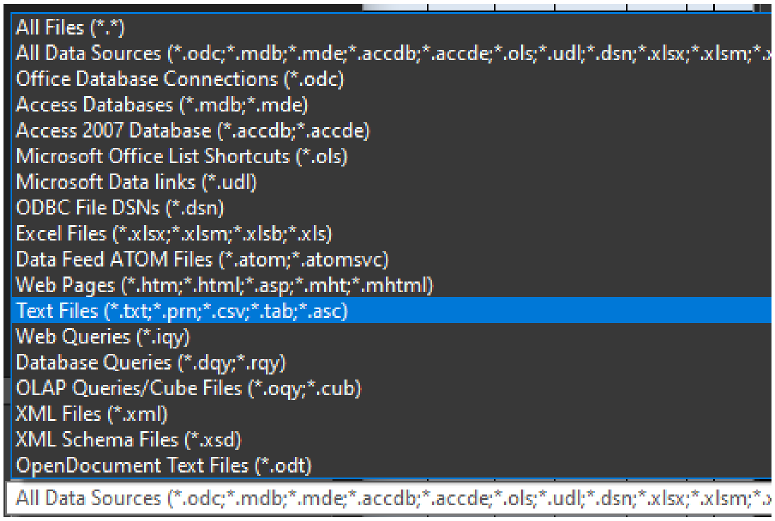

Figure 18. The list of file formats highlighting the Text Files that provide the .csv extension.

e. Browse to a location and select the pXRF .csv file (fig. 19).

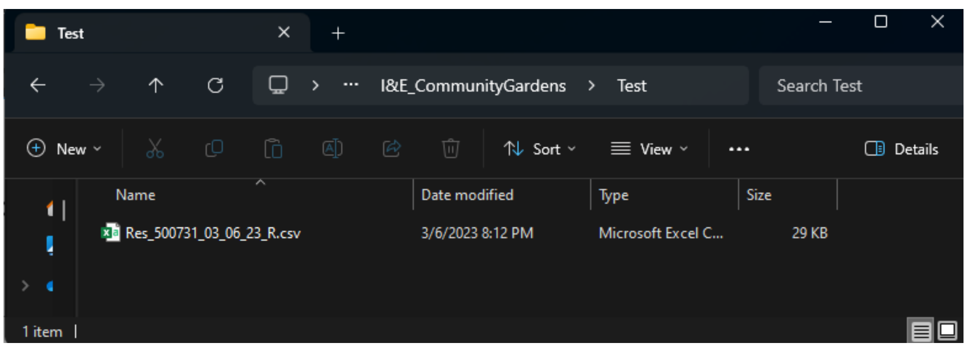

Figure 19. NRCS staff browse to the location for the pXRF .csv file.

1) This file location will become a default location for the template.

2) This file could be a "dummy" .csv file located in the same folder as the template.

f. After selecting the .csv the Text Import Wizard will open. Complete the data import with proper delimiter. Step 1 allows user to select the data type and if the data has headers. In the Text Import Wizard – Step 1 of 3 window, perform the following (fig. 20):

1) Select Delimited – Characters such as commas or tabs separate each field for the original data type.

2) Check the **My data has headers** box.

3) Select the **Next** button.

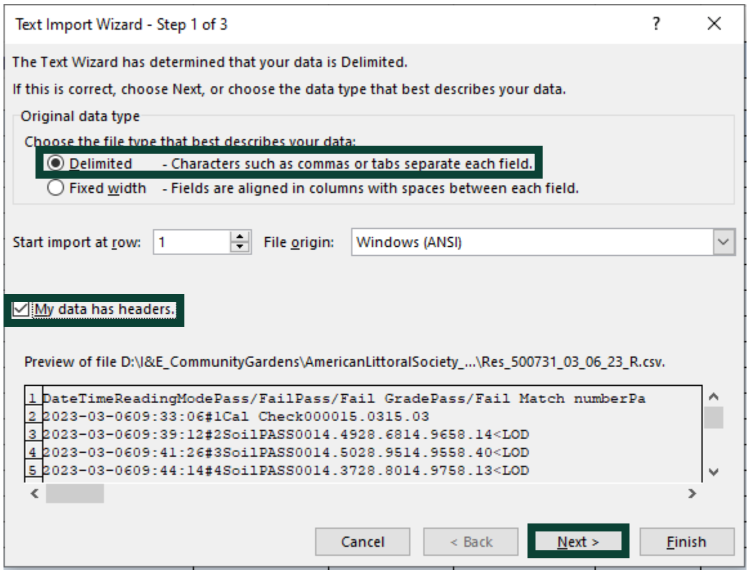

Figure 20. Step 1 of the Text Import Wizard.

g. In Step 2, users can select the type of delimiters. In the Text Import Wizard – Step 2 of 3 window, complete the following (fig. 21):

1) Check the box next to the Tab option.

2) Select **Next**.

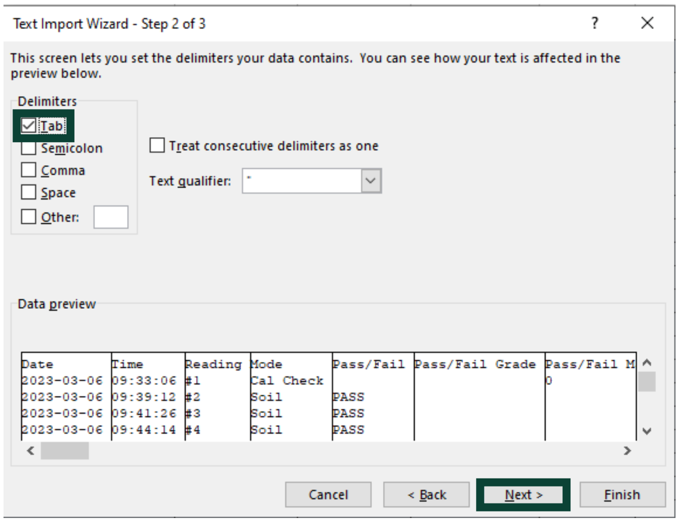

Figure 21. Step 2 of the Text Import Wizard.

h. For Step 3, the user has the flexibility of changing the column format or use the default (recommended). In the Text Import Wizard – Step 3 of 3 window, complete the following (fig. 22):

1) Select **General** for the column data format.

2) Select **Finish**.

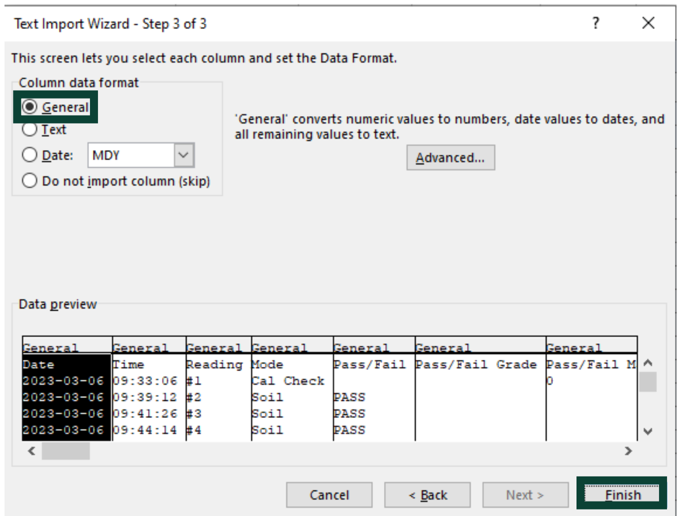

Figure 22. Step 3 of the Text Import Wizard.

i. After selecting **Finish** in the Text Import Wizard – Step 3 of 3 window, the Import Date tool window automatically opens. The user should select **Properties…** in the lower left corner of the Import Data tool (fig. 23).

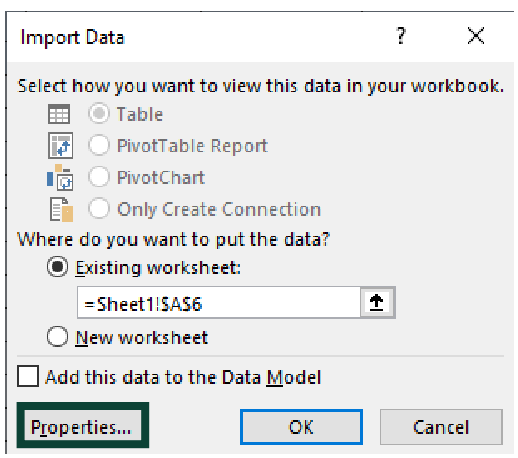

Figure 23. The Import Data tool.

j. After selecting **Properties…** in the Import Data tool, the External Data Range Properties tool opens. Under If the number of rows in the data range changes upon refresh, users should select the **Overwrite existing cells with new data, clean unused cells** option and then select **OK** to complete the format section (fig. 24).

