SAMPLING DESIGNS FOR VERIFICATION OF CLEANUP AT PCB SPILL SITES

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Various sampling designs are considered for use in verifying that a PCB spill site is adequately free from contamination. The selected design is a hexagonal grid of equilateral triangles; comparisons with competitors are given. We then consider extension to compositing, or grouping, of samples followed by individual analysis if the group level is in an indeterminate range. Properties of the compositing schemes' effectiveness and efficiency are found through simulation (directly for some cases). It is found that compositing of the samples, which are measured on a continuous scale, is superior to individual sampling in many instances, and is uniformly better under some conditions. The results could be useful to many other field sampling problems.

1. INTRODUCTION

As part of the ban on polychlorinated biphenyls (PCBs) enacted into law in the Toxic Substances Control Act, the Environmental Protection Agency (EPA) is responsible for ensuring the control and cleanup of PCB spills, especially those posing a substantial risk to human health or the environment. After a spill has occurred and cleanup by the responsible party has taken place, it is the role of EPA to verify for certain selected sites that cleanup has been adequate, and to order remedial action if necessary. An important aspect of the cleanup verification process is planning how to sample the site, and the present paper addresses this and related problems.

It was decided [1] that the quantity of interest in verifying cleanup is the maximum PCB concentration at the spill site. That is, cleanup is considered inadequate and recleaning of the site required, if even one sample taken shows PCB levels above an allowable limit. Therefore, "hot spots" rather than average PCB levels at the site are of concern.

Two types of error traceable to sampling and analysis are possible. The first is a false positive, i.e., concluding that PCB's are present at levels above the allowable limit when, in fact, they are not. The false positive rate for the present situation should be low, because an enforcement finding of non-compliance must be legally defensible; that is, a violator must not be able to claim that the sampling results could easily have been obtained by chance alone. The second type of error possible is a false negative, i.e., failure to detect the presence of PCB levels above the allowable limit. The false negative rate will depend on the size of the contaminated area and on the level of contamination. For large areas contaminated at levels well above the allowable limit, the false negative rate must, of course, be low to ensure that serious violators are caught. The false negative rate can be higher for slightly contaminated areas or for small areas. In the extreme case, no sampling scheme will be able to detect a tiny contaminated area with much reliability.

In following sections of the paper, we compare random and grid designs. These designs will be compared under a model discussed in the next section.

We then evaluate compositing, or grouping, of individual samples in the search for remaining areas of residual contamination. Under this strategy, the groups of samples are analyzed first for the presence of unacceptably high levels of PCB, and only individually for borderline cases.

2. FORMULATION OF THE PROBLEM: THE MODEL

To determine what type of sampling design is likely to perform well in the field, it is necessary to identify what may be reasonably encountered. One representation of the problem, which is somewhat of a worst case in terms of detection difficulty, is the case where there is only one small contaminated spot and where the rest of the site is clean. Also, as a first approximation, let us assume that any contamination will occur within r feet of the source of contamination such as a utility pole.

We thus have a situation (model) as shown in Figure 2.1, where the area of possible contamination is a circle centered at the source of contamination, and where there is a single contaminated spot. For definiteness, and with little likely loss of applicability, let us assume that the spot is circular.

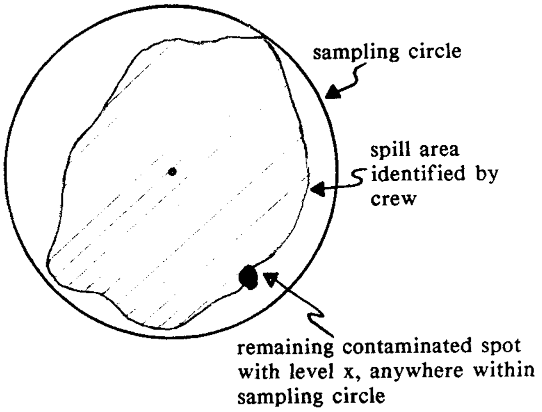

Figure 2.1 The model chosen. The center of the remaining circle of contamination is assumed to be randomly located within sampling circle.

