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# SURFACE SAMPLING TO DETECT HOT SPOTS PRESENTING UNACCEPTABLE HUMAN HEALTH RISK

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## ABSTRACT

An equation is presented which may be used to estimate the minimum number of sampling locations required to detect a surface hot spot which presents an unacceptable human health risk. A second equation provides a means of calculating the number of sampling locations required to assure adequate representation of a hot spot for average site concentration calculation. The number of samples required is shown to be dependent on a preselected contaminant concentration which may represent the detection limit of an analytical technique. It also depends on the maximum expected site contaminant concentration, and a risk-based allowable average site concentration.

The equations focus the user on the problem variables resulting in a better understanding of the uncertainties involved in identifying conditions representing unacceptable human health risk. They may be used directly to calculate the surface sampling requirements which reasonably assure detection and representation of significant hot spots.

## INTRODUCTION

Identifying conditions which present an unacceptable risk to human health is paramount to environmental site investigations. The required number of surface soil samples collected is frequently determined by arbitrarily selecting the "hot spot" size and applying basic statistical concepts to assure detection with adequate confidence. The method of selecting hot pot size varies from site to site and often is selected to represent the reasonable size of a contaminant spill. It is based on historical records or observations. This approach does not attempt to assure detection of a hot spot which represents a human health risk.

The term "significant hot spot" is introduced to describe a hot spot which presents an unacceptable human health risk.

An equation is presented which estimates the minimum number of randomly collected samples required to detect a significant hot spot. A smallest hot spot which potentially poses an unacceptable risk to human health is hypothesized and sought.

The number of samples is dependent on a preselected contaminant concentration, which may represent the detection limit of an analytical technique, and the maximum expected contaminant concentration at the site. It also depends on the minimum acceptable average concentration which would result in a threat to human health .

Detecting the presence of a hot spot which may present a human health risk is essential, however, average site concentrations are often sought for risk assessment. These values are generally obtained by composite sampling. An equation is presented to accommodate this need. It yields the number of randomly collected specimens required to reasonably assure that a specified number of them are obtained from within a significant hot spot. A better estimate of the average site concentration is obtained as the number of specimens increases.

Many site and exposure conditions are simplified for mathematical convenience. These simplifications are discussed so the reader may develop an understanding of the uncertainties involved in the analysis. The derivation of presented equations is beyond the scope of this paper. An in-depth discussion of equation derivation is scheduled to be presented at the First International Conference on Geotechnical and Environmental Engineering and included in the proceedings (1).

## SAMPLING TO DETECT A SIGNIFICANT HOT SPOT

The term significant hot spot refers to a hot spot which presents an unacceptable health risk. Herein, it is defined as a hot spot which, by itself, causes the average exposure unit concentration to be greater than some acceptable risk-based value, $C_{index}$. An exposure unit is the smallest area containing hot spots of contamination to which a person may be exposed.

The definition of significant hot spot inherently implies that a person may randomly encounter the hot spot many times before acquiring an unacceptable dose of contaminant. This is not expected to be a permissible assumption for all sites or

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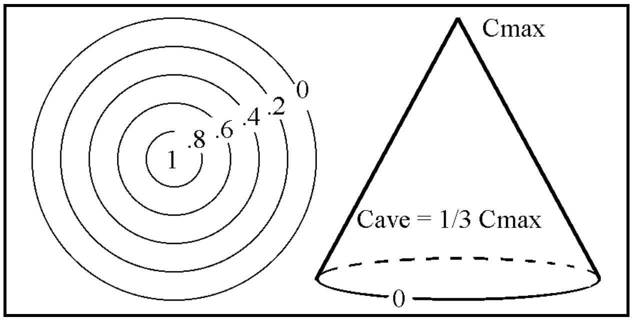


**Figure 1**. Conceptual Hot Spot Model. Contours of Concentration Normalized with respect to $C_{max}$.

contaminants. Consequently, the number of samples calculated to find significant hot spots must be considered a minimum sampling requirement.

A significant hot spot must exhibit a contaminant concentration distribution. Any reasonable distribution could be selected. All distribution models would require some definition of a maximum concentration. Figure 1 presents a conceptual hot spot model which accommodates reasonable boundary conditions, i.e. it has a maximum concentration located in its interior and is limited in extent. This simple model is used to represent a significant hot spot. The smallest significant hot spot is determined by estimating the maximum contaminant concentration which could reasonably exist in the exposure unit, $C_{max}$, then calculating the hot spot area which would cause the average exposure unit concentration to be greater than $C_{index}$.