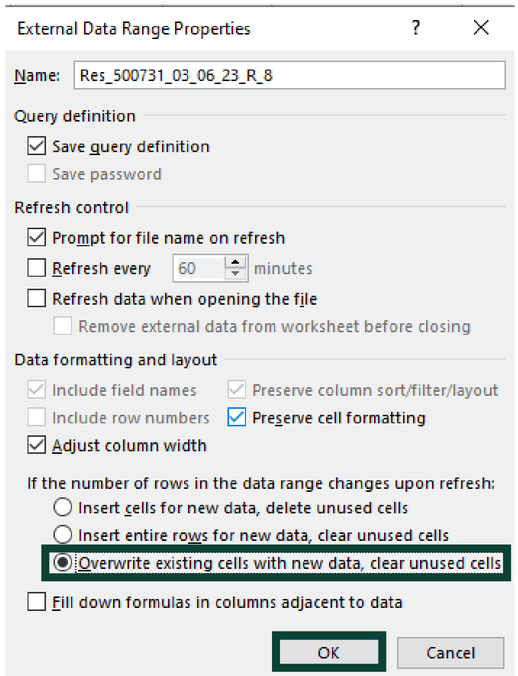

Figure 24. The External Data Range Properties tool.

8. After all formatting is completed, the file must be saved as a template.
    a. Select the **File** tab.
    b. Select **Export**.
    c. Select Change File Type.
    d. In the Workbook File Type window, select **Template**.
    e. Type the name for the template.
        1) Make sure the file is saved in \Documents\Custom Office Templates.
    f. Select **Save**.
9. When prompted to clear data, select **Yes** (fig. 25).

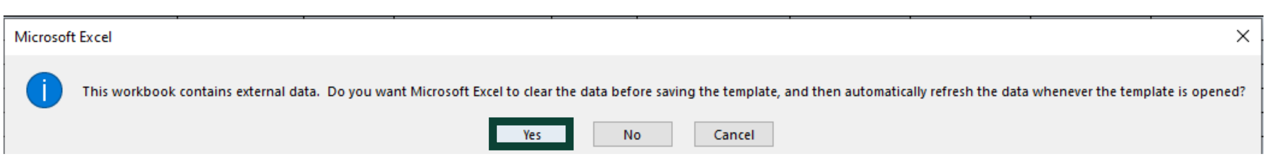

Figure 25. The final step of saving the template clears the spreadsheet of any external data used during the creation of the template.

Options for Customizing a Template

Users can customize the template by creating conditional formatting to highlight concentrations of trace elements above background or soil clean-up standards.

1. Change format and add color scheme using the options under Styles – Format as Table or freelance the color of preference (fig. 26).

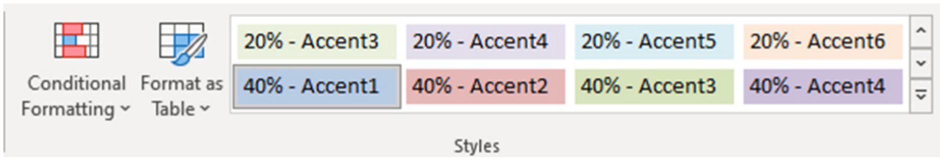

Figure 26. Example color scheme.

Users can add conditional formatting. Conditional formatting allows user to add a green to red color scheme or different icons for highlighting values under or over the local clean-up standard. For additional information, see Microsoft Support's [Use Conditional Formatting to Highlight Information](#).

Users can manually add information about references of local soil remediation standards and the maximum concentrations allowed by the trace elements to the template (fig. 27). Including this information helps the customer understand what the values mean.

				Nickel	Copper	Zinc	Arsenic	Lead	Bismuth
Date	Time	Reading	Mode	Ni	Cu	Zn	As	Pb	Bi
8/4/2023	10:46:09	#57	Soil	<LOD	28	177	<LOD	196	
8/4/2023	10:47:49	#58	Soil	<LOD	36	128	11	147	
NJDEP Soil Remediation Standards				**1600**	**3100**	**23000**	**19***	**400**	
Residential Direct Contact Health Based Criteria									
*The Soil Remediation Standard for Arsenic is based on natural background levels in soil.									

Figure 27. Example showing how the standards and maximum concentrations can be added to increase customer understanding.

Using the Template

1. To use the template.
   a. Open Excel.
   b. There are two options on the Start screen for the selecting the created template
      1) The Home screen provides a list of all new templates (see fig. 28).
      2) The New screen provides a list of all new created templated (fig. 28).

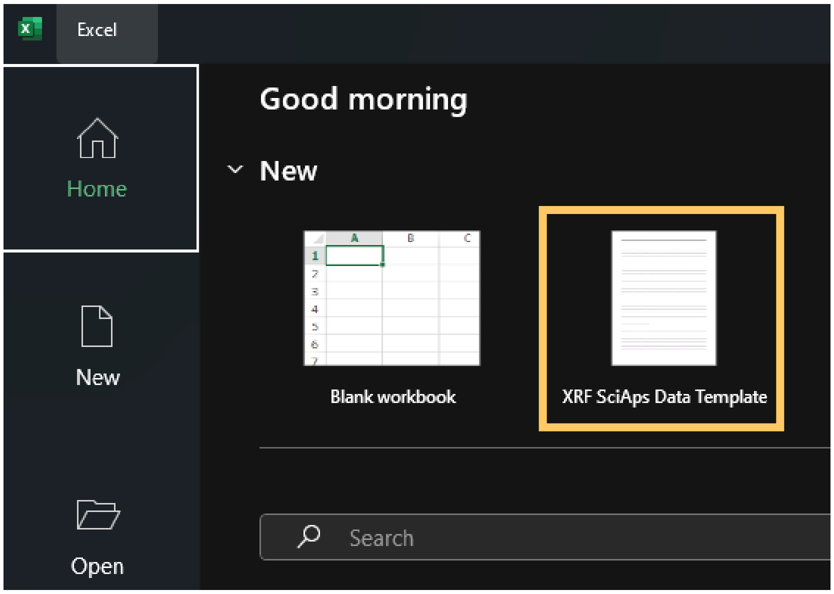

Figure 28. The newly created template for the pXRF will appear in the Start screen list of templates.

If the created template does not show in Home or New screen, users can select the **Personal** option and browse for the template (fig. 29).

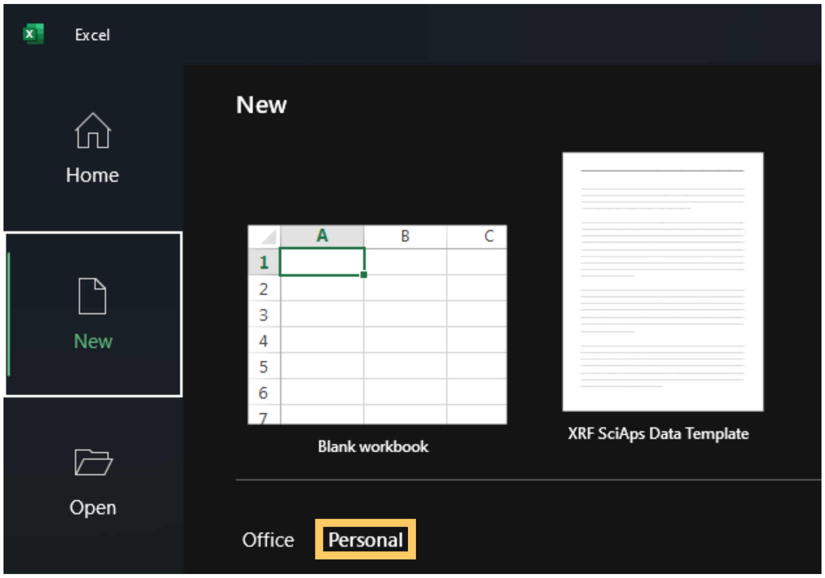

Figure 29. The newly created template for the pXRF will appear when the Personal option is selected.

c. When the pXRF template is selected, a window will open to browse to the .csv file containing the pXRF data.

d. Browse to the location of the .csv with the data to import in the template and select **Import**.

e. After importing the data in the spreadsheet, edit the spreadsheet by removing any columns or rows that will not be used in the final report. The removed columns or rows could be any data with elements that are not reported. A list of reported elements is provided in appendix C.

f. Save the spreadsheet in the customer's folder, and check that the extension is .xlsx (fig. 30). Otherwise, the template will be overwritten.

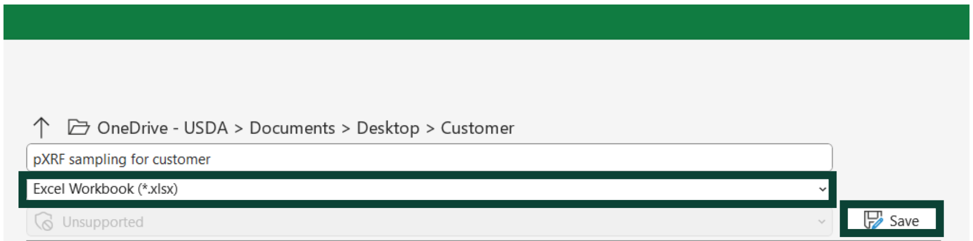

Figure 30. The spreadsheet file extension selection appears under the text box for the file name.

Geographic Information System Data Join

Data join is a process to either temporarily or permanently merge the GPS point data to the data collected with the pXRF. The data join is based on a common field that shares the same format, and it must be a one-to-one join to ensure the correct information is used for spatial analysis.

The template can be used in a geographic information system (GIS) as a join table. To do this, a new column needs to be created with an ID value and format that will correspond to the join field in the GIS. In addition to the join field, the data to be joined must have a numeric format. Some pXRF data downloads include numeric values and text information or value, such as <LOD, or lower than the limit of detection, in the same column. The <LOD text value must be deleted creating NULL values. These NULL values are acceptable in GIS and are not used for analysis (for a more detailed explanation, see the GIS Data Management section).