In practice, of course, the contaminated area from a spill will be irregular in shape. However, in order to standardize the sample design and to protect against underestimation of the spill area by the cleanup crew, sampling within a circular area surrounding the contaminated area is proposed. Guidance on choosing the center of an irregularly shaped region, and the radius of the superscribed circle was given by [1], p. 18.

To summarize, the main parts of the model are: within the sampling circle there may be one or more areas of residual contamination, probably of irregular shape. We will approximate this as a (single) circle of residual contamination. We then come to the following detection problem: try to detect a circular area of uniform residual contamination whose center is randomly placed within the sampling circle. See Figure 2.1.

2.1 Discussion of the Model

All sampling designs will perform better under some circumstances than others. For a practical problem like this and where the resulting procedure will be used at more than one location, it is important that the chosen design have two characteristics:

1) It must perform well under specific conditions which are likely to occur in practice.
2) It must not be based on optimizing for a single situation such that it performs poorly under other reasonable scenarios. Thus it is preferable that no suppositions in a model are sensitive to small changes in conditions.

Let us now consider the assumptions of the model one at a time.

a) Circular sampling area--Obviously a circle will not exactly represent the area of original contamination. However, a circle does represent the region within a fixed distance of a point (such as a capacitor) and so seems reasonable to use as a standardized region for easy field implementation. Furthermore, the exact area of potential contamination cannot be known in general by the EPA inspector. The weakest case for application of this assumption is probably in the situation where the area of potential contamination is a very "eccentric" ellipse. However, standardization and considerably more simplicity (and resulting lower cost and less chance of implementation error) seem to us to outweigh this consideration.

b) Single circle of residual contamination, uniformly contaminated--The shape of the region of residual contamination will obviously not be a perfect circle, but it may very well be a convex shape such that a circle is the most reasonable approximation.

For purposes of modeling a single contaminated circle was used. The results could easily be extended to several independent circles of contamination.

To represent the EPA inspector's ignorance of the distribution of levels within the region of residual contamination, we have used a uniform distribution. A more complicated distribution of levels would not be very useful anyway, from a practical standpoint, since we can only sample one, thoroughly mixed unit at each sampling point.

c) Center of residual contamination randomly placed within sampling circle--Since the entire area of contamination was supposedly cleaned up, with added emphasis given to the obviously dirty areas, it seems logical to assume that any residual contamination would be randomly placed within the sampling site. Furthermore, the field samplers are completely free, and encouraged, to take discretionary samples when warranted (if they feel that this assumption may be even slightly off).

d) The rest of the site is clean to negligible levels--The final justification for this can only come from actual field studies. However, background levels of PCB have been found to be very low [5]. Also, the effect of violation of this assumption would be virtually no change in probability of detection, but an increase in the average number of analyses required for some cases due to the unnecessary analysis of individual samples when the composite cannot determine a compliance finding because of the elevated background levels. Noncompliant sites will be determined as such more quickly, and correctly, if non-negligible background levels are present.

3. RANDOM AND GRID DESIGNS

With a model in place, the goal is now to sample the area of potential contamination as thoroughly as possible with the fewest number of samples (the role of the model is to provide a means to evaluate competing designs). The two general types of designs possible for this detection problem are grid designs and random designs. Random designs have two disadvantages compared to grid designs for this application. First, random designs are more difficult to implement in the field, since the sampling crew must be trained to generate random locations on site, and since the resulting pattern is irregular. Second, grid designs are more efficient for this type of problem than random designs. A grid design is certain to detect a sufficiently large contaminated area while some random designs are not. For example, the suggested design (the hexagonal grid discussed later in this chapter) with a sample size of 19 has a 100% chance to detect a contaminated area of radius 2.8 ft within a sampling circle of radius 10 ft. By contrast, a design based on a simple random sample of 19 points has only a 73% chance of detecting such an area. (See Appendix A for added detail.)

Therefore, a grid design is proposed. A hexagonal grid based on equilateral triangles (see Figure 3.1) has two advantages for this problem. First, such a grid appears to minimize the circular area certain to be detected (among all grids with the same number of points covering the same area). For example the hexagonal grid based on equilateral triangles is 30% more efficient than a square grid; see Appendix B. Second, some previous experience [2,3] suggests that the hexagonal grid performs well for certain soil sampling problems. The hexagonal grid may, at first sight, appear to be complicated to lay out in the field. Guidance is provided in Section IV.2.b of [1] which shows that a layout utilizing the equilateral triangles is quite straightforward in practice.

