Jul 1st, 12:00 AM

Visual Sample Plan (VSP): A Tool for Balancing Sampling Requirements Against Decision Error Risk

B. A. Pulsipher

R. O. Gilbert

J. E. Wilson

Visual Sample Plan (VSP): A Tool for Balancing Sampling Requirements Against Decision Error Risk

B.A. Pulsipher, R.O. Gilbert, and J.E. Wilson

Pacific Northwest National Laboratory, Richland, Washington, United States.

Abstract: Environmental characterization is necessary to support remediation and monitoring decisions and to construct and validate contaminant dispersion models. The more samples obtained, the greater is the protection against making incorrect decisions. However, taking too many samples wastes valuable resources. The US Environmental Protection Agency has developed several guidance documents on the Data Quality Objectives process to support systematic planning of data gathering campaigns to ensure that the right type, quality, and quantity of data are obtained to support confident decision making.

Visual Sample Plan (VSP) is a publicly available software tool sponsored by the US Department of Energy, US Environmental Protection Agency, and the US Department of Defence to support environmental characterization and confident decisions. VSP helps the user determine the optimal number and location of samples using defensible statistical sampling design methods and displays those locations on maps or aerial photos. Sample coordinates can be output for use with GPS systems. An automatic report summarizing the assumptions and parameter inputs is generated and can be included in a sampling and analysis plan. VSP features and capabilities will be outlined in this paper. VSP can be downloaded at no cost from http://dqo.pnl.gov/vsp.

Keywords: Statistical Sampling; Decision Risks; Data Quality Objectives; Confidence.

1. BACKGROUND

In the early 1990s, the US Environmental Protection Agency (EPA) and the US Department of Energy (DOE) embraced a systematic process for planning environmental characterization efforts called the Data Quality Objectives (DQO) process. The DQO process is a seven-step process that ensures that the right type, quality, and quantity of data are gathered to support confident environmental decisions [US EPA 2000]. The Pacific Northwest National Laboratory (PNNL) conducted DQO training and began an extensive pilot DQO development and implementation effort across the DOE complex. Many complex sites and facilities were selected for implementation of the DQO process with facilitation and statistical support provided. Although these DQO process pilots demonstrated significant cost savings (>$25M), streamlined regulator acceptance, and improved defensibility, once the pilots were completed, site personnel were often left without the necessary on-site statistical expertise required to perform additional DQO processes for other sites.

In an effort to support site needs for statistical tools that could be used to implement the quantitative statistical sampling design aspects of the DQO process, PNNL began developing Visual Sample Plan (VSP). VSP is a software tool based on the DQO process that specifically facilitates the last two steps of the DQO process, namely, Determining Acceptable Decision Error Tolerances, and Optimal Sampling Design.

The DQO process and VSP are applicable for a variety of environmental data gathering applications including characterization of soils, building surfaces, air, surface water, and groundwater. Currently specialized VSP modules are under development for unexploded ordnance detection, firing range contaminant spread bounding, and biological and chemical agent building decontamination.

2. WHAT IS VISUAL SAMPLE PLAN (VSP)?

Simply stated, VSP is a software tool that helps determine how many samples are needed at what locations to ensure confident decisions. The probability of making incorrect decisions based on less than 100% characterization and less than 100% accurate/precise measurements is explicitly managed using statistical methodologies. VSP has a map-based user-friendly visual interface and is designed for the non-statistician. It is focused primarily on sampling design but some modules also incorporate statistical analysis routines for analysing the data once it has been gathered.