Preparing Data

1. Use the template described in the previous section to import the pXRF data (fig. 31).

USDA United State Department of Agriculture
Natural Resources Conservation Services

X-Ray Fluorescence Soil Screening Report
Project: Spreadsheet Example

Instrument SN	Model
X505-01959	SciAps
Unit	**Method Name**
PPM	Soil

					Lead	Arsenic	Copper	Zinc	Nickel	Chromium	Cadmium	Vanadium
Test #	ID	Layer	Latitude	Longitude	Pb	As	Cu	Zn	Ni	Cr	Cd	V
204	1	Surface	40.1228237	-74.81709928	136	12	16	238	ND	27	ND	40
205		Subsurface	40.1228237	-74.81709928	206	ND	24	370	ND	21	ND	85
206	2	Surface	40.12283344	-74.8172811	346	132	96	900	ND	114	ND	56
207		Subsurface	40.12283344	-74.8172811	113	41	43	527	39	80	ND	104
208	3	Surface	40.12285183	-74.8174657	283	23	22	393	ND	26	ND	39
209		Subsurface	40.12285183	-74.8174657	37	6.8	24	178	ND	27	ND	35
210	4	Surface	40.12287853	-74.81764548	123	9.2	ND	263	ND	ND	ND	25
211		Subsurface	40.12287853	-74.81764548	34	ND	ND	147	ND	ND	ND	31
212	5	Surface	40.12290541	-74.81783781	75	ND	ND	155	ND	25	ND	32
213		Subsurface	40.12290541	-74.81783781	588	68	235	1413	ND	245	ND	104
214	6	Surface	40.12292384	-74.81793369	53	10	ND	197	ND	ND	ND	29
215		Subsurface	40.12292384	-74.81793369	92	ND	19	233	ND	ND	ND	31
216	7	Surface	40.12286238	-74.81786008	120	12	37	242	ND	ND	ND	51
217		Subsurface	40.12286238	-74.81786008	9.8	ND	ND	46	ND	ND	ND	36
218	8	Surface	40.12282867	-74.81767322	97	ND	ND	179	ND	42	ND	37
219		Subsurface	40.12282867	-74.81767322	13	8.4	ND	55	ND	19	ND	37
220	9	Surface	40.12280429	-74.81749255	144	ND	ND	212	ND	20	ND	34
221		Subsurface	40.12280429	-74.81749255	85	8.5	ND	243	ND	26	ND	42
NJDEP Soil Remediation Standards					**400**	**19***	**3100**	**23000**	**1600**		**71**	**390**
Residential Direct Contact Health Based Criteria												
*The Soil Remediation Standard for Arsenic is based on natural background levels in soil.												

This data set is not designed for use as a primary regulatory tool in permitting or citing decisions, but may be used as a reference source. This information and may be interpreted by organizations, agencies, units of government, or others based on needs; however, they are responsible for the appropriate application. Federal, State, or local regulatory bodies are not to reassign to the Natural Resources Conservation Service any authority for the decisions that they make. The Natural Resources Conservation Service will not perform any evaluations of these data for purposes related solely to any regulatory programs.

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Figure 31. The pXRF data imported in the spreadsheet template to in GIS.

2. Add a new sheet by selecting the plus sign next to Sheet 1 (fig. 32).

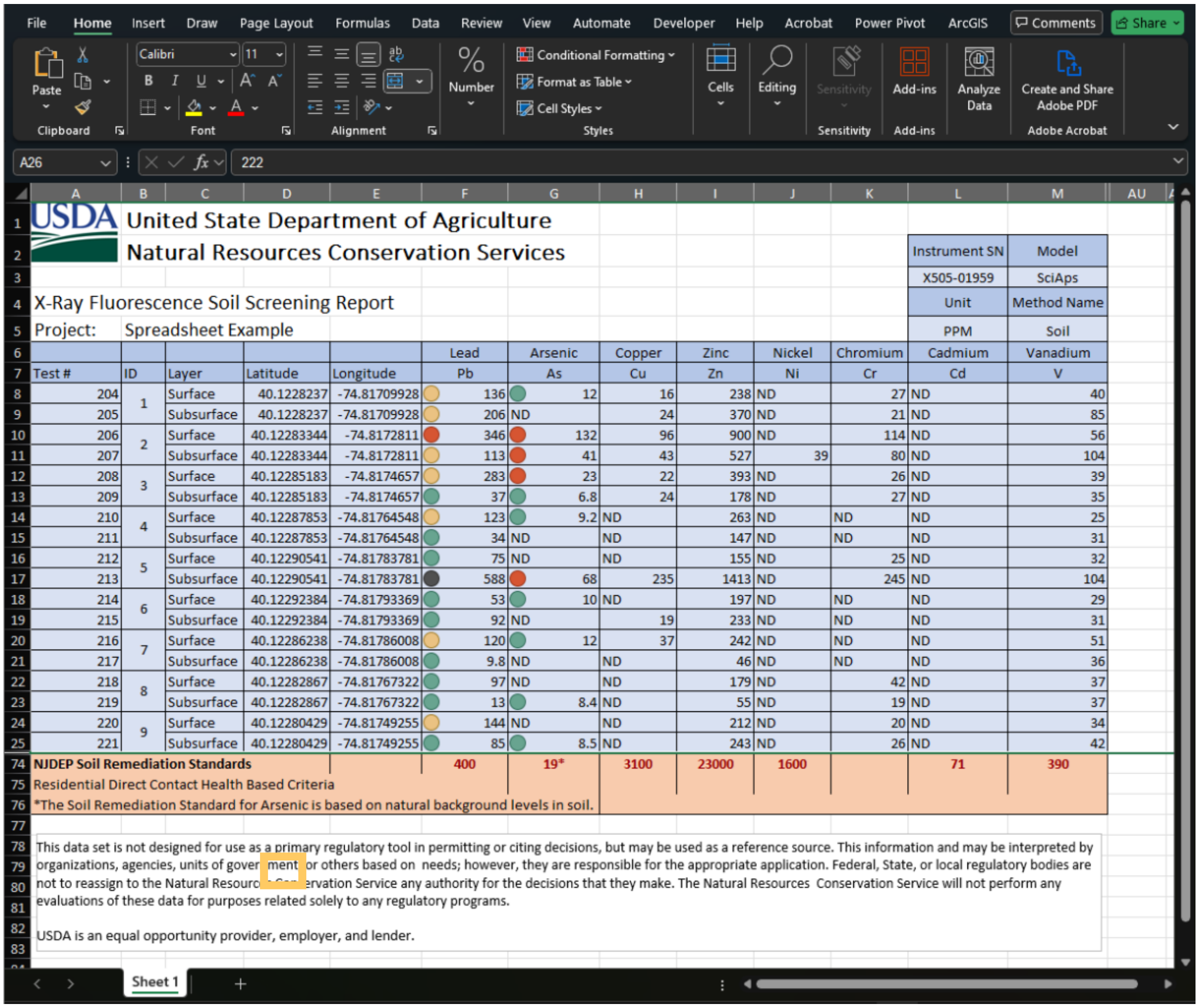
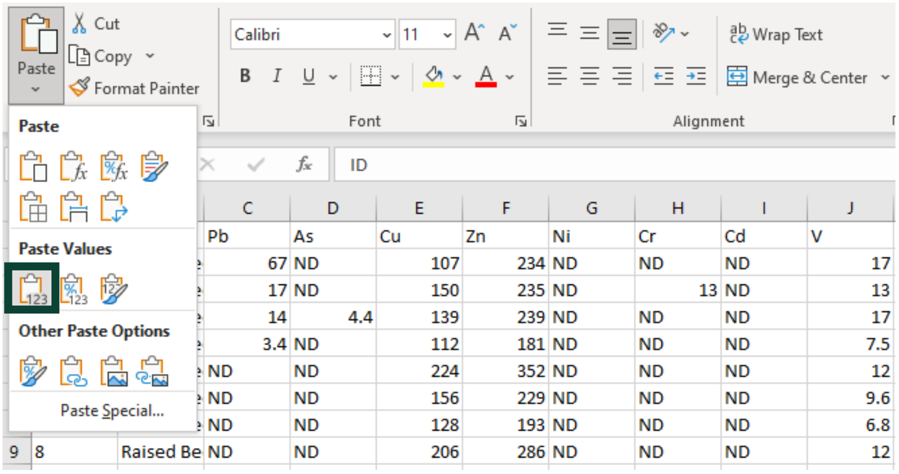


Figure 32. The plus-sign to add new sheet is located at the bottom of spreadsheet.

