

Environmental Security Technology Certification Program

ESTCP

Using the VSP-UXO Modules to Support Site Characterization

ESTCP Project # 200325



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1. Introduction

The Environmental Security Technology Certification Program (ESTCP) and Strategic Environmental Research and Development Program (SERDP) have funded the development and implementation of statistical site characterization protocols for sites potentially contaminated with unexploded ordnance (UXO). These site characterization protocols are focused on the identification and delineation of potential target areas occurring at a site using limited amounts of geophysical transect data. Developments over the past several years include approaches for transect design, target identification and boundary delineation, and geophysical anomaly density mapping.

These design and analysis tools have been implemented in the Visual Sample Plan (VSP) software. VSP is a statistics-based environmental and threat contamination sampling software tool with an easy-to-use visual interface that provides users who are not experts in the field of statistics the ability to obtain a specified amount of data quality based on the required objectives for the site (commonly called data quality objectives [DQO]). For a more detailed description of the additional sampling designs and functionality of VSP see Matzke (2007). This free software can be downloaded from the VSP website at <http://dgo.pnl.gov>.

This report summarizes the basis for and implementation of the analyses in VSP to meet four sampling goals considered to be priorities during characterization of a potential UXO site. These four goals are 1) transect design to ensure that target areas of concern are identified with a prescribed confidence level, 2) flagging of potential target areas along the transects obtained at the site, 3) mapping of the estimated anomaly density at all locations across the site based on the transect data and the model of spatial variation derived from those data, and 4) delineation of the target boundary from the anomaly density maps. These four sampling and analysis goals are attained within VSP using the dialogues found under “**Sampling Goals > Find UXO Target Areas**” as shown in Figure 1. These goals and the mechanics of achieving them in VSP are discussed in this report. In addition to these four priority goals, a fifth goal of assessing the probability of traversing a target area after the data collection is complete is also discussed in this report. The different topics and the report sections in which they are discussed are listed below:

- Transect spacing needed to locate a UXO target area (Section 2)
- Locating and marking UXO target areas intersected by transects based on elevated anomaly density (Section 3)
- Geostatistical mapping of anomaly density across site area (Section 4)
- Delineation of target area boundaries (Section 5)
- Assessing probability of target area traversal based on actual transect pattern (Section 6).

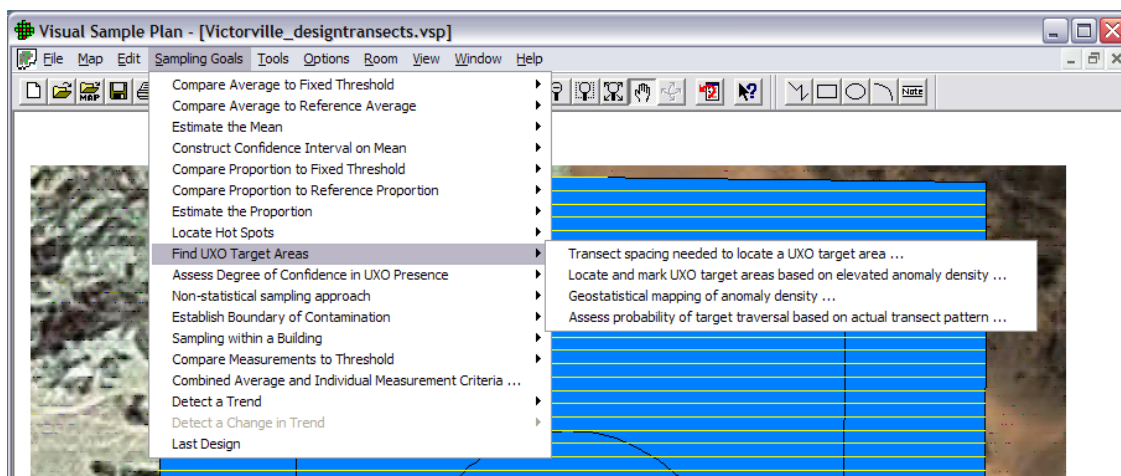


Figure 1. Image of VSP “Sampling Goals” menu structure and the sub-menu for “Find UXO Target Areas.”

2. Transect Design Approach

VSP provides the user with two methods for creating a transect design to meet desired DQOs. The “Traversal” design (see Section 2.5) can demonstrate a specified probability that at least one transect will traverse a target area of a specified size and shape. The other design, “Traversal and Detection” (see Section 2.6) demonstrates a specified probability that a target area of a defined shape, size, and density will be traversed and detected with a specific transect design and assumed background density. In addition to these two methods, the user can manually place transects within a sample area- the “Manual” method (see Section 2.7). All three of these methods are contained within the “Transect spacing needed to locate a UXO target area” dialog.

Table 1 lists the variables that can be adjusted in this dialog and identifies which transect design method uses the variable. The three different methods are identified as Traversal, Traversal and Detection, and Manual in this table. The “additional information” column provides general information about the variable. Each of these variables will be described in more detail in the following sections. The first four variables listed in the table (Transect Pattern, Transect Width, Target Area Shape, Target Area Orientation) are generally defined by the survey equipment and the specific site use. The design objective selected will determine the importance of the remaining variables. The design objectives are specifically stated in VSP as “Ensure High Probability of Traversal Only” (Traversal), “Ensure High Probability of Traversal and Detection” (traversal and detection), and “Manual Transect Spacing” (manual).

Of the three transect design methods, the traversal and detection design objective provides the most valuable information about the specific transect design selected. However, as Table 1 shows, it requires knowledge and input for many more variables than the other two. The traversal design guarantees that the assumed target area will have a specified probability of being traversed but falls short of any estimate that the target area will actually be identified.

Table 1. Variables that can be adjusted in the “Transect spacing needed to locate a UXO target area” design dialog with selected additional information about the variable and if the variable is used in one of the three transect design methods.

Variable	Additional Information	Traversal	Traversal and Detection	Manual
Transect Pattern	Select from Parallel, Square, Rectangular designs	x	x	x
Transect Width	Enter value in meters, feet, or inches	x	x	x
Target Area Shape	select from area, length of axes, shape	x	x	
Target Area Orientation	select random or enter known degrees	x	x	
Required Probability of Traversing Target	Enter value between 50 and 100.	x		
Transect Spacing	Enter value in units defined by the map in use.			x
Starting location	Select from random or fixed X,Y location on the map			x
Background Density	Enter value in acres, hectares, or square feet, meters, inches, kilometers, or miles		x	
Background Decision Rule	Stated in terms of percent confident density > bkg		x	
Instrument False Negative Rate	Enter any value between 50 and 99.99		x	
Proposed Evaluation Transect Spacing	Input the minimum and maximum transect spacing in the same units as the map.		x	
Target Area density (above background) range	Input the minimum and maximum density in the same units as background density		x	
Target Area density above background	Enter value in same units as background density.		x	
Target Area Density Distribution	Uniform or bivariate normal		x	
Density Input	Only used for the bivariate normal target area density distribution. Select outer edge, center, or average of the target area.		x	
Minimum Precision	A proportion between 0.05 and 0.20		x	
Maximum Error	A proportion between 0.005 and 0.10.		x	
Search Window diameter	Enter value in units defined by the map in use.		x	

2.1. Building the Conceptual Site Model

A conceptual site model (CSM) is a basic description of how the site was used and the possible contaminants which could be in the system. The CSM identifies essential information about the site and provides an essential framework for assessing risks from contaminants. Often the most difficult part, or at least the most important part, of the final transect design for a specific site is reaching consensus on the size, shape, and overall density of the target area of interest. Often, this information can be obtained from archive search reports (ASR), previous Conceptual Site Models (CSM's), other previous studies, current imagery (i.e., lidar, orthophotography), and site experts. Even with all of this information, there still can be uncertainties about proper design assumptions.

As with any environmental work, it is important that all interested parties agree to the assumptions of the current CSM. Even when information necessary to make the “best” decision is missing, there is often enough information to make a conservative decision to which all parties can agree.

2.2. Map design and data import

The user can import previously made DXF or SHP files to create the appropriate sample areas or use the tools within VSP to manually draw sample areas. In addition to creating interactive sample areas, background images can be imported into VSP. Figure 2 provides an example of a VSP project with a background image behind the defined sample area. The VSP user's manual contains a more detailed description of how to use these and all the other map design tools (Matzke, 2007).

Load map from file

Figure 3 shows the VSP dialog obtained by following the menu structure “**Map > Load Map from File.**” This is the method used to open any SHP or DXF file in VSP. VSP will open a SHP file without the associated DBF, SHX, AUX, or PRJ files. If there is an associated PRJ file then VSP will automatically load the units for the opened SHP file. If the PRJ file is missing, the “Map Settings” dialog (Figure 4), found under “**Map > Map Settings,**” allows the user to manually set the map units.

Background picture

Through the menu structure “**Map > Background Picture > Load from File,**” a JPG image file can be loaded. After an image is loaded into a VSP project, users can manually georeference the image by using “Calibrate with Map” and following the instructions shown Figure 4. If the loaded JPG file has an associated world file (JGW), selecting “**Map > Background Picture > Load World File**” from the menu structure will allow the selection of the matching world file and automatically georeference the previously loaded image file.

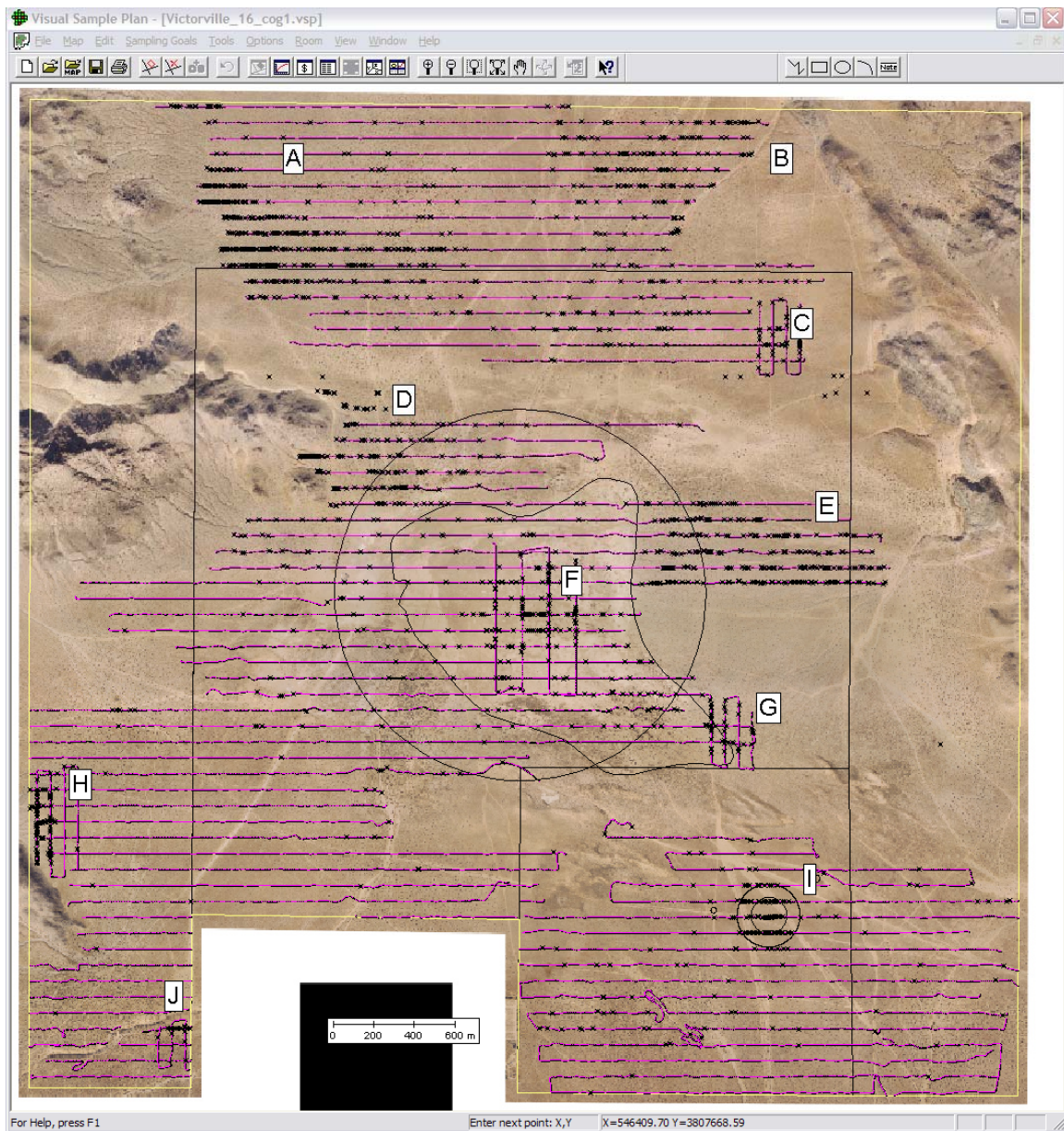


Figure 2 Example of a background image used with a VSP project. This is the Victorville, California site discussed in Sections 3.2.2 and 3.2.3.

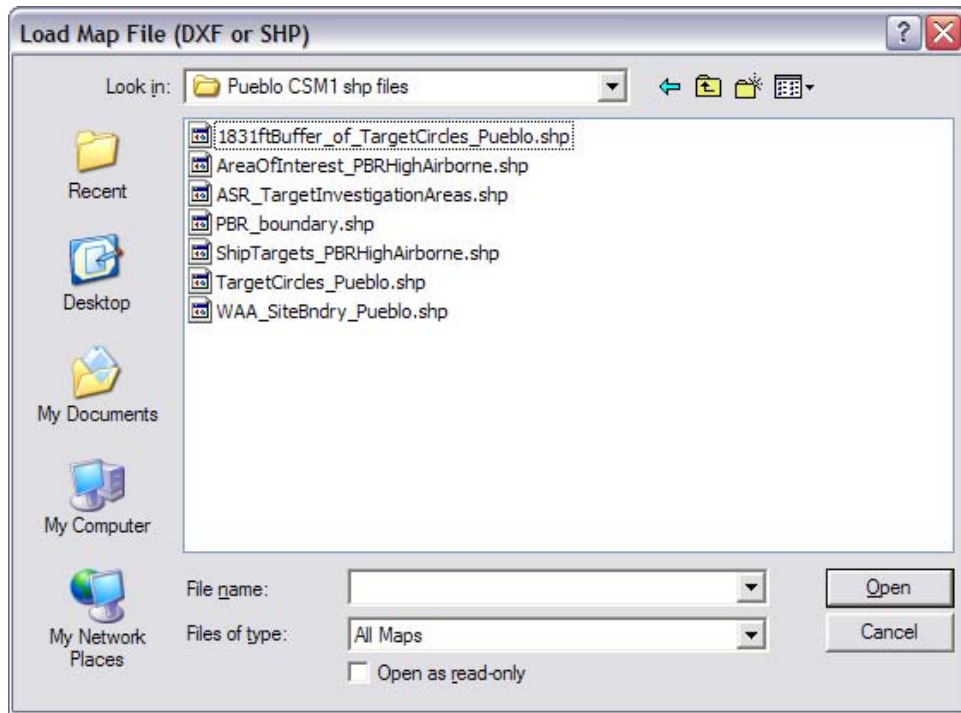


Figure 3. Menu to import SHP or DXF files. Found from the drop down menu “Map > Load Map from File.”

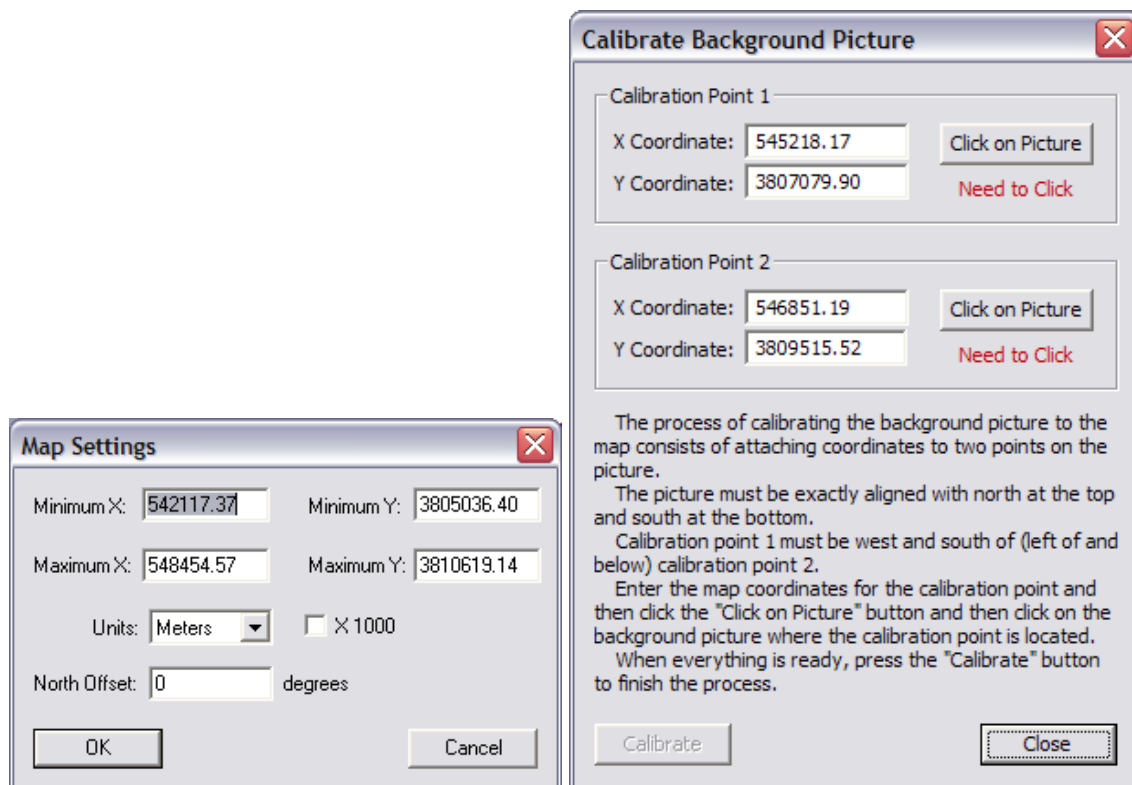


Figure 4. Map Settings dialog to manually alter the map in the current VSP project (left). Calibrate Background Picture dialog used in VSP to georeference a loaded JPG file (right).

2.3. Target Area Size, Shape, and Orientation

Before using many of the tools available with the transect design dialog the user must gather the current information from the CSM to identify the size, shape, and orientation of the target area of interest. Typically the information in the current CSM does not include the specific size, shape, and orientation to be used so that must be derived from the munition-use information provided. Currently, the typical information includes the different munitions used on the site, the number of years the site was used, and direction from which the munitions were fired. This information used in combination with information from munition-firing tables can be used to calculate the final size, shape, and orientation of the target area of interest. These tables are explained in various manuals and technical documents. Field Manuals 6-40 (U.S. Army 1996) and 7-90 (U.S. Army 1992) are two military manuals that contain information and examples used to create the information shown in Figure 5.

The Target Sizing Modeling Methods project funded by ESTCP (MM-0507) is developing functionality to allow a user to specify the munition of interest along with other input information to identify the size, shape, and orientation of target areas that result from indirect fire weapons. It is anticipated that the target sizing tools developed in that project will be integrated into VSP in the future.

The following discussion details how the target area is currently derived for use in VSP from the information in Field Manuals 6-40 (U.S. Army 1996) and 7-90 (U.S. Army 1992). These manuals detail how the shells from a single gun will tend to deviate around the specific target (dispersion rectangle) as well as the distance fragments will travel from the point of impact for each of the shells (fragmentation range). Figure 5 shows how these two inputs are used to derive the final target area size and shape.

Fragmentation range radius

Figure 5 shows the assumed fragmentation range of a single exploded munition as the pink circle in the upper right. For any specific munition, the fragmentation range estimates can vary quite a bit. Some tables report small radii values that identify the range at which lethal damage would occur while other tables report the much larger radii values based on the maximum distance fragments could fall from the impact point. The optimal fragmentation range radius will fall between these values and requires agreement among all involved in the site characterization effort.

Dispersion rectangle and probable errors

The center of the dispersion rectangle (green box of grids shown in the upper left of Figure 5) is the specific target at which the munitions are fired. The points of impact of the projectiles will be scattered both in deflection and in range. Dispersion is caused by inherent (systemic) errors. It should never be confused with round-to-round variations caused by either human or constant errors. This rectangular shape of the box represents the two types of probable errors: 1) range probable error and 2) deflection probable error.

From the definition of probable error, 50 percent of all rounds will impact within one probable error in range or deflection of the mean point of impact (25 percent over and 25 percent short or 25 percent left and 25 percent right), the grids in this dispersion rectangle are derived. Moving out four probable errors (the entire box of grids) will contain all the impact points when the munitions are fired at the target. For a more detailed discussion of range and deflection probable error see Field Manual 6-40 (U.S. Army 1996).

Target area size and shape

The final target area size and shape represents the merging of this information as the bottom ellipse shows in Figure 5. This figure provides an example of one possible munition. Often, the fragment dispersion radius is the primary driver of the final target area size as it is usually much larger than the impact zone. Conservative estimates of the final target area are usually circular with the radius of the circle resulting from the semi-minor axis of the ellipse derived from the process shown in Figure 5.

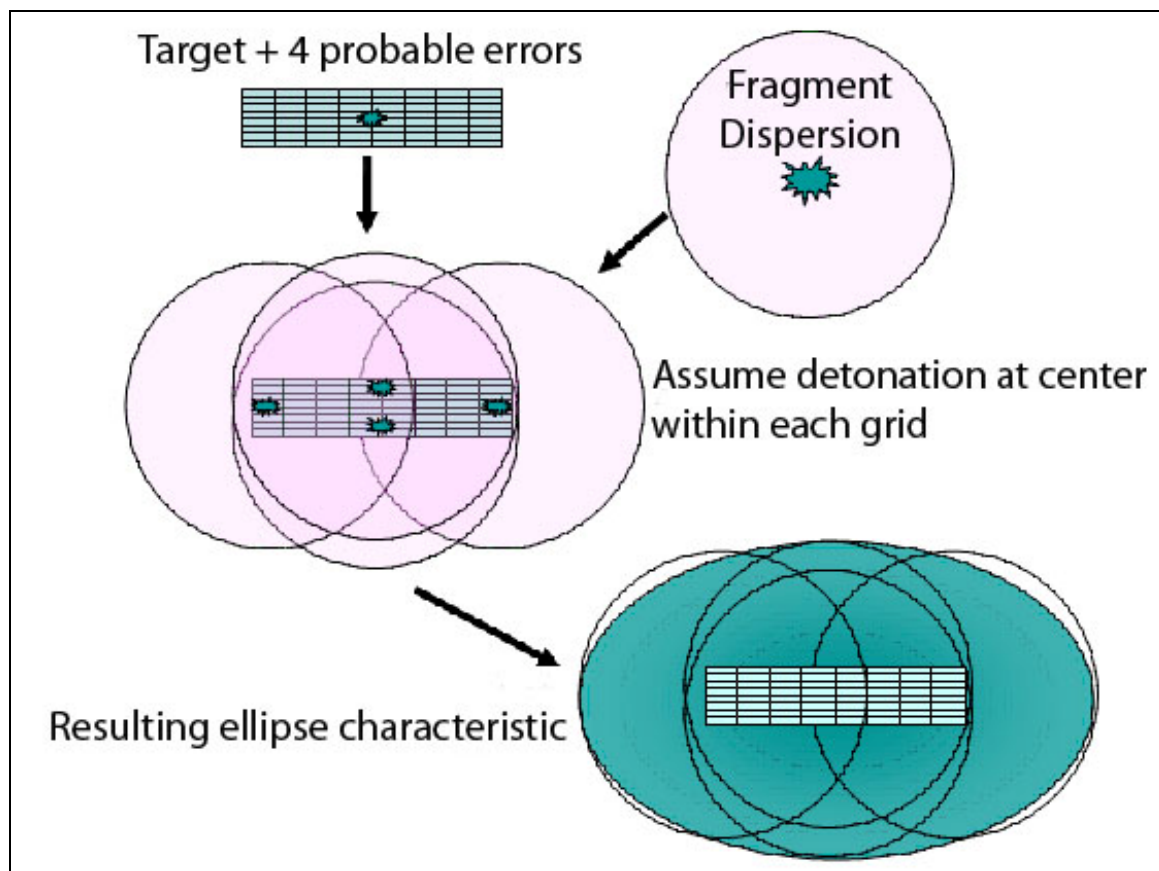


Figure 5. Diagram of the process of identifying the target area size and shape for a specific munition.

