Integration of RBCA Frameworks and Remediation Technologies

Joseph E. Odencrantz • David Duran

Joseph E. Odencrantz, Ph.D., P.E., is a registered civil engineer with approximately 15 years of experience in the fields of environmental engineering and water resources. He is the founder and President of TRI-S Environmental, Sensible Strategies and Solutions for the Environment. David Duran, Ph.D., is currently Professor of Chemistry at Pacific Union College in Angwin, California. His fields of expertise span several topics in the areas of hazardous waste, human health and ecological risk assessment, development of cleanup criteria for site remediation, probabilistic risk assessment, and statistical evaluation for environmental impact assessment.

Decisions that determine the proper risk-based remediation approach are based on technical, regulatory, cost, legal, and political factors. A wide variety of options such as the ASTM RBCA tiered approach, the API Decision Support Software, and a host of agency-specific methods and commercial risk assessment software are all available. The optimization of a remediation project requires the right remediation technology coupled with the appropriate analytical framework. For groundwater remediation, the application of various "risk reduction" technologies can be classified as aggressive (pump and treat), moderate intensity (air sparging), low intensity (oxygen release compound-ORC®), and intrinsic (monitor only). The time frame of risk analysis will establish the proper risk reduction strategy. The selection process is inherently iterative, and the approach by which an optimal solution can be derived forms the basis of this article. A case study of a Texas site put these issues into context.

The current state of the art in the field of remediation of contaminated soil and groundwater sites involves the coupling of the movement of chemicals in air, soil, and water (transport) with the estimation of their effects once they have reached their "location" of interest. Risk estimation involves the averaging of chemical concentrations at receptor locations for varying periods of time and their pathways into the human body (human health risks) or the natural environment (ecological risks). Risk-based corrective action (RBCA) has become the latest attempt at merging transport and risk (ASTM, 1995). The application of RBCA involves a tiered approach starting with a screening look-up exhibit with default parameters (Tier I) to a complicated approach for difficult sites involving multi-parameter models and uncertainty analysis (Tier III). The American Petroleum Institute has developed the Decision Support Software (DSS) (API, 1994) to aid with the implementation of RBCA.

Both RBCA and DSS contain a wide array of analytical methods that affect the choice of remediation technologies; most practicing environmental consultants have managed projects in which cleanup goals were so affected. The ultimate goal at any site is to manage the contamination problem in the most cost-efficient manner possible and to make decisions that comply with local regulatory methods and result in prompt risk

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reduction of the chemicals. The optimization of a remediation project requires the right remediation technology coupled with the appropriate analytical framework (i.e., risk calculation procedures.)

For groundwater remediation, the application of various "risk reduction" technologies can be classified as aggressive (pump and treat), moderate intensity (air sparging), low intensity (oxygen release compound-ORC®) and intrinsic (monitor only) (Brown et al., 1996). Pump and treat as well as air sparging have been common methods of risk reduction for several years. Low-intensity methods such as ORC® (Odencrantz et al., 1996) and documentation of intrinsic risk reduction (Buscheck and Alcantar, 1995) have become more commonplace in the past few years. Coupling an analytical framework/software program with these options is the single largest challenge for the environmental practitioner.