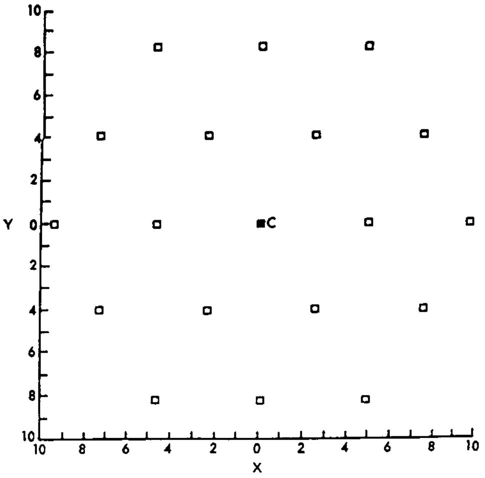

Figure 3.1 Location of sampling points in 19-point grid. The outer boundry of the contaminated area is assumed to r=10 feet from the (C) center of the spill site.

3.1 Details on the Hexagonal Grid of Equilateral Triangles

The smallest hexagonal grid has 7 points, the next 19 points, the third 37 points (see Figure 3.1). In general, the grid has $3n^2 + 3n + 1$ points. To completely specify a hexagonal grid, the distance between adjacent points, s, must be determined. The distance s was chosen to minimize, as far as possible, the size of the residual contaminated circle which is certain to be sampled. Values of s so chosen together with number of sampling points and radius of smallest circle certain to be detected are shown in Table 3.1. For example, the grid spacing for a circle of radius 20 ft for the 7-point design is s = (0.87)(20) = 17.4 ft. For a given size circle, the more points on the grid, the smaller the residual contamination area which can be detected with a given probability. The choice of sample size depends on the cost of analyzing each sample and the reliability of detection desired for various residually contaminated areas. Section IV.2.a of [1] provides suggested sample sizes for different spill areas.

Table 3.1 Parameters of hex designs for a sampling circle of radius r feet

No. of points	Distance between adjacent pts., (s ft.)	Radius of smallest circle certain to be sampled
7	.87r	.5r
19	.48r	.28r
37	.3r	.19r

4. COMPOSITING STRATEGIES

Once the samples have been collected at a site, the goal of the analysis effort is to determine whether at least one sample has a PCB concentration above the allowable limit. This sampling plan assumes the entire spill area will be recleaned if a single sample contaminated above the limit is found. Thus, it is not important to determine precisely which samples are contaminated or even exactly how many. As we will see in later sections, this means that the cost of analysis can be substantially reduced by employing compositing strategies, in which groups of samples are thoroughly mixed and evaluated in a single analysis. If the PCB level in the composite is sufficiently high, one can conclude that a contaminated sample is present; if the level is low enough, all individual samples are clean. For intermediate levels, the samples from which the composite was constructed must be analyzed individually to make a determination. Thus, the number of analyses needed is greatly reduced in the presence of very high levels of contamination in a few samples or in the presence of very low levels in most samples.

For purposes of this discussion, assume that the maximum allowable PCB concentration in a single soil sample is 10 ppm. The calculations can easily be adapted for a different level or for different types of samples. Based on review of the available precision and accuracy data [4], method performance of extracting 80% of the true total amount (20% downward bias) with 30% relative standard deviation should be attainable for soil concentrations above 1 ppm.

To protect against false positive findings due to analytical error, the measured PCB level in a single sample must exceed some cutoff greater than 10 ppm for a finding of contamination. Assume that a 0.5% false positive rate for a single sample is desired. As will be shown later, this single sample false positive rate controls the overall false positive rate of the sampling schemes to acceptable levels. Then, using a normal approximation for the distribution of the level, the cutoff level for a single sample is

$$(0.8)(10) + (2.576)(0.3)(0.8)(10) = 14.2 \text{ ppm},$$

where 0.8(80%) represents the percent extracted by the analytical method, 10 ppm is the allowable limit for a single sample, 2.576 is a coefficient from the standard normal distribution, and 0.3(30%) is the relative standard deviation of the analytical method. Thus, if the measured level in a single sample is 14.2 ppm or greater, one can be 99.5% sure that the true level is 10 ppm or greater.