Survey and target area pattern tab

The “Survey & Target Area Pattern” tab from the “Transect spacing needed to locate a UXO target area” dialog, shown in Figure 6, lets the user input the target area

information in a few different methods. The user must identify the total area of the target area or the length of the semi-major axis and either the length of the semi-minor axis or the shape of the oval. As Figure 6 shows, two of the options (“Area of Target Area” and “Length of Semi-Minor Axis”), which are not selected, cannot be manipulated; however, VSP does report the actual values based on the other two selected values (“Length of Semi-Major Axis” and “Shape”).

Figure 6. The “Survey & Target Area Pattern” tab located within the “Transect spacing needed to locate a UXO target area” design dialog.

Target area orientation

When the identified target area is not a circle, the angle of orientation between the target area major axis and the transect orientation on the map can be defined or marked as random in the “Angle between Major Axis and Transects” box. The orientation of the target area is derived from knowing the target location and the direction from which the target was fired upon. The random option is selected when the orientation of firing point to target area is unknown. The orientation of the surveyed transects to target areas, which have a strong elliptical shape, can have a significant impact on the final transect design. This relationship is discussed further in the next section.

2.4. Selecting a Transect Pattern, Width, and Orientation

Figure 6 also shows the “Transect Pattern” options box that can be selected and the input where the transect width can be entered. Transects can follow a parallel, square, or rectangular pattern. As these options are selected, the dialog shows an image of the transect pattern next to the transect inputs.

Transect pattern

Typically, the parallel transect pattern has been preferred for circular target areas, but the square and rectangular transect patterns may be desired for different types of elliptical target areas. If the CSM does not identify a specific transect pattern, then any of the three patterns can be selected and evaluated for performance. Practical, site-specific considerations of transect collection will also impact the transect pattern selection.

Transect width

The transect width can be entered in the units of feet, meters, or inches and can be any value chosen by the user. The transect width is a function of the footprint of the equipment being used on the site and is usually set to the width of the equipment footprint.

Transect orientation

By selecting “**Edit > Sample Areas > Set Grid Angle,**” the orientation of transects on the map can be changed. After this option is selected, the user must click on the map and draw a straight line representing the transects orientation on the site.

The orientation of transects is an important input if the target area is elliptical and the orientation of the major axis of the target area is known. The final impact of knowing the orientation of the target area with respect to the transects is dependent on many other inputs and should be evaluated in relationship to the finalized inputs selected for a specific design.

2.5. Ensure High Probability of Traversal Transect Design

The “Required Probability of Traversing Target” variable is the only probabilistic input required to obtain a specified transect design if the “Ensure high probability of traversal only” design objective is selected on the “Transect Spacing” tab (see Figure 7). The red text shown in Figure 7 summarizes the resulting transect spacing based on the inputs. This text used the information from Figure 6 and Figure 7 and says, “If 1-meter-wide transects with a parallel pattern are spaced 60.96 m between transects (61.96 m on centers) over the entire site, these transects will traverse any 200-ft-diameter (60.96 m) circular target area 100 percent of the time.” For a more technical explanation of how these calculations are performed see Gilbert (2001).

If the only objective of the transect design is to ensure a high probability of traversal the required probability entered is usually 100 percent. Other values as low as 50 percent can be entered if desired by the user. The specified transect spacing will be applied to the entire map if the “OK” or “Apply” buttons are pressed. In addition, a summary of the transect design and the associated inputs will be created in the report view of VSP (see Section 2.8).

If traversal is the only design objective and an elliptical target area with a known orientation is assumed, then orienting the transects to be perpendicular to the semi-major axis will require fewer transects over the site.

The “target detection performance” information box which falls below the DQO design statement in Figure 7 is not required for this design objective. This information is there to provide the user with the ability to evaluate detection performance with different inputs based on the selected transect spacing. The details of the “Target Detection Performance” box are explained in Section 2.6.

The screenshot shows a software dialog box titled "Transect Spacing Needed to Locate a UXO Target Area". It has three tabs: "Survey & Target Area Pattern", "Transect Spacing" (which is selected), and "Costs".

Under the "Transect Spacing" tab, the "Design Objective" is set to "Ensure high probability of traversal only". Below this, the "Required Probability of Traversing Target" is set to "100.00 %". A red text box provides a summary: "If 1 meter wide transects with a parallel pattern are spaced 60.96 meters between transects (61.96 meters on centers) over the entire site, these transects will traverse any 200 foot diameter (100 foot radius) circular target area 100% of the time."

The "Target Detection Performance" section contains several input fields: "Background Density" is set to "8" per "Acre"; "Decision Rule" is "Flag if at least 95.00 % confident density > bkg"; "Instrument False Negative Rate" is "10.00 %"; and "Target Area Density Evaluation Range" has "Min: 10" and "Max: 200" per acre.

Below these fields are two buttons: "Create Graph" and "Graph Options". A checkbox labeled "Graph additional detection curves (will slow graphing process)" is currently unchecked.

At the bottom of the dialog box are four buttons: "OK", "Cancel", "Apply", and "Help".

Figure 7. “Transect Spacing” tab view when the design objective “Ensure high probability of traversal only” is selected.

2.6. Developing a Probability of Detection and Traversal Transect Design

The “Transect Spacing” tab when the design objective is “Ensure high probability of traversal and detection” is shown in Figure 8 (and subsequently in Figure 13). This design uses a Monte-Carlo simulation to identify the appropriate transect spacing and associated probability of detecting a specified target area. This design requires the user to identify more specific DQOs and provide more information about the conditions of the study area to be surveyed. Table 2 lists all of these associated variables and how they impact the simulation running time and the results which come from the simulation. Each variable has a recommended value and some additional information for improved understanding. For more detailed information about the variables and the simulation process see (Matzke 2006).

Figure 8 shows the design objective “Ensure high probability of traversal and detection” with the probability of detection selected to be a function of the transect spacing. When this option is selected, the final transect spacing is interactively selected from the target detection performance graph, and the resulting red text shown in Figure 8 summarizes the selected design objective based on the simulation parameters entered. These graphs represent the data from the Monte-Carlo simulation. The simulation then begins, and the graphs are created when the “Create Graph” button, shown in Figure 8, is pressed. The “Additional Parameters” dialog in Figure 8 automatically opens when the “Create Graph” or “Graph Options” buttons are selected. The “Additional Parameters” dialog provides the ability to adjust the remaining variables from Table 2 that are not shown in the “Transect Spacing” tab.

Transect Spacing Needed to Locate a UXO Target Area

Survey & Target Area Pattern | **Transect Spacing** | Costs

Design Objective: Ensure high probability of traversal and detection

Target Detection Performance

Background Density: 8 per Acre

Decision Rule: Flag if at least 95.00 % confident density > bkg

Instrument False Negative Rate: 0.00 %

Transect spacing evaluation range: Min: 10 Max: 200 meters

Expected Target Area Density Above Background: 85 per acre

Graph Transect Spacing vs. Probability of Detection

Create Graph Graph Options

☐ Graph additional detection curves (will slow graphing process)

Selected Transect Spacing: 52.8889 meters

Create Graph and select a spacing from the resulting graph

If 1 meter wide transects with a parallel pattern are spaced 52.8889 meters between transects (53.8889 meters on centers) over the entire site, these transects have an approximately 95% chance of traversing and detecting any 200 foot diameter (100 foot radius) circular target area having a bivariate normal distribution with an outer edge density of 85 anomalies per acre above the background density of 8 anomalies per acre. This assumes the instrument false negative rate is 0% and flagged windows have at least 95% confidence they have density greater than background.

OK Cancel Apply Help

Figure 8. “Transect Spacing” tab when the “Ensure high probability of traversal and detection” design objective is selected and the “Transect spacing evaluation range” is selected.

Table 2. Variables which are used with the probability of traversal and detection design simulation. The variables are listed along with additional information about how these variables affect the running time of the simulation and the results obtained from the simulation.

Variable	Input Values and Options	Recommended Values	Effects on Simulation Running time	Effects on Transect Design and Probability of Detections	Additional Notes
Background Density	Enter value in units per acre, hectare, or square feet, meters, inches, kilometers, or miles.	The background density expected on the site. This can often be estimated by initial geophysical transects conducted in areas with no prior munitions use.	Large background densities increase the simulation time and small background values decrease it.	The larger the background density the harder it is to identify any target areas.	The background density and Target Area density above background variables are dependent on each other for a specific transect spacing. In many scenarios the ratio of Target Area density to Background density is important to keep in mind.
Background Decision Rule	Stated in terms of percent confident that density > bkg. Enter any value between 50 and 99.99.	More than 95 percent.	Higher background decision rule values require longer run times.	As the background decision rule moves from 99.99 percent to 50 percent, the specific transect design will have a higher probability of detecting the target area, but a lot of these detections may just be a result of finding an unusually high background density.	The value that will require the tightest transect spacing (conservative) with all the other variables remaining constant is 99.99 percent.
Instrument False Negative Rate	Enter any value between 50 and 99.99.	0	Generally, no effect on the simulation process.	The larger the false negative rate, the harder it is to identify any target areas.	The false negative rate is used in the simulation to quantify how well anomalies are found. A value of 10 percent would remove 10 percent of the anomalies from each simulated site before the window calculations are performed.

Variable	Input Values and Options	Recommended Values	Effects on Simulation Running time	Effects on Transect Design and Probability of Detections	Additional Notes
Target area density (above background) range	Input the minimum and maximum density in the same units as background density.	The target area densities expected on the site.	Generally, a wider range increases the simulation time and a smaller range decreases it.	No effect on the transect design.	The simulation procedure uses the minimum and maximum values entered. The number of other simulated target area density values along the curve varies for each range.
Proposed Evaluation Transect Spacing	Input the minimum and maximum transect spacing in the same units as the map.	Varies, no less than 0.25 or greater than 1.25 of the target area diameter.	Generally, a wider range increases the simulation time and a smaller range decreases it.	No effect on the transect design.	The simulation procedure uses the minimum and maximum values entered. The number of other simulated transect spacing values along the curve varies for each range.
Target Area Density Above Background	Enter value in same units as background density.	The expected density of the target area of interest.	The effect varies depending on the combination of the other variables.	Higher densities are easier to detect with any given transect spacing and background density.	Make sure the appropriate target area density distribution is selected for the value input. In many scenarios the ratio of target area density to background density is important to keep in mind.
Target Area Density Distribution	Uniform or bivariate normal	Bivariate normal	The effect varies depending on the combination of the other variables. Generally, the choice of the uniform distribution runs faster than selecting the bivariate normal distribution.	This interacts heavily with the transect spacing. The bivariate normal density target areas are detected more easily when the transect spacing is tight (transects have a higher chance of traversing the high density center). But in general, Uniform density target areas are easier to find.	Generally, the default value of using the bivariate normal distribution is the proper choice.

Variable	Input Values and Options	Recommended Values	Effects on Simulation Running time	Effects on Transect Design and Probability of Detections	Additional Notes
Density Input	Only used for the “Bivariate Normal Target Area Density Distribution” option. Select outer edge, center, or average of the target area.	Any choice is valid.	No effect on the simulation process.	No effect on the transect design.	Any of the three can be selected, but the target area density (above background) values should change as different inputs are selected.
Minimum Precision	A proportion between 0.01 and 0.20	Default value	A small minimum precision increases the simulation time while a large minimum precision decreases it.	A smaller minimum precision will simulate more points on the graph, and give more information on which to make a decision.	Increasing the minimum precision simulates fewer unique range values.
Maximum Error	A proportion between 0.005 and 0.1.	Default value	A small maximum error increases the simulation time while a large maximum error decreases it.	A smaller maximum error will increase the accuracy of points on the graph, and allow for better decisions.	A smaller maximum error requires more Monte-Carlo iterations at the specified range value.
Search Window diameter	Enter value in units defined by the map in use.	Default value	A larger window size typically makes the simulation faster.	See Section 3.2.1.	The default value is almost always the appropriate choice.

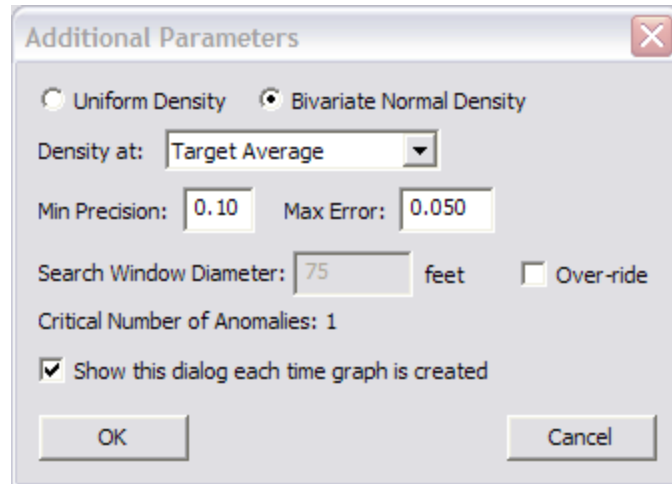


Figure 9. Additional simulation parameters that appears when “Graph Options” is selected from the “Graph Target Area Density vs. Probability of Detection” box.

Transect target detection performance graphs

Figures 10 and 11 show two transect target detection performance graphs. These graphs show the probability of detecting a 200-m-diameter target area with 2-m-wide transects. The graph in Figure 10 was produced assuming the target area anomalies are uniformly distributed, while the graph in Figure 11 was produced assuming the target area anomalies follow a bivariate normal distribution. Both graphs used all the default values from Table 2, 95 percent for the background decision rule, parallel transects, and 10 anomalies per acre (ApA) for the background density. Three different assumed target area densities are represented by the different color lines as labeled in the graphs. The red curve represents the target area (TA) density which was selected in the design dialogue. The other two curves are provided to show the sensitivity of the transect spacing based on different TA densities. Generally, the default option to model the bivariate normal distribution for the Target area densities is the most realistic choice (see Table 2 for additional information).

The vertical yellow line outlined in black in Figure 10 identifies the transect spacing which is equal to the size of the target area. As the transect spacing extends beyond the size of the target area the transect detection performance is heavily impacted by the reduction in the chances that the transects will even traverse the specified target area.

The probability of detection values shown in these graphs identify how often at least one region within a target area will have an average density significantly greater than the background density. Currently, the “false positive” detection performance (probability of identifying a target area that doesn’t actually exist) cannot be controlled by the user during the design process. The “false positive” detections can be managed during an actual analysis of the surveyed data (see Sections 3 through 5) by the use of the spatial clustering of high density areas to distinguish between “false positive” detections and actual high density areas on the site.

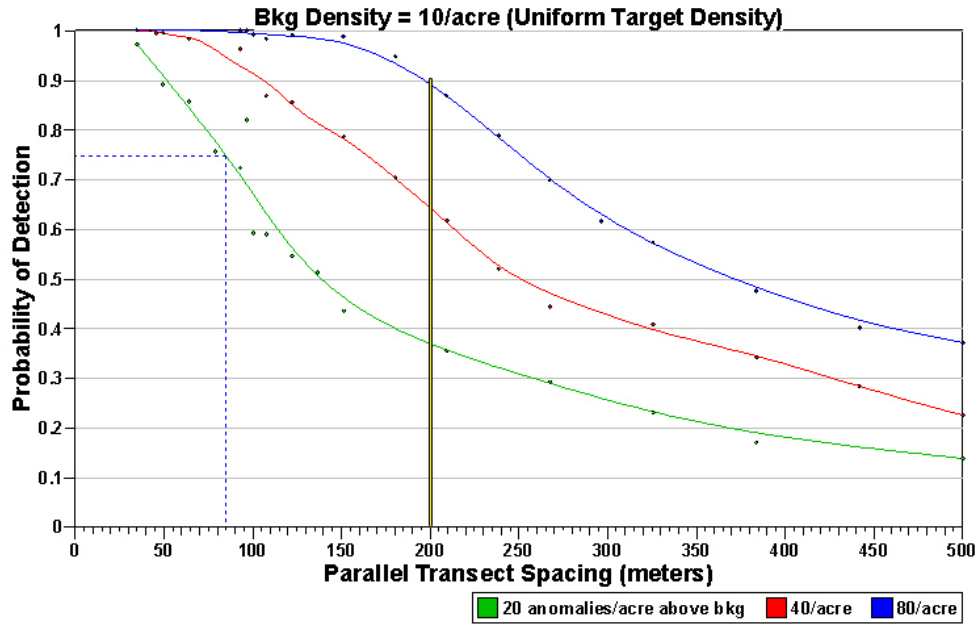


Figure 10. Target detection performance graph to detect a 200-m-diameter target area with 2-m-wide transects. This simulation used all the default values from Table 2, 95 percent for the background decision rule, parallel transects, 10 ApA for the background density, and a uniform target density. Three different assumed target area densities are represented by the different color lines as labeled in the graph.

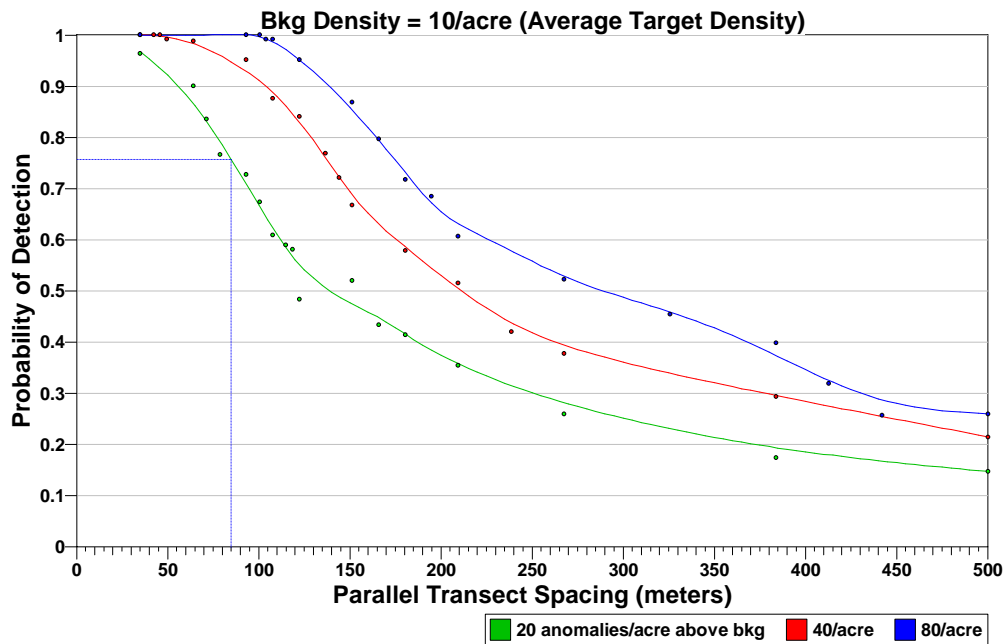


Figure 11. Target detection performance graph to detect a 200-m-diameter target area with 2-m-wide transects. This simulation used all the default values from Table 2, 95 percent for the background decision rule, parallel transects, 10 ApA for the background density, and a bivariate normal target density. Three different assumed average target area densities are represented by the different color lines as labeled in the graph.

Density target detection performance graphs

Figure 12 shows a density target detection performance graph when the probability of detection is a function of the target area density. The “Transect Spacing” tab associated with this target detection performance graph is shown in Figure 13. The transect spacing is an input that can be altered by the user, but defaults to the selected transect spacing from the previously run transect target detection performance graph. The density target detection performance graphs provide an improved understanding of the sensitivity of the selected transect spacing as a function of the TA density and allows the user to modify the specific data quality objectives stated in the dialog (see red text in Figure 8) based on this improved understanding.

These target detection performance graphs identify the performance of different transect spacing options and provide the ability to select an appropriate spacing based on the defined DQOs. Besides showing the performance of a particular design using a defined set of values for the variables in Table 2, the target detection performance graphs provide an efficient method to evaluate the sensitivity of different transect spacing options as compared to varied target area densities.

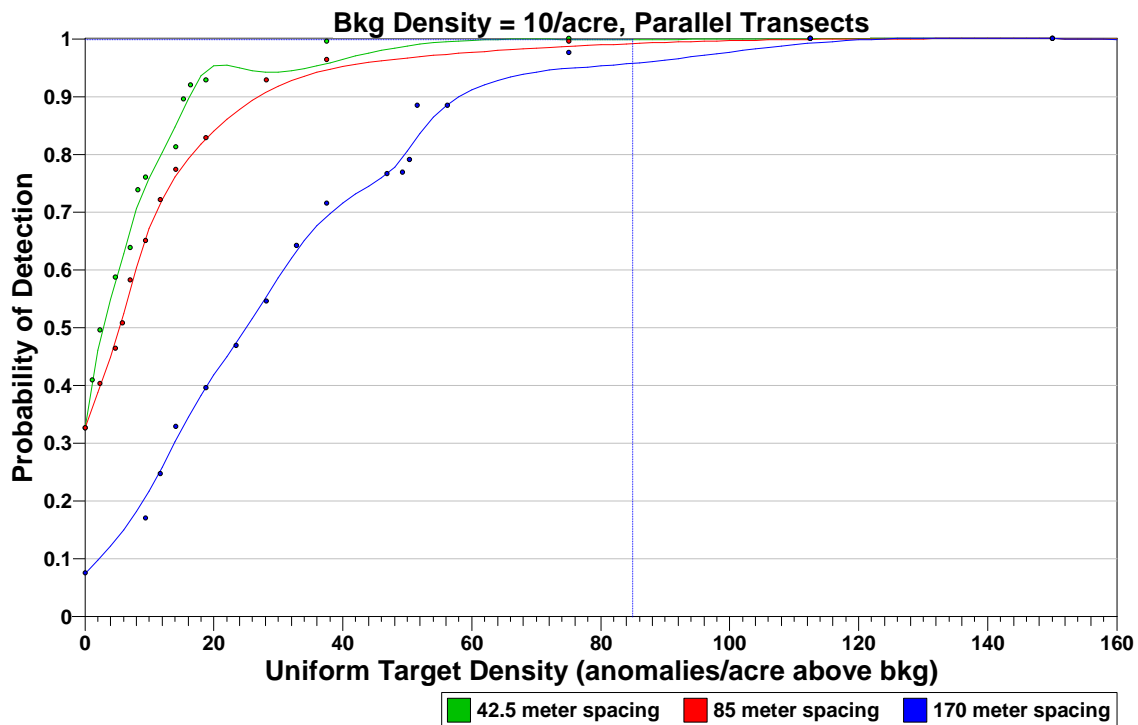


Figure 12. Target detection performance graph to detect a 200-m-diameter target area with 2-m-wide transects. This simulation used all the default values from Table 2, 95 percent for the background decision rule, parallel transects, 10 ApA for the background density, and a uniform target area density. Three different transect spacing options are represented by the different color lines as labeled in the graph.

The dialog box is titled "Transect Spacing Needed to Locate a UXO Target Area". It has three tabs: "Survey & Target Area Pattern", "Transect Spacing" (selected), and "Costs".

Design Objective: Ensure high probability of traversal and detection

Target Detection Performance

Background Density: 8 per Acre

Decision Rule: Flag if at least 95.00 % confident density > bkg

Instrument False Negative Rate: 0.00 %

TA density (above background) range Min: 8 Max: 32 per acre

Proposed Evaluation Transect Spacing: 52.8889 meters

Graph Target Area Density vs. Probability of Detection

Create Graph Graph Options

☐ Graph additional detection curves (will slow graphing process)

Selected Transect Spacing: 52.8889 meters

Create Graph and select a density from the resulting graph

If 1 meter wide transects with a parallel pattern are spaced 52.8889 meters between transects (53.8889 meters on centers) over the entire site, these transects have an approximately 88% chance of traversing and detecting any 200 foot diameter (100 foot radius) circular target area having a bivariate normal distribution with an outer edge density of 31.4901 anomalies per acre above the background density of 8 anomalies per acre. This assumes the instrument false negative rate is 0% and flagged windows have at least 95% confidence they have density greater than background.