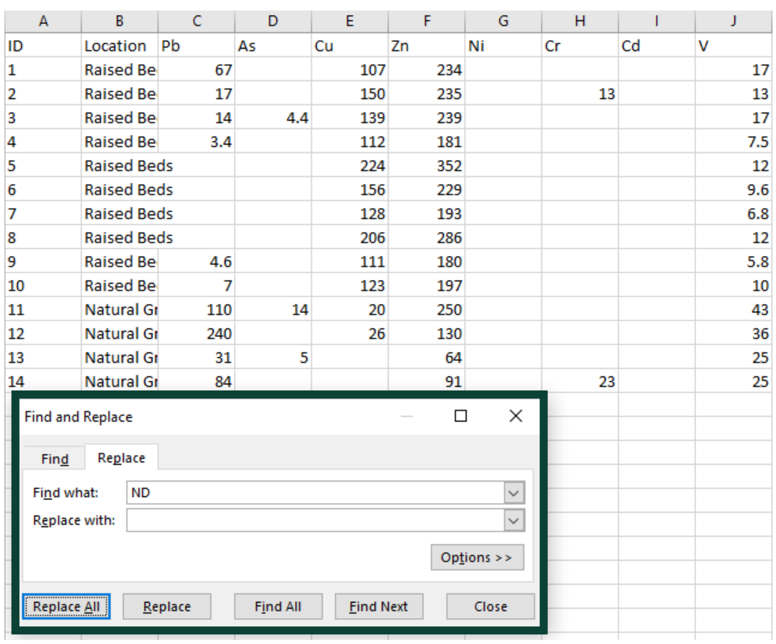
3. Copy the data from Sheet 1. Select the **Values** option under Paste Values to paste the data into Sheet 2 (fig. 33). This copy must include just the header line with symbols and data.



C	D	E	F	G	H	I	J
Pb	As	Cu	Zn	Ni	Cr	Cd	V
67	ND	107	234	ND	ND	ND	17
17	ND	150	235	ND	13	ND	13
14	4.4	139	239	ND	ND	ND	17
3.4	ND	112	181	ND	ND	ND	7.5
ND	ND	224	352	ND	ND	ND	12
ND	ND	156	229	ND	ND	ND	9.6
ND	ND	128	193	ND	ND	ND	6.8
ND	ND	206	286	ND	ND	ND	12

Figure 33. The pXRF data copied and pasted into the new sheet using the value format option in black box.

4. Remove all text labels from the data, such as ND or <LOD. Leave the cell blank. This step is necessary otherwise GIS will create a join and assign the field as text rather than using numeric format.
5. Use the Find and Replace tool to replace the ND or <LOD with blank cells (fig. 34).



ID	Location	Pb	As	Cu	Zn	Ni	Cr	Cd	V
1	Raised Be	67		107	234				17
2	Raised Be	17		150	235		13		13
3	Raised Be	14	4.4	139	239				17
4	Raised Be	3.4		112	181				7.5
5	Raised Beds			224	352				12
6	Raised Beds			156	229				9.6
7	Raised Beds			128	193				6.8
8	Raised Beds			206	286				12
9	Raised Be	4.6		111	180				5.8
10	Raised Be	7		123	197				10
11	Natural Gr	110	14	20	250				43
12	Natural Gr	240		26	130				36
13	Natural Gr	31	5		64				25
14	Natural Gr	84			91		23		25

Figure 34. In this example, the Find and Replace tool is being used to replace all ND values to blank cells.

6. Save the spreadsheet. Now the data is ready to be joined in GIS.

Create a Table Join in GIS

1. With the GPS point data loaded in GIS, right click in the point feature layer and select **Attribute Table** (fig. 35). **Note:** This is one way to open the attribute table. There are other ways to open the attribute table using shortcuts or by making similar selections in the main menus.

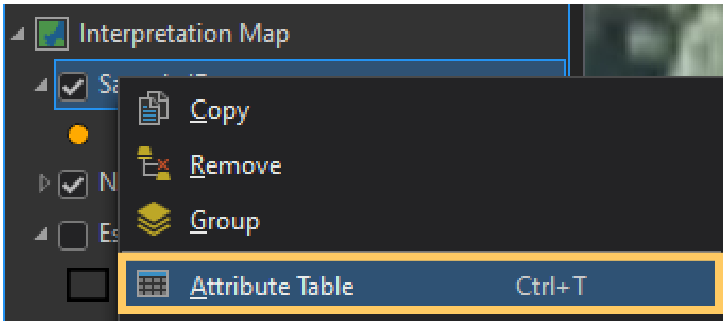


Figure 35. The Attribute Table option for the GIS point data.

2. Hover the pointer on top of the field header to find format type (fig. 36). This format type must match the format of the join field in the spreadsheet.

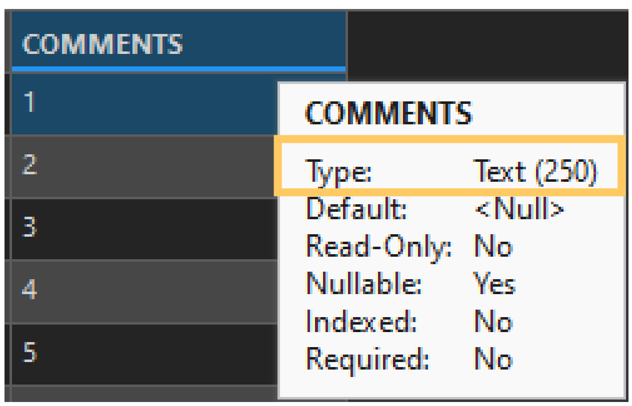


Figure 36. Example showing the field format type as a text field.

3. In the spreadsheet, it is also a text field (fig. 37).

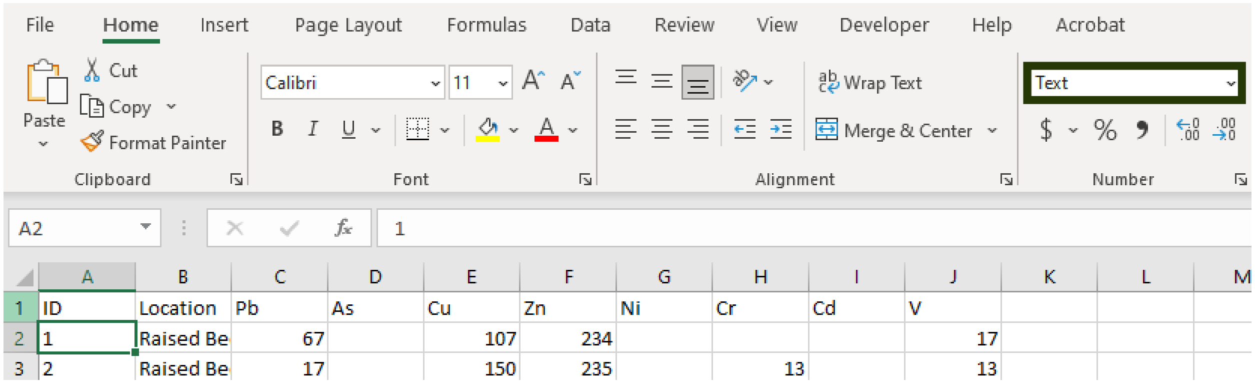


Figure 37. The column format in the spreadsheet (highlighted with the black rectangle) must match the field format in the GIS attribute table.

4. In GIS, select the point feature layer **Joins and Relates**, and then select **Add Join** (fig. 38).

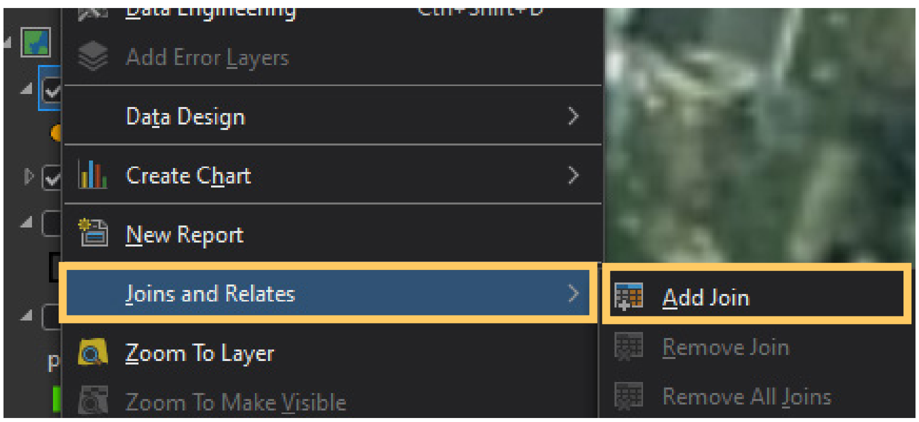


Figure 38. The Add Join option appears to the right of the selected Joins and Relates option.

5. In the Add Join window, fill in the requested information in the tool. For the Join Table, browse to the spreadsheet that contains the data in Sheet2$ if the table was not added to the project (fig. 39).