Now suppose that a composite of, say, 7 samples is analyzed. The true PCB level in the composite (assuming perfect mixing) is simply the average of the 7 levels of the individual samples. Let X ppm be the measured PCB level in the composite. If $X \leq (14.2/7) = 2.0$, then all 7 individual samples are rated clean. If $X > 14.2$, then at least one individual sample must be above the 10 ppm limit. If $2.0 < X \leq 14.2$, no conclusion is possible based on analysis of the composite and the 7 samples must be analyzed individually to reach a decision. These results may be generalized to a composite of any arbitrary number of samples, subject to the limitations noted below.

The applicability of compositing is potentially limited by the size of the individual specimens and by the performance of the analytical method at low PCB levels. First, the individual specimens must be large enough so that the composite can be formed while leaving enough material for individual analyses if needed. For verification of PCB spill cleanup, adequacy of specimen sizes should not be a problem. The second limiting factor is the analytical method. Down to about 1 ppm, the performance of the stipulated analytical methods should not degrade markedly. Therefore, since the assumed permissible level is 10 ppm, no more than about 10 specimens should be composited at a time. Similar considerations might be important for other problems.

In compositing specimens, the location of the sampling points to be grouped should be taken into account. If a substantial residual area of contamination is present, then contaminated samples will be found close together. Thus, contiguous specimens should be composited, if feasible, in order to maximize the potential reduction in the number of analyses produced by the compositing strategy.

5. PERFORMANCE OF CHOSEN DESIGN

The critical measures of design performance here are the error rates and the average number of analyses that it takes to determine either noncompliance or acceptability. Estimates of average number of analyses and probabilities of false positives (incorrectly declaring the site contaminated above the limit), and false negatives (failure to detect residual contamination) were obtained for various scenarios.

Since the direct calculation of the average number of analyses and probability of a noncompliance declaration are very complicated and time-consuming, for most cases it is necessary to calculate these two quantities by Monte Carlo simulation. The calculations were done for each combination of sample size, compositing strategy, and level and extent of residual contamination.

To actually carry out the calculations, there are a few other approximations or details warranting restatement along with the basic model of section 2:

a) All samples are of the same type, having the same accuracy, precision, cost, etc.
b) If a composite does not give a definitive result (positive or negative), the individual specimens from which the composite was formed are analyzed in sequence before any other composite.
c) Samples are grouped to minimize the distance between samples as much as possible and the group with the largest number of samples is analyzed first.

5.1 The 7-point Designs

Three "compositing" plans will be considered: (1) group the entire 7 points and analyze; if within indeterminate range, analyze the samples individually; (2) form two initial composites of 3 adjacent points and 4 adjacent points; if necessary then analyze individual samples as discussed earlier; (3) begin directly by analyzing individual samples one at a time; i.e., "no compositing."

Tables 5.1 and 5.2 show the expected numbers of analyses under the 3 different compositing strategies for areas of residual contamination of 1% and 9% (r=1 and 3), and Table 5.3 shows the probability of a declaration of violation for the 3 strategies for the 9% case.

The probabilities of a declaration of violation are approximately the same for the three strategies (and also are for other sizes of residual contamination). However, the average numbers of analyses vary considerably between the three strategies. For Table 5.1, with an area 1% of the size of the cleanup site remaining contaminated, there is a dramatic decrease in the numbers of analyses required when compositing is used -- for all levels of residual contamination; the single composite case provides even more of an improvement over the individual analysis approach than the 2 composite approach. For individual analysis, the average number of analyses ranges from about 6.8 - 7.0 chemical analyses; for the 2 composite plan the average number ranges from about 2.0 - 2.1; and for the 1 composite plan the range is 1.0 - 1.3.

Turning to Table 5.2, for the case where an area 9% of the size of the cleanup site remains contaminated, the ordering of plans is a little less clear, but the pattern is quite similar. Both compositing strategies do better than the individual analysis strategy; however, this time the 2 composite plan does better for some intermediate levels of PCB contamination, namely, when the PCB level is between 25-150 ppm. For the higher and lower PCB levels in Table 5.2, the single composite plan does better -- sometimes even requiring only half as many analyses on average.