OK Cancel Apply Help

Figure 13. “Transect Spacing” tab when the “Ensure high probability of traversal and detection” design objective is selected and the “Target area density (above background) range” is selected.

2.7. Manual Transect Design

As the term “manual transect spacing” implies in the design objective shown in Figure 14, this design does not rely on any statistical support for the transect design. This tool is in VSP to provide the user with the ability to use all the other features of this transect design module. The user must enter the desired transect spacing and choose if the first transect must pass through a specific X, Y coordinate or be randomly placed on the map. Typically, this option is used to augment an already existing transect design. As with the traversal only design objective, when this option is selected the “Target Detection Performance” information box is not necessary to create the specified design on the map. As was explained in Section 2.6, the “Target Detection Performance” information box does provide the user with the ability to evaluate detection performance with different inputs based on the selected transect spacing.

The dialog box is titled "Transect Spacing Needed to Locate a UXO Target Area". It has three tabs: "Survey & Target Area Pattern", "Transect Spacing" (selected), and "Costs".

Design Objective: **Manual transect spacing**

Transect Spacing: **60.96** meters (61.96 meters on centers)

Starting Location:

- ☐ X: **542802.4296** Y: **3805468.190**
- ☒ Random Start

Target Detection Performance:

Background Density: **8** per **Acre**

Decision Rule: Flag if at least **95.00** % confident density > bkg

Instrument False Negative Rate: **0.00** %

Target Area Density Evaluation Range: Min: **8** Max: **32** per acre

Graph Expected Target Area Density vs. Probability of Detection

☐ Graph additional detection curves (will slow graphing process)

Buttons: **OK** **Cancel** **Apply** **Help**

Figure 14. “Transect Spacing” tab when “Manual transect spacing” is selected as the design objective.

2.8. Using Transect Design Information in Reports and External Software

After a user has created and finalized a site transect design, the information within the VSP project file can be exported for use in external software or for use in reports. By selecting “**Map > Export > to SHP**” from the VSP menus and using the export dialog shown in Figure 15, all the map information shown on the map in Figure 16 can be exported using the ArcGIS SHP format. All the necessary files to use these SHP files with external GIS software are included when the SHP file is created.

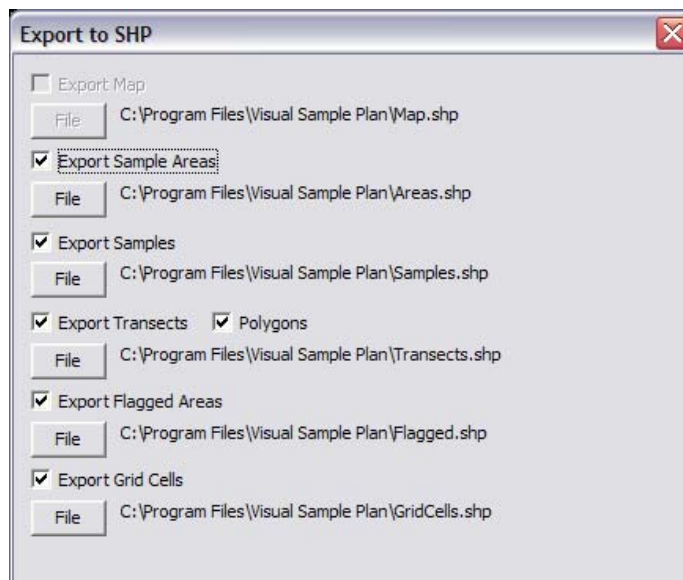


Figure 15. Export to SHP dialog found within VSP when the UXO dialogs have been used. This figure shows all the different information that can be exported for any of the UXO designs. VSP will open with marked boxes where information is present.

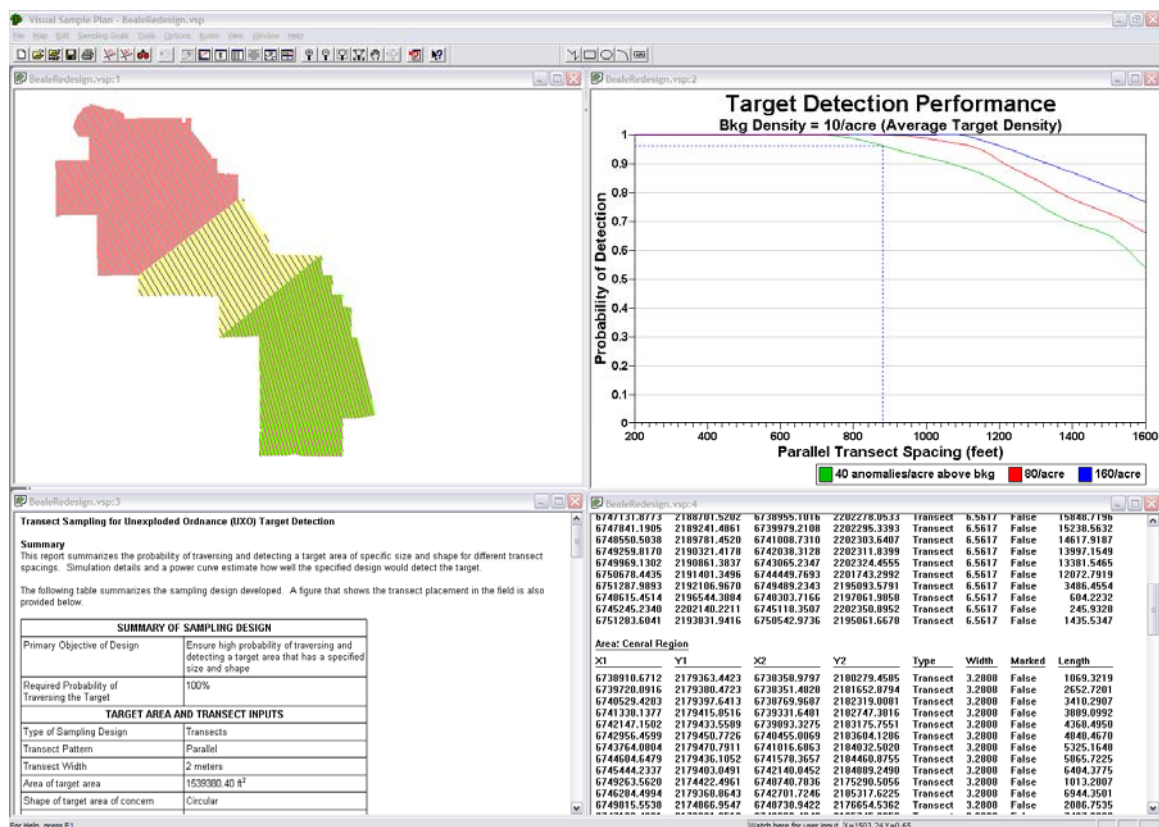


Figure 16. Quad view in VSP of the four primary views to display data from a specific VSP project file.

Figure 16 shows the four views VSP provides for a specific transect design project file. The upper left corner has a map of the site with transects based on a selected design. This specific map has three unique areas within one site. The munition use in each area was different and required unique designs. The lower left shows the report view that summarizes the variable settings used to create the most recent transect design and the statistical assumptions and algorithms used to create these designs. The graph in the upper right stores the most recent target detection performance graph generated from the “Transect spacing needed to locate a UXO target area” dialog. The lower right window summarizes the information of the specific transect locations on the site. The beginning and end points for each transect are listed with a summary of the width and length.

3. Target Area Identification Approach

Once a transect design has been accepted and the geophysical survey completed, the surveyed data (i.e., the transect course-over-ground and anomaly location data) is imported into VSP and analyzed. Section 3.1 details how these data can be imported and manipulated in VSP. Section 3.2 describes the methods used to evaluate the anomaly density distribution of the site and determine an appropriate critical density to identify high density areas within it. The information from this target area identification analysis in VSP can also be exported for use in reports or other software (see Section 7 for a detailed explanation).

3.1. Importing Course-Over-Ground and Anomaly Files into VSP

The data entry tab shown in Figure 17 provides the ability to import ASCII (plain text) files identifying the course over ground (COG) and anomalies (anomaly) data. Table 3 shows an example of the COG file (left) and anomaly file (right) structure used within VSP. Oasis Montaj can be used to generate COG and anomaly files like those shown in Table 3 (Geosoft, 2007). VSP can also import the COG and anomaly information if they are saved in common TXT and CSV formats. The two files shown in Table 3 show the most information that can be included in the file. At a minimum, the file to be imported must have two columns representing the X and Y coordinates in that order. The COG coordinates mark the X, Y location for the center of the survey equipment path. As the file does not provide transect width information, the user must obtain it from the survey team. The anomaly coordinates are locations where the survey team has identified an object of possible metallic origin.

Table 3. Example of ASCII files that can be imported into VSP for the course over ground transect data and the associated anomaly location data.

Example of COG file	Example of anomaly file
/ ----- / CSV EXPORT [06/22/2007] / DATABASE [.\07172015.gdb] / ----- / /X,Y,GPS_Time //Flight 0 //Date 2007/06/21 Random GGK 643636.04,4335445.66,76968.5 643638.10,4335446.86,76970.5 643641.17,4335449.01,76972.5 643643.34,4335451.14,76974.5 643645.11,4335453.27,76976.5 643646.96,4335455.55,76978.5 643648.91,4335457.71,76980.5 643650.77,4335459.62,76982.5 643652.71,4335461.39,76984.5 643654.58,4335463.04,76986.5 643656.47,4335464.60,76988.5 643658.61,4335466.29,76990.5	/ ----- / CSV EXPORT [06/22/2007] / DATABASE [.\07172015_anomaly.gdb] / ----- / /Fiducial,X,Y,Grid_value //Flight 0 //Date 2007/06/22 Random 07172015_Targets 0,643685.125,4335486.500,40.21 1,643803.250,4335587.000,84.87 2,643907.750,4335681.125,45.61 3,643918.875,4335707.000,1119.21 4,643948.250,4335742.875,83.94

Data entry tab

The data entry dialog in VSP provides the user with the ability to import and identify all the necessary files for analysis. Figure 17 shows this “Data Entry” tab that is included in the “Locate and mark UXO target areas based on elevated anomaly density” and “Geostatistical mapping of anomaly density” dialogs. The tab provides import, export, removal, and file summaries for the COG and anomaly files in two separate boxes. When importing COG information, the user is prompted to define the width of the transects in the file before it is imported. VSP provides a summary that includes the file name, number of lines imported, width of the transects, and the units associated with the transect width. The anomaly data is imported and summarized in a similar manner. The “Sel” column shown in each box provides a method to manipulate individual files. If the box is blank, the file is not selected. When the user enters a “T,” then the identified files can be removed or exported from the project. If the box is marked next to “Mark points that are outside Sample Areas,” then any points in an imported file that fall outside of the selected sample areas are shown as red lines. This feature helps the user identify locations where the survey went beyond the identified sample boundaries.

Data Entry | Statistics | Plots

Course Over Ground Data

Import Delete Selected Export Selected

ID	File	Num	Width	Units	Sel
1	all_COG_2m_Jun 28_1.txt	74444	2	meters	
2	all_COG_Jul 11_1.txt	18199	1	meters	

Anomaly Data

Import Delete Selected Export Selected

ID	File	Num	Sel
1	all_Jun 28_anomaly.txt	5778	
2	all_1m_Jul 11_anomaly.txt_Th15.5.txt	3580	

☐ Mark points that are outside Sample Areas

Figure 17. Data entry tab found within the “Find UXO target areas” dialog and “Geostatistical mapping of anomaly density” dialog.

3.2. Locating and Marking UXO Target Areas Based on Elevated Anomaly Density

After the sample area has been identified and the necessary files have been imported into VSP, the user can analyze the data. VSP provides two dialogs for analyzing the spatial data. This section details the dialog “Locate and Mark UXO Target Areas Based on Elevated Transect Anomaly Density” which identifies those locations within the transects that are identified as being high density (i.e., high number of anomalies within a specified amount of the surveyed transect area).

3.2.1. Selecting a Smoothing Window for Analysis

To identify high density areas along transects, VSP passes a window over segments of the site and calculates the anomaly density for each segment. The window diameter specifies the size of the circular area over which the average density is computed. Figure 18 shows where the window diameter is selected in this VSP analysis dialog. Figure 19 provides an example of how the window diameter is used to calculate transect grid densities. The window diameter defines the size of a centered circular window (orange and blue circles in Figure 19), which moves every one-sixth of the selected diameter and uses the anomaly count with the transect area within the window to calculate a density assigned to the central transect grid (orange and blue boxes in Figure 19) centered in the window. Each grid has dimensions of one-sixth the window diameter. The green dots in Figure 19 represent the identified anomalies within the two surveyed transects. This figure provides an example of two of the multiple transect grid densities which would be calculated on these transects.

The selection of an appropriate window diameter is dependent on the size of the target area of interest, transect width, and spacing between transects. The optimum window diameter is one which has sufficient traversed transect area within the window without including such a large area that potential high density areas can be masked by the surrounding low density areas in the window. The blue window in Figure 20 provides an example of a window that is too large. If the window diameter is too small (red window in Figure 20), then the limited amount of traversed transect area within the window is not sufficient to make accurate transect grid density estimates. Within these two extremes, there are often many different window diameters that would be appropriate. As a general rule, the window diameter should be less than the diameter of the target area of interest and no smaller than the spacing between the original transect design. Selecting the appropriate window diameter for each specific site analysis is currently left to the user.

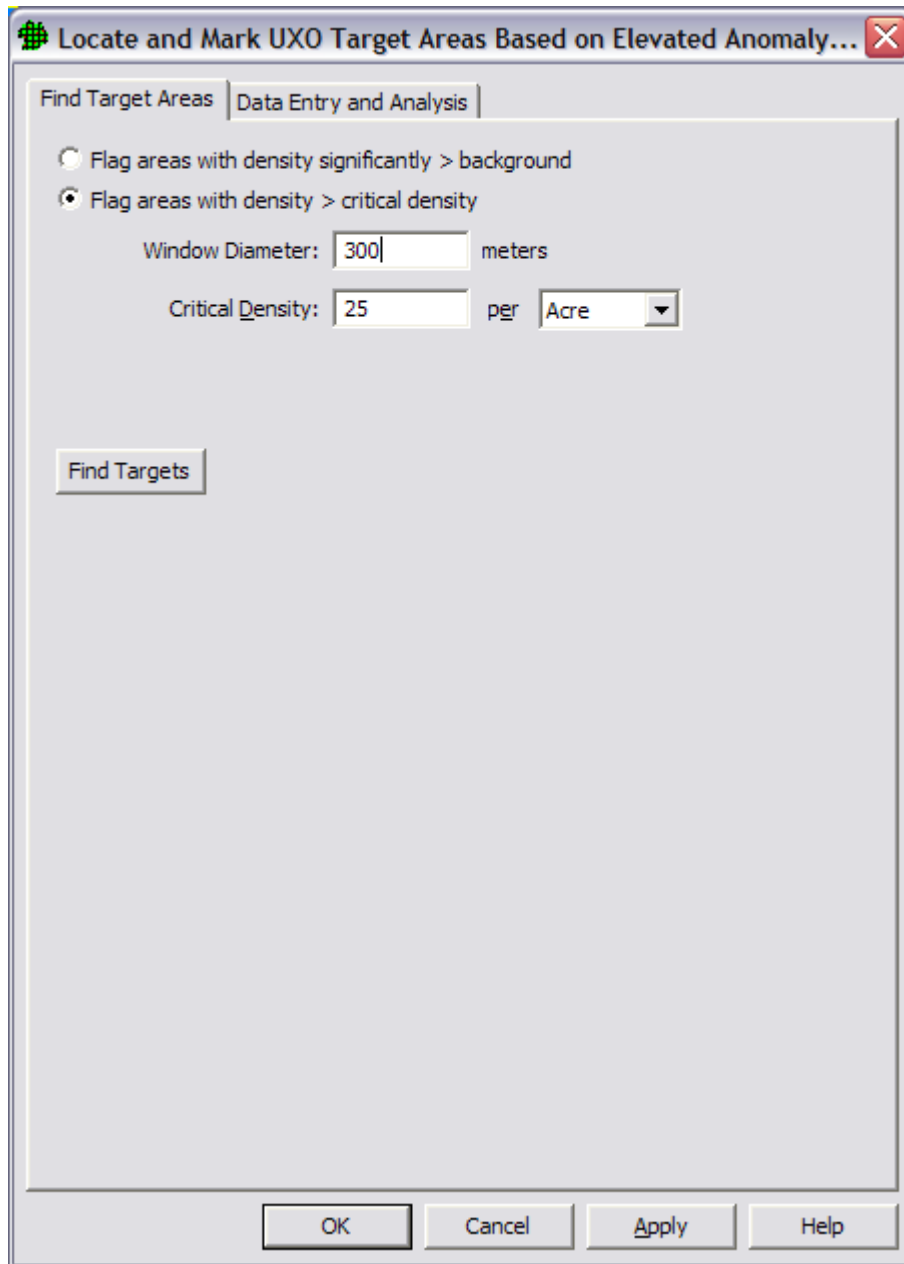


Figure 18. “Locate and Mark UXO Target Areas Based on Elevated Transect Anomaly Density” dialog where the window diameter is specified.

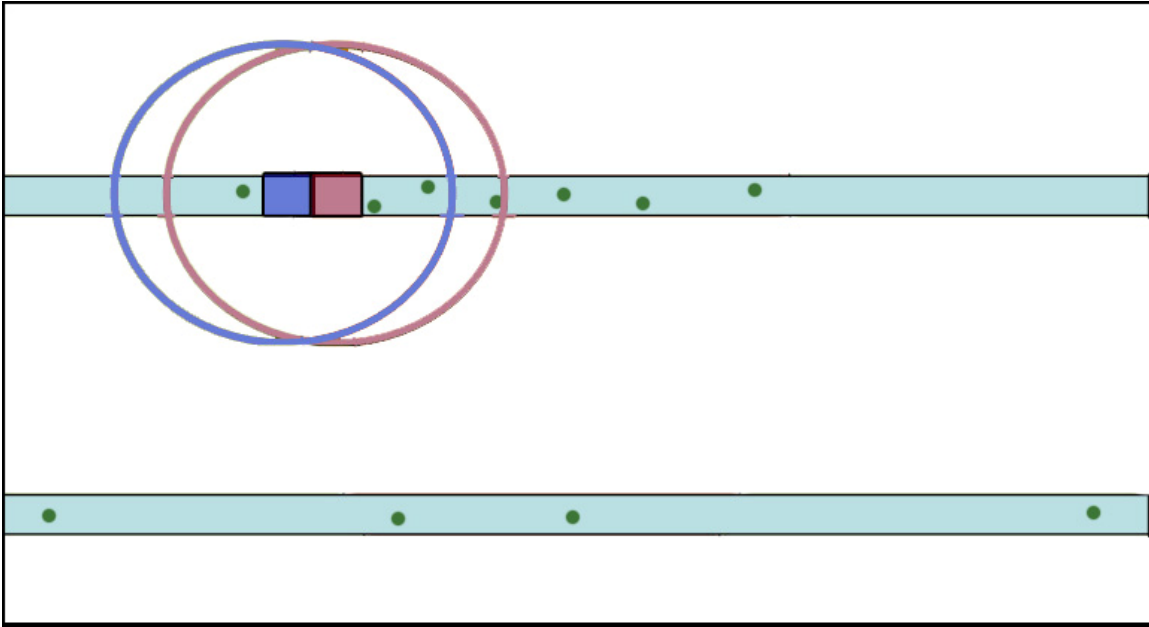


Figure 19. Depiction of the window density calculation process used in the process to identify high density regions within a site.

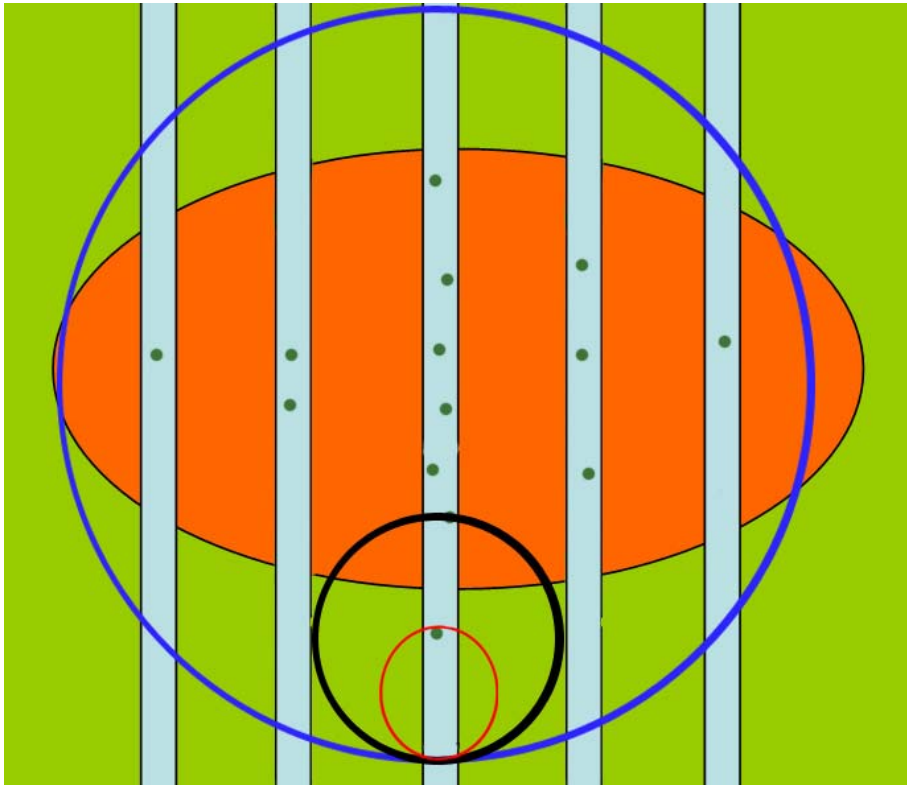


Figure 20. Example of different window sizes and how they would encompass the transects.

3.2.2. Evaluating the Anomaly Density Distribution of the Site

Using the moving window algorithms above, VSP provides a histogram of the anomaly densities across the site. In cases where the anomaly density distribution of the site is unknown and there is no reliable historical data to use as an estimate, a histogram of the density calculations for the entire site can provide a good understanding of the anomaly density distribution. These density calculations use the information from the transect grid densities (see Figure 19) but include an additional averaging computational routine to remove overlapping transect grid density values from the histogram. The primary purpose for this histogram is to help select a critical density above which areas will be flagged by distinguishing between high density target areas and lower density background values.

The three histograms in Figure 21 are shown to illustrate one way in which densities associated with background and densities associated with a potential target area appear when combined into one histogram. The top histogram shows an example of background densities with an average density of 15 ApA and standard deviation of 15 ApA. The red line marks the point below which 99 percent of the background densities lie, assuming a Gamma distribution for the background grid densities. The middle histogram shows a possible distribution of target area transect grid densities for an area which had an average density of 50 ApA and standard deviation of 10 ApA. The green line marks the point above which 99 percent of the densities lie when the distribution of target area densities follows a normal distribution. The bottom histogram combines the information from the other two histograms to show what would be seen when analyzing a site with these characteristics within VSP. The histograms in Figures 21 through 24 are generated histograms for demonstration and do not represent the transect grid densities at any specific site.