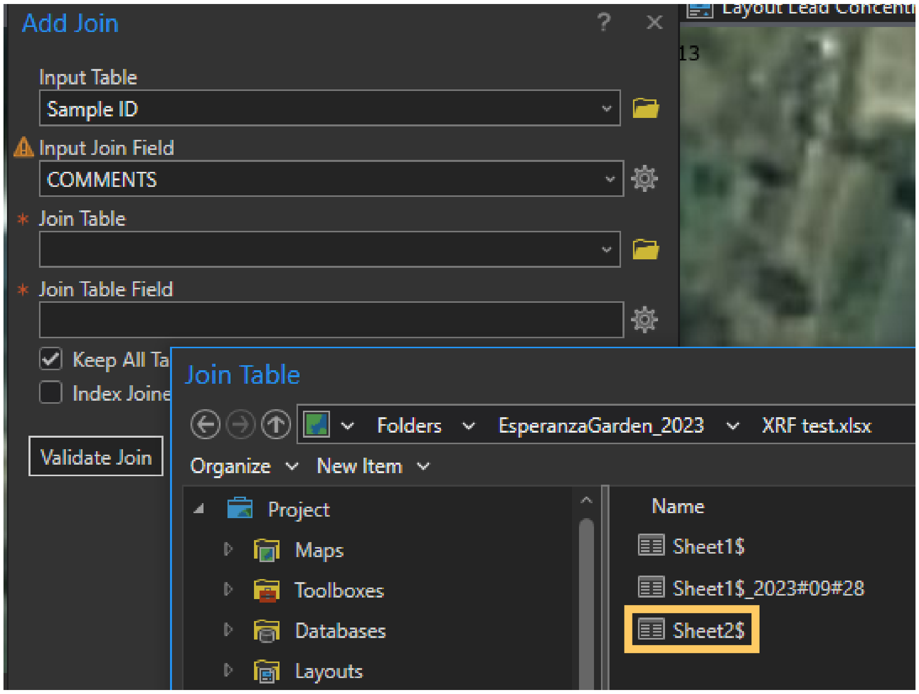
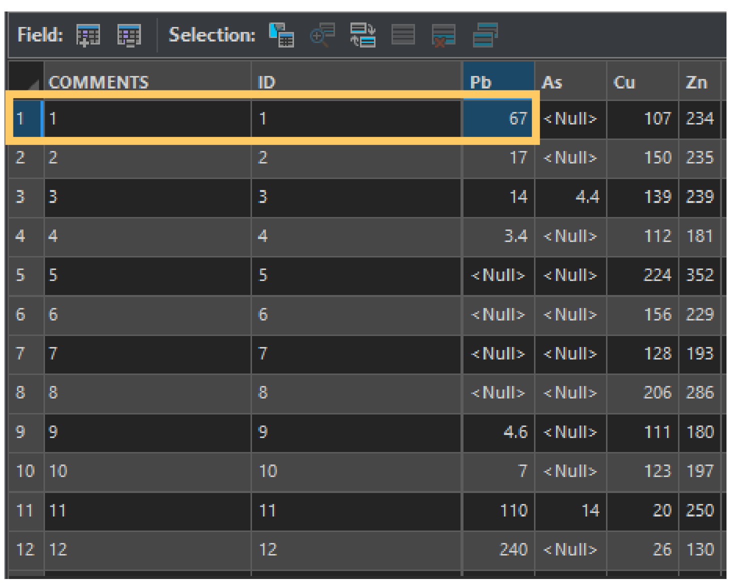


Figure 39. Window showing the sheet selection and parameter selection to create a table join.

6. Select **OK** button in the tool window located in the lower right corner.
7. Select the **Join Table Field** that contains the Join Field.
8. Select **OK** to create the table join. Now the point feature layer contains the tabular data that is ready for spatial analysis (fig. 40).



	COMMENTS	ID	Pb	As	Cu	Zn
1	1	1	67	<Null>	107	234
2	2	2	17	<Null>	150	235
3	3	3	14	4.4	139	239
4	4	4	3.4	<Null>	112	181
5	5	5	<Null>	<Null>	224	352
6	6	6	<Null>	<Null>	156	229
7	7	7	<Null>	<Null>	128	193
8	8	8	<Null>	<Null>	206	286
9	9	9	4.6	<Null>	111	180
10	10	10	7	<Null>	123	197
11	11	11	110	14	20	250
12	12	12	240	<Null>	26	130

Figure 40. Example showing the pXRF data joined in GIS with the spreadsheet.

Mapping Software: Esri ArcGIS – Pro or Golden Surfer

NRCS staff should assign a unique ID code for the spatial point data and the pXRF tabular data. This unique ID code will be used to join the points data collected at sampling locations to the pXRF (see the Create a Table Join in GIS section).

The two options used to indicate trace element concentrations that can be used in place of the ID code: proportional symbols by element or graduated colors by element quantity classes (figs. 41–43).

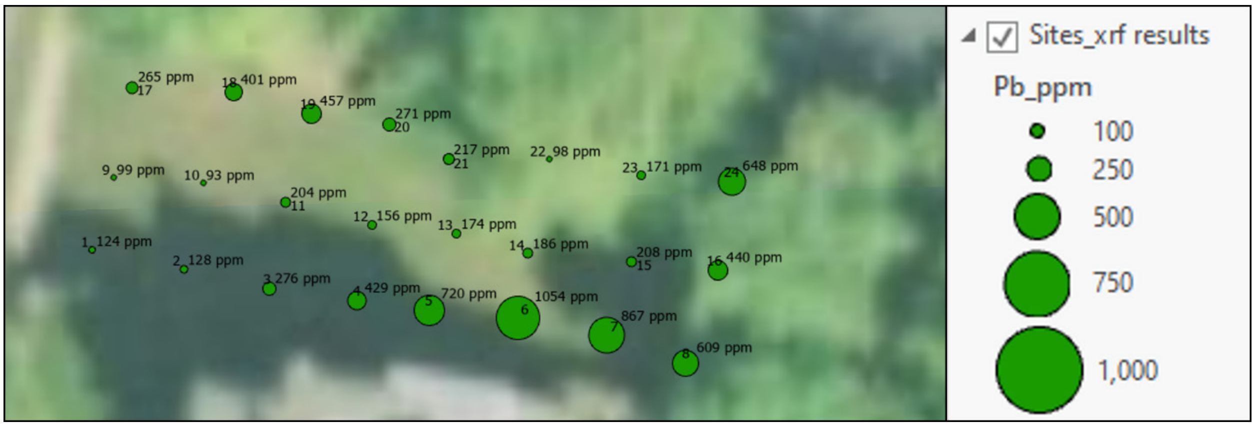


Figure 41. In this example, trace elements concentrations are displayed using the same symbol (a green dot) in multiple sizes. An increase in the size of the symbol indicates higher concentrations.

Figure 42. In this example, trace elements concentrations are displayed using the same symbol, but the color of the symbol corresponds to a set range.

A third option allows the user to develop a contour mapping of element and denote potential hot spots (fig. 43). This option generates an interpretation map showing the spatial distribution of a trace elements based on the point data collected with the pXRF (see the Spatial Analysis section for the two most common spatial analysis models).

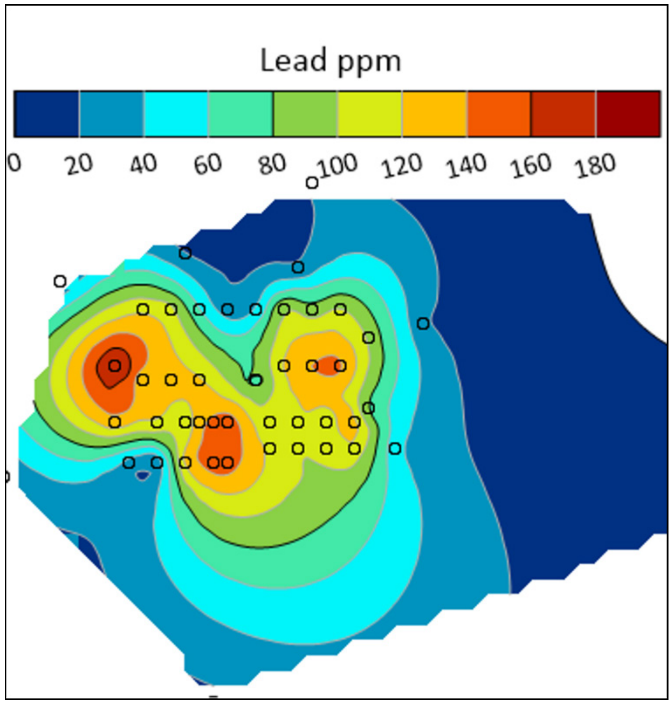


Figure 43. Spatial distribution of lead concentrations using a spatial analysis model.

Imagery

Imagery is an important tool when working in GIS, and imagery resolution plays an important role with photo interpretation in small study areas. Resolution of the National Agriculture Imagery Program (NAIP) imagery at 1-meter resolution is often insufficient to distinguish community garden beds and other urban farming sites (fig. 44). State imagery is often available in submeter resolution (i.e., 1- to 1.5-foot resolution).

Figure 44. NAIP-2022 1-meter resolution (left) compared to 2022 state leaf off imagery at 0.15-meter resolution (right).

Spatial Analysis

In GIS, the spatial distribution of the data collected with the pXRF equipment is generated using a variety of spatial analysis tools. The most commonly used are the inverse distance weighted (IDW) and the kriging; however, these tools are not part of the basic ArcGIS license. A valid ESRI Extension for Spatial Analysis is required to conduct this type of analysis (fig. 45).

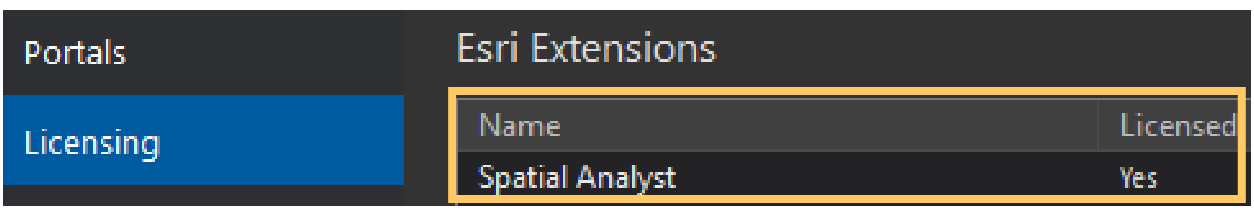


Figure 45. The licensing window in ArcGIS and the spatial analysis extension selected as licensed.