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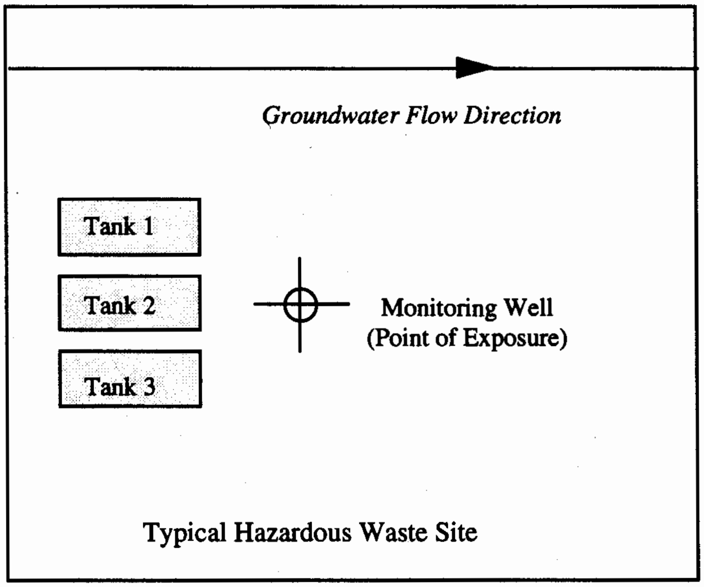
The time frame of risk analysis will establish the proper risk reduction strategy. The subtleties of choosing endpoints, exposure pathways, and possible legal constraints can have a substantial effect on the selection process. The submodels (transport and risk calculations) which make up the selected RBCA framework, coupled with uncertainty and parameter identification, can also influence the design. The selection process is inherently iterative, and the approach by which an optimal solution can be derived forms the basis of this article. The exposure pathway of groundwater has been selected to illustrate the main premise of our work, the coupling of remediation selection with the analytical approach to risk evaluation. The concepts presented in this article have direct implications for the typical brownfield redevelopment site.

CONCEPTUAL RISK TIME HISTORY VERSUS REMEDIAL TECHNOLOGY (VARIABLE SPEEDS)

The time variability of chemical concentrations at a groundwater monitoring well is used to illustrate the result of applying various remediation technologies. **Exhibit 1** is a conceptual diagram of a typical hazardous waste site with a downgradient monitoring well which will be our point of exposure (POE). The chemical of concern (COC) throughout this article will be benzene, and the source of contamination is petroleum hydrocarbons (gasoline). The conclusions and concepts are applicable to all groundwater chemicals of concern and source of contamination. The groundwater breakthrough curves at the POE for each of the remediation techniques (aggressive, moderate, low and intrinsic) are illustrated in the form of instantaneous benzene risk (**Exhibit 2**).

These curves are conceptual and were generated to illustrate the range of possibilities. The risk variability is shown on a linear scale to show clearly the changes over one log cycle. The contamination scenario can be deduced by the shape of the curves themselves. The aggressive remedial technology prevents the risk from exceeding normal regulatory levels, contrasted to the intrinsic technology, which has excess risk for nearly the full-time history of ten years. The effect of effective solubility (free-phase product near the source area) is visible from the intrinsic curve by its flattening out at 1×10^{-5} risk for nearly a three-year period. The moderate

Exhibit 1. Conceptual Diagram for Demonstration of Varying Degrees of Remedial Effort (Variable Speed)



and low curves show lower risk for increasing remedial effort in both the maximum risk achieved and the average risk over the ten-year period.

The average risk at any given time for the different technologies is shown in **Exhibit 3**. The shape of each curve is significantly different from the instantaneous view of risk in Exhibit 2. The average risk at any time is the sum of all linear-time-weighted risk divided by the total time. We term this a *cumulative running average*. The curves shown in Exhibit 3 are assumed to be the future breakthrough curves at the monitoring well (POE) and are assumed to be completely accurate with real site data, generated by a transport model. The model used to generate these curves is part of an overall analytical framework which accounts for the time variability of the remediation system and its effect on chemical reduction across the site. In order to get a sense of the true risk involved with each of the remedial technologies, there are horizontal lines drawn at each of the three risk levels (2×10^{-6}, 4×10^{-6}, and 6×10^{-5}). The time each remedial technology spent in excess of these values is tabulated in **Exhibit 4.**

The values in Exhibit 4 represent times that most regulatory case managers are often most interested in. For example, if a risk level of 4×10^{-6} was the cutoff in a particular state, the aggressive technology would be the only acceptable one if no average excesses were to be permitted. If there was a possibility of negotiation, the moderate technology would have an excess of 1.25 years and the low an excess of 8.75 years. Another