In the example from Figure 21 the target area densities fall in the tail of the background densities and the critical density would be selected somewhere between 20 and 35 ApA. The bottom histogram in Figure 22 shows an example of an average target area density that is much larger than the average background density, which would make it very easy to identify a critical density that flags transect grids that are only associated with the target area. Figure 23 and Figure 24 show how the combined histograms are affected when the size of the target area is small (Figure 23) or large (Figure 24) and the average target area density is not as distinguishable from the average background density. It is not clear that an appropriate critical density could be selected using only the bottom histogram in Figure 23, but the critical density from the bottom histogram in Figure 24 would be somewhere between 18 and 25 ApA. As explained, the examples in Figures 21, 22, and 24 would be sites where the histogram alone could provide a good understanding of the density distributions on the site and possible critical densities. It would be more difficult to understand the combination of density distributions or an appropriate critical density in cases represented by the bottom histogram in Figure 23.

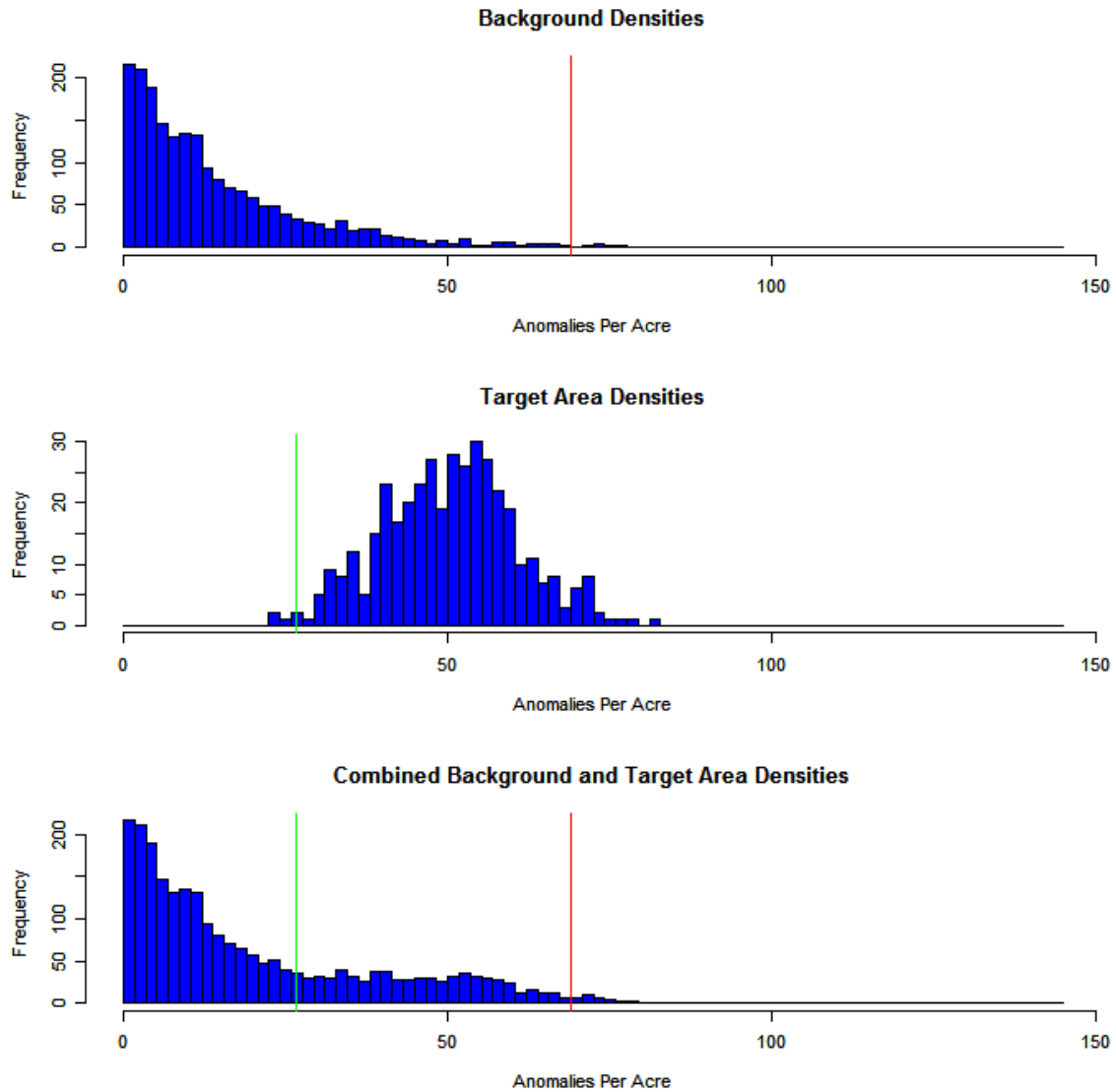


Figure 21. The gamma distribution of background densities with an average density of 15 ApA and a standard deviation of 15 ApA (top). The Gaussian distribution of target area densities with an average density of 50 ApA and a standard deviation of 10 ApA (middle). The bottom histogram is an example of the combined density distribution. The green line at 27 ApA is the point at which 99 percent of the target area densities are larger. The red line at 70 ApA is the point where 99 percent of the background densities are smaller.

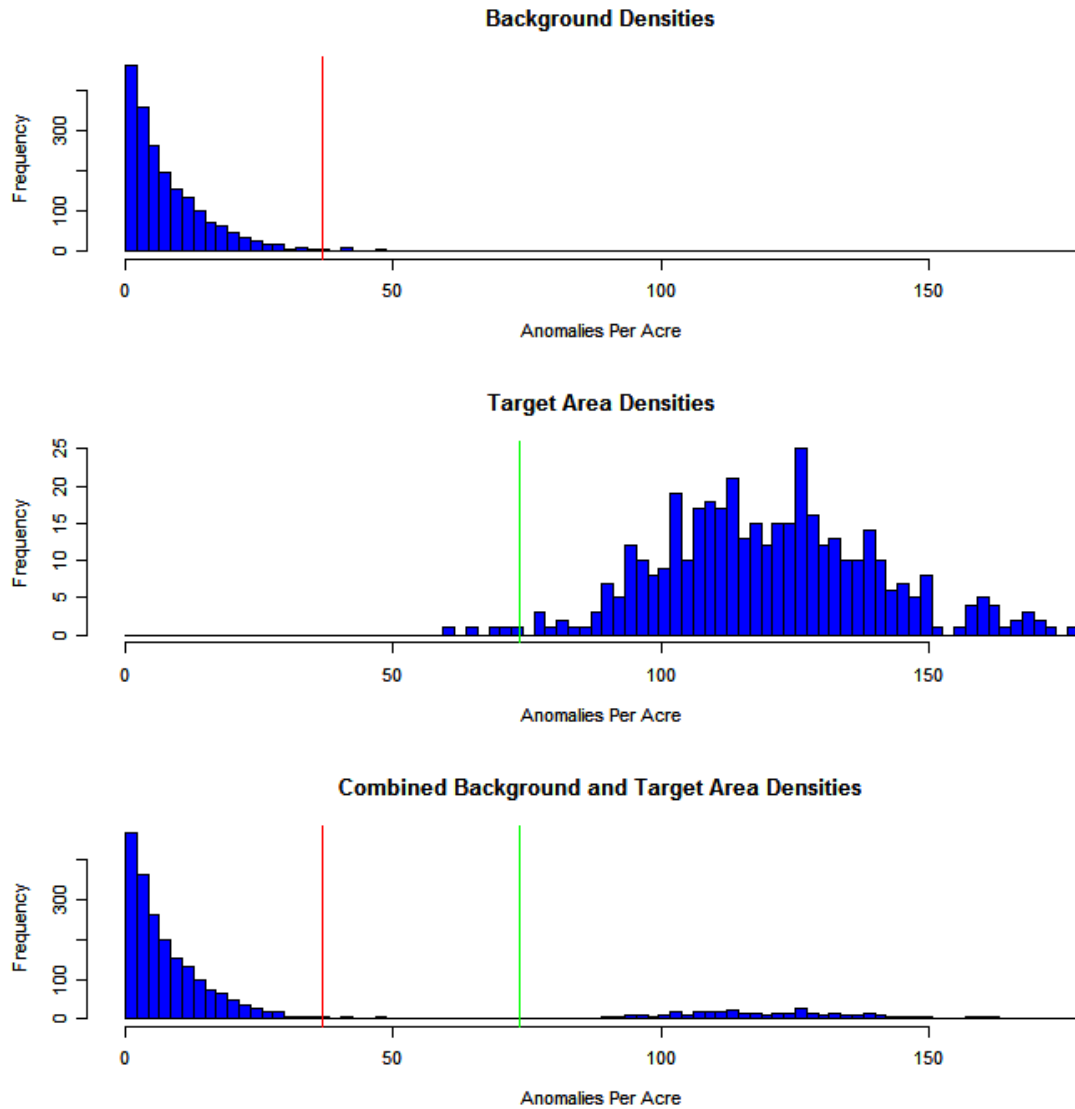


Figure 22. The gamma distribution of background densities with an average density of 8 ApA and a standard deviation of 8 ApA (top). The Gaussian distribution of target area target area densities with an average density of 120 ApA and a standard deviation of 20 ApA (middle). The bottom histogram is an example of combined density distribution. The green line at 73 ApA is the point at which 99 percent of the target area densities are larger. The red line at 37 ApA is the point where 99 percent of the background densities are smaller.

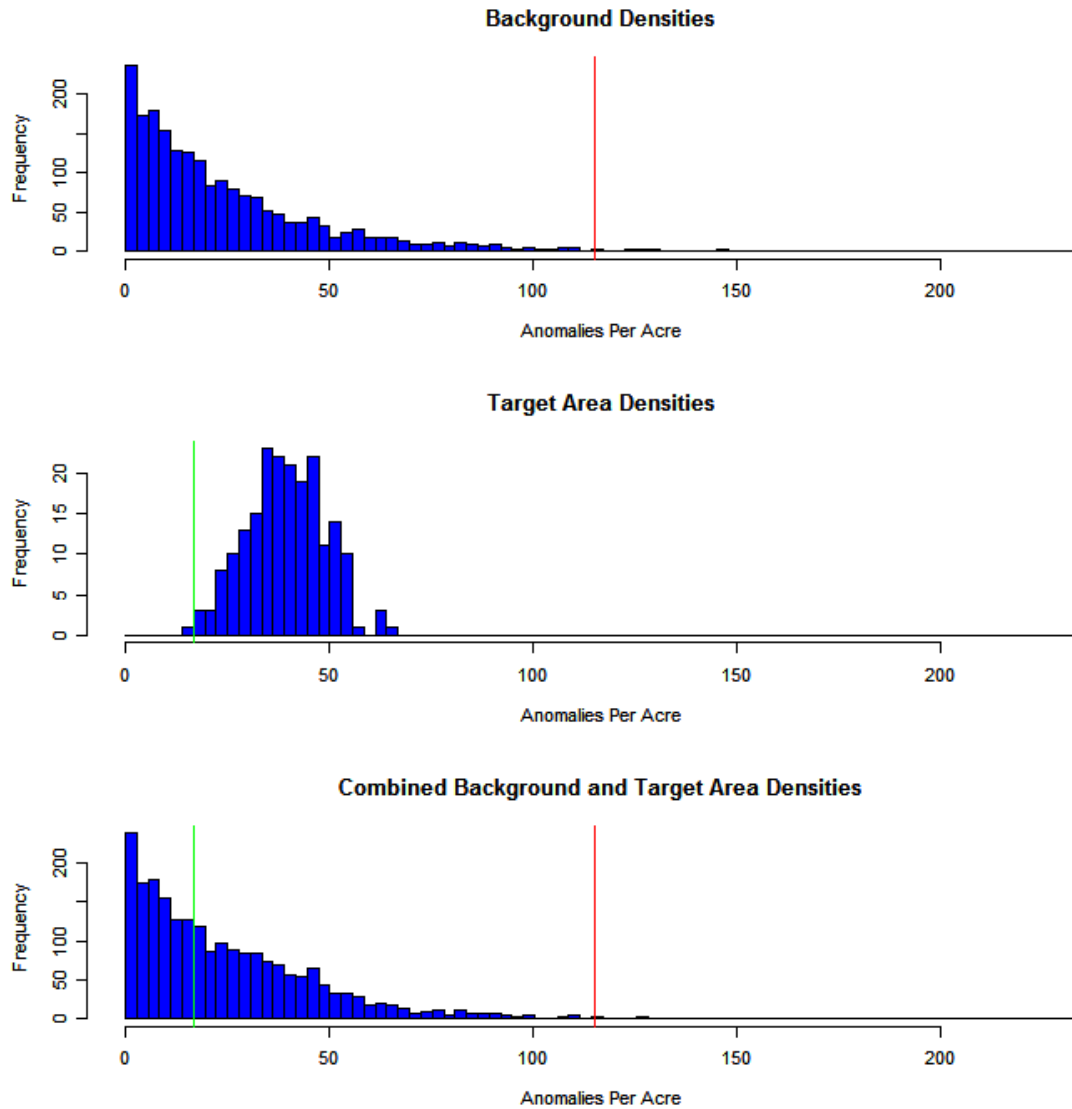


Figure 23. The gamma distribution of background densities with an average density of 25 ApA and a standard deviation of 25 ApA (top). The Gaussian distribution target area densities from a small target area with an average density of 40 ApA and a standard deviation of 10 ApA (middle). The bottom histogram is an example of combined density distribution. The green line at 18 ApA is the point where 99 percent of the target area densities are larger. The red line at 115 ApA is the point where 99 percent of the background densities are smaller.

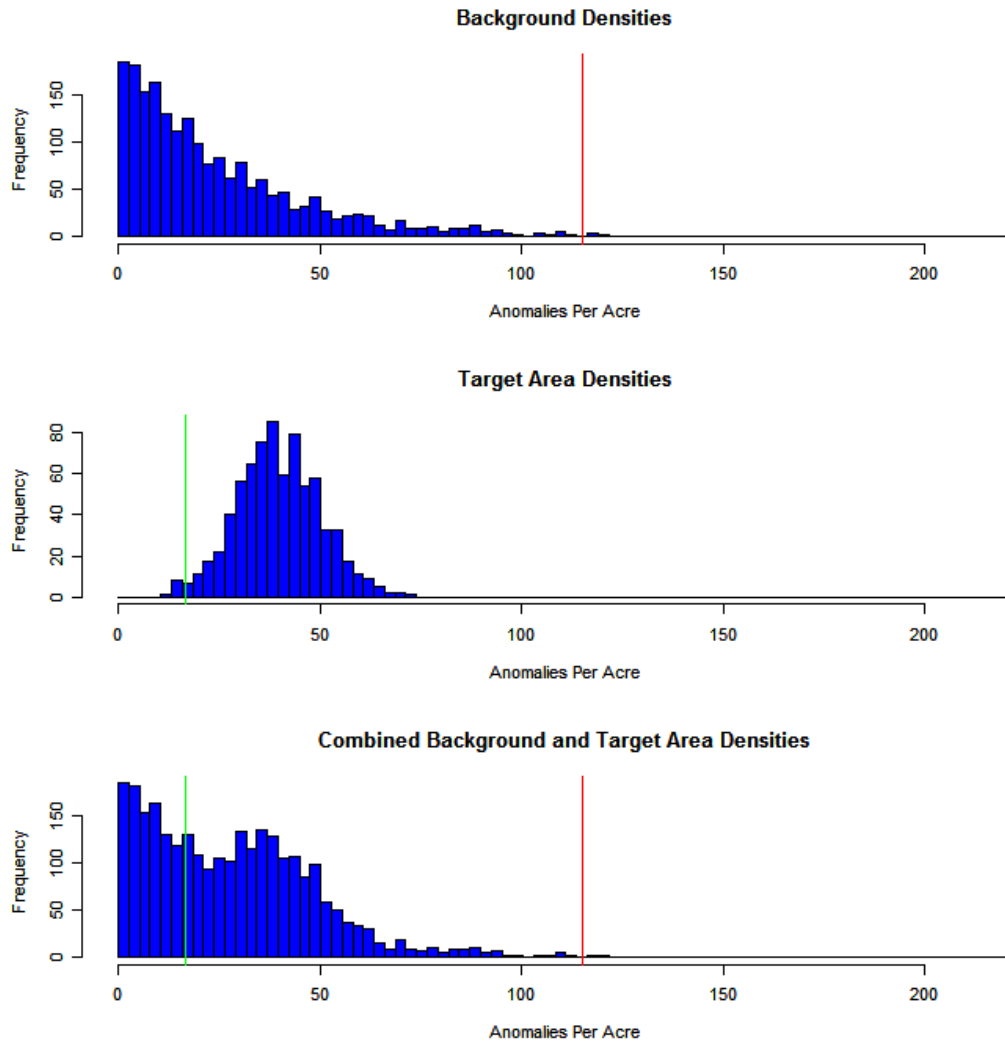


Figure 24. The gamma distribution of background densities with an average density of 25 ApA and a standard deviation of 25 ApA (top). The Gaussian distribution of target area densities from a large target area with an average density of 40 ApA and a standard deviation of 10 ApA (middle). The bottom histogram is an example of combined transect grid density distribution. The green line at 18 ApA is the point where 99 percent of the target area densities are larger. The red line at 115 ApA is the point where 99 percent of the background transect grid densities are smaller.

Figure 25 and Figure 26 are histograms of the site densities from the transects shown in Figure 2. This is an actual site studied as a part of the larger Wide Area Assessment project funded by ESTCP. This site is located in northern California and is a small part of the larger Victorville Precision Bombing Range (Hathaway 2006). Figure 26 shows the same densities as Figure 25, but the frequency axis is transformed logarithmically to accentuate the lower count bins. This transformation is done by clicking the “Log Y” box when examining the histogram within VSP. This site had multiple high density areas of which each had a unique average density. Figure 26 provides a view that is similar to what is shown Figure 24. This histogram helped in selecting 45 ApA as the threshold used to identify all the high density areas on the site (Hathaway 2006).

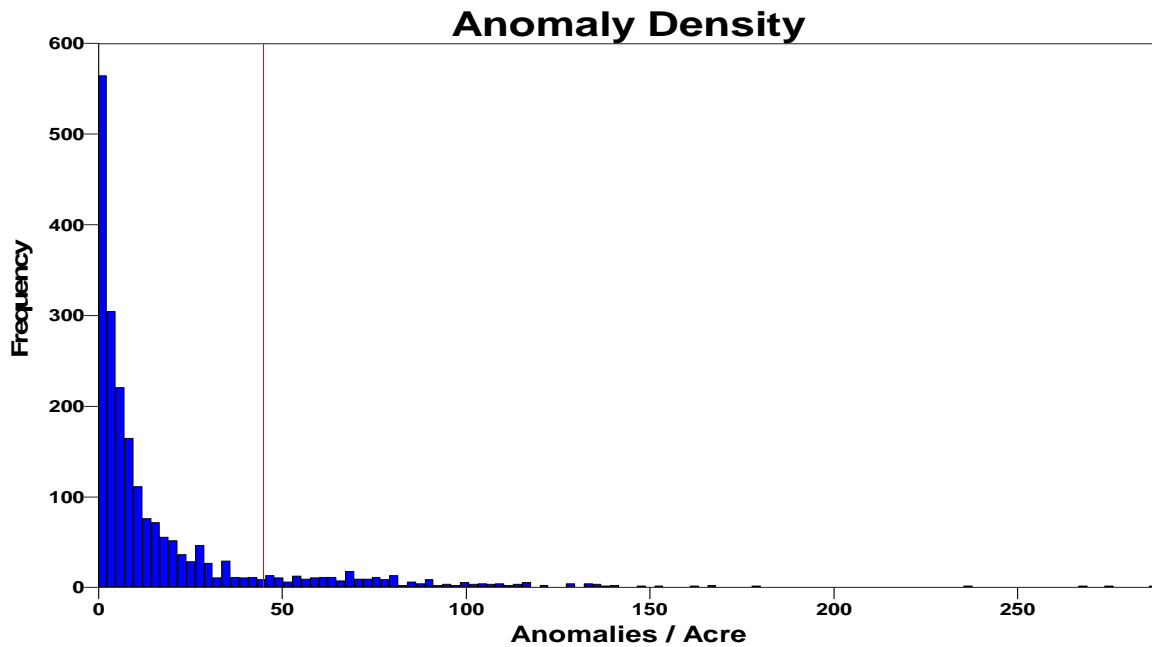


Figure 25. Histogram produced using the “Find UXO Target Areas” target area identification dialog in VSP of the calculated site densities from a survey performed at wide area assessment site located near Victorville, California. The window diameter was 300 m and the red line at 45 ApA marks a possible critical density.

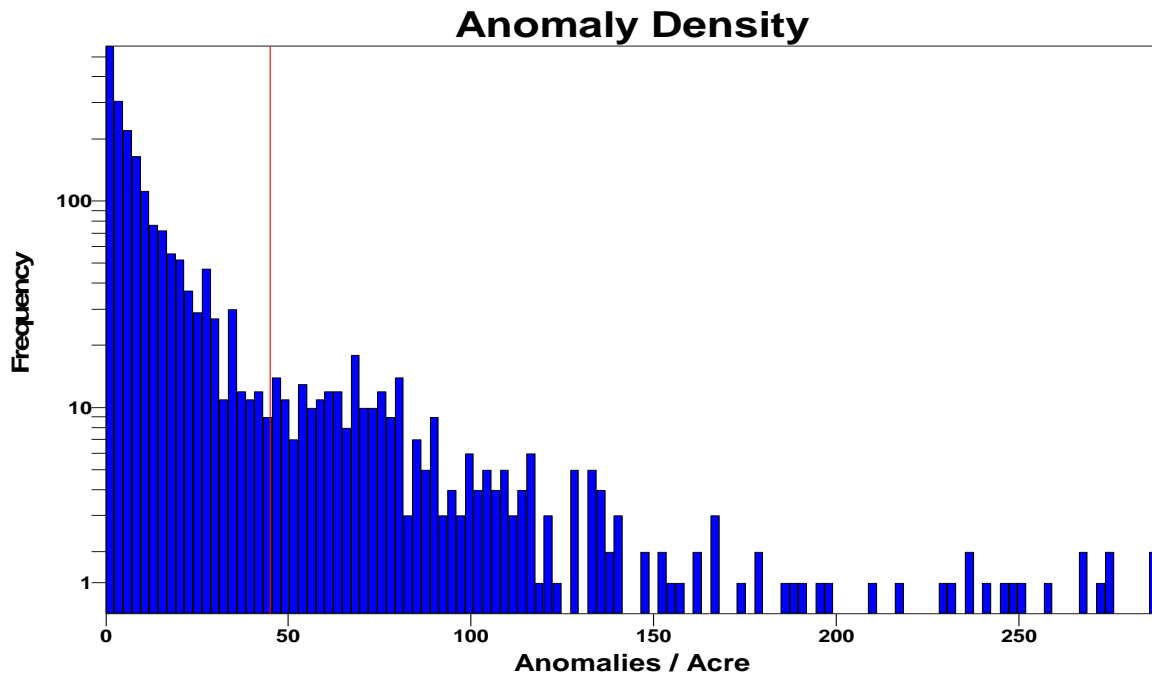


Figure 26. Histogram produced from VSP using the same data from Figure 25, but the frequency axis is transformed to accentuate the bins with low counts.

3.2.3. Selecting a Critical Density for identification

The selection of a final threshold that identifies and delineates all the specified target areas must use the spatial location of the high density areas with the information provided in the histograms explained previously. The final threshold will identify the maximum boundaries of the clustered high-density regions without including a lot of small sparsely located regions on the site. Figure 18 shows the dialog in VSP that provides the user with tools to identify the high density areas.

The “Locate and Mark UXO Target Areas Based on Elevated Transect Anomaly Density” provides a method to flag locations within the transects that have an anomaly density above a selected critical density. This method does not attempt to estimate anomaly densities between the transects and only requires the user to select a window diameter and density threshold to perform an analysis of a site. This method “flags” those areas on the transects that have densities above the specified threshold (see Figure 27).

Figure 27 depicts a transect survey done in southern California on a smaller section of the Victorville Precision Bombing range which was explained previously. This site was approximately 5500 acres and included two previously identified impact areas. The general locations of Areas E, F, and H were previously identified as munitions related impact areas. However, there was no other information that identified the remaining regions as munitions related. Further work on this site showed that the remaining regions of high anomaly density were due to geology. This site is a good example of the limitations of these tools. Identified and delineated regions are only based on the number of identified metallic related signals from the survey equipment. These high density areas will include any munitions related areas but may also include areas with high densities from geologic or anthropogenic material.