For very large areas of residual contamination, such as the case where an area 25% of the size of the cleanup site remains contaminated, larger composites do better at the higher and lower levels of contamination but less well or even worse at intermediate ranges. However, although strictly speaking it depends upon what size and type of remaining contamination will be encountered, it appears that more often a strategy of compositing as much as possible (down to the lowest level of the capability of the analytical method) is best. That is, compositing as many samples as possible (to the limit of the analytical method) is the best strategy except for cases where there are large areas of residual contamination at intermediate concentrations.

5.2 The 19-Point Designs

As with the 7-point design, the probabilities of declaring a site in violation remain constant for the various 19-point compositing plans over the range of PCB level and areas of residual contamination of interest. Thus, the main criterion for judging the usefulness of compositing is the average number of chemical analyses required.

Table 5.4 shows the average numbers of analyses for 3 compositing plans (area of residual contamination equal to 9% of spill site size). Since 10 is the most individual samples that may be composited, the plan with maximum compositing forms two groups, one of 10 and one of 9 individual samples. At the other extreme, we may do no compositing. An intermediate position is to form 6 groups from the individual samples. The average numbers of analyses are shown only for these cases, since the other plans have characteristics primarily intermediate between the three shown.

Even for the remaining three compositing schemes that are shown in Table 5.4, the average numbers of analyses follow a pattern such that the plan with 6 composites is often intermediate between the 2 extremes of maximally compositing versus "no compositing" (and always so for smaller sized areas of residual contamination). For smaller areas of residual contamination, individual analysis is the worst and the 2 group plan the best. For "intermediate-sized" areas of residual contamination as shown in Table 5.4, compositing into 2 groups is best for the higher and lower levels of residual contamination, the 6 group composite is best between the ranges of approximately 25-150 ppm PCB, and the individual analysis scheme is always far worse than either compositing plan. Similarly, for larger areas of residual contamination such as when 25% of the site remains contaminated, the 2 group composite is best for the higher and lower levels of PCB; the 6 group composite is best at the "intermediate" levels (between 25-50 ppm).

In summary, the 2 group composite appears to be the best over most ranges of interest, although "less compositing," such as the 6 group composite, is better over some ranges discussed above. For a general design, the 2 group composite appears to be the best choice.

5.3 The 37-Point Design Chosen

For the same reasons as discussed above, the design with the most compositing possible is the preferred approach. For 37 sampling points, the largest composites will result in 4 composites with 10, 9, 9, and 9 points since the analytical method allows for compositing up to 10 points.

5.4 Comparison Between Designs Using Different Numbers of Samples

As we have seen above, compositing appears to be the better strategy for field sampling due to a reduction in the typical number of analyses required with no change in error rate. But what about the differences in performance between sampling plans with different numbers of sampling points?

Table 5.5 shows both the average numbers of analyses and the probabilities of a noncompliance declaration for the maximally composited designs for 7, 19, and 37 point samples and for the individually analyzed samples of 7 and 19 points; the table is for a residual contamination of 9%, of the spill site size.

The two most interesting comparisons in the table are: (1) the individually analyzed 7 point design versus the 19 point design with 2 groups; and (2) the individually analyzed 19 point design versus the 37 point design with 4 composites.

For the first main comparison, we see that the plan using 2 groups with a 19 point grid always has a higher probability of detection than the individually analyzed plan using a 7 point grid for all noncompliant levels, that is, those with x > 10 ppm. In fact, at PCB levels of 50 ppm or higher the 19 point, 2 group plan is twice as likely to correctly detect the site as noncompliant. However, this plan requires only the same number of analyses on average at intermediate levels and far fewer at high or low levels. This trend continues for cases where the spill size is different; all cases except that of a large spill contaiminated at intermediate levels are more effectively analyzed and at lower cost by the compositing plan.

Similarly, for the second main comparison, we see that the plan using 4 groups with a 37 point grid generally outperforms the individually analyzed plan using a 19 point grid. For larger remaining areas of contamination the benefit only remains for high and low levels of PCB, but for smaller contaminated areas the gain is very dramatic for all PCB levels.