There are many possible uses of data derived from environmental sampling that support various decisions. For example, data may be summarized by calculating the average (mean) and comparing that average against a contaminant regulatory threshold. Sampling objectives refer to these pre-defined purposes for gathering and summarizing data. VSP is organized around these possible sampling objectives. Some VSP sampling objectives include

- Compare an Average Against a Threshold.
- Compare an Average Against a Reference Average (Background)
- Compare a Proportion Against a Threshold
- Compare a Proportion Against a Reference Proportion
- Find a Hotspot
- Construct a Confidence Interval for a Mean
- Estimate the Mean
- Delineate a Contamination Zone Boundary
- Find and Delineate Unexploded Ordnance Target Areas
- Demonstrate Low Probability of Unexploded Ordnance Presence

There are also many statistical and non-statistical sampling design options that could be applicable for many of the sampling objectives listed above. Those incorporated into VSP include:

- Simple Random Sampling
- Systematic Grid Sampling (square, triangular, rectangular)
- Sequential Sampling
- Collaborative Sampling
- Rank-Set Sampling
- Adaptive Cluster Sampling
- Stratified Sampling
- Composite Sampling
- Judgmental Sampling
- Continuous Transect Sampling

A number of factors must be considered when determining sampling requirements. A discussion of the more common ones follows. One must choose the null hypothesis; that is, decide whether to assume that the site is contaminated until proven clean or assume that the site is clean until proven contaminated. Defining acceptable probabilities for concluding that the site is contaminated if it is really clean or concluding that the site is clean if it is indeed contaminated is an important input as well. Measurement uncertainty and sampling variations relative to the decision threshold values for the parameter of interest will also affect the sampling and analysis requirements. The assumed statistical distribution (normal, lognormal, etc.) affects sampling requirements and cost or feasibility must also be considered. These factors are all incorporated within VSP to develop the optimal sampling strategy.

3. KEY FEATURES OF VSP

3.1 Maps, Areal Photos, Floorplans, Drawings

Visualization of the sample design and diagnostic graphics are important features that help the user quickly evaluate the sampling scheme. Maps can be imported into VSP as .DXF (Autocad) or .SHP (ArcView) files. Figure 1 shows a site map that was originally created as a .DXF file and imported into VSP.

Site maps can also be created within VSP using the drawing tools. Similarly, two dimensional floorplans of buildings can be imported and rooms or zones selected for sampling. Rooms can also be interactively drawn and laid out in two dimensions. Figure 1 also illustrates how areas within the maps or floorplans can be designated as the areas where samples will be taken. Aerial photos can also be imported or overlaid and aligned with site maps.

3.2 Decision Error Tolerances and User Specified DQO Input Dialog Boxes

As mentioned previously, a number of factors affect sampling requirements. A typical user dialog box that allows user-specified DQO and cost parameters is depicted in Figure 2. When these factors and parameters are defined, the number of samples can be calculated. For example, Figure 2 is the dialog box for comparing the average contaminant concentration to some decision threshold (action level). Suppose the