3.2.4. Identifying UXO Target Areas Based on Elevated Transect Anomaly Density

The flagging routine in VSP uses the transect grid densities calculated as described in Section 3.2.1 along with the selected critical density to “flag” those grids that are above the critical density with the use of the dialog shown in Figure 18. The “flags” are sized to represent one-sixth of the window diameter used during the analysis. When using this dialog, the user can select “Flag areas with density significantly > background” or “Flag areas with density > critical density” to flag high density areas on the site. The dialog shown in Figure 28 allows the user to input the average background density if known and identify those transect grids with an anomaly density significantly greater than the average (Matzke, 2006). The examples provided in this section use “**Flag Areas with Density > Critical Density**” (Figure 18) to demonstrate how a critical density and window diameter would be selected during an analysis.



Figure 27. Depiction of different flagged areas based on a 300-m-diameter window (bottom two maps) and a 650-m-diameter window (top two maps) when a critical density of 25 ApA (left two maps) or 45 ApA is used (right two maps).

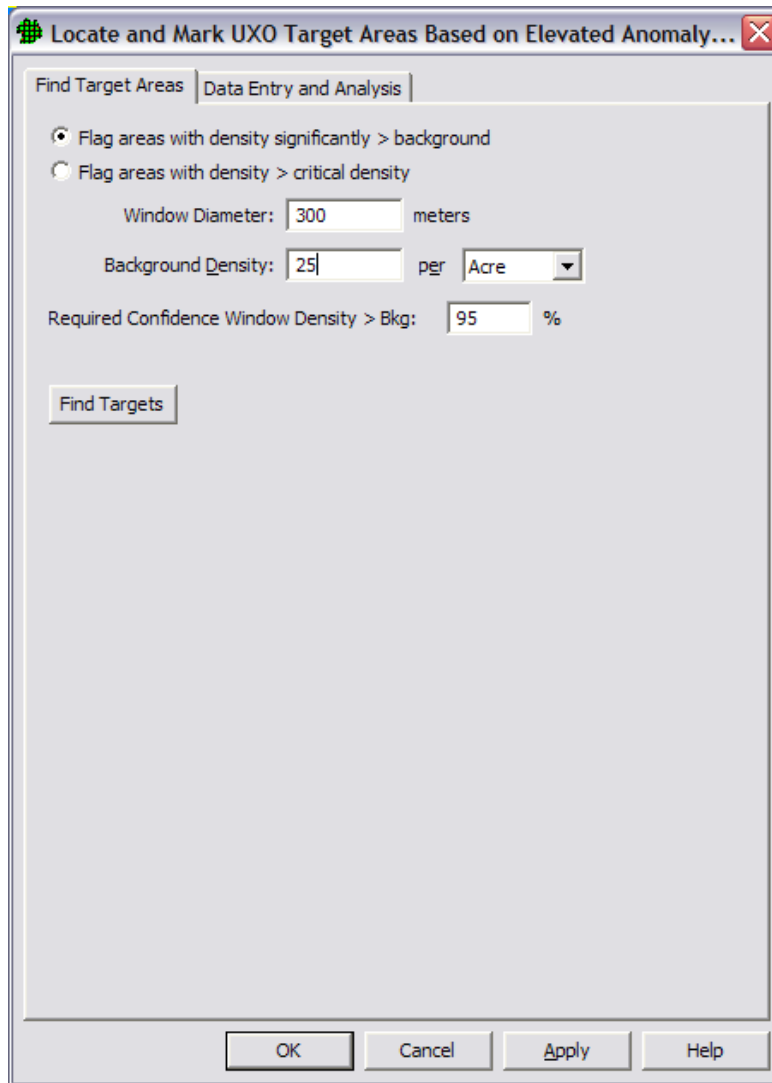


Figure 28. “Locate and Mark UXO Target Areas Based on Elevated Transect Anomaly Density” design dialog when an average background density and associated confidence are selected to flag high density transect grids on the site.

The distribution of the site densities is affected by the size of the window diameter used during the analysis. Figure 30 shows the distribution of these densities for the Victorville site when a 300-m-diameter window is selected while Figure 29 is the same site but uses a 650-m-diameter window. These two figures provide an example of how the distribution of site densities and the optimum critical density are affected by the selected window diameter. The histogram which used a 650-m-diameter window has a reduced maximum value and many of the low density values have moved from zero to slightly higher values. It should also be noted that a larger window diameter also increases the window step size which reduces the number of windows (individual density estimates) on the site and in the histogram. As different window diameters are examined, the resulting histograms should be analyzed to find an appropriate critical density for the respective diameter selected.

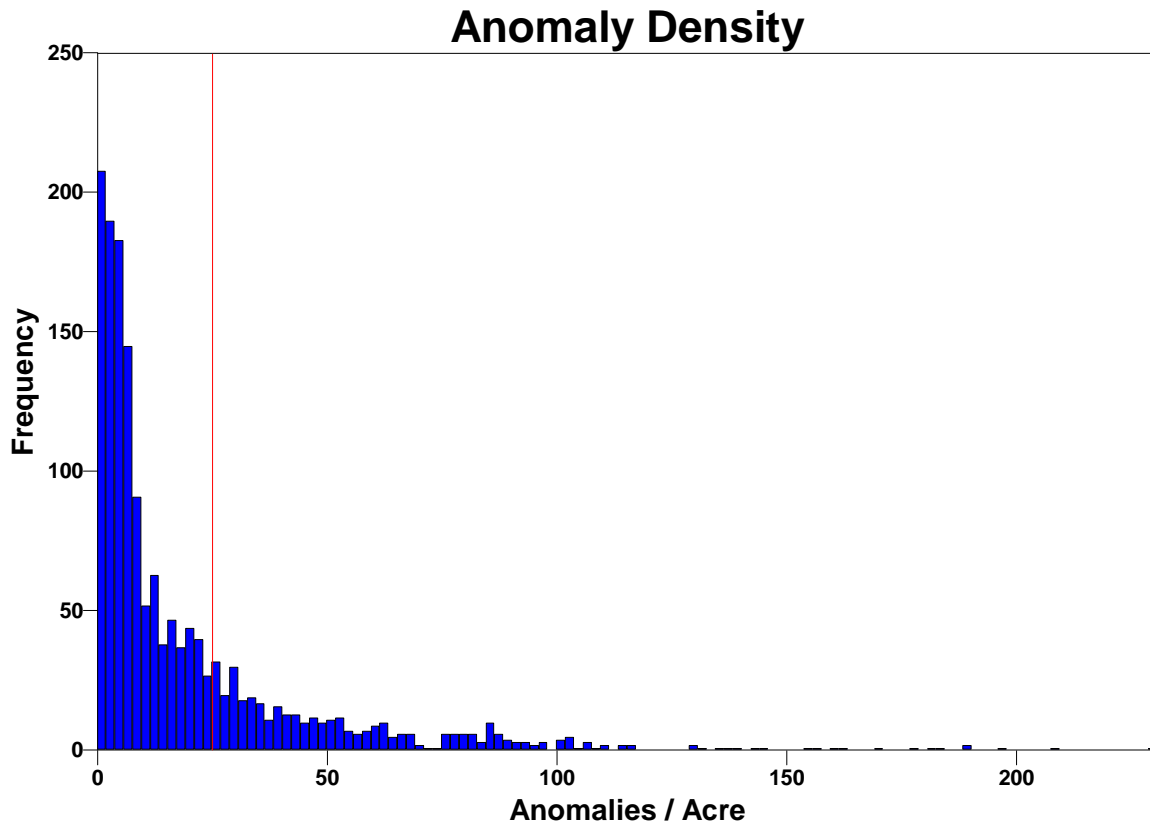


Figure 29. Distribution of transect grid densities for the Victorville site when a 650-m-diameter window is selected. The red lines represent a possible critical density of 25 ApA.

Figure 27 shows the flagged areas for the Victorville site based on the use of a 650-m-diameter window (top two maps) or a 300-m-diameter window (bottom two maps). The two maps on the left are flagged with a critical density of 25 ApA and the two maps on the right use a critical density of 45 ApA. Figure 27 exhibits four different perspectives of the survey data and provides a small example of the iterative process of identifying the proper window diameter and critical density combination. The map in the lower right uses a 300-m-diameter window with a 45 ApA critical density and was used during the analysis of this data to identify the labeled areas which are shown in all four maps (Hathaway 2006). The other three maps show an example of the iterative process used to select the combination of 300-m-diameter and 45 ApA. The map in the upper left tends to identify all the high density areas, but the large window diameter (650 m) and low critical density (25 ApA) appear to include too much area around the perimeter of each of the high-density areas. This window diameter fails to identify any high density grids near area of interest I (AOI-I). The map in the lower left (300 m) uses the same critical density of 25 ApA and identifies all the identified AOI; however, there are many smaller flagged regions which are sparsely located over the site. Finally, the map in the upper right identifies five tightly clustered high density regions without a lot of additional area included around these identified areas, but the combination of a 650-m-diameter window and a 45 ApA critical density made the map in the upper right the only one that did not

identify AOI-E, AOI-F, and AOI-G. In summary, the resulting final flagged areas are a function of the user-defined values of the critical density and the window size.

4. Geostatistical Mapping of Anomaly Density

To this point in the analysis, the questions being asked and the calculations and products produced using VSP have been confined to the actual data that have been collected. The next step is to exploit the collected data to provide details, albeit estimated details, of the areas outside of the sampling transects. For example, what does the target area boundary look like between the relatively small number of points where it intersects the transects? Also, what is the best estimate of the total number of anomalies contained within the target area? To fill in these types of details, it is necessary to extrapolate the collected data away from the transects in a repeatable and defensible manner. We accomplish this goal using geostatistical estimation tools

The geostatistical mapping of anomaly densities provides a continuous estimate of the density of magnetic anomalies for the entire study site. This spatially continuous representation is important in the visual detection of high-density areas. This estimation also provides the basis for estimating the total number of anomalies within portions of the site as used in cost estimating and in providing a basis for other spatial analyses such as target boundary delineation. The basic output from this process is a map showing an estimate of how the magnetic anomaly density varies across the study site. This map is composed of a number of equal sized cells, typically on the order of 50 by 50 m, and the estimation process provides the spatially varying average anomaly density within each cell across the site.

Within VSP, the geostatistical anomaly density mapping is composed of two primary tasks. The first task is modeling of the spatial variability of the measured anomaly densities as determined from the geophysical transect data. This task involves the development of a variogram based on the window-averaged transect density values. A variogram depicts how the variability of a set of values changes as the distance between the spatial locations of these values increases. The second task involves the estimation of anomaly density at unsampled locations within the study area through a geostatistical methodology known as kriging. Kriging uses the model of spatial variation as captured by the variogram to provide an unbiased, minimum-variance estimate of the anomaly density. Kriging is the procedure that creates the final anomaly density map.

An anomaly density map can be created from the sample transect data by opening the “Geostatistical mapping of anomaly density” dialog (Figure 30). This dialog is opened through the Sampling **“Sampling Goals > Find UXO Target Areas > Geostatistical mapping of anomaly density”** selection. This selection presents a menu with three screen tabs. The default tab “Map Anomaly Density” presents several options for mapping anomaly densities. The second tab “Variogram Model” provides an alternate means of accessing variogram fitting parameters once the variogram has been computed.

The third tab “Data Entry and Analysis” provides the ability to import files identifying the course over ground and anomalies as explained in section 3.1.

There are two pathways to create the anomaly density estimates. The basic pathway will create an estimate of anomaly density based on a series of default values computed from the current data set. The advanced pathway allows more control over the variogram and kriging parameters, but requires the user to possess a greater understanding of geo-statistical analysis to be used in a meaningful manner. Each of these pathways is discussed below.

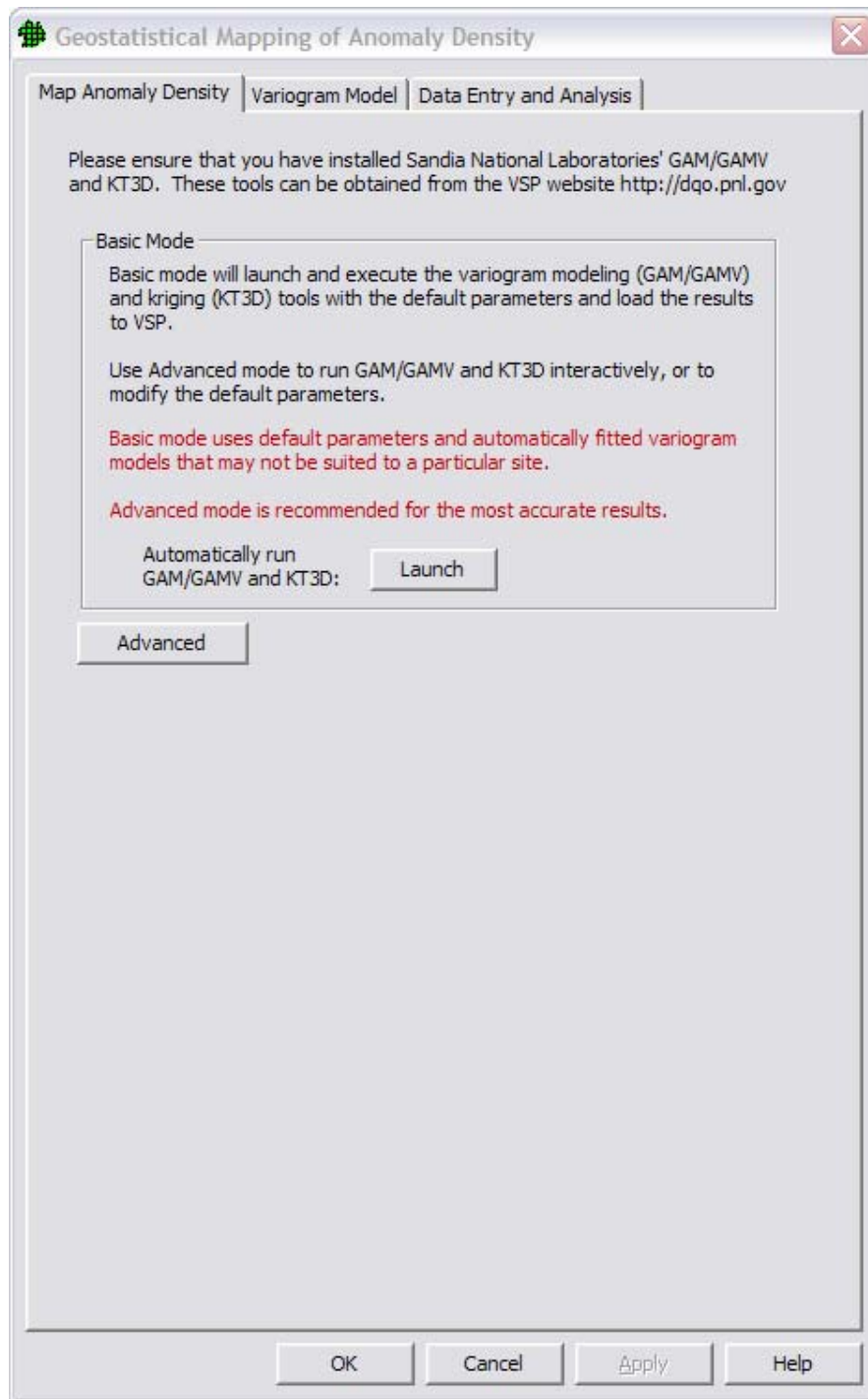


Figure 30. “Geostatistical Mapping of Anomaly Density” dialog. This view shows the basic mode without the advanced operations screen box displayed.

4.1. Basic Geostatistical Mapping

Under the default “Map Anomaly Density” tab of the “Geostatistical mapping of anomaly density” dialog, the user is presented with two choices for computing the anomaly density

map. In “Basic Mode,” the VSP will automatically compute a variogram and perform the kriging necessary to develop a spatial estimate of anomaly density. In this mode, a series of default values are computed for the data set and used in the variogram and kriging analyses. This mode is fully automatic and is the recommended path for new users to follow.

To use the automatic mode, click on the “Launch” button within the “Basic Mode” screen box (Figure 30). Clicking on this button will launch a series of programs that will momentarily flash several operational windows to the screen before returning to the “Geostatistical Mapping of Anomaly Density” dialog. After successful completion of this process, the modeled variogram can be viewed by clicking on the “Variogram Model” tab in the “Geostatistical Mapping of Anomaly Density” dialog. Clicking on the “OK” button will close this dialog and load the anomaly density estimate map as an overlay onto the main VSP site map. At this point, the primary VSP mapping tools can be used to investigate the details of the estimated anomaly density map.

4.2. Advanced Mode Geostatistical Mapping

In the “Advanced” mode, the user is given complete control over all the parameter settings involved in the variogram and kriging analysis. This mode is recommended for experienced users or when specific analysis parameters are necessary.

Advanced mode is selected by clicking on the “Advanced” button under the “Map Anomaly Density” tab of the “Geostatistical Mapping of Anomaly Density” dialog. Clicking on this button will open a screen box with various selections for advanced mode operation (Figure 31). These selections include the averaging window diameter, a check box to select indicator kriging, and a check box to reset negative estimate values.

The averaging window diameter parameter specifies the size of the averaging window used in computing the anomaly density values used in the geostatistical mapping. The impact of this parameter on anomaly density calculations is discussed in Section 3.2.1. The variogram lag distance and kriging grid cell size are also affected by this parameter. The lag distance is the separation distance between pairs of data points and is used to group the data pairs and is discussed further below. The initial lag spacing and kriging grid cell size are set to be one-sixth of the averaging window diameter by default. If an averaging window diameter other than the default value is desired, it should be changed before proceeding with the next steps in the analysis. The initial lag spacing and kriging grid cell size also can be changed independently of the window size by manually entering them using the advanced mode.

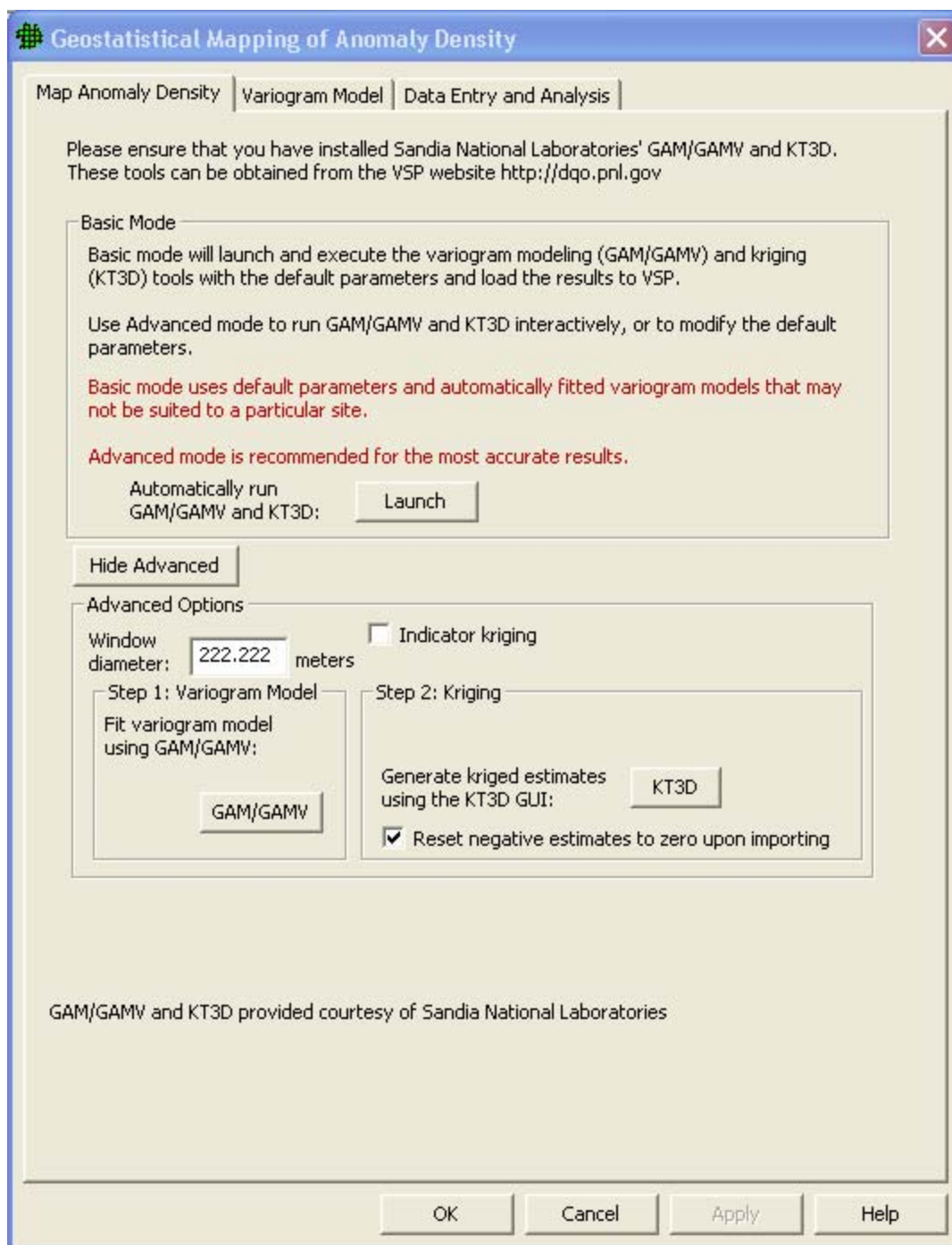


Figure 31. Advanced mode for geostatistical anomaly density mapping.

Checking the selection box labeled “Indicator Kriging” in the advanced mode window will produce probabilistic estimates of exceeding a specified anomaly density threshold. In contrast to the standard kriging of anomaly density values, indicator kriging transforms the observed anomaly density values into an indicator variable based on a specified anomaly density threshold. Measured anomaly density values at or above this threshold are given a value of 1, while observations below the threshold are assigned a value of 0. These indicator variable values of 1 and 0 are then used in the variogram calculation and modeling and in the kriging estimation in place of the original anomaly density values. The kriging estimates resulting from this then range from 0 to 1 and represent the probability of exceeding the specified anomaly density threshold. When the indicator kriging checkbox is selected, an additional window for specifying the anomaly density threshold value is provided. This value should be entered in standard units of anomalies per acre.

The final selection option displayed in the advanced mode window is the option to reset negative estimate values. This selection is checked on by default. Under certain circumstances, the kriging equations can sometimes produce estimates outside of the range of the original conditioning data. This may lead to negative anomaly density values within the kriging estimation. Because this is physically impossible, the option is given to reset negative estimation values to zero before the results are displayed within VSP. This option should remain selected unless there is a compelling reason to investigate the untransformed kriging values.

The following discussion presents details regarding advanced mode operation for the geostatistical estimation procedure. Although the examples that are presented focus on anomaly density estimation, the same basic procedures are applicable for indicator kriging. In cases where differences do exist, additional information regarding the indicator kriging procedure is provided.

Once the processing options have been set, the first processing step in using “Advanced Mode” is to click on the button labeled “GAM/GAMV.” This selection will initiate the variogram calculation and then open a separate screen presenting a graphical interface for additional variogram analysis. At this point, the automatically fit variogram model can be viewed by clicking on the “Fitting” tab of the GAM/GAMV” screen (Figure 32). Here, the user will see the empirical variogram values as well as the automatically fit variogram model and its parameters (Figure 33). The variogram is computed from the averaged anomaly density values obtained from the geophysical survey transect data. The averaged anomaly densities are automatically computed using the averaging window diameter specified under the “Advanced Options” screen box, and the previously loaded anomaly locations and course over ground information. These values are then automatically passed to the GAM/GAMV code. In the case of indicator kriging, the data that is passed to the GAM/GAMV code are the 1 and 0 values of the indicator variable created using the specified anomaly density threshold.