6. CONCLUSIONS

The hexagonal grid of equilateral triangles is very effective in determining residual contamination under the model presented. Furthermore, a strategy of analysis which utilizes compositing of samples may provide substantial advantages. The main findings on compositing are:

- Within the design plans of the same number of points (e.g., 7-point, 19-point) the probabilities of a violation declaration are very close under all conditions examined
- Compositing as many samples as possible reduces the expected (average) number of analyses, with no loss in detection capability, for all but the larger-sized spills contaminated at "intermediate" levels
- Plans with larger numbers of composites (of at least 3 per group) with smaller groups has performance characteristics between that of individual sampling and composites of larger numbers of points
- Under many conditions, it is possible to use larger numbers of sampling points (e.g., 19 points versus 7 points) with compositing and to achieve both lower error rates and fewer analyses on average. This characteristic emphasizes the potential gains of compositing.

ACKNOWLEDGEMENTS

Research funded by the U.S. Environmental Protection Agency under Subcontract No. F-4138(8149)-435 to the Washington Consulting Group through main EPA Contract No. 68-01-6721 to Battelle Columbus Laboratories. This paper has not been subject to the Agency's review and therefore does not necessarily reflect the views of the Agency. No official endorsement should be inferred.

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Appendix A. Comparison of Simple Random Sampling and Hexagonal Design of Equilateral Triangles

This appendix compares the detection capability of simple random sampling (SRS) to that of the proposed hexagonal sampling design, in the context of the simple model of residual PCB contamination used in this study. To simplify the calculations, we will ignore the measurement error of the analytical method and focus, for each scheme, on the probability of sampling the residually contaminated area at least once. We will refer to this as the "probability of detection."

Table A1. Comparison of 7-point hexagonal design and SRS

Radius of residual contamination	Detection probabilities 7-point hex, 1 Composite	SRS
0.1	0.070	0.065
0.2	0.242	0.229
0.3	0.492	0.433
0.4	0.811	0.622
0.5	1.000	0.769
0.7	1.000	0.928

Table A2. Comparison of 19-point hexagonal design and SRS

Radius of residual contamination	Detection probabilities 19-point hex, 2 Composite	SRS
0.1	0.180	0.167
0.2	0.661	0.504
0.3	0.999	0.778
0.32733	1.000	0.828
0.4	1.000	0.918

Appendix B. Comparison of Hexagonal Grid Based on Equilateral Triangles and Square Grid

The general hexagonal grid has $3n^2 + 3n + 1$ points. If s is the grid spacing, then it can be shown that the area covered by the grid is $A = 3\sqrt{3}\ n^2 s^2 /2$ and the radius of the smallest circle certain to be detected by the grid is $s/\sqrt{3}$. For a square grid of n^2 points with spacing s, the area covered is $(n-1)^2 s^2$ and the "certainty radius" is $s/\sqrt{2}$.

A reasonable basis for comparison of the two types of grid is to fix the area covered and the certainty radius and then compare the number of points for each type. Let the hex grid have parameters n_1, s_1, and the square n_2, s_2. We have the two equations

$$3\sqrt{3}\, n_1^2/s_1^2/2 = (n_2 - 1)^2 s_2^2$$

$$s_1/\sqrt{3} = s_2/\sqrt{2} \qquad \text{Thus, } n_1 = 2(n_2 - 1)3^{-5/4} .$$

Hence the ratio of the sample sizes is

$$\frac{\#\text{ hex points}}{\#\text{ square points}} = \frac{4(n_2 - 1)^2/3\sqrt{3} + 2(n_2 - 1)3^{-1/4} + 1}{n_2^2}$$

$$= 0.77(1-n_2^{-1})^2 + 1.52(n_2 - 1)/n_2^2 + 1/n_2^2$$

Table B1 shows this ratio for various values of n_2 and demonstates that the hex design requires between 18% and 23% fewer points for the same detection capability as the square grid.

Table B1. Relative efficiency of square vs hex design

Square parameter n_2 [1]	# hex points / # square points
2	0.82
3	0.79
4	0.78
5	0.78
6	0.77
:	
∞	0.77

[1] # square points = n_2^2.