IDW interpolation determines cell values using a linearly weighted combination of a set of sample points. This method assumes the variable being mapped decreases in influence with distance from its sampled location (ESRI, 2023a).

Kriging is a statistical relationship among the measured points. Accordingly, geostatistical techniques not only have the capability of producing a prediction surface but also provide some measure of the certainty or accuracy of the predictions. Kriging assumes the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface. Kriging is most appropriate when there is a known spatially correlated distance or directional bias in the data and is often used in soil science and geology (ESRI, 2023b).

Report Development

A field report is a compilation of information consisting of project location and purpose, data collection methodology, pXRF data, maps, and interpretations that NRCS staff use to help explain soil conditions. As part of the methodology, NRCS staff describe the site layout, sample size, transect method, equipment used, and method used for data processing (for more information, see the On-Site Evaluation section).

Document Land Ownership

Urban soils are located within cities, park areas, recreation areas, community gardens, green belts, lawns, and land used for other purposes. It is highly recommended that NRCS staff record information, such as township name for public land or owner and operator name for private land.

Document Past Land Use History

It is important to understand the past historical context of the land being surveyed, particularly in relation to the specific city's industrial past in the case of urban environments. NRCS staff working with community gardeners or urban farmers use site assessments to discover what existed on the land decades ago and to identify best practices to circumvent issues related to problematic previous land use history. Knowing the site history can help gardeners and urban farmers increase their understanding of soil quality and soil health and take appropriate measures, such as capping the soil, creating raised beds, or bringing in clean soil from another source.

Document Present Land Use History

- Plant species (grass and legume types).
- Tillage practices (tools used including rotary tillers, hand tools, shovels, tillage depth, and timing).
- Compost (types and quantity applied per square foot).
- Mulch (types, quantities, frequency of application, and application methods).
- Seed bed (size and depth).
- Commercial or organic fertilizers (types, quantity, frequency of applications, and method of applications—surface, subsurface, or both).

Document Land Cover

Land cover consists of the surface components of land that are physically present and visible. Documentation of land cover provides a means to examine landscape patterns and characteristics, which are important in understanding

- The extent, availability, and condition of lands.
- Ecological system extent, structure, and condition.
- The potential for dispersion and effects of chemicals and other pollutants, particularly heavy metals, in and on the environment.

Land cover is a starting point from which a variety of monitoring activities can be performed. Land cover information is used for many purposes, such as assessing nonpoint sources of pollution, understanding landscape variables for ecological analyses, assessing the behavior of chemicals, such as trace elements (arsenic, cadmium, chlorine, chromium, copper, lead, nickel, vanadium, or zinc), and analyzing the effects of air, water, and soils pollution.

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Appendix A: Element Adjustment

Some pXRF equipment allows the default library to be adjusted through the addition of a user factor. The user factor is created by comparing the pXRF readings against sample results obtained from certified laboratory procedures. It is highly recommended that the samples used to generate the user factor include a wide range in concentrations for the intended use (i.e., concentrations close to the equipment limit of detection and greater than the maximum value for the soil clean-up standard).

To obtain the user factor, various samples are analyzed and plotted against their assay to get a linear regression. The plot should be assay (X) versus pXRF results (Y), and the resulting slope should equal one. If it is not, the user factor should be applied to correct the slope to equal one. In other words, the user factor is the inverse of the slope. It is highly recommended that NRCS staff apply the user factor and confirm the results. Each user factor affects only the element it is set for; therefore, changing the factor for one element does not affect the rates of other elements.

For example, the recommendation for lead is to use samples with concentrations in a range spreading between 5 mg/kg to 1,200 mg/kg. About 50 soil samples were analyzed following the EPA lab procedure and then analyzed with the pXRF to compare total lead concentrations. With higher total lead concentrations, it becomes less likely that the data will conform to a linear model. With lead concentrations of 5,000 mg/kg or fewer, the data conforms very well, and any outliers should be removed to reduce the introduction of errors to the model. The plotted values in figure A-1 show a slightly higher trend, and in this case, the user factor to apply would be the inverse of the slope (i.e., 1/1.2117 equals 0.8253).

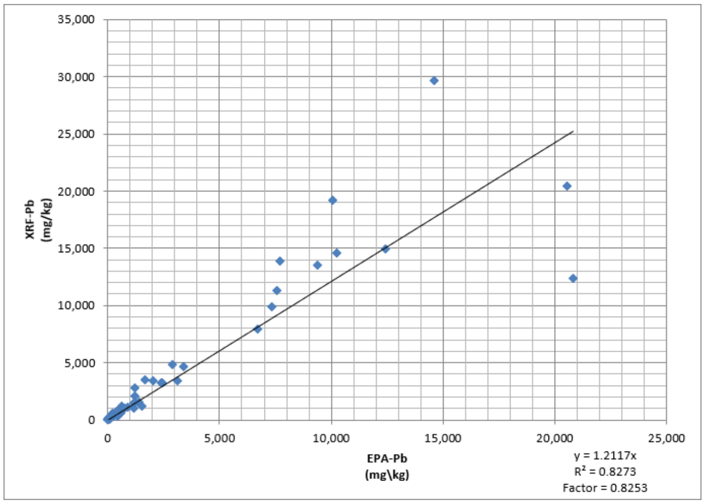

Figure A-1. Graph showing the linear relation between laboratory results using the EPA method for lead and data gathered using the pXRF and the estimation of a user factor.

Appendix B: Additional Resources

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Resources by State

Connecticut

- Connecticut Department of Public Health. (2014). What you need to know about growing and eating fruits and vegetables safely.
- Pettinelli, D. (2023a). Lead in garden soils. University of Connecticut Soil Nutrient Analysis Laboratory.
- Pettinelli, D. (2023b). Soil lead interpretation sheet. University of Connecticut Soil Nutrient Analysis Laboratory.

New Jersey

- Bakacs, M., and Melendez, M. (2015). Food safety, soil, and water testing recommendations for school and community gardens (Cooperative Extension E350). Rutgers New Jersey Agriculture Experiment Station (NJAES).
- Hamel, S., Heckman, J. and Murphy, S. (2010). Lead contaminated soil: Minimizing health risks (Cooperative Extension Fact Sheet FS336). Rutgers NJAES Cooperative Extension.
- Murphy, S. (2020). Soil for raised beds (Cooperative Extension Fact Sheet FS1328). Rutgers NJAES.

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New York

- Cornell University. (2024). Healthy soils, healthy communities: Science-based information about soil contaminants and healthy gardening practices.
- Cornell Waste Management Institute. (2015). Metals in urban gardens. Cornell University.
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- GrowNYC. (2014). Resilient NYC community garden guide.
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Pennsylvania

- Finlay, E., and Faust, A. (2023). How to construct a raised bed in the garden. Penn State University, Penn State Extension.
- Penn State Master Gardeners in Philadelphia. (2023). Gardening from the ground up: Soil health and best practices for urban gardens. Penn State University, Penn State Extension.

Vermont

- Grubinger, V., Ross, D., and Faulkner, J. (2023). Interpreting the results of soil tests for heavy metals. University of Vermont Extension.
- Vermont Department of Health. (2023). Chemical-specific soil guidance values, residential soil values (rsvs) and commercial soil values (CSVs).

Appendix C: Metals and Metalloids Evaluated

Levels of concern or background levels are not included in this user guide because that information is State specific. It is recommended obtaining this information with your local environmental protection agency.

Arsenic (As)

In the soil environment arsenic exists as either arsenate, As(V) (AsO_4^{3-}), or as arsenite, As(III) (AsO_2^-). Arsenite is the more toxic form of arsenic. The behavior of arsenate in soil is analogous to that of phosphate, because of their chemical similarity. Like phosphate, arsenate forms insoluble precipitates with iron, aluminum, and calcium. Iron in soils is most effective in controlling arsenate's mobility (McLean and Bledsoe, 1992).

Cadmium (Cd)

Cadmium may be adsorbed by clay minerals, carbonates, or hydrous oxides of iron and manganese or may be precipitated as cadmium carbonate, hydroxide, and phosphate. The chemistry of cadmium in the soil environment is, to a great extent, controlled by pH. Under acidic conditions cadmium solubility increases and very little adsorption of cadmium by soil colloids, hydrous oxides, and organic matter takes place. At pH values greater than 6, cadmium is adsorbed by the soil solid phase or is precipitated, and the solution concentrations of cadmium are greatly reduced. Cadmium forms soluble complexes with inorganic and organic ligands, in particular chlorine (Cl). The formation of these complexes will increase Cd mobility in soils (McLean and Bledsoe, 1992). Sanderson et al. (2019) found that soil pH and zinc (Zn) concentration were dominant factors influencing cadmium accumulation in potato tubers.

Chlorine (Cl)

Sodium chloride (NaCl) is commonly used in de-icing of roads. Chloride is a key component in road salt. If sodium (Na) is not measurable with pXRF equipment, consider chlorine total elemental analysis if high salt accumulation is a concern.