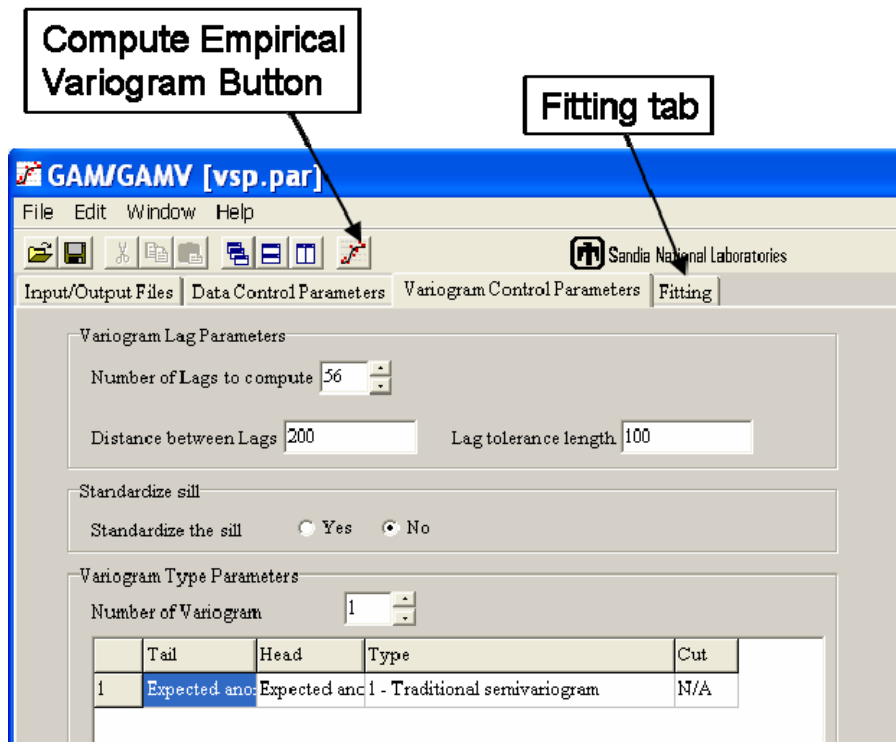


Figure 32. Aspects of the GAM/GAMV interface screen.

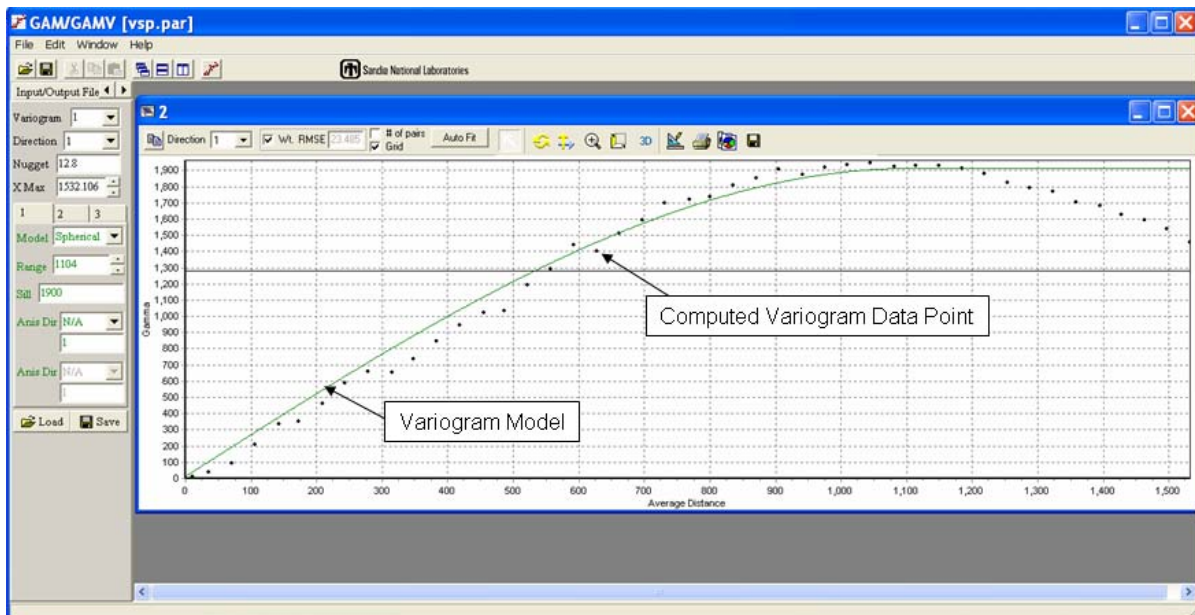


Figure 33. Variogram fitting screen from the GAM/GAMV window. Dots show computed variogram values, and the solid green line shows the model fitted to variogram values. Parameters for this model are listed along the left side of the window.

There are various other tabs in the GAM/GAMV screen that provide access to other variogram analysis parameters. Details regarding these other input parameters are given in GAM/GAMV interface interactive help files, and a full discussion can be found in Deutsch and Journel (1998). When running within the VSP environment, the data file and output file names should never be changed from their default values. In general, the only control parameters that might typically be altered at this stage in the analysis are the lag spacing, lag tolerance, and number of lags to compute. These parameters control how the observations for computing the empirical variogram are grouped and the maximum separation distance that should be considered. These parameters are discussed further below.

The GAM/GAMV code is used to compute a variogram for the averaged anomaly density data. A variogram depicts how much the variation between pairs of sample values (anomaly density in the case here) changes as the distance between pairs increases. The lag distance is the separation distance between pairs of data points. The lag distance is used to group the data pairs into groups based on separation distance. Then the “semi-variance” is computed for each group and plotted as part of the empirical variogram. Because most sample points will not be separated by exactly the specified lag distance, the lag tolerance is given to include those observations that are within the tolerance value of the specified lag distance. For example, using a lag distance and tolerance of 200 m and 100 m, respectively, will generate the following grouping of separation distances:

0 to 100 m	group 1
100 to 300 m	group 2
300 to 500 m	group 3

A semi-variance, or “Gamma”, value for each group is then computed using all the data points with separation distances falling within the distance boundaries for that group. The separation distances are simply the straight line distances between the sample pairs based on the sample point locations. The computed semi-variance values are then plotted along with the average separation distances for each group to create an empirical variogram (Figure 33). The empirical variogram is a graph showing one-half the average squared differences between all pairs of observations for a series of average lag distances.

The solid dots in Figure 33 show the computed empirical, or experimental, variogram values for specific lag distances. The X-axis shows the lag distance in length units (meters in this case), and the Y-axis shows the computed semi-variance value. In this example, the lag distance was 200 m and the lag tolerance was 100 m. The actual location of each data point on the X-axis is determined by the average actual lag distance of all the data pairs in that group. The solid green line shows the automatically fit variogram model for this data set.

One-half the average squared difference for all of the pairs of observations for each group will show up as a single data point on the experimental variogram. Within VSP, the along transect data point spacing is controlled to be one-sixth the averaging window diameter; this is typically the minimum lag distance that should be used. This minimum

value is a good place to start the variogram analysis and typically is sufficient for most studies. To include all data points and avoid overlap between variogram point groups, the lag tolerance should be set to one-half the lag distance. After changing any of the GAM/GAMV input parameters, the variogram will need to be recomputed by clicking on the “Compute Empirical Variogram” button (Figure 32). This selection will recalculate the empirical variogram and display the results under the “Fitting” tab.

The “Fitting” tab of the GAM/GAMV window (Figure 32) interface will display the computed empirical variogram, and will also automatically compute an initial model to fit the data points. This model consists of a continuous function that closely matches the distribution of the empirical variogram data points. A continuous function that will produce a positive definite covariance matrix for solution of the kriging equations is required as a model of spatial variability. Although a single model typically is sufficient, up to three different models can be simultaneously nested to provide a proper fit to the empirical data points. Excessive time should not be spent in creating a best fit model of the empirical variogram data. Typically, the focus of the variogram model fitting should be on matching the experimental variogram points at the shortest lag spacings and at the variance of the data set, shown by the solid horizontal black line, which provides the theoretical maximum variogram value (see Figure 34). A reasonably good fit is usually sufficient when using a transect survey data set.

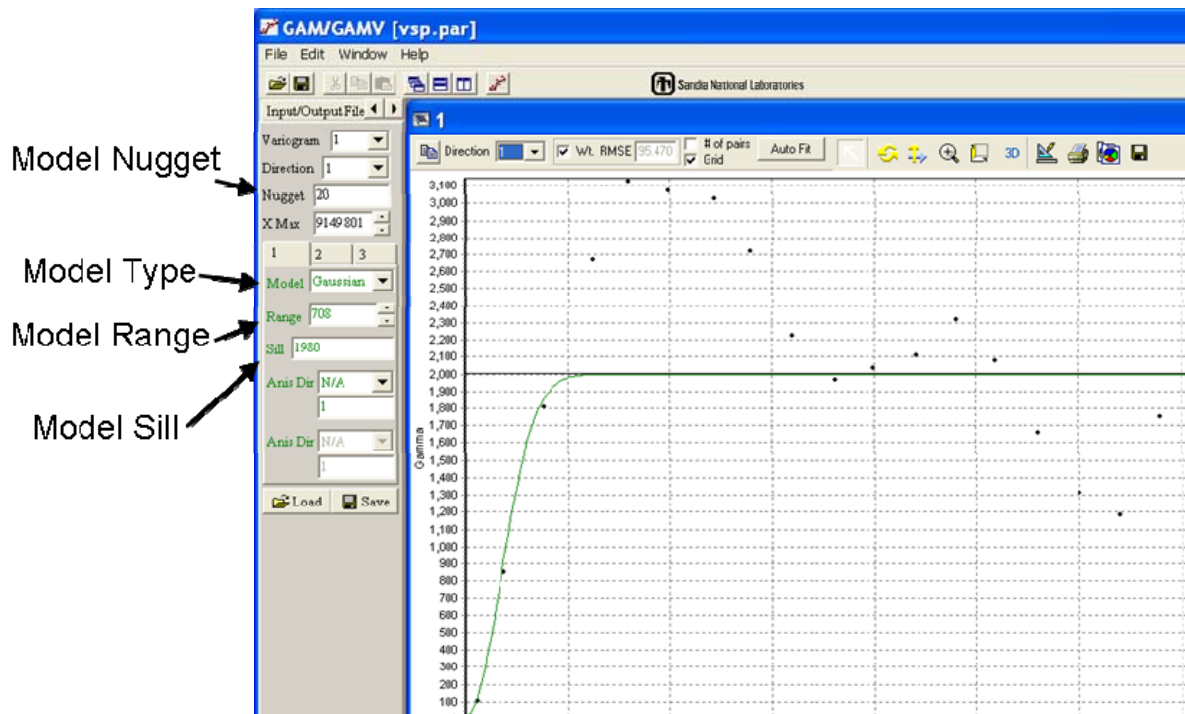


Figure 34. Variogram model parameters settings within the GAM/GAMV graphical interface.

The variogram model is reshaped by changing the range, nugget and sill values (Figure 34). The sill controls the height of the variogram model while the range controls the distance scale of the model. If a large initial jump in the variance is needed to match the empirical data, the nugget value can be increased. The nugget, sill, and range can be adjusted to match the computed variogram data points as needed. In addition, the basic model type (spherical, Gaussian, exponential, etc.) can also be changed as needed. The variogram model line will update dynamically as any of the modeling parameters are altered.

Figure 35 shows the effects of changing the range and sill values of the variogram model. The sample anomaly data for these plots were from a magnetometer survey of a portion of the Pueblo Precision Bombing Range located in southeastern Colorado. The magnetometer transects from this survey were nominally spaced at 155 m and crossed two large high-density areas. As seen in these plots the range and sill values can be adjusted until a sufficiently close match to the empirical data is made.

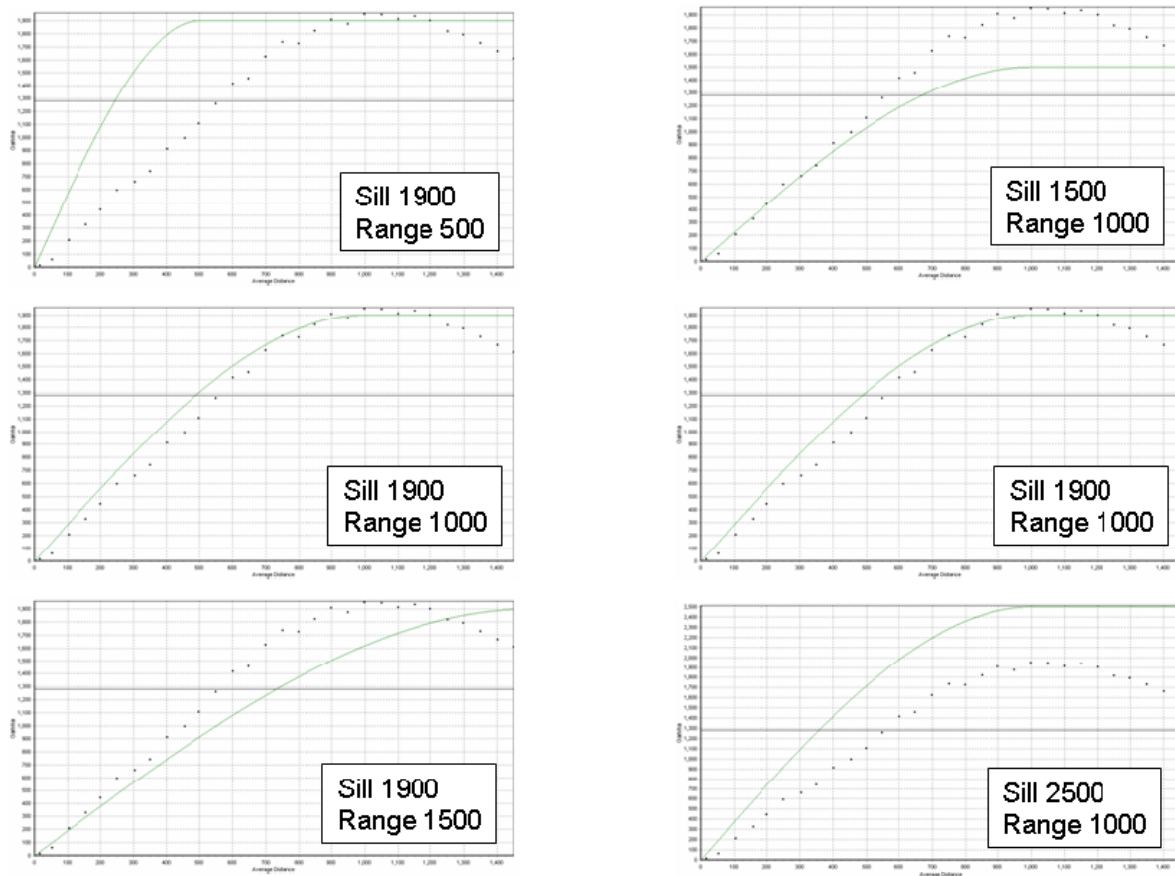


Figure 35. Effects of changing sill and range values for variogram model. Left column of plots shows effects of altering range value; right column shows effects of altering sill value. In each plot, dots represent empirical variogram values, and the green line shows model variogram.

Once the variogram model is satisfactorily fit, the GAM/GAMV interface can be closed, which automatically saves the variogram model parameters. The next step is to use the information in the variogram model to create a map of the anomaly density (or probability, if indicator kriging is used) across the site. The spatial estimation tool is “KT3D.”(Deutsch and Journel, 1998) To begin, click on the KT3D button within the “Geostatistical Mapping of Anomaly Density” dialog. This will open the KT3D graphical user interface. The variogram model parameters developed using GAM/GAMV will automatically be passed to KT3D.

The KT3D interface provides full control of all parameters for the KT3D kriging code. A number of default parameters are already set, so the code can be run immediately by clicking on the “Run” button (Figure 36). This will generate a kriging estimate and display the results within the KT3D interface screen. To display the kriged estimate within VSP, simply close the KT3D interface screen then click “OK” or “Apply” within the “Geostatistical Mapping of Anomaly Density” dialog box.

The other advanced options for running KT3D can be accessed through the various tabs under the main “Parameters” tab on the interface screen. A complete explanation of these various options is presented in the associated help files contained within the KT3D

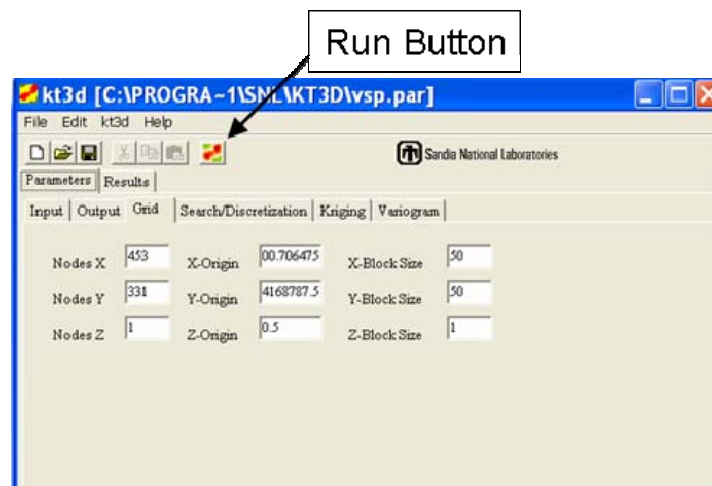


Figure 36. KT3D interface screen.

tool. When running within the VSP environment, the observation data file and kriging output file names should never be changed from their default values.

The KT3D parameters most likely to be changed from their defaults are the gridding and search parameters. These parameters, which control the number, size, and extent of the estimation cells used to discretize the site and the search of local data to be used in the estimation of any location, respectively, are located under the “Grid” and “Search/Discretization” tabs. A full explanation of these parameters can be found in help files associated with the KT3D program, and a full discussion on the background of kriging estimation can be found in Deutsch and Journel (1998).

After all the parameters are set, the user clicks on the “Run” button to run KT3D. The kriging results are automatically displayed within the KT3D interface sub-window. In addition to the anomaly density estimate, the kriging variance also is displayed in an adjacent window. Closing the KT3D interface window will take you back to VSP and the “Map Anomaly Density” dialog. Clicking on “OK” or “Apply” will display the kriging results in the VSP display.

4.3. Display of Kriging Results within VSP

Whether run from “Basic” or “Advanced” mode, clicking on the “Apply” or “OK” button in the “Map Anomaly Density” screen will display the current kriging results within the VSP mapping window. The anomaly density or probability map is displayed in VSP as a color-shaded value map. Figure 37 shows kriging results displayed in VSP. The anomaly density estimate in Figure 37 was developed from magnetometer surveys from a portion of the Pueblo Precision Bombing Range. This site is a World War II era bombing range that shows evidence of two large target areas. The default color scheme in the map display has the highest density values shown in red and the lowest values shown in green. A color scale is provided to aid in interpretation of the results. The lack of color shading

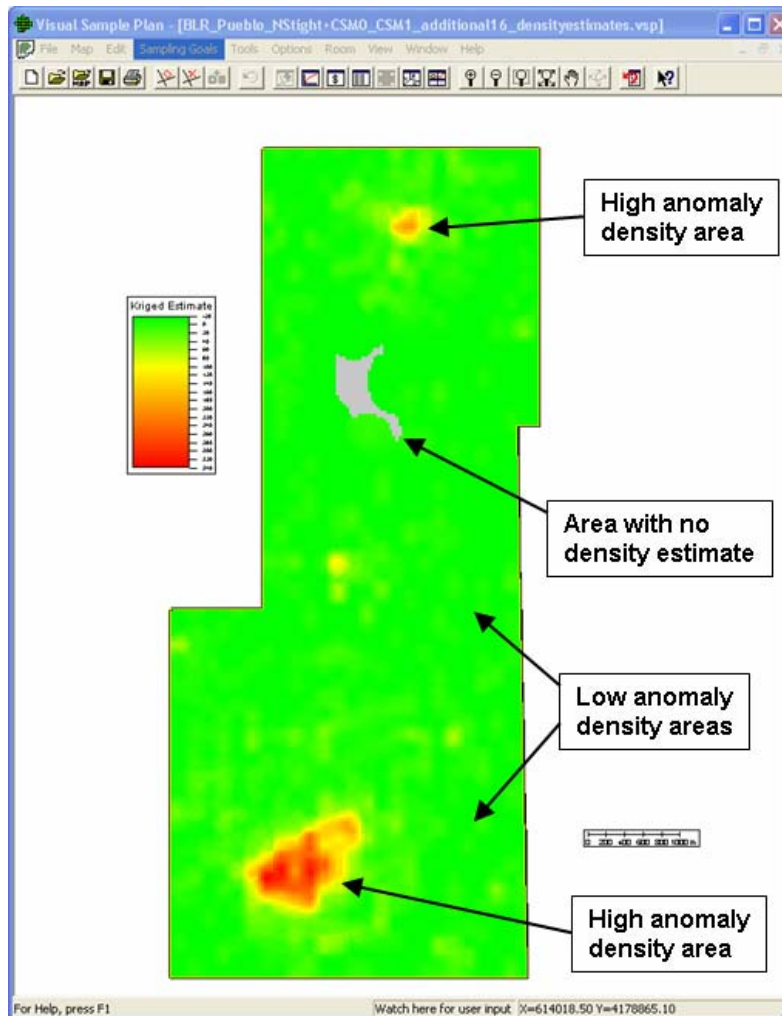


Figure 37. Results of anomaly density kriging estimation displayed in VSP.

(background color is displayed) indicates that no kriging estimation was performed for that location. This typically is the result of a lack of enough sample transect data within the search window for reliable estimates within that area. An example of this can be seen in Figure 38 as a gray area in the northern portion of the study area. Survey transects were not collected in this area because of vegetation and terrain issues. Because of this gap, no kriging estimates were developed for this area.

During examination of the anomaly density map it is useful to turn on the display of the transect survey traces and the detected anomaly locations as aids in interpreting the anomaly density map (Figure 38). The controls for turning different map elements on and off are located under the “View” menu on the main VSP screen. This menu provides a listing of different mapping elements which can be checked on or off to control their display. The transect survey traces and detected anomaly locations provide a visual relationship between the kriging results and the support data used in the kriging analysis. For example, the transect traces shown in Figure 38 explain the gap in the kriging results in the northern portion of the Pueblo Precision Bombing Range study area.

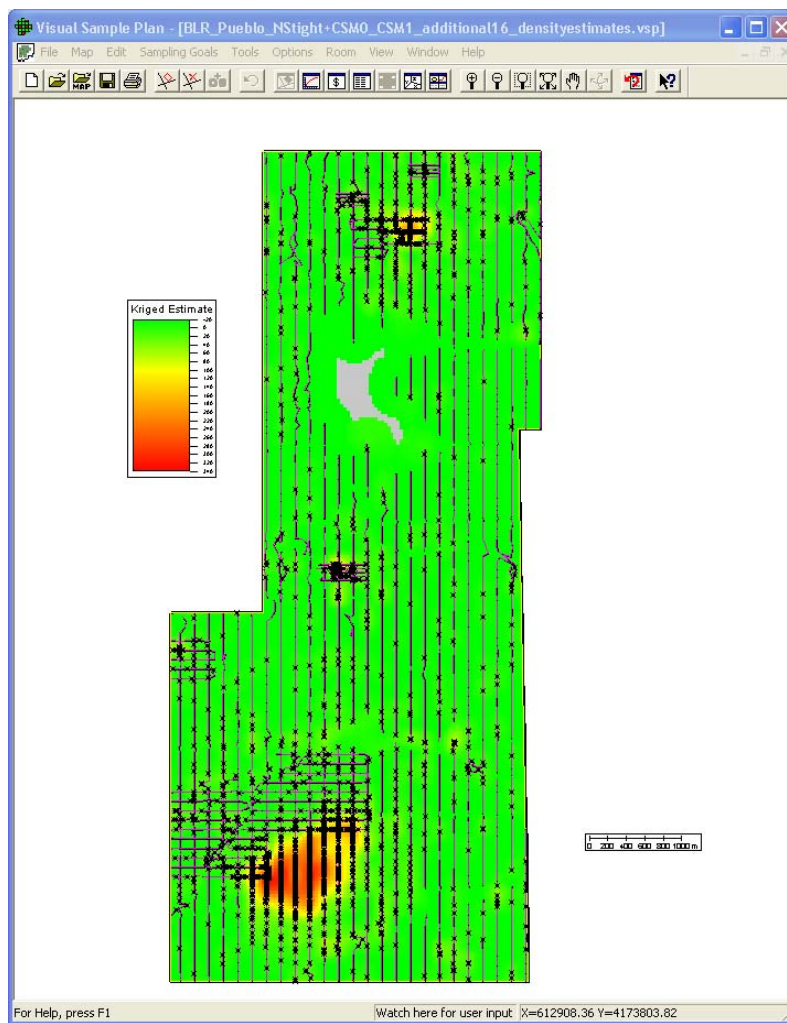


Figure 38. Results of kriging estimation displayed in VSP along with COG traces and anomaly locations.

