DISCUSSION

Assessment of health risks in the redevelopment of contaminated land

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The Authors are to be congratulated on providing a valuable overview. It is particularly gratifying to see included a discussion of the neglected issue of site sampling.

The Authors do not, however, draw attention to the fact that available guidance on sampling is at best inconsistent and at worst wildly misleading. For example, the Authors cite the British Standards Institution Draft for development (1988) as recommending at least 25 sampling points for a 1 ha site and then, citing the Institution of Environmental Health Officers (1989), state that 'this intensity of sampling will locate a contaminated area of 1000 m² with a 95% confidence limit' (i.e. 10% of the total site area). In fact the IEHO recommendation for this purpose is a square grid spacing of 18 m taken from Cairney (1987) which, in turn, was taken from Bell, Gildon & Parry (1983) who actually calculated 30 sampling points. However, the binomial model used by Bell *et al.* (1983) applies only to random sampling and grossly overestimates the number of sampling points required if square grid sampling is used. Furthermore, Bell *et al.* (1983) conclude by stating that they base their site surveys on 'a 95% confidence level for locating a total contaminated area of 5% of the total site area for residential afteruses, resulting in a total of 60 excavations per hectare . . .' In fact, using an efficient systematic search pattern, about 30 samples would be enough for the stated purpose (for a single contaminated hot spot) and only about 20 for an equant hot spot. These numbers apply for any site area because the target size is expressed as a proportion of total site area; the per hectare rate quoted is an unfortunate error and may have misled site investigators into grossly over-sampling a site.

The Department of the Environment has long recognized the importance of sampling design and its relevance to health risk assessment. Accordingly it has recently funded a study to review current guidance and to develop improved guidance as necessary. Some interim key points of the study are now summarized.

Most published sources of guidance recommend either a regular (square grid) or stratified random sampling pattern. New computer experi-

ments show that stratified random sampling is inefficient compared with square grid sampling. The latter performs well except when the contaminated area being sought ('the target') is elongate and roughly parallel to the grid directions, when performance is seriously degraded. A herringbone search pattern (Fig. 1) is even more efficient than the square grid for circular targets and, with elongate targets, is only weakly affected by orientation.

Published advice on the number of samples required varies widely; it ranges from 20 to 300 sample locations for a 5 ha site. Little of the advice appears to have a statistical basis—sound or otherwise.

Statistical experiments show that for most target shapes about 25–30 sampling locations are required to give at least 0.95 probability of detecting a target occupying 5% of the total site area (i.e. the relative target size f is 0.05). This assumes use of the most efficient sampling pattern (herringbone). For a target occupying only 1% of total site area ($f = 0.01$) the number of sampling locations N rises to well over 100 for the same detection probability. For planning and costing site investigations, the equation $N = 1.4/f$ is reasonably conservative with respect to target shape. For a circular target the corresponding equation $N = 1.08/f$ is similar in effect to that recommended in the Dutch draft standard for a site with suspected point-source pollution ($N = 4 + 1/f$).

The problem is more complicated when the critically contaminated area is made up of more than one target. For up to five equally sized circular targets occupying in total 5% of the total site area, sampling may succeed in detecting one or more of the targets. The approximate numbers of samples needed to give a 0.95 probability of success with a herringbone search are shown in Table 2.

These above comments all assume that each part of a site has an equal probability of containing a target although, in practice, an investigator is likely to modify this assumption on the basis of information gained through a desk study or walk-over survey. Further work is in progress to address this prior-information problem and to explore efficient designs for multistage sampling.

Fig. 1. Herringbone search pattern

The Authors' emphasis on the importance of sampling in health risk assessment is most welcome. It is to be hoped that, by providing updated and expanded information, this discussion will enhance the value of the Authors' overview to practitioners. This discussion is based on work funded by the Department of the Environment although the views expressed do not necessarily represent those of the Department.

Authors' reply

Professor Ferguson represents an interesting and informative contribution. In many cases the person responsible for the site investigation will have some idea of where the most heavily contaminated areas are likely to be found, so that any statistical analysis based on the assumption that there is no prior knowledge cannot be viewed as more than a guide. The results of Pro-

fessor Ferguson's current work, in which the problem of prior knowledge is addressed, should therefore be particularly useful.

The 'per hectare' error of the original reference is not repeated in the Paper. As Professor Ferguson points out, the number of sampling points required to detect a contaminated zone which occupies a fixed proportion of the total area is independent of the area of the site. The phrase 'per hectare' is therefore spurious in the IEHO guidance (1989), where the size of the contaminated area sought is expressed as a proportion of the total site. However, it will more often be desirable to detect contaminated zones of a certain size, whatever the total area of the site: the required number of sampling points will then increase with the size of the site. For this reason, the Authors consider that it is preferable to express the area of the target zone in absolute terms, rather than as a proportion of the total site. The correct interpretation of the IEHO guidance (1989) is given in the Paper: the quantification of the size of the target zone as a proportion of the total area of the site was introduced in discussion by Professor Ferguson.

Although the apparent recommendation (IEHO, 1989) of a certain number of sampling points per hectare might lead to over-sampling if the aim of the investigator is to detect contaminated areas of 10% of the total site, this will not be the case if the intention is to detect contaminated areas of 1000 m², irrespective of the size of the site. Indeed, 1000 m² is a considerable area and it will often be necessary to detect smaller contaminated zones. This will require more, not fewer, sampling points. It is important, however, for those responsible for planning the investigation of a contaminated site to be aware of the rationale behind the methodology they adopt; it is rarely acceptable to choose an appropriate strategy for the wrong reasons. It is to be hoped that this discussion will eliminate any remaining uncertainty.

REFERENCES

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Table 2

Number of targets	Minimum number of hits				
	1	2	3	4	5
5	45	67	83	103	137
4	42	60	78	107	
3	38	53	78		
2	31	49			
1	22				