It can be argued that the conceptual hot spot is not conservative and therefore inappropriate. However, it is expected that the larger uncertainty involved in estimating $C_{max}$ surpasses the magnitude of uncertainty associated with using the simple conceptual model. In either case, any model can be selected and the derivation modified to fit.

It is desired to assure that a significant hot spot is not left undetected in an exposure unit. Consequently, the number of surface soil samples is sought which assures that at least one sample will be obtained from within a significant hot spot at a detectable concentration, $C_d$. Surface soil samples may be point samples or composite samples with very small sampling support relative to the size of a significant hot spot. $C_d$ may be a value equal to or greater than the detection limit of the analytical method selected to evaluate contaminant concentration.

The number of randomly collected samples required to assure that at least one sample is obtained from within the detectable area of a significant hot spot with 1-α confidence is given by:

$$= \frac{\log(\alpha)}{\log(1-3\frac{C_{index}}{C_{max}}(1-z\frac{C_{index}}{C_{max}})^2} \qquad \textbf{(1)}$$

where

$$z = \frac{C_d}{C_{index}}$$

Equation 1 is valid for values of z less than 4/9 and

$$3\frac{C_{index}}{C_{max}}(1-z\frac{C_{index}}{C_{max}})^2<1$$

These mathematical limits result from the need to assure that the hot spot size be restricted to the size of the exposure unit and calculated values of N decrease as $C_{max}$ approaches $C_{index}$ (1).

Values of z greater than 4/9 can be used, however, a staged sampling plan is required. This condition is expected when screening technologies are used to detect hot spots. Large significant hot spots which have maximum concentrations less than $3C_d$ may be missed when z is greater than 4/9. This problem is easily overcome by testing a limited, randomly selected, number of samples using an analytical method having a lower detection limit. Equation 1 may be used to determine the second stage sampling requirements by setting $C_{max}$ equal to three times the value of $C_d$ used in the first stage, $C_{d1}$. $C_{index}$ remains the same and z is calculated using the detection limit, $C_d$, of the second stage analytical testing procedure, $C_{d2}$.

## AVERAGE EXPOSURE UNIT CONCENTRATION

The average concentration of an exposure unit is often sought to perform risk assessments. Equation 1 assures with 1-α confidence that at least one sampling event occurs in the detectable region of a significant hot spot. It is unreasonable to assume that the average of all sample concentrations would guarantee adequate representation of exposure unit average concentration with similar confidence.

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To obtain a reasonable representation of the average exposure unit concentration, a composite sampling program is recommended. The number of composite samples may be considerably less than the number of samples used to detect a hot spot. However, the number of specimens collected may be several times greater.

A significant hot spot must be adequately characterized by specimens collected as part of the composite sampling program to assure accurate portrayal in the average exposure unit concentration. The following equation relates the number of specimens which must be randomly collected in a composite sampling program, M, to the value of N from equation 1.

$$\frac{\log \sum \left( \frac{M!}{(i!(M-i)!)} (p)^{i} (1-p)^{\prime} \right.}{\log(1-p)} \quad (2)$$

where i is the desired number of specimens to be collected from within the hot spot minus one; the summation is with respect to i; and p is equal to $3C_{index}/C_{max}$. The confidence, 1-α, used to calculate N is also applicable to the calculation for M. The user must select the minimum desired number of specimens to be obtained from the smallest significant hot spot, i+1. Confidence in the calculated average exposure unit concentration may be no greater than the confidence associated with estimating the average concentration of the smallest significant hot spot with i+1 specimens.

An iterative approach must be used to solve for M given N. This involves guessing M, solving for N, improving the guess of M and again solving for N. The process is repeated until the selected value of M yields the desired N. A BASIC computer program which solves equation 2 is presented in the appendix.

## EXAMPLE

The following hypothetical situation exemplifies the use of equations 1 and 2.

An old transformer storage site in the midst of a national park has potential PCBs hot spot contamination. The site is approximately 25 acres and it has been 15 years since transformers were stored there. Historical record review, site inspection, and cursory analyses estimating the extent of the PCBs volatilization and leaching are conducted. It is concluded that the maximum expected value of PCBs, $C_{max}$, that could exist at this time is approximately 4000 mg/kg. A casual risk assessment estimates that a hot spot which causes the site average concentration to be greater than 10 mg/kg, $C_{index}$, would represent an unacceptable risk.

A three stage program is used to assure that adequate information is obtained for risk assessment. Stage 1 will detect small hot spots having high PCBs concentrations whereas stage 2 will find large hot spots having low concentrations. A third stage will consist of a composite sampling program to be used to determine the average site concentration. It is desired to have a minimum of 5 specimens (i=4) obtained from the smallest significant hot spot. Ninety-five percent confidence is desired.