The color scheme used for the anomaly density display can be changed by selecting the “View” pull down menu on the main VSP screen, then choosing “Kriged Data,” and then selecting “Color Options.” Various color palettes are available. Selecting one with a larger color range will bring out more details in the anomaly density estimate. Figure 39 shows the same anomaly density estimate for the Pueblo Precision Bombing Range as shown in Figure 37, but it uses a different color palette (MBCGYOR-Grad) to enhance the variations in anomaly densities, thus bringing out some of the subtle details in the higher density areas.

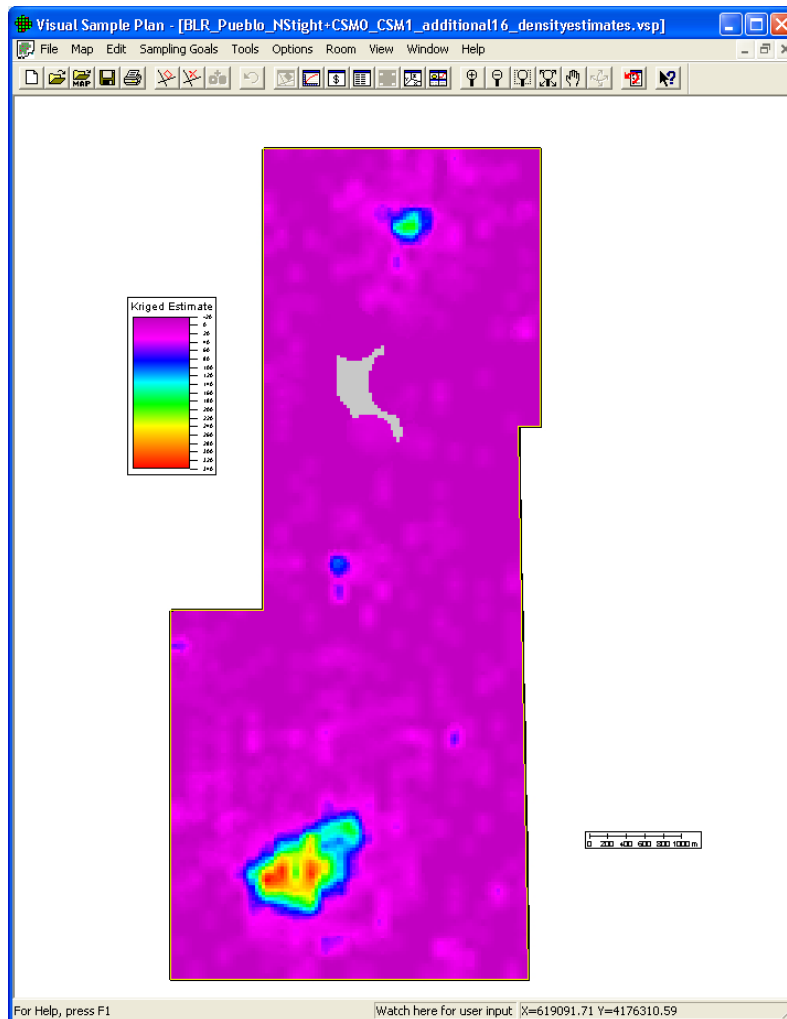


Figure 39. Kriging results displayed in VSP using an alternate color scheme.

In addition to the estimate of anomaly density or probability, the kriging procedure also generates a map of the estimation variance. Figure 40 shows the kriging estimation variance computed for the kriging results from the Pueblo Precision Bombing Range study area. The estimation variance shows the uncertainty of the kriging estimate and is a function of the data configuration and the variogram model. Estimates of anomaly density for locations on or near sampling transects should be very accurate and, hence, have a low uncertainty. Conversely, estimates distant from the sample transects are likely to be less accurate with a relatively high uncertainty. The value of the estimation variance reaches a maximum at distances greater than or equal to the variogram range away from the nearest data point. The map of estimation variance shows how the variance of the anomaly density changes across the study site. In Figure 40, the highest variance values are shown in shades of red; the lowest values in shades of green. The highest variance values occur in the northern portion of the site where there is a large gap in the sample transects because of terrain and vegetation issues. The maximum variances occur on the edge of the region where no estimates could be made. These high variance values indicate that some areas exist within the site where there are enough nearby data

points to create a kriging estimate, but the uncertainty in these estimates is large. While not explored further here, the kriging variance provides a means of identifying regions of high uncertainty and can be used to design additional transect surveys. The lowest variance values are found at the survey transect locations.

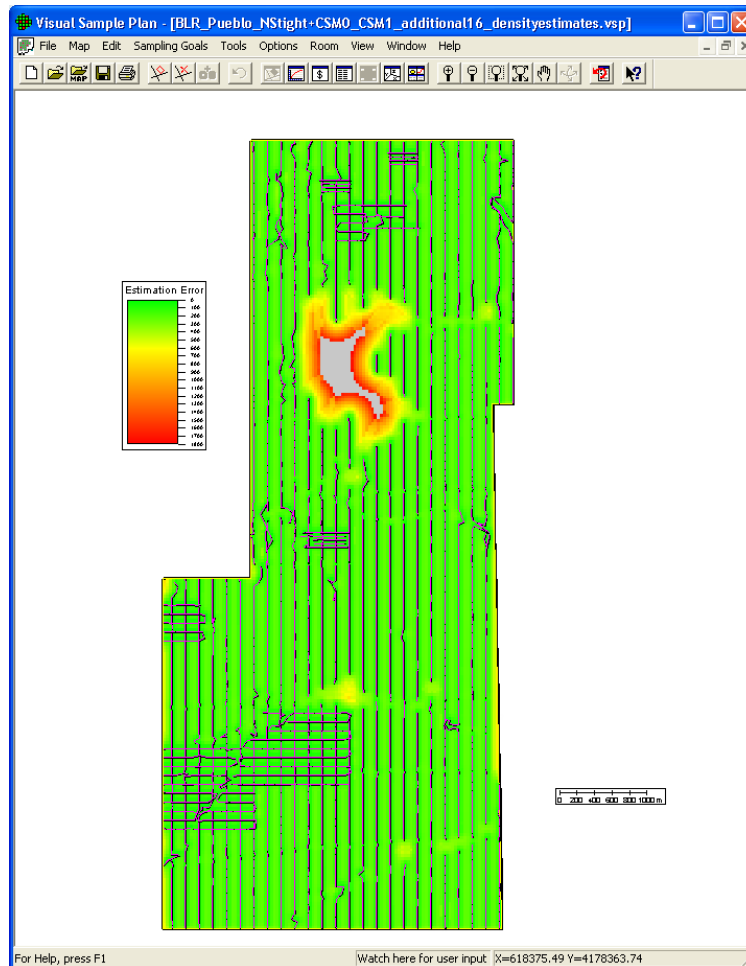


Figure 40. Kriging variance displayed in VSP along with COG traces. The highest variance values are shown in red, and the lowest values are shown in green.

To view the estimation variance, select the “View” pull-down menu on the main VSP screen, then choose “Kriged Data,” and then select “Kriging Variance.” As shown in Figure 40, there is a strong relationship between the sample transect locations and the kriging variance. The variance is low closest to the transects and increases with increasing distance from the sample locations. This can be used as a quick check to confirm that all the appropriate sample data have been included in the kriging analysis and to identify areas where the confidence in the kriging results could be increased with additional sample data.

If desired, the anomaly density estimates and variance values can be exported to a file format that is compatible with the ESRI ArcGIS geographic information software system.

This is done by selecting “**Map > Map Layers > Export**” from the main VSP screen. This will provide options for exporting the current kriging estimates or the kriging variances. Maintaining the filename extension of “ASC” will provide direct recognition of the export file within ArcGIS. This export file format can be directly read into ArcGIS.

5. Delineating High Density Areas

As seen in Figure 37 there appear to be two main high anomaly density areas at the Pueblo Precision Bombing Range; one in the northern part of the site, and a larger area in the south. The anomaly density, transect coverage and kriging variance (Figure 38 and Figure 40) confirm that these areas are well sampled and contain a large number of magnetic anomalies. At this point, the anomaly density estimate map can be used as a tool to identify those high density areas which are probable former target locations.

The initial step in target area delineation is to focus the kriging anomaly density estimate so that only high-density locations are displayed. The results from this process are very similar to those obtained from the density flagging routine (see Section 3.2.3). The goal is to adjust the color range used to display the kriging results so that only those high-density areas that are likely target locations are displayed. This provides an interactive analysis technique that gives rapid feedback on the spatial extent of potential target areas. This process can be performed within VSP, or the kriging estimates can be exported and brought into ArcGIS for this analysis.

To change the kriging display within VSP, go to “**View > Kriged Data > Color Options.**” This will present a dialog box that will allow the user to change the minimum and maximum display values. Change the minimum display value to a value that is considered to be slightly above background. This will change the kriging data display to show only those values above the selected minimum. Changing the minimum display density is similar to setting the critical density in the VSP flagging routine (Section 3.2.3). Review of the spatial distribution of the kriging display will lead to refinement in this critical density value (see below). This interactive technique is iterative, thus allowing different critical density cutoff values to be investigated. A more automated technique is currently under development for inclusion into VSP.

To perform the critical density analysis within ArcGIS, first export the kriged density estimate data (see Section 4.3) to an ASCII file, and then import this file into ArcGIS. Once imported, the anomaly density data will be displayed as a color-shaded grid similar to that used in VSP. At this point, the display properties can be altered in a similar fashion to that used in VSP to control the critical density cutoff level. This process requires some familiarity with ArcGIS and how to control the symbology of the displayed layers.

Regardless of whether the target boundary identification is done within VSP or ArcGIS, the process of using critical density cutoff levels is similar. The process of investigation

of different cutoff levels is shown in Figure 41 through Figure 43. Figure 41 shows the anomaly density display resulting from using a critical density level that is too low to allow accurate delineation of specific target areas. In this figure, several compact high density areas (shown in red) are displayed, but they are surrounded by halos of irregularly shaped low density areas (shown in green). The irregular shape and discontinuous nature of these green areas indicates that they are more likely related to the background anomaly distribution at the site rather than to any concentrated munitions use which would be expected for a target area.

Figure 42 shows the anomaly density display resulting from using a critical density level that is too high to provide assurance that all the major target areas have been identified. In this figure several of the original compact higher density areas have been dropped from the display, including the high density area in the northern portion of the study area. In addition, the size of the high density area in the southern part of the Pueblo Precision Bombing Range site has been dramatically reduced.

Figure 43 shows the anomaly density display resulting from a more appropriate choice of anomaly density cutoff level. In this figure, the highest density areas are represented by continuous compact features (shades of yellow and red) that do not have excessive fingering around their perimeter. Several large high density areas can be readily identified as likely target areas. Additional smaller, low-density areas are also present, but the history of this site (i.e., an aerial bombing range) suggests that these areas are too small in scale to be considered as likely target areas. With the exception of the small, isolated low density areas, the areas shown in Figure 43 can be used as boundaries for delineating likely target areas.

As an example of how indicator kriging can be used in the delineation of high density areas, Figure 44 shows indicator kriging results for the Pueblo Precision Bombing Range using the same transect data as used to generate the anomaly density estimates shown in Figure 43. The example indicator kriging results shown in Figure 44 are based on investigating an anomaly density threshold of 40 ApA. The values shown in Figure 44 depict the probability of exceeding this threshold value. The color-shading shows those locations with a probability greater than 0.05 of being above the threshold value. There is less than a 5% chance of the anomaly density being equal to or greater than 40 ApA at any location with a grey color. This information could then be used in a probabilistic assessment of high density areas based on this threshold value. Other threshold values could also be investigated to aid in delineating the high density areas of concern.

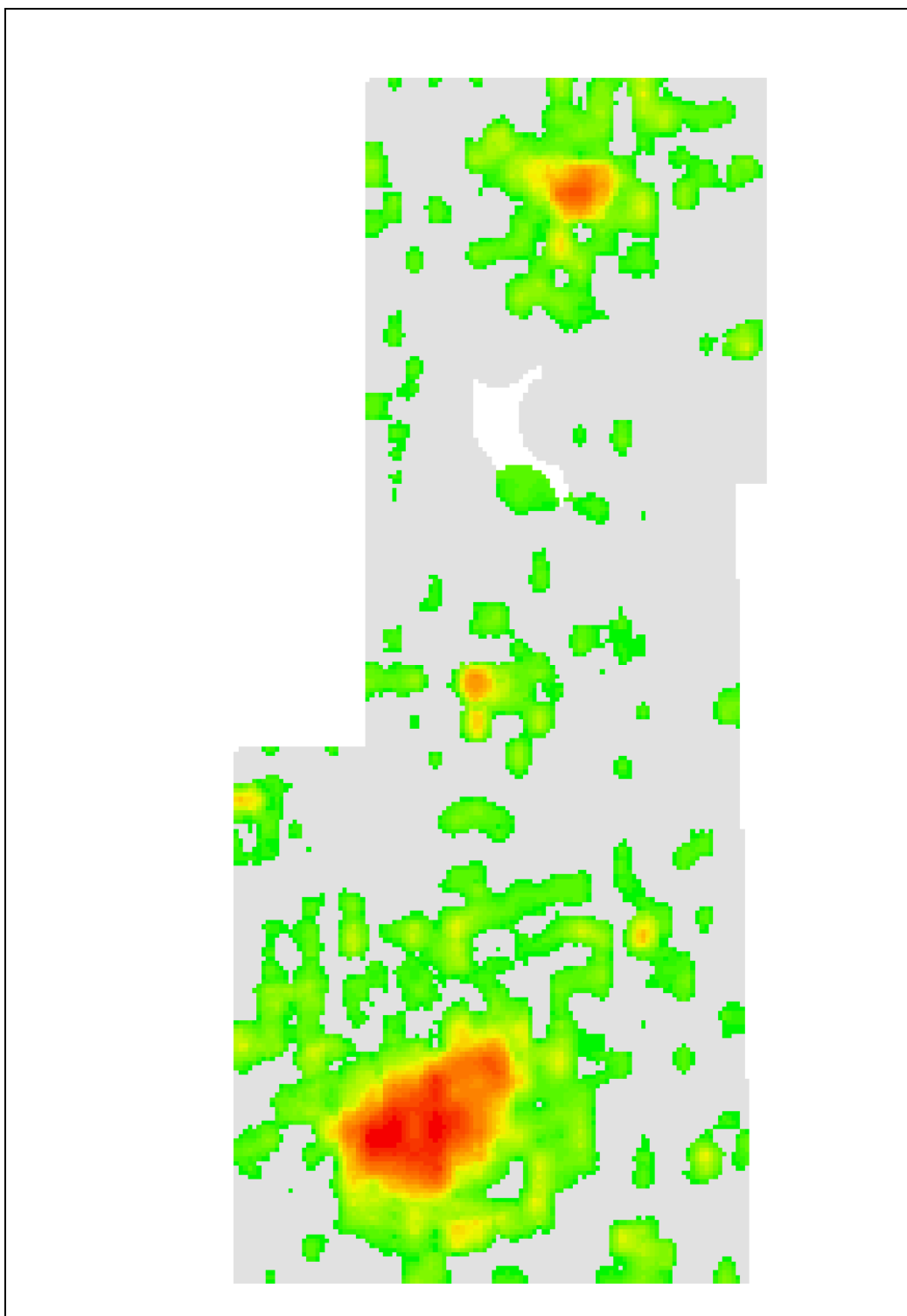


Figure 41. Anomaly density display for the Pueblo Precision Bombing Range WAA site resulting from selection of a critical density cutoff level that is too low. The highest anomaly density areas are shown in red, and the lowest density areas are shown in green. Gray areas show locations where the anomaly density is below the critical density.

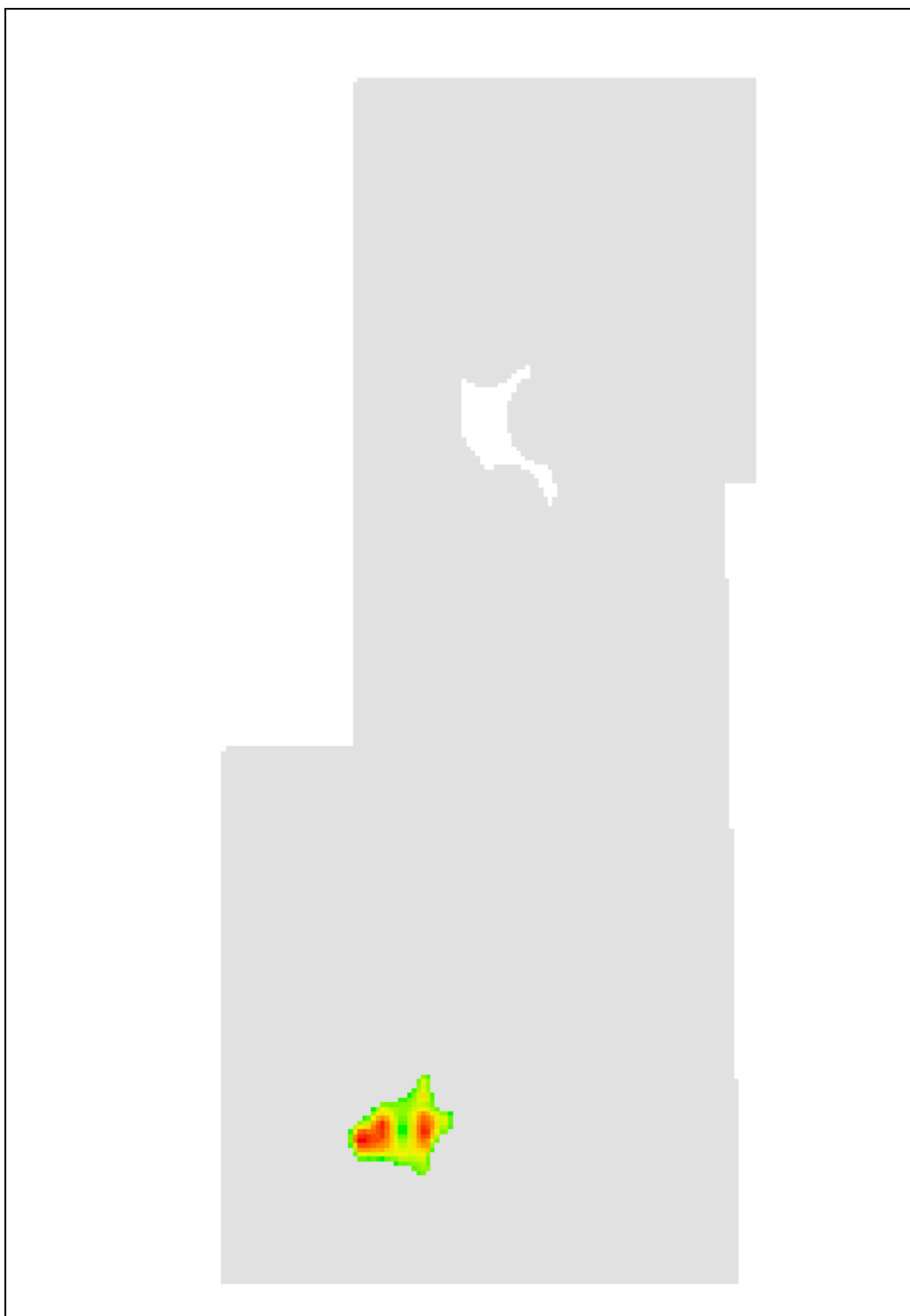


Figure 42. Anomaly density display for the Pueblo Precision Bombing Range WAA site resulting from selection of a critical density cutoff level that is too high. The highest anomaly density areas are shown in red, and the lowest density areas are shown in green. Gray areas show locations where the anomaly density is below the critical density.

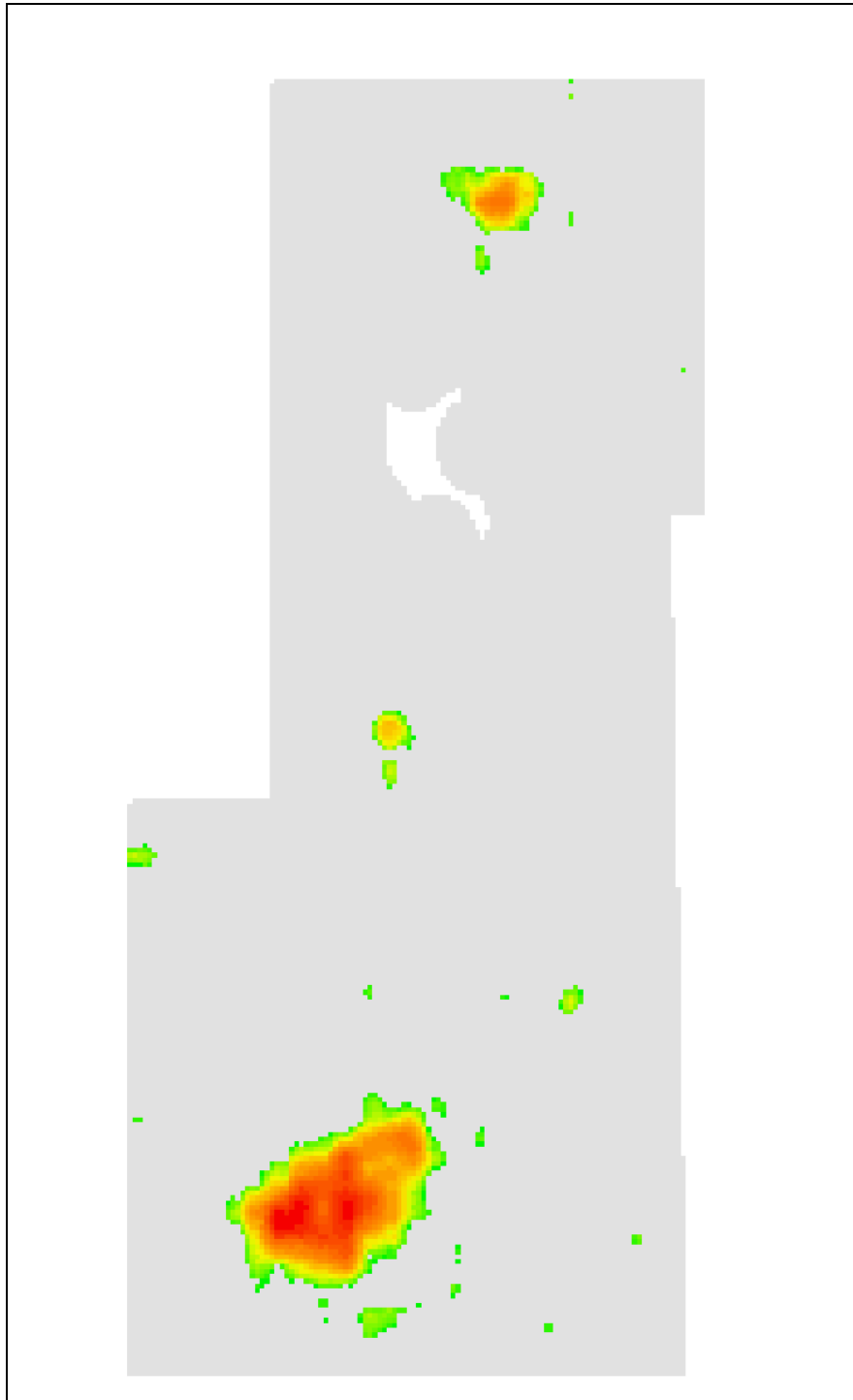


Figure 43. Anomaly density display for the Pueblo Precision Bombing Range WAA site resulting from selection of an appropriate critical density cutoff level. The highest anomaly density areas are shown in red, and the lowest density areas are shown in green. Gray areas show locations where the anomaly density is below the critical density.