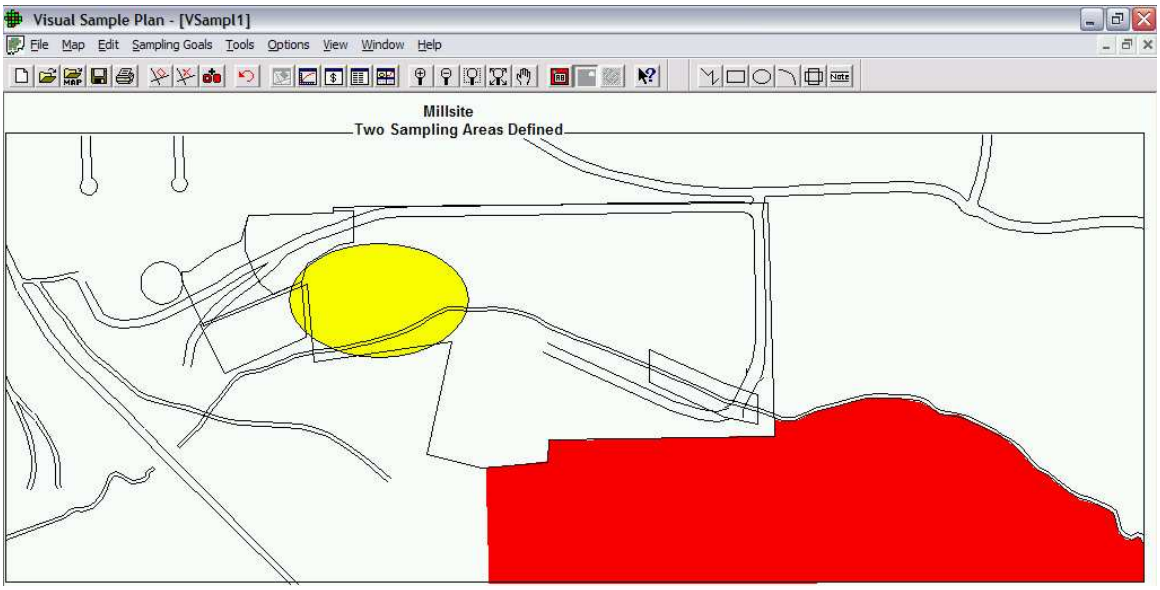

Figure 1. Site Map Depicting Two Sample Areas

action level for this particular contaminant were 10 ppm, and the standard deviation were 3 ppm. If we wanted no more than a 5% chance of concluding that the site was clean if the true contaminant concentration were equal to or greater than the action level (alpha=0.05) and we wanted no more than a 15% chance of concluding that the site is clean if the true contaminant concentration were equal to or less than 8 ppm (beta=0.15), then we would need to take 18 samples to meet these desired decision error thresholds.

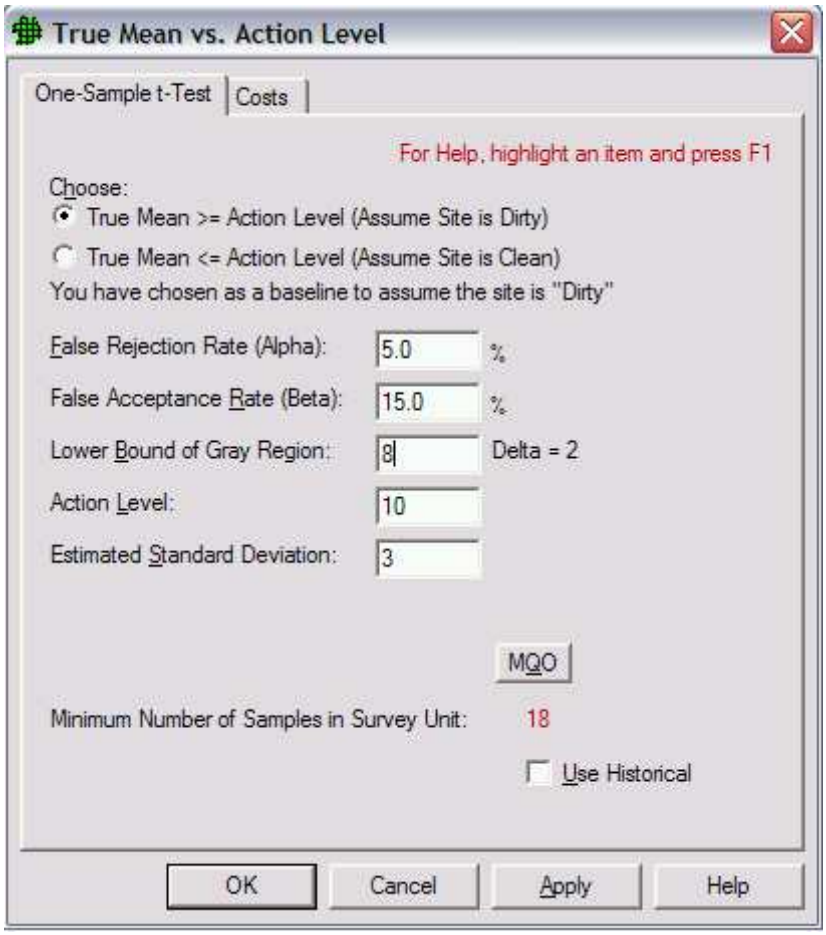

Figure 2. Typical VSP Dialog Box

The dialog boxes and input parameters will be different depending upon the sampling objective and the statistical sampling methodology.

3.3 Diagnostic Interactive Graphics

The Decision Performance Goal Diagram (DPGD) is a visual aid for assessing the performance of a particular sampling scheme relative to the achieved decision error probabilities. This diagram is akin to what statisticians refer to as the power curve. Figure 3 illustrates a typical DPGD that is automatically generated within VSP.