Table 5.1 Comparison of expected number of analyses for different compositing strategies for the 7-point design, when an area 1% of the size of the cleanup site remains contaminated

Level of residual PCB contamination (ppm)	1 Composite	2 Composites	Individually
Compliant			
4	1.00	2.00	7.00
8	1.00	2.00	7.00
10	1.00	2.00	7.00
Noncompliant			
12	1.04	2.02	6.98
14	1.10	2.05	6.96
16	1.15	2.07	6.92
20	1.24	2.10	6.88
25	1.26	2.11	6.84
50	1.28	2.09	6.80
100	1.21	1.98	6.78
200	1.03	1.96	6.80
500	1.00	1.96	6.81

Table 5.2 Comparisons of expected number of analyses for different compositing strategies for the 7-point design, when an area 9% of the size of the cleanup site remains contaminated

Level of residual PCB contamination (ppm)	1 Composite	2 Composites	Individually
Compliant			
4	1.00	2.00	7.00
8	1.00	2.00	7.00
10	1.02	2.01	6.99
Noncompliant			
12	1.17	2.09	6.91
14	1.63	2.32	6.69
16	2.03	2.50	6.49
20	2.57	2.77	6.06
25	2.85	2.79	5.65
50	2.93	2.60	5.45
100	2.53	1.85	5.46
200	1.15	1.72	5.45
500	1.01	1.71	5.45

Table 5.3 Comparison of probability of a declaration of violation of the 10 ppm cleanup standard for different compositing strategies for the 7-point design, when an area 9% of the size of the cleanup site remains contaminated

Level of residual PCB contamination (ppm)	1 Composite	2 Composites	Individually
Compliant			
4	<.01	<.01	<.01
8	<.01	<.01	<.01
10	<.01	<.01	.01
Noncompliant			
12	<.01	<.01	.03
14	.02	.02	.10
16	.06	.06	.17
20	.20	.21	.31
25	.34	.34	.43
50	.49	.47	.49
100	.49	.49	.49
200	.49	.49	.49
500	.49	.49	.50

Table 5.4 Comparison of expected number of analyses for different compositing strategies for the 19-Point design, when an area 9% of the size of the cleanup site remains contaminated

Level of residual PCB contamination (ppm)	2 Composites	6 Composites	Individually
Compliant			
4	2.00	6.00	19.00
8	3.01	6.19	19.00
10	3.72	6.32	18.96
Noncompliant			
12	4.57	6.54	18.40
14	5.16	6.74	16.90
16	5.89	6.83	14.86
20	6.26	6.33	11.89
25	6.20	5.74	10.22
50	5.96	4.45	8.94
100	5.37	3.34	8.64
200	2.61	3.17	8.63
500	1.48	3.17	8.62

Table 5.5 Comparison of sampling designs for r = 3 (9% of spill site size)

Level of contaminated area, x	7 pts., 1 group	7 pts., indiv.	19 pts., 2 groups	19 pts., indiv.	37 pts., 4 groups
4 :	1.00	7.00	2.00	19.00	4.41
	<.01	<.01	<.01	< .01	<.01
8 :	1.00	7.00	3.01	19.00	9.01
	<.01	<.01	<.01	<.01	<.01
10 :	1.02	6.99	3.72	18.96	10.56
	<.01	<.01	<.01	<.01	.01
- - - - - - - noncompliant for x > 10 ppm - - - - -					
12 :	1.17	6.91	4.57	18.40	10.94
	<.01	.03	.03	.07	.10
14 :	1.63	6.69	5.16	16.90	10.21
	.02	.10	.11	.23	.36
16 :	2.03	6.49	5.89	14.86	9.08
	.06	.17	.26	.45	.62
20 :	2.57	6.06	6.26	11.89	7.28
	.20	.31	.56	.73	.88
25 :	2.85	5.65	6.20	10.22	6.53
	.34	.43	.78	.87	.96
50 :	2.93	5.45	5.96	8.94	5.39
	.49	.49	.98	.99	>.99
500 :	1.01	5.46	1.48	8.62	2.22
	.49	.50	>.99	>.99	>.99

Legend--Top number = average number of analyses. Bottom number = probability of declaring out of compliance (for levels of PCB, x,10 ppm and below this will be the probability of false positive; forlevels above 10 this will be the probability of detection.)