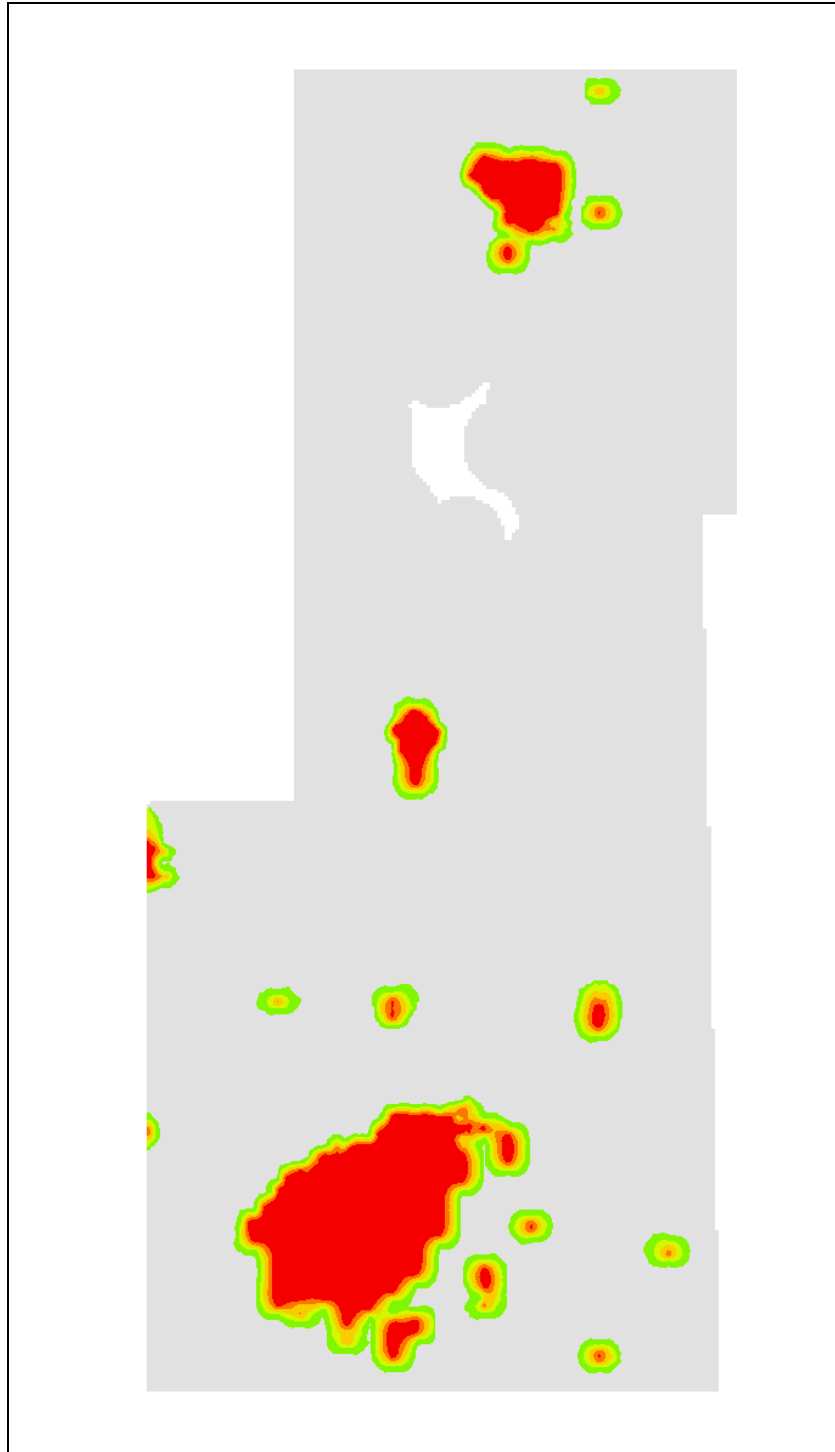


Figure 44. Example indicator kriging results using a threshold of 40 ApA. Color-shading depict probabilities of being above the threshold value. Value range for color-shading (green-red) is from 0.05 to 1.

6. Post-Survey Probability of Traversal

The “Post-Survey Probability of Traversal” dialog is shown in Figure 45. This dialog uses the COG data to identify any locations on a site where a target area of the shape defined in the “Target Zone” tab could be located and not traversed. The map shown in Figure 46 contains a small portion of the Victorville site described in Section 3.2.3. The points identified on this map are the center points where a 500-ft-diameter target area could be located and not traversed. As the “Detection Simulation” tab in Figure 45 shows, the transects within this area had an 82 percent probability of traversing all possible 500-ft-diameter target areas.

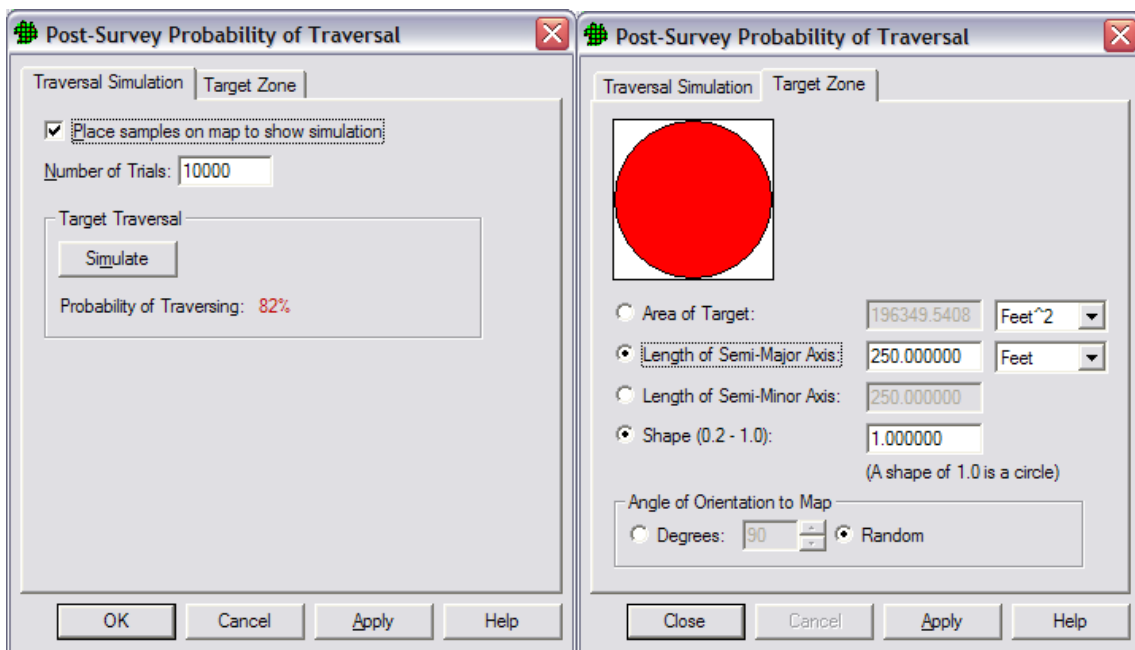


Figure 45. “Post-Survey Probability of Traversal” dialog used to assess the probability of traversal based on the actual transect survey. This dialog has the “Detection Simulation” tab (left) and the “Target Zone” tab (right).

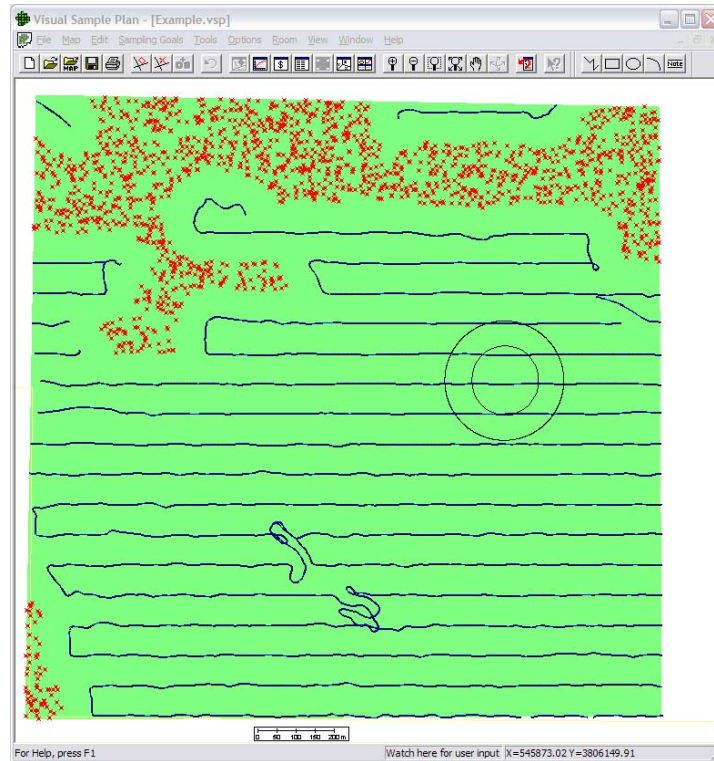


Figure 46. Example of the map view after clicking on the “Simulate” button on the “Detection Simulation” tab of the “Post-Survey Probability of Traversal” dialog.

7. Using VSP Analyses in Reports and External Software

Upon completion of a site analysis, the information within the VSP project file can be exported for use in external software or for use in reports. All the map information shown in Figure 27 can be exported using the ArcGIS SHP format. This option, which is found by selecting “**Map > Export > to SHP**” from the VSP menus, opens the export dialog shown in Figure 15. When exporting data from an analysis, all the files listed in Figure 15 will be checked. The user can clear the box for those files that do not need to be exported and click on the “File” button to change the location of the saved file. All the necessary files for use with external GIS software are included when the SHP file is created.

The data entry tab explained in Section 3.1 allows the imported COG and anomaly files to be exported from VSP to a file in ASCII format. These data are shown in Table 4. The dark black lines separate the three data sets. The COG data is on the left and has three columns. Two columns identify the X, Y locations and the third column identifies the GPS time. If no GPS time was provided in the imported file, that column will not be included in the exported file. VSP includes a blank line between each unique COG transect surveyed on the site. The anomaly file exported from VSP contains four columns as labeled and is shown in the center of Table 4. If a grid value is not associated with an X, Y coordinate in VSP, the Grid value column will be blank for that anomaly. If no anomaly locations have an associated value, that column will not be exported. The

last file shown in Table 4 is obtained by clicking the “File Data” button when the histogram dialog shown in Figure 47 is open. This dialog is found by clicking the “Find Targets” button within the VSP dialogs shown in Figure 18 and Figure 28. This file contains the X, Y location of the density grid centers, the density for each value shown on the histogram, and the number of windows used to derive the averaged density value. The number of windows indicates how many individual density estimates (i.e., transect grid densities) were averaged into that anomaly density value (see Section 3.2.2).

Table 4. Example of the COG file (left), the anomaly file (center), and the grid densities from the histogram dialog (right). Each of these files is provided in ASCII format.

VSP exported COG file			VSP exported anomaly file				VSP exported anomaly grid data file			
X	Y	GPS_Time	/Fiducial	X	Y	Grid_value	Density (Anomalies/Acre)	Windows	X	Y
543425.47	3810332.02	67944.6	0	543531	3810330	288.47	202.602	2	545422.14	3805507.29
543477.12	3810331.41	67946.6	1	545430.3	3810330.3	65.52	43.4406	2	545500.34	3805507.29
543545.98	3810333.1	67948.6	2	543588.5	3810330.8	126.93	0	1	545578.54	3805507.29
543623.68	3810332.12	67950.6	3	543598	3810330.8	57.83	0	2	545656.74	3805507.29
543688.31	3810331.74	67952.6	4	545353.5	3810330.8	187.65	102.544	2	545734.94	3805507.29
543753.7	3810330.25	67954.6	5	543590.5	3810331	82.60	156.454	1	545813.14	3805507.29
543837.39	3810332.92	67956.6	6	543685	3810331.3	66.30	80.7637	2	545891.34	3805507.29
543923.63	3810332.03	67958.6	7	543543.8	3810331.5	53.37	131.453	1	545969.54	3805507.29
544019.59	3810331.95	67960.6	8	543622.3	3810332	148.77	60.6845	2	546047.74	3805507.29
544123.79	3810332.85	67962.6	9	543688.8	3810332	69.05	3.36988	1	546125.94	3805507.29
544227.04	3810331.81	67964.6	10	543694.3	3810332	80.37	28.8424	2	546204.14	3805507.29
544332.54	3810331.23	67966.6	11	543696	3810332	88.87	64.6605	2	546282.34	3805507.29
544434.79	3810332.25	67968.6	12	543741.5	3810332	54.55	75.2976	1	546360.54	3805507.29
544546.7	3810331.92	67970.6	13	545456.8	3810332	50.66	75.7235	2	546438.74	3805507.29
544661.42	3810332.03	67972.6	14	543617	3810332.3	46.58	15.5402	1	546516.94	3805507.29
544777.96	3810332.13	67974.6	15	543732.8	3810332.5	58.44	85.9175	2	546595.14	3805507.29
544894.58	3810331.88	67976.6	16	543514	3810332.8	58.46	32.0518	1	546673.34	3805507.29
544999.14	3810332.04	67978.6	17	543719	3810333	127.30	49.9516	2	546751.54	3805507.29
545110.55	3810331.86	67980.6	18	543500.3	3810334.3	57.47	33.3487	1	546829.74	3805507.29
545232.15	3810332.18	67982.6	19	545665.5	3810252.3	69.80	49.5986	3	546907.94	3805507.29
545349.98	3810331.22	67984.6	20	543687.5	3810252.5	153.03	70.9009	2	546986.14	3805507.29
545437.88	3810331.04	67986.6	21	546339.5	3810252.8	51.59	66.1721	1	547064.34	3805507.29
545481.77	3810331.79	67988.6	22	544188.8	3810253.3	43.80	28.7683	2	547142.54	3805507.29
			23	545419.8	3810253.5	120.52	25.8045	1	547220.74	3805507.29
546439.79	3810251.52	68992.6	24	545635.3	3810253.5	81.48	32.8722	2	547298.94	3805507.29
546381.92	3810254.54	68994.6	25	545638.8	3810253.5	70.54	43.185	1	547377.14	3805507.29
546306.55	3810253.59	68996.6	26	546254.3	3810253.5	78.47	57.8358	2	547455.34	3805507.29
546220.09	3810253.93	68998.6	27	545410.5	3810253.8	60.96	32.3786	2	547533.54	3805507.29
546122.99	3810253.9	69000.6	28	546084.8	3810253.8	76.17	34.4028	2	542841.53	3805585.49

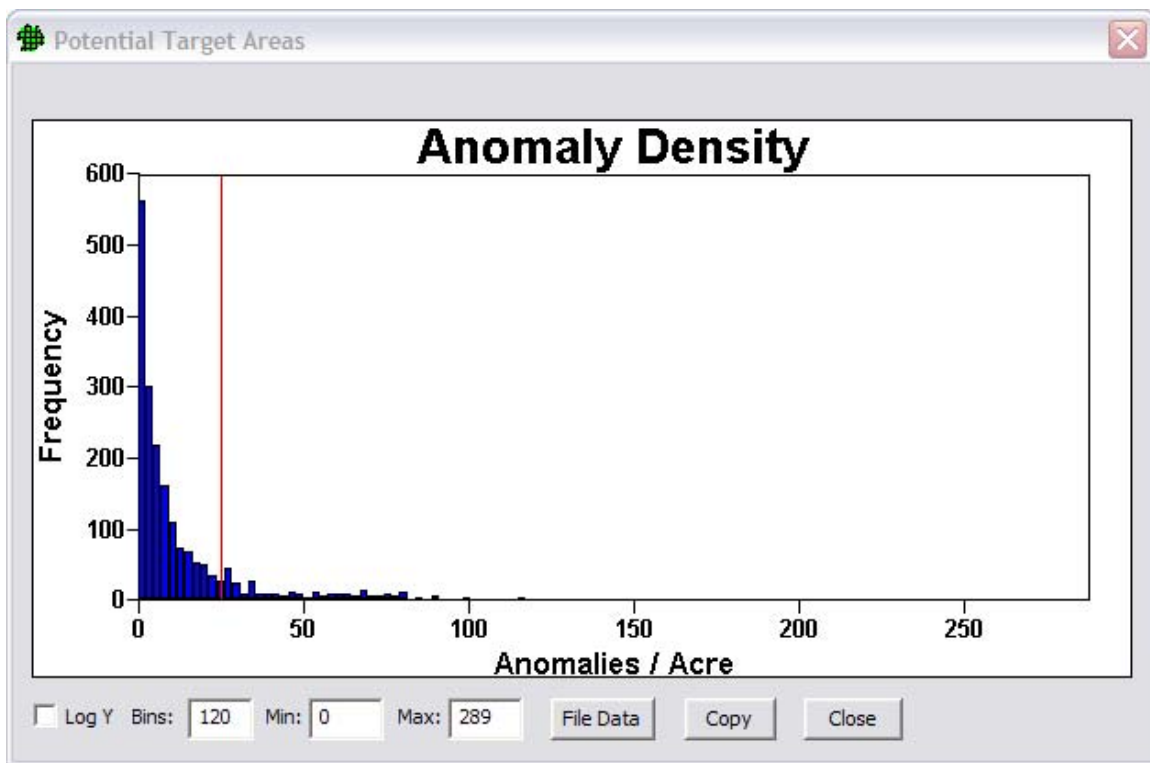


Figure 47. Example of histogram dialog that is opened when the “Find Targets” button is selected as shown in Figure 18 and Figure 28. The “file data” button allows the transect grid density information to be exported from VSP.

As explained previously, the anomaly density estimates from kriging analysis using the “Geostatistical mapping of anomaly density” dialog then can be exported to a file format that is compatible with the ESRI ArcGIS geographic information software system. By selecting “**Map > Map Layers > Export**” from the main VSP screen, the options for exporting the current kriging estimates or the kriging variances are provided. Maintaining the filename extension of “ASC” will provide direct recognition of the export file within ArcGIS. This export file format can be directly read into ArcGIS.

VSP also provides an automatically generated report for the three analysis dialogs that summarizes the inputs used to create the map shown in VSP. When “**Flag Areas with Density > Critical Density**” is selected on the “Locate and Mark UXO Target Areas Based on Elevated Transect Anomaly Density” dialog and the report button (highlighted in green in Figure 48) is selected, a report summarizing the primary inputs of the window diameter and critical density used to create the flagging map in the VSP project file are shown. The report associated with “Geostatistical Mapping of Anomaly Density” dialog is different and will provide the information needed to create the displayed geostatistical maps such as those shown in Section 4.3.

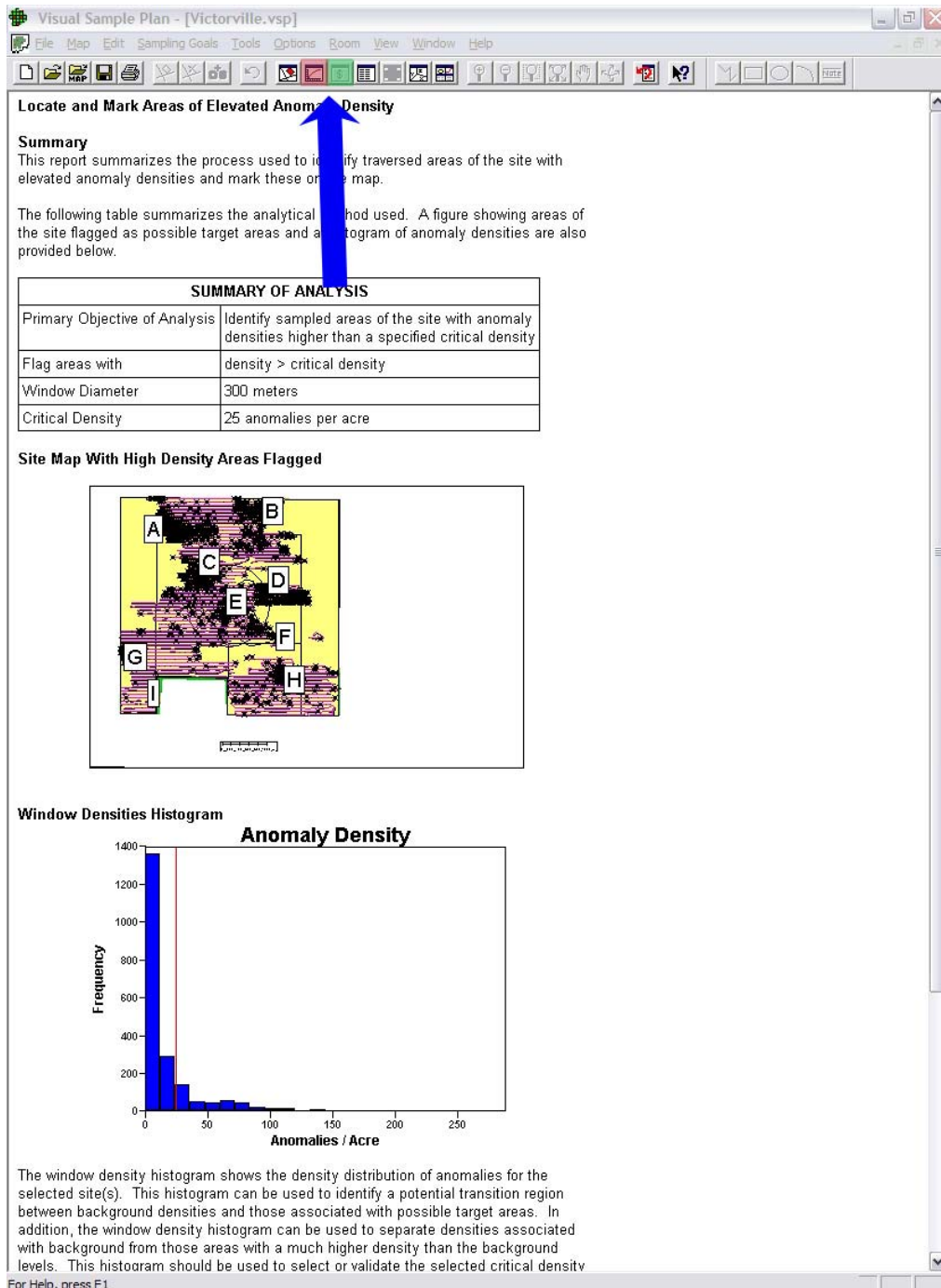


Figure 48. Example of report view in VSP. These reports can be seen by clicking the “Apply” button on the VSP dialog and then clicking the report button (highlighted in green). The graph view button (highlighted in red) provides an improved view of the VSP generated graphs. For the “Locate and Mark UXO Target Areas Based on Elevated Transect Anomaly Density” dialog, the graph view presents the histogram of transect grid densities.

8. Conclusions

The four sampling goal priorities during site characterization explained in this report are:

- 1) Transect design to ensure that target areas of concern are identified with a prescribed confidence level.
- 2) Flagging of potential target areas along the transects obtained at the site.
- 3) Mapping of the estimated anomaly density at all locations across the site based on the transect data and the model of spatial variation derived from those data.
- 4) Delineation of the target boundary from the anomaly density maps.

These four sampling and analysis goals are attained within VSP using the dialogues found under “**Sampling Goals > Find UXO Target Areas.**” The functionality within the VSP UXO modules will provide DoD and contractor users with a set of useful tools for transect design, target area identification and delineation, and anomaly density mapping and estimation. However, many additional features and functions are planned and will be added to improve usability in VSP.

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