For the DPGD shown in Figure 3, the red vertical line is the action level. The curved red line is the probability of concluding the site is contaminated if the true contaminant concentration were the value along the horizontal axis. The blue horizontal dashed lines indicate the user-defined acceptable decision error probabilities. The standard deviation is indicated as the length of the green line. These VSP DPGDs are interactive such that the user can change key parameters by clicking and dragging with the mouse any of the lines representing key parameters (alpha, beta, std. dev., or grey region) and immediately see the effect on sample requirements.

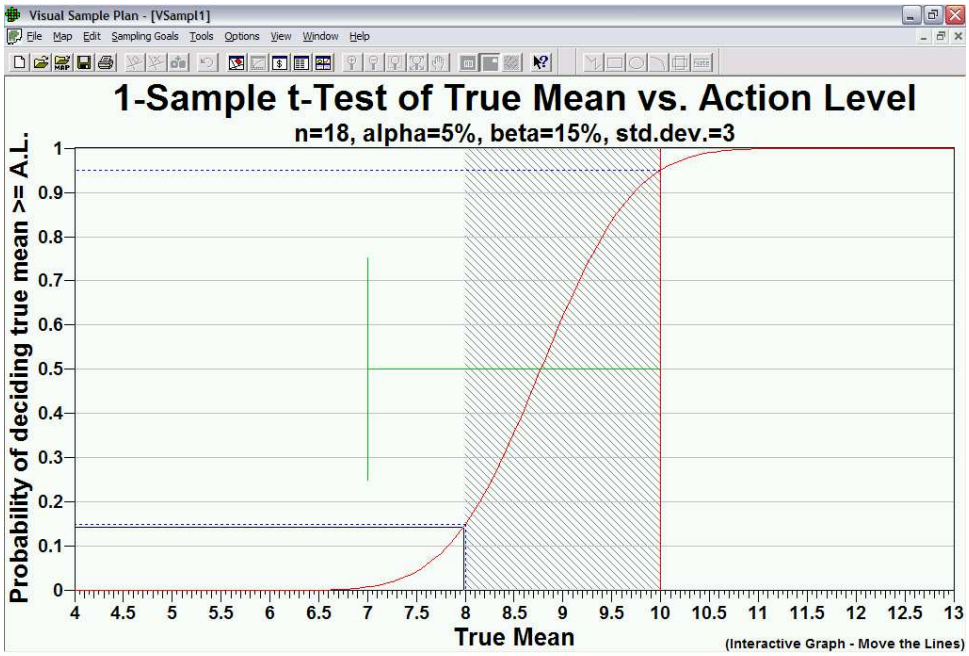

Figure 3. Decision Performance Goal Diagram

Another example of VSP graphical functions is shown in Figure 4. This figure depicts the changing sample mean for sequential sampling and shows whether one can conclude with confidence that the site is either dirty (mean in red zone) or clean (mean in green zone) or whether additional samples are required (mean in yellow zone).

Other diagnostic graphics exist for the various sampling objectives and statistical approaches.

3.4 Report Generator and Sensitivity Analyses

To preserve the integrity and defensibility of VSP output and facilitate documentation of the derived sampling plans with all inherent assumptions and calculations, VSP automatically generates an electronic report. This report contains the following information about the sampling design that was generated and chosen within VSP.

- Site summary including sample area size, sampling objective, decision rule, hypotheses, and number of samples required.
- Site map/photo, floorplan, room, or drawing.
- Sample location coordinates.
- Selected sampling objective and approach.
- Equations used for calculating sampling requirements.
- Selected DQO parameters
- Decision Performance Goal Diagram or other diagnostic graphics.
- Statistical assumptions
- Sensitivity analysis table
- Cost summary
- Recommended data analyses.

