

Appendix B

Plume Length Algorithm

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Plume length is the primary plume metric of interest in this study because it reflects the potential of the contaminant to impact nearby receptors such as water supply wells. Furthermore, other important plume metrics, such as the plume rate-of-growth, are necessarily defined in terms of plume length. Nevertheless, plume length is an inherently nebulous concept because of the highly irregular morphology of solute plumes in the subsurface environment, exacerbated through biases created by monitoring well network configurations. Therefore, it is important to establish an objective protocol for the systematic quantification of plume length for each CVOC at each site in the study. It is not possible to accomplish this using interpreted plume contour maps because such maps are not always defined objectively, particularly from site to site among different investigators. Hence, it is preferable to prescribe a plume algorithm to estimate plume lengths directly from CVOC concentration data and well locations at each site.

For the purposes of this study, plume length is defined as the distance from the source area (specifically, the well exhibiting maximum concentration of the CVOC of interest) to the farthest leading edge of the plume at a defined concentration contour (either 10-, 100-, or 1000-parts-per-billion). This definition is two-dimensional in nature; spreading of the plume in the vertical direction is not evaluated due to the limited amount of depth-specific data available, the higher relative importance of plume length, and the complexity of three-dimensional versus two-dimensional modeling. Given a sparse monitoring well network, the distance from the source area to the leading plume edge must be interpolated. Logically, the minimum plume length, L_{\min} , is constrained by the distance from the well exhibiting the maximum historical CVOC concentration to the furthest down-gradient well exhibiting a concentration higher than the defined contour. Exponential projection of the concentration profile through this well pair can be used to provide an alternative plume length estimate (L_{proj}). However, experience has shown that exponential projection tends to overestimate plume lengths in comparison to visual inspection of plume maps. In practice, the harmonic mean of the constrained minimum plume length and the exponential projected plume length was found to yield the most satisfactory match with observed plume lengths measured from site maps and was thus selected as the plume length (L) algorithm for the study:

$$\frac{1}{L} = \frac{1}{2} \left(\frac{1}{L_{\min}} + \frac{1}{L_{\text{proj}}} \right) \quad (\text{Eq. B-1})$$

For each plume, plume length was estimated by year using annually-averaged concentrations in each monitoring well. The maximum historical plume length was then chosen as the plume length for the given CVOC at the site. This takes into account the highest degree of plume delineation as more monitoring wells come on line over time and yet avoids incorporating the effects of remediation activities on plume length in later years.

A comparison of plume lengths taken from site maps with the plume lengths computed using the plume length algorithm is shown in Figure B-1. The concept of plume length as defined in this study was applied in like manner to both the original contaminant CVOCs (e.g., PCE) as well as to probable daughter product compounds (e.g., vinyl chloride). Thus, daughter product plumes lengths were defined with reference to the maximum concentration of the daughter product, rather than to the maximum concentration of the presumed parent product. This strategy was necessary for two reasons:

1. The precise location of the source of a contaminant plume was not known or reported in many instances. Even for a single species, this complicated the task of defining a plume length. For this reason, the location at which the maximum historical concentration was measured provided a systematic, objective basis for defining plume length because: (1) it could always be defined for any plume, and (2) in most instances, the highest concentrations would in all likelihood be encountered in close proximity to the source area. When possible daughter product plumes are introduced, the problem of identifying the source area is even more difficult. At many sites, mixtures of contaminants were released in several locations, making it difficult to associate a daughter product plume with a specific parent product source location. For example, there are 55 TCE plumes and 32 PCE plumes in the data set. Many of these PCE and TCE plumes coexist at individual sites, raising the question of whether or not a *cis*-1,2-DCE or vinyl chloride plume at these sites should be associated with the PCE source or the TCE source. Within the data set, there are instances where either a PCE and/or a TCE plume are not evident and yet a *cis*-1,2-DCE and/or a vinyl chloride plume is present. In such cases, it would be very difficult to measure the daughter product plume length with respect to a parent product source area when the latter cannot be defined. A further potential difficulty is that reductive dehalogenation may take place only locally, so that a small, localized daughter product plume could develop far downgradient of the parent product source area. In such instances, defining a daughter product plume length with respect to the parent product plume origin would yield a non-physical daughter product plume of excessive length. Such a plume length could not be used in multivariate analyses as it would distort the relationships with respect to site variables. For all of these reasons, defining daughter product plume length with respect to the maximum historical concentration of the daughter product compound was the best strategy for preserving objectivity in the analyses. In this way, plume lengths could be defined independently from the type of source responsible for the plume's existence (e.g., DNAPL dissolution, leaching of dissolved a CVOC from the vadose zone, or reductive dehalogenation).
2. For several of the CVOCs included in the study, the original contaminant-daughter product role cannot be unambiguously identified. A well-known example is that of TCE, which certainly exists at many sites as an original contaminant but may also exist as a reductive dehalogenation daughter product of PCE. Chloroform and 1,1-DCA have both been used as solvents in a variety of industrial applications (Pankow et al., 1996) and yet may also be produced as reductive dehalogenation intermediates. 1,1-DCE presents an especially troublesome example, having industrial uses and hence being a possible original contaminant (Montgomery and Welkom, 1990), being produced as a reductive dehalogenation product of PCE and TCE, and being produced as an abiotic transformation product of 1,1,1-TCA.