Chromium (Cr)

Chromium exists in soils as trivalent chromium, Cr(III), and hexavalent chromium, Cr(VI), (McLean and Bledsoe, 1992). Some of the sources of chromium are natural processes or mining, smelting, metal processing, industrial production, and agriculture. Chromium translocation into plants is binding with iron (Fe), sulfur (S), and phosphorous (P) (Wallace et al., 1976, from Shanker et al., 2005). Cr(III) is an essential nutrient trace element, non-toxic, and difficult to absorb. In contrast, Cr(VI) is one of the most toxic forms that can be absorbed in the body by inhalation, ingestion, and skin contact (Deng et al., 2019 from Xu et al., 2023; Sharma et al., 2022; Tumolo et al., 2020).

Copper (Cu)

Copper is adsorbed to a greater extent by soils and soil constituents. Copper, however, has a high affinity for soluble organic ligands, and the formation of these complexes may greatly increase copper mobility in soils (McLean and Bledsoe, 1992). Chiou and Hsu (2019) found that copper concentration in soil greater than 250 mg/kg reduces plant height and fresh weight in some leafy vegetables. In regard to copper and soil microbial activity, Yáñez et al. (2022) found that copper was inconclusive to microbial response in anthropogenic soils; however, Schoffer et al. (2020) mention that copper concentration negatively affects soil and litter microbial activity.

Lead (Pb)

Lead solubility is greatly reduced by the interaction with clays, phosphates, sulfates, carbonates, hydroxides, and organic matter. At pH values above 6, lead is either adsorbed on clay surfaces or forms lead carbonate (McLean and Bledsoe, 1992; Zimdahi and Skogerboe, 1977). Anthropogenic sources include atmospheric deposition by traffic emissions, mining, smelting, lead-based paint, footpath surfaces, sewage irrigation, agricultural practices, like fertilizers and pesticide application, and waste dumping and disposal (Kumari et al., 2023).

Nickel (Ni)

Nickel will adsorb to clays, iron and manganese oxides, and organic matter and is thus removed from the soil solution. The formation of complexes of nickel with both inorganic and organic ligands will increase nickel mobility in soils (McLean and Bledsoe, 1992).

Vanadium (V)

Vanadium and nickel are present in higher concentrations in heavy oils and bitumen (Dechaine and Gray, 2010; Gol'dberg et al., 1986). Vanadium mobility is reduced by interacting with biochar, aluminum and silica minerals, organic acids, various clay minerals and iron, titanium, manganese, and aluminum oxides (Haak and Indraratne, 2023), redox potential, soil pH, organic matter, and microorganisms. Vanadium mainly accumulates in plant roots with very limited translocation to shoots and can interfere with plant phosphorus uptake (Chen et al., 2021). However, at low concentrations, vanadium may have beneficial effects on plant growth and development (Hanus-Fajerska et al., 2021).

Zinc (Zn)

Zinc is readily adsorbed by clay minerals, carbonates, or hydrous oxides. Zinc adsorption increases with pH (Baruah, 2018; McLean and Bledsoe, 1992). Anthropogenic sources of zinc in soil come from discharges of smelter slags and wastes, mine tailings, coal and bottom fly ash and the use of commercial products, such as fertilizers and wood preservatives, that contain zinc (ATSDR, accessed 2023).

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Appendix D: Operation Best Practices

- Before starting soil screening NRCS staff should analyze the reference samples and the blank to verify results as recommended by the equipment manufacturer. Verifying the blank at the end of sampling is also recommended to ensure the window screen of the pXRF was not contaminated during soil screening.
- Place a thin plastic bag (not a freezer bag) or a biaxially-oriented polyethylene terephthalate (BoPET) film as a barrier between a sample and the window screen to provide another layer of protection. BoPET film has been recommended by the equipment manufacturer. The equipment manufacturer manual notes that testing through a thin plastic bag has little effect on test results, however, analysis results for the elements chromium (Cr), vanadium (V), and barium (Ba) will be lower by 20-30 percent. It is a good practice to test the BoPET film with the pXRF equipment to ensure that the film does not contain any trace elements of interest that will interfere with results.
    - Reduce soil particles or dust contaminating the pXRF window screen and reduces error.
    - Protect the delicate membrane by the sampling window and protect internal components if the membrane is broken.
- Perform a calibration check twice daily or every 4 hours.
- Analyze blank every 20 samples.
- Analyze (NIST or OREAS) reference sample at least once per day.
- Avoid collecting data in saturated soil conditions. The overall error can be minimized when the soil moisture content is between 5 and 20 percent (EPA, 2007).
- Run each screening with a 30-second test time per beam used (fig. D-1).
    - For screening of lead (Pb), ensure the primary beam is selected in the pXRF equipment. Figures D-2 and D-3 show the list of elements for the primary beam for the Vanta and Delta equipment.
    - Use measuring times of 30 seconds for initial screening and hot spot delineation. Measurement times up to 300 seconds are typically used to meet higher precision and accuracy requirements (EPA, 2007).

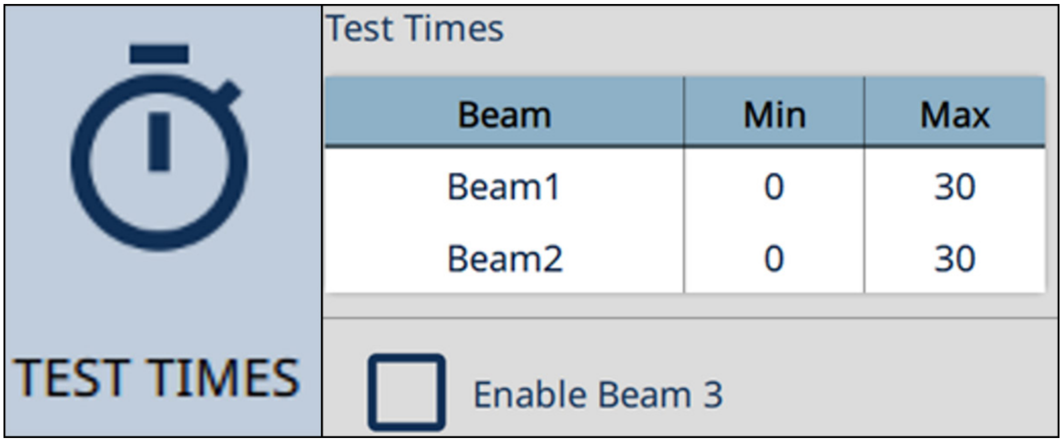

Figure D-1. Enlarged Test Times icon (left) and minimum and maximum time of exposure by beam in the Vanta pXRF equipment (right).

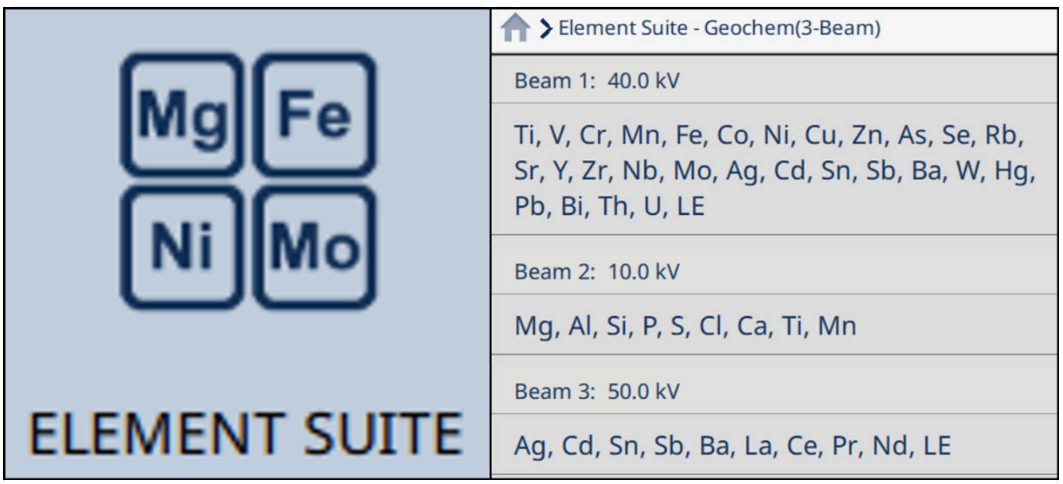

Figure D-2. Enlarged Element Suite icon (left) and list using alternating rows to show the data: the beam number is on one row and the elements detected on the row below that (right).

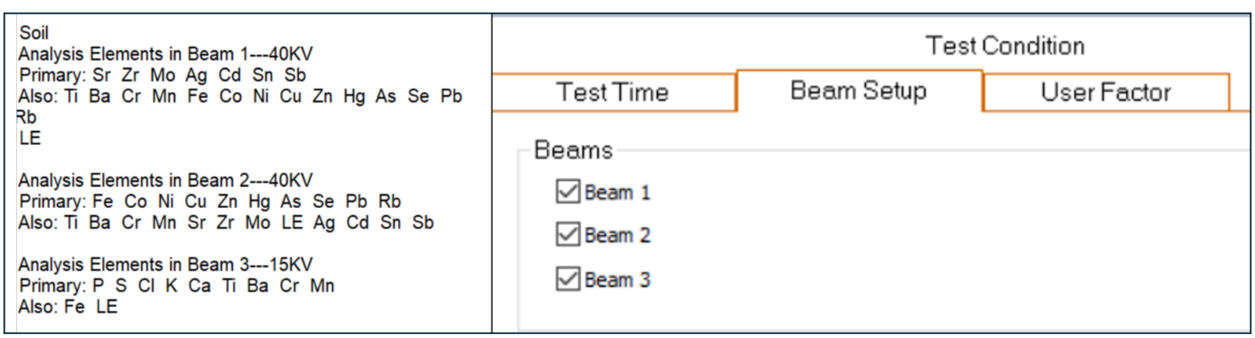

Figure D-3. Elements detected for each of the beams and beam energy shown on the left, and the beam selection for the Delta pXRF equipment shown on the right.