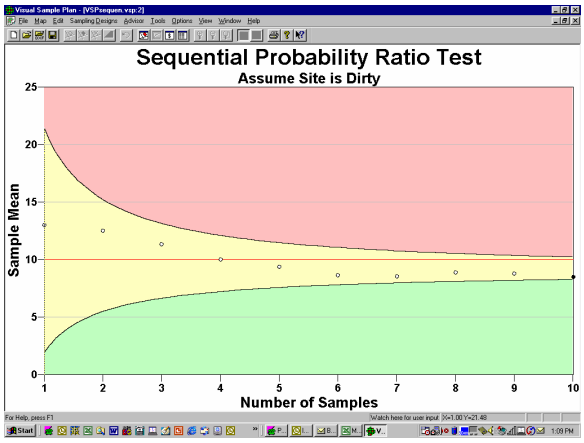

Figure 4. Control Chart Graphic for Sequential Sampling.

This report can be cut and pasted into a Quality Assurance Project Plan (QAPP) or a more extensive sampling and analysis plan.

Within VSP's automatic report generator, a customized sensitivity analysis table can be created. Figure 5 illustrates such a sensitivity analysis table that was generated within VSP for the example shown in sections 3.2 and 3.3.

3.5 Other VSP Features

There are many other VSP features that cannot be illustrated within this paper. Some of those features include

- Output of x,y sample location coordinates for use with GPS systems
- Location of largest un-sampled areas
- Performance of statistical hypothesis tests using gathered data for some modules
- Non-parametric statistical methods for non-normally distributed data
- Online help functions including documentation of calculation methods
- User's Manual
- Separate handling of measurement uncertainty and sampling variation (MQO options).
- Assessments of effectiveness of geophysical characterization through meandering pathways

VSP is an integrated tool that allows simultaneous viewing and evaluation of statistically based sampling schemes. Figure 6 depicts a VSP screen capture showing the site map, diagnostics graphics, report generator, and sample coordinate locations all on a single screen.

4. CONCLUSIONS

A systematic planning process such as the Data Quality Objectives process is critical to ensure that the right amount of data of sufficient quality are obtained to support confident decision making. Sampling design is an inherently statistical issue that requires explicit management of decision risks. Visual Sample Plan is a software tool that helps the user develop statistically defensible sampling strategies while managing the uncertainties associated with sampling and analyses.

VSP is an evolving environmental characterization and analysis software package designed for the non-statistician. The visualization features permit quick assessments of the adequacy of proposed sampling approaches. The interactive features allow stakeholders to quickly evaluate the tradeoffs between alternative sampling plans through the examination of costs, risks of decision errors, measurement uncertainties, and decision criteria.

5. ACKNOWLEDGEMENTS

The authors acknowledge the many contributions of the other members of the VSP software development team including Deb Carlson, Bob O'Brien, Nancy Hassig, Rick Bates, and Craig McKinstry. We also wish to thank Luci Walker and Nell Cliff for their tremendous administrative and secretarial support. Finally we wish to acknowledge the excellent continued support of sponsors of VSP including DOE-EM, EPA-OSWER, EPA-OEI, DoD SERDP, DoD NAVSEA, and DHS-TSWG.

Number of Samples / Sampling Cost ($)							
AL=10		α=5		α=10		α=15	
		S=6	S=3	S=6	S=3	S=6	S=3
LBGR=90	β=10	310 / 156000.00	79 / 40500.00	238 / 120000.00	60 / 31000.00	194 / 98000.00	49 / 25500.00
	β=15	261 / 131500.00	67 / 34500.00	195 / 98500.00	50 / 26000.00	156 / 79000.00	40 / 21000.00
	β=20	224 / 113000.00	57 / 29500.00	164 / 83000.00	42 / 22000.00	128 / 65000.00	33 / 17500.00
LBGR=80	β=10	79 / 40500.00	21 / 11500.00	60 / 31000.00	16 / 9000.00	49 / 25500.00	13 / 7500.00
	β=15	67 / 34500.00	18 / 10000.00	50 / 26000.00	13 / 7500.00	40 / 21000.00	11 / 6500.00
	β=20	57 / 29500.00	16 / 9000.00	42 / 22000.00	11 / 6500.00	33 / 17500.00	9 / 5500.00
LBGR=70	β=10	36 / 19000.00	10 / 6000.00	28 / 15000.00	8 / 5000.00	23 / 12500.00	6 / 4000.00
	β=15	31 / 16500.00	9 / 5500.00	23 / 12500.00	7 / 4500.00	18 / 10000.00	5 / 3500.00
	β=20	27 / 14500.00	8 / 5000.00	19 / 10500.00	6 / 4000.00	15 / 8500.00	5 / 3500.00

S = Standard Deviation
LBGR = Lower Bound of Gray Region (% of Action Level)
β = Beta (%), Probability of mistakenly concluding that μ > action level
α = Alpha (%), Probability of mistakenly concluding that μ < action level
AL = Action Level (Threshold)

Figure 5. VSP Sensitivity Analysis Table

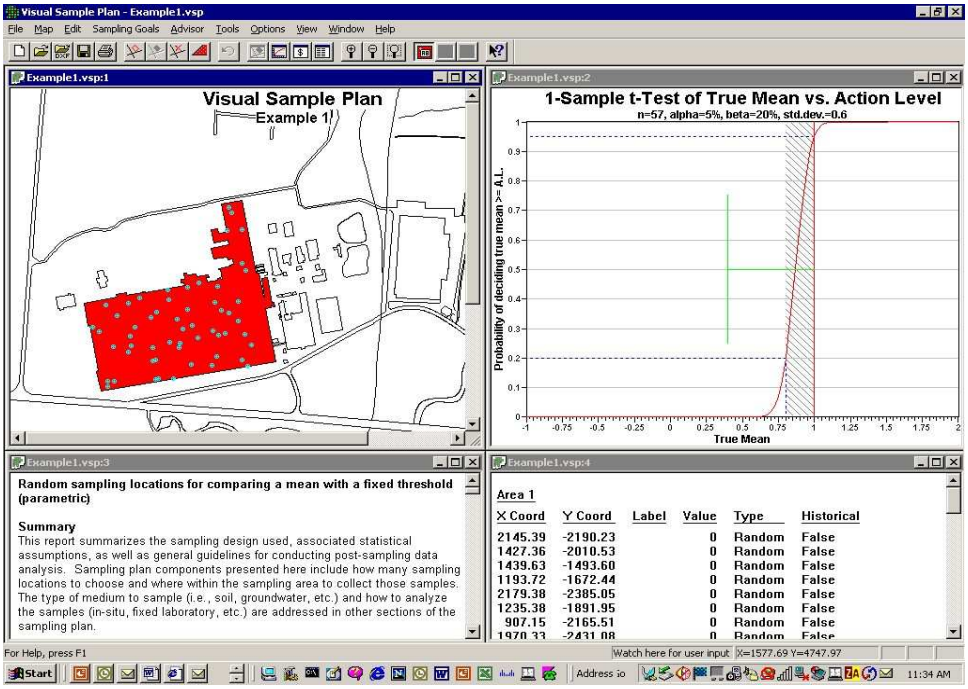

Figure 6. VSP 4 Panel Screen Shot

6. REFERENCES

Hassig, N.L, et al., Visual Sample Plan Version 2.0 User's Guide, PNNL-14002, Pacific Northwest National Laboratory, Richland, WA, USA, 2002.

Gilbert, R.O., et.al., Version 2.0 Visual Sample Plan (VSP): Models and Code Verification, PNNL-13991, Pacific Northwest National Laboratory, Richland, WA, USA, 2002.

Gilbert, R.O. et. al., Version 2.0 Visual Sample Plan (VSP): UXO Module Code Description and Verification, PNNL-14267, Pacific Northwest National Laboratory, Richland, WA, USA, 2003.

Gilbert, R.O., *Statistical Methods for Environmental Pollution Monitoring*, John Wiley & Sons, Inc., New York, 1987.

US EPA, Guidance for the Data Quality Objectives Process, QA/G-4, EPA/600/R-96/055, US Environmental Protection Agency, Washington, DC, 2000.

US EPA, Guidance for Choosing a Sampling Design for Environmental Data Collection, QA/G-5S, US Environmental Protection Agency, Washington, DC, 2001.