References

- Montgomery, J. H., and L. M. Welkom (1990), *Groundwater Chemicals Desk Reference* (Lewis Publishers, Chelsea, Michigan), pp. 230–234.
- Pankow, J. F., S. Feenstra, J. A. Cherry, and M. C. Ryan (1996), “Dense chlorinated solvents in groundwater: Background and history of the problem,” in *Dense Chlorinated Solvents*, Pankow, J. F., and J. A. Cherry, Eds. (Waterloo Press, Portland, Oreg.), pp. 1–52.

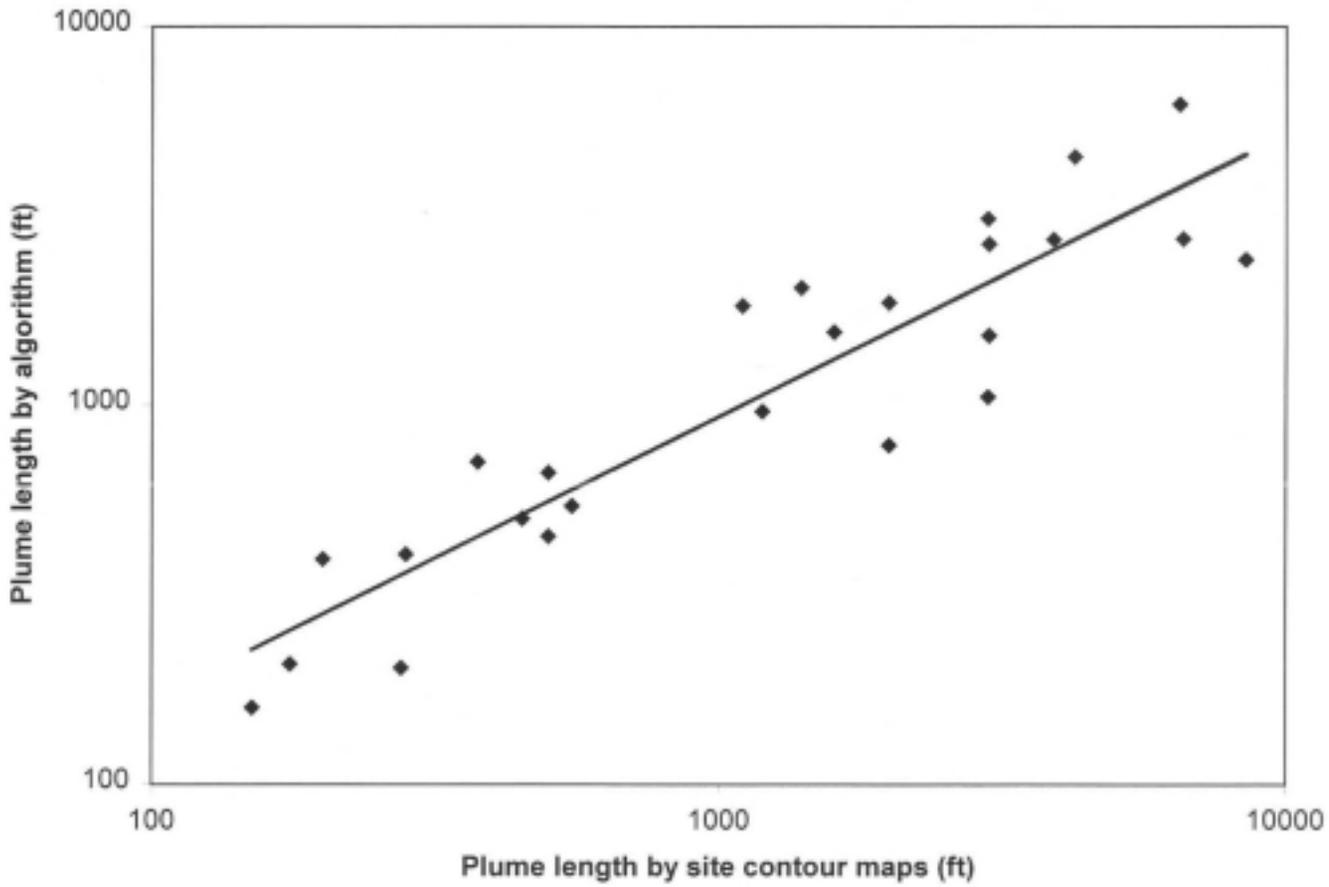


Figure B-1. Comparison of plume-algorithm-generated plume lengths with those interpreted from plume maps provided in individual site reports (as delineated by the 10-ppb contour).