- Average three screening values as the result.
- Use uniformly dry and homogenized (mortar and pestle) samples to obtain the best results.
    - Sample the cup. The sample cup is a plastic container with an opening covered with a thin-film used for intrusive analysis (fig. D-4).
    - Sample the bag, taking in consideration limitations for chromium (Cr), vanadium (V), and barium (Ba).

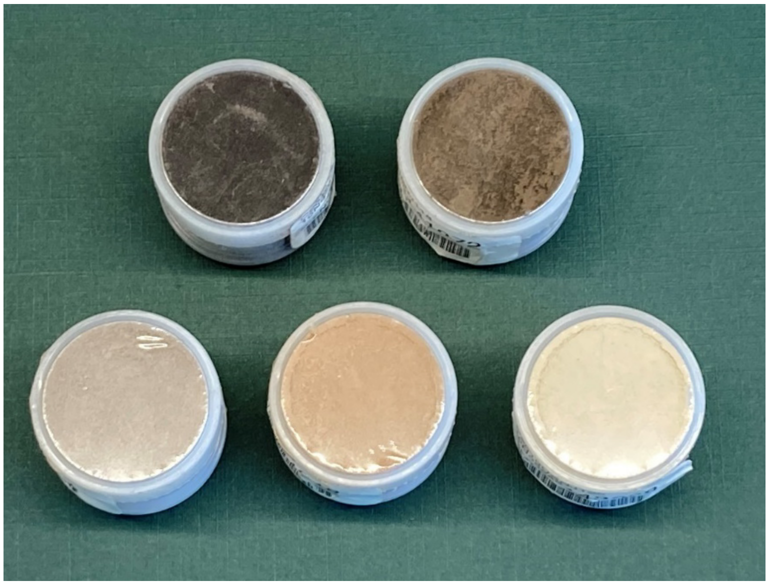

Figure D-4. Reference sample in a sample cup.

- If collecting samples in bags, scan the sample through the bag in three places, and calculate the average from the three scans. Avoid rocks or other materials, such as leaves or debris.
- After performing calibration checks, analyze reference samples from NIST or OREAS, and blank. After anaysis of all samples, export results in .csv format to a laptop.

Reference

U.S. Environmental Protection Agency (EPA). (2007). *SW-846 test method 6200: Field portable x-ray fluorescence spectrometry for the determination of elemental concentrations in soil and sediment*.

Appendix E: Global Position System Units

The use of GPS units in combination with pXRF provides the capacity for the exact location on each of the data points collected with the pXRF equipment. This GPS information is needed for the data visualization and spatial analysis process. NRCS staff use a variety of GPS equipment that is selected by different regions depending on the local needs.

- Geode units from Juniper Systems are an example of a GPS receiver capable of collecting real-time submeter data, which means that the Geode delivers submeter data with high precision. Additional information about Juniper Systems Geode can be found in the owner's manual.
- Bad-Elf is an external GPS unit that works in multiple platforms with a 1-meter resolution and submeter through post processing. Specifications can be found in GNSS Surveyor User Guide.
- Trimble is a brand of equipment with integrated GPS systems capable of running applications to collect different types of feature classes such as points, lines, or polygons.
- Handheld data collectors are also capable of interacting with an external GPS to increase GPS resolution.

It is a good practice to sketch out site and sampling point intervals that can later be transferred to mapping software in the event the accuracy of the GPS is insufficient or as a backup.

GPS Unit Software

Geode Connect software for Geode2 units is currently CEC approved software. However, if a smart phone app is needed, NRCS staff need to submit an OCIO help ticket and request for support to obtain the software.

Trimble units have SD cards that support shapefile transfer of points taken. Data may also be transferred by microUSB and, in the case of old units, by the use of Mobile Device Center. A BitLocker exemption for GPS or camera use of USB or SD cards should be requested through OCIO since these units do NOT support encryption on the device.

Appendix F: Uses and Correlation with Geophysical Instruments

Electromagnetic Induction (EMI) is a nondestructive geophysical method for data collection using a magnetic field to identify soil anomalies. This method works by sending a magnetic field that penetrates the soil and then generates a secondary magnetic field when it encounters a soil anomaly or objects buried in the ground. This secondary magnetic field is recorded by the EMI instrument data collector and used to generate soil interpretations. Some of the soil anomalies could be the result of an increase of metal concentrations in the soil in a localized area.

The implementation of rapid, cost-effective, and accurate methods and field tools to measure trace elements in urban areas have been increasing and improving over the years. Some of the benefits of using EMI is that in-phase and quadrature measurements are collected simultaneously. Hrouda et al. (2013) also mention the benefit of analysis that could be conducted for metal and nonmetal. The use of pXRF is a proven and reliable tool for total elemental concentration data collection, but it could be time-consuming in large areas if a highly detailed sampling grid is established. However, a combination of pXRF and EMI data collection will increase performance in trace elements data analysis interpretation reducing data collection time. A case study conducted in three urban agriculture sites in New Jersey showed the potential of integrating these two tools for urban agriculture. However, more study is necessary to include other parameters, such as elemental interference, and possible differences between artifactic and combustic anthropogenic soil material (Muniz, 2023).

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Appendix G: Frequently Asked Questions

Q: What is pXRF, and how does it work?

A: Portable x-ray fluorescence (pXRF) spectrometry equipment is used to identify the elemental concentration of a material. It identifies elements and quantifies the amount present of those elements. Each element is defined by its characteristic x-ray emission wavelength or energy. The amount of an element present is determined by measuring the amount of energy emitted by the element.

Q: What is the accuracy and precision of the pXRF?

A: Accuracy and precision vary among equipment manufacturers. Also, elemental interference can affect accuracy and precision. However, some manufacturers mention that interference could be reduced by calibration for a specific element. In a comparability assessment the EPA conducted between laboratory analysis and six pXRF equipment sets showed an excellent r2 value from 0.80 to 0.99 for arsenic, copper, lead, and zinc. In the case of barium and chromium, the use of a user factor to match laboratory data is recommended (EPA, 2007).

Q: What are the potential uses and benefits?

A: The pXRF data can be correlated to pedogenic processes, such as argillic horizon or discontinuity in parent material, atmospheric deposition in natural and anthropogenic soils, trace element composition in anthropogenic soils, and urban agriculture.

Q: Does data collected from the pXRF replace laboratory run data methods?

A: Even though the EPA provides a methodology for in situ use of pXRF (Method 6200-Field Portable X-Ray Fluorescence Spectrometry for the Determination of Elemental Concentrations in Soil and Sediment), in urban environments as well as in many other environments, soil material is highly variable. The use of pXRF should be considered a soil screening method and not used as an alternative to soil analysis conducted at a certified soil laboratory.

Q: Who can operate the pXRF? Do you need special training, certificates, or licensing to operate?

A: Within the USDA, pXRF operators must be registered and certified by the OHS-RSD. The RSD is the operational radiation safety office for all of the USDA. It implements policies and procedures established by the USDA Radiation Safety Committee to ensure the safe acquisition, use, and disposal of ionizing radiation sources within the USDA.

Q: Does the pXRF equipment need to be registered?

A: In addition to registering the equipment with the RSD, the operator must review local regulations. Most states require some form of registration. Generally, they require the registration to be received within 30 days of receipt of the system.

Q: How does a participant request a pXRF soil screening?

A: Request varies by state. The request could be a direct contact with the pXRF operator by a local organization or through a technical soil service request submitted to the NRCS field office, NRCS urban conservationist, or others. The operator should follow the state's standard operating procedure, if available, for technical assistance.

Q: How do you store and transport pXRF equipment?

A: NRCS staff must follow RSD procedures for storage and transportation of equipment. Non-NRCS staff must follow local procedures.

Q: What types of sites can the pXRF be used to collect data? Are there sites where NRCS staff should not provide technical assistance?

A: The pXRF is intended to be used at any site where technical soil services are requested in accordance with the NRCS mission. Operators must not expose themselves to any unsafe conditions or areas known to be highly polluted, also known as superfund sites.

Q: What are the radiation and safety risks?

A: Maximum exposure for an operator's hand, at the trigger, is less than 1µSv/h, and an annual exposure to a hand is less than 2mSv. The radiation intensity in radiation dose to the body per hour is µSv/h, and mSv is unit of measurement of radiation dose. Maximum exposure under the International Commission on Radiological Protection (ICRP) regulations is 500 mSv for radiation workers and 50 mSv for the general public. Exposure to the operator's torso is so low it cannot be measured. To be conservative, the equipment operator uses half the value as the trigger, less than 0.5µSv/h. The annual exposure described above is then estimated at less than 1 mSv. Maximum exposure allowed for radiation workers is 20 mSv (1 mSv for general public) under ICRP.

Reference

U.S. Environmental Protection Agency. (2007). *SW-846 test method 6200: Field portable x-ray fluorescence spectrometry for the determination of elemental concentrations in soil and sediment*.