Exhibit 2. Instantaneous Benzene Risk at Conceptual POE

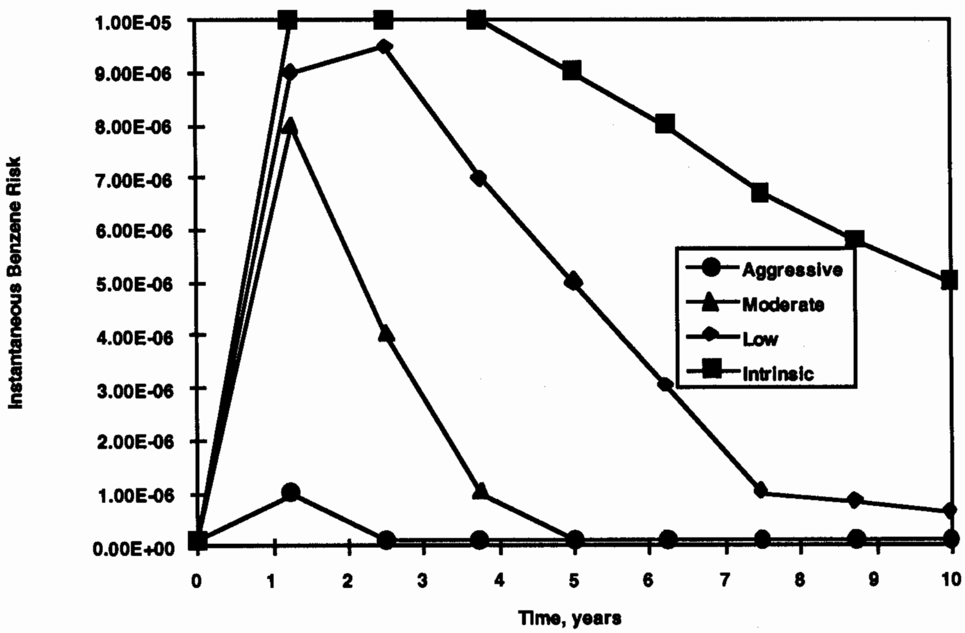


Exhibit 3. Conceptual Cumulative Running Average of Future Benzene Risk at Conceptual POE

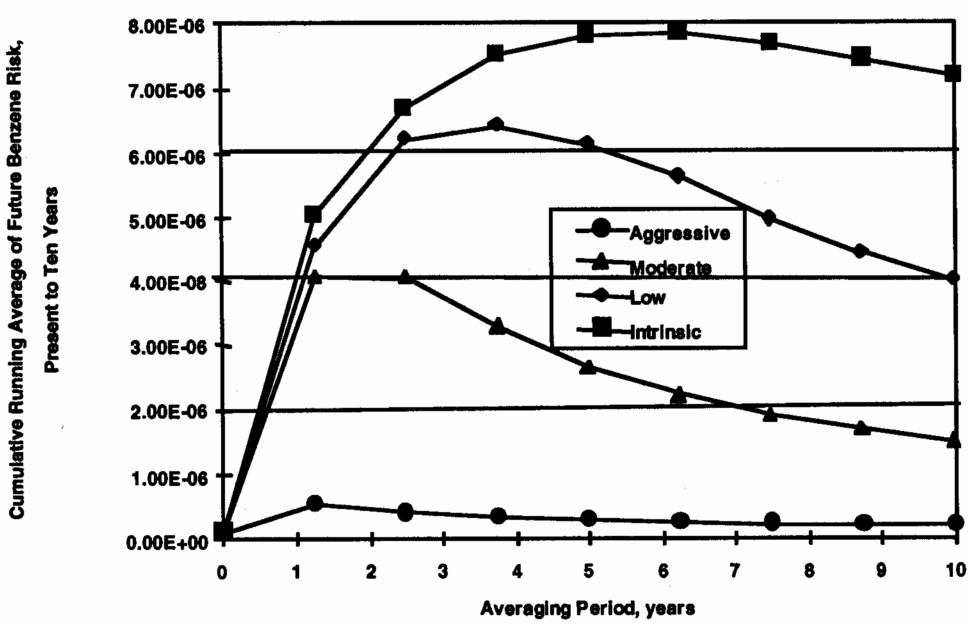


Exhibit 4. Exceedence of Cumulative Running Average Risk Thresholds for Various Remediation Technologies

		Remedial Approach		
	Aggressive	*Moderate*	*Low*	*Intrinsic*
Risk Level				
$2x10^{-6}$	NR	6.3	> 9.5	> 9.6
$4x10^{-6}$	NR	1.25	8.75	> 8.75
$6x10^{-6}$	NR	NR	2.9	> 8.1

NR = Risk Level Not Reached

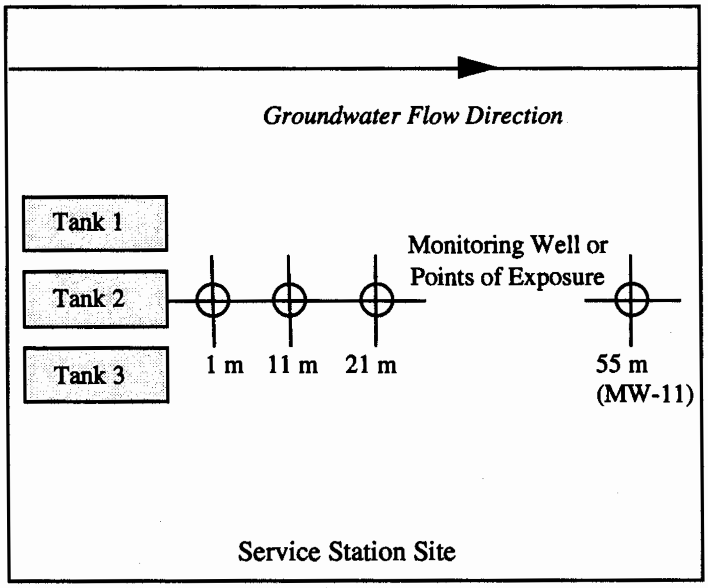
point in favor of the moderate technology is that the average risk level of 6×10^{-6} is not reached. Other positions for the appropriate remediation technology can be made by using the curves in Exhibit 3 in conjunction with Exhibit 4.

RISK TIME HISTORY AT DOWNGRADIENT WELLS AT TEXAS SITE

The coupling of the analytical frameworks with remedial technologies is illustrated by a case history from a real site in Texas. In the previous example, we demonstrated the effect of various remedial technologies on instantaneous and cumulative running averages of risk. The prediction of the time variation of risk/concentration at monitoring wells for a remedial technology is commonly performed with groundwater transport models. Transport models account for the interaction of advection, dispersion, sorption, degradation, and other processes that affect the ultimate fate of the COC (Odencrantz et al., 1992 and Valocchi et al. 1993). RBCA projects involve the dissection of a site into concentration time histories at various receptors/media and pathways; therefore, it is critical to know with certainty what these curves will look like. In short, no predictive groundwater modeling can be used with any degree of certainty unless there is site data available with which to calibrate the model. We have emphasized the importance of time variability at a POE in groundwater in the previous section.

Exhibit 5 is the site diagram from a gasoline service station in Texas which underwent remediation and a RBCA process. There are four POEs in groundwater which have groundwater breakthrough curves (**Exhibit 6**). The groundwater model (AT123D as part of APIDSS 1994) included a degradation rate of 0.000538 day^{-1} (half life of 129 days), an interstitial groundwater velocity of 4 m/year, and a linear retardation coefficient of 1.05. The groundwater model was calibrated to all the wells, and the furthest downgradient well at 55 m (MW-11) was off-site. The goal of this

Exhibit 5. Texas Site Diagram with Four Exposure Points



section is to present the time histories of concentrations in a risk framework.

The first look at risk may entail an examination of the maximum concentration at each POE in groundwater. **Exhibit 7** is a graph of the maximum risk at each POE calculated from the maximum concentration at each well in Exhibit 6. There is an obvious trend downgradient of the source which appears to have a similar shape as a steady-state solution (Domenico, 1987) as discussed in Buscheck and Alcantar (1995). As we will demonstrate, the time variability of risk at POEs in groundwater combined with the presentation of risk is essential for proper evaluation of a site. The steady-state case can miss several key features of the system which must be accounted for.

The maximum concentrations for a ten-year period for each of the breakthrough curves in Exhibit 6 were selected. These values were converted to risk by dividing by the maximum contaminant level (MCL) of 0.005 mg/l and multiplying by 1×10^{-6} (risk associated with the MCL). We realize that all carcinogens and noncarcinogens would need to be addressed in addition to benzene; however, we will continue to focus our work on benzene in this article. **Exhibit 8** shows the instantaneous risk for each of the POEs in the maximum ten-year period. These data were then translated to cumulative running averages (as discussed in the previous section) and are presented in logarithmic form in **Exhibit 9**. Lines at 1×10^{-6}, 1×10^{-5}, and 1×10^{-4} are drawn as risk threshold values. **Exhibit 10** summarizes the exceedences of risk thresholds for each of the monitoring wells.

Exhibit 6. Benzene Breakthrough Curves at Four Downgradient POEs

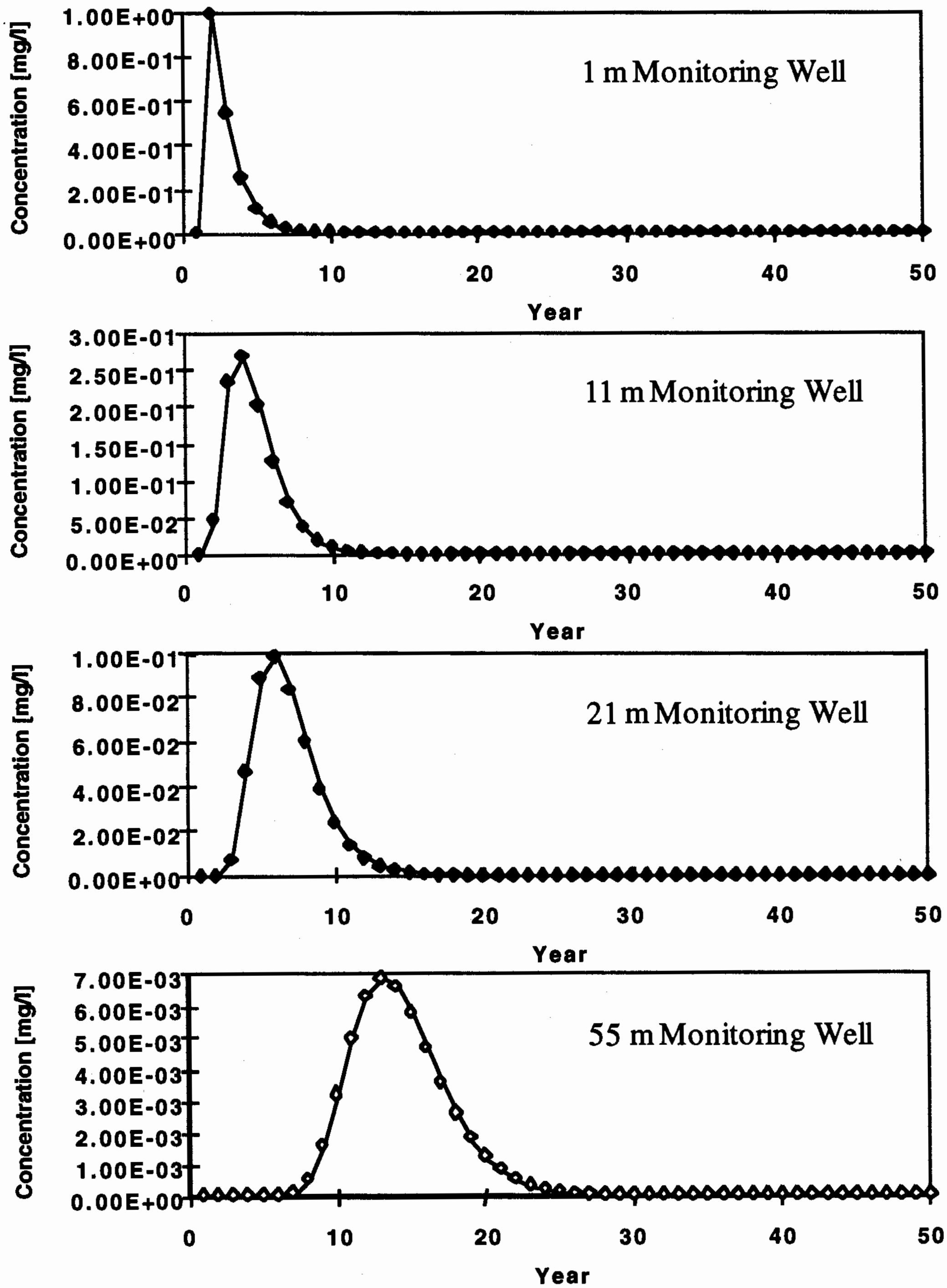
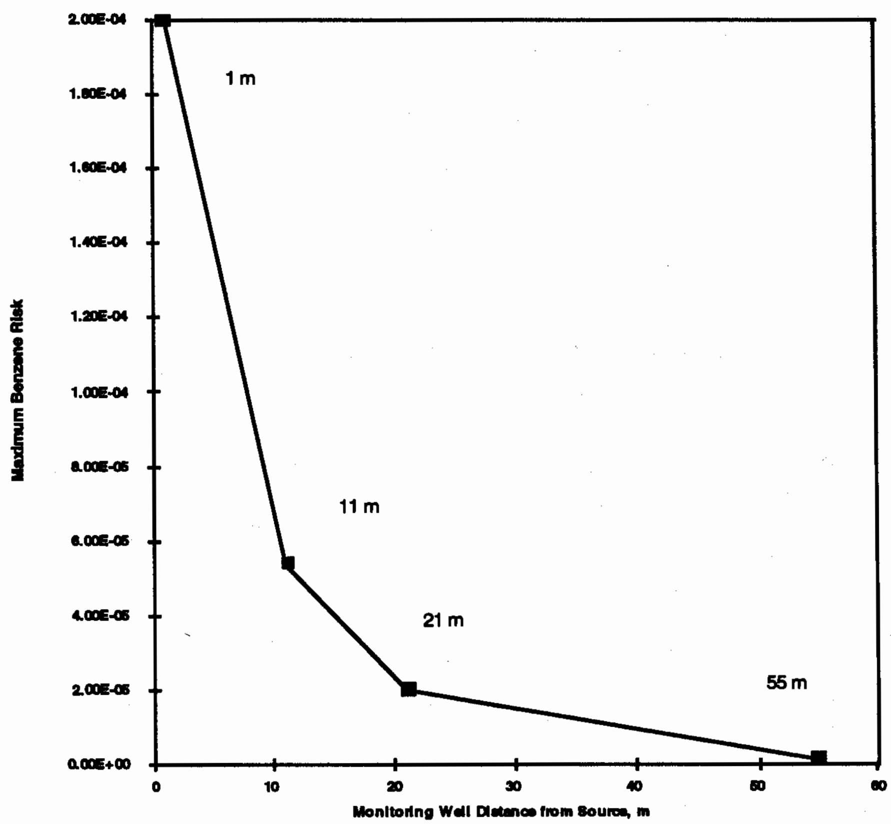


Exhibit 7. Maximum Benzene Risk at Four Downgradient POEs



The decision criteria for the data in Exhibit 10 is different from that of choosing a remedial technology as discussed in the previous section. Here we have a means to summarize the time-varying risk succinctly for a given level of remedial effort. The data tell us if 1 x 10^{-5} was the regulatory level, MW-11 (55 m) is the only well in full compliance, and we will exceed the risk level for seven years at the 21 m downgradient well.

REGULATORY SIGNIFICANCE

In the recent interest in developing the thousands of so-called brownfield sites across the country (Maldonado, 1996; and Wright, 1996), there is a purpose for examining alternate ways of coupling remediation technology selection with the framework of risk interpretation. There are issues that need to be discussed in meetings with regulatory authorities that far surpass anything that can be predicted with any model. The putting into context of data that are either easily available or can be obtained easily at a site is powerful. The examination of time history of risks for each COC in monitoring wells will aid in the prompt resolution of many risk-related regulatory issues.

Exhibit 8. Benzene Risk Comparison for Each POE's Maximum Ten-Year Period

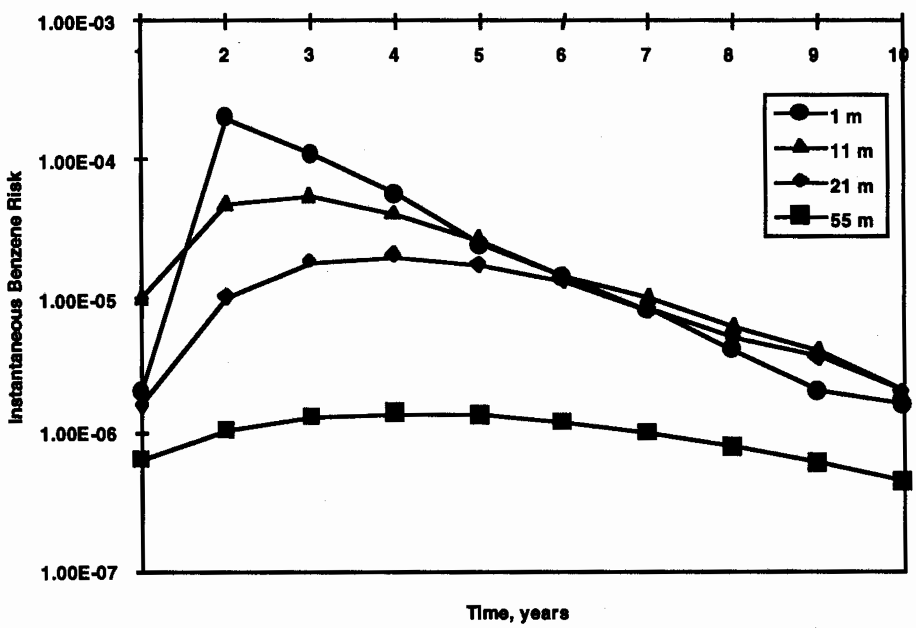


Exhibit 9. Cumulative Running Average of Benzene Risk for Each POE's Maximum Ten-Year Period

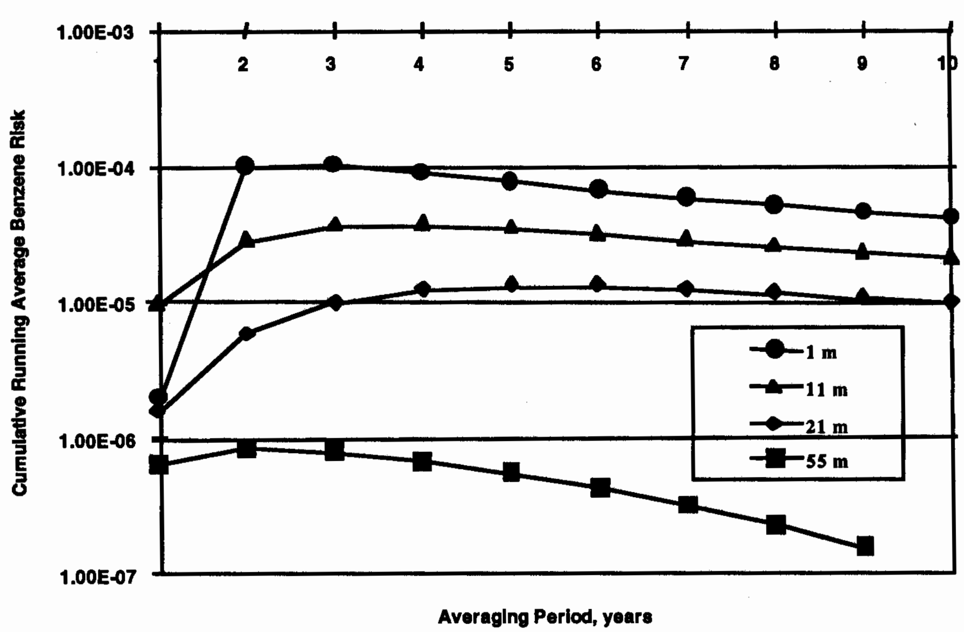


Exhibit 10. Exceedences of Cumulative Running Average Risk for Various POEs

	POE / MW			
	1 m	*11 m*	*21 m*	*55 m*
Risk Level				
$1x10^{-6}$	> 10	> 10	> 10	NR
$1x10^{-5}$	9	> 10	7	NR
$1x10^{-4}$	1.25	NR	NR	NR

NR = Risk Level Not Reached

CONCLUSIONS

A methodology for the use of an appropriate analytical framework in conjunction with the selection of most appropriate remediation technology has been presented. The change in the time history of risks associated with varying degrees of remedial efforts illustrated the importance of considering time variations of concentrations in monitoring wells as part of an overall risk evaluation process. The necessity for calibration in conjunction with model application was emphasized. The tabulation of time in excess of threshold risk values proved useful in interpreting the overall effect of risk reduction of the various remediation technologies. More importantly, the selection of an optimal remediation technology is simplified by facilitating regulatory discussions with the tabulated values of cumulative running averages of risks.

A site from Texas was used as an example application of examining the time histories of risks at four downgradient monitoring wells. The site calibration parameters were used to fit the modeled versus observed concentrations at three monitoring wells. The concentrations distributions at the various wells are converted to ten-year maximum risk time histories and presented as cumulative moving averages for each. An exhibit that summarizes the exceedences of threshold risk values can be used to facilitate regulatory negotiations when the remediation process is ongoing. The use of these exhibits will be of mutual benefit for the regulatory agency and the consultant when discussing/assessing site risks. ■

REFERENCES

ASTM. 1995. Risk-Based Corrective Action Applied at Petroleum Release Sites, E-1739-95. Sept.

API. 1994. American Petroleum Institute's Decision Support System for Exposure and Risk Assessment (DSS), Version 1. May.

Brown, R.A., R.E. Hinchee, R.D. Norris, and J.T. Wilson. 1996. "Bioremediation of Petroleum Hydrocarbons: A Flexible, Variable Speed Technology." *Remediation*, 6(3):95-109.

Buscheck, T.E. and C.M. Alcantar. 1995. *"Regression Techniques and Analytical Solutions to Demonstrate Intrinsic Bioremediation."* Proceedings of Batelle *In-Situ* Bioreclamation Conference. San Diego. 109-116.

Domenico, P.A. 1987. "An Analytical Model for Multidimensional Transport of a Decaying Species." *Journal of Hydrology*. 91:49-58.

Maldonado, M. 1996. "Brownfields Boom." *Civil Engineering Magazine*. American Society of Civil Engineers. New York. May. 36-40.

Odencrantz, J.E., J.M. Farr and C.E. Robinson. 1992. *Transport model sensitivity for soil cleanup level determinations using SESOIL and AT123D in the context of the California Leaking Underground Fuel Tank Field Manual*, Journal of Soil Contamination, Volume 1, Number 2, 159-183.

Odencrantz, J.E., J.G. Johnson, and S.S. Koenigsberg. 1996. "Enhanced Intrinsic Bioremediation of Hydrocarbons Using an Oxygen-Releasing Compound." *Remediation*, 6(4): 99-114.

Valocchi, A.J., J.E. Odencrantz, and B.E. Rittmann. 1993. "Computational Studies of the Transport of Reactive Solutes: Interaction Between Adsorption and Biotransformation." Proceedings of the