A PCBs surface soil screening using an analytical method with a 50 mg/kg detection limit, $C_{d1}$, is used for stage 1. A laboratory analytical method with a detection limit of 1 mg/kg, $C_d$, is used for stages 2 and 3.

Equation 1 is used to calculate that 408 sample locations are required to be screened for stage 1. Stage 2 sampling requirements are calculated using equation 1 by setting $C_{max} = 3C_{d1} = 150$ mg/kg and $C_d=C_{d2}$. Stage 2 requires 14 samples be tested using the laboratory analytical procedure.

Equation 2 is used to calculate the stage 3 composite samples specimen requirement. The number of composite specimens required, M, is determined by trial and error using the computer program presented in the appendix. Composite samples should incorporate 1234 specimens.

It is decided to perform stage 1 screening on a 50 ft. grid having a randomly selected origin. This will result in approximately 440 stage 1 point samples. Grid sampling was selected instead of random sampling for simplicity. Samples will be obtained at 14 randomly selected locations to determine PCBs concentration by the laboratory method. This will accommodate stage 2 data needs.

Twenty-five composite samples will be collected each consisting of fifty specimens, two randomly selected specimens from each of the sites 25 subdivided acres for 1250 stage 3 specimens. The selection of 25 composites samples was arbitrary for this example.

The average of the composite sample specimens is expected to provide a reasonable estimate of the site average concentration even for the condition of a smallest single significant hot spot. If no significant hot spots exist on the site then the calculated mean is expected to be less than $C_{index}$. The variance of the composites will provide an estimate of the accuracy with which the mean may be estimated. It is considered unreasonable for composite sampling to indicate a mean concentration greater than $C_{index}$ without point samples identifying significant hot spots. If this happens, the conceptual model is probably in error and the sampling program needs would require reevaluation.

The need to characterize individual hot spots for risk assessment purposes will be determined after the proposed sampling and analyses are complete.

## CONCLUSION

An equation is presented which permits the calculation of the number of surface samples required to assure detection of a hot spot which may pose a threat to human health. A second equation permits the calculation of the number of composite sample specimens required to assure a specified number are from a significant hot spot. The equations may be modified and adjusted to meet the specific needs of the user. It is expected that the numerous simplifying assumptions will provide a basis for discussion and future improvement. Understanding how the selected variables influence sampling density will assist the user in developing an adequate sampling program.

These equations may be solved to estimate minimum sampling requirements or used to help understand the representation of a proposed sampling plan.

The presented method considers only a single contaminant, however it can be used with multiple contaminants. A discussion of the equations use with multiple contaminants is expected to be presented in a subsequent paper (1).

## BIBLIOGRAPHY

(1) Gemperline, M. C. 1994. Surface Sampling to Detect Unacceptable Human Health Risk, Proc. of the First International Congress on Environmental Geotechnics, July 10-15, 1994, Edmonton, Canada.

## APPENDIX: BASIC COMPUTER PROGRAM FOR SOLUTION TO EQUATION TWO

The following BASIC language computer code solves equation 2 for N. The user must provide appropriate values of M, i, and p.

```
DECLARE SUB fact (value!, factM!, exponent!)
M = 1234
i = 4
p = 3 * 10 / 4000
sum = 0
FOR j = 0 to i
  value = M
  CALL fact(value, factM, exponent)
  A1 = factM
  A2 = exponent
  value = j
  IF j = 0 THEN
   exponent = 0
   factM = 1
  END IF
  IF j < > 0 THEN CALL fact(value, factM, exponent)
  B1 = factM
  B2 = exponent
  value = M - j
  CALL fact(value, factM, exponent)
  C1 = factM
  C2 = exponent
  Denom1 = B1*C1
  Denom2 = B2+C2
  Div1 = A1 / Denom1
  Div2 = A2 - Denom2
  Fraction = Div1 * 10 ^ Div2
  sum = sum + (Fraction*p^j*(1-p)^(M-j))
NEXT J
N = LOG(sum) / LOG(1-p)
PRINT N
END

SUB fact (value, factM, exponent)
factM = 1
exponent = 0
FOR k = 1 to value
  fact M = fact M * k
  test = 0
100
  IF factM > 10 THEN
   factM = factM / 10
   exponent = exponent +1
   IF factM > 10 THEN test = 1 ELSE test = 0
  END IF
IF test = 1 THEN GOTO 100
NEXT k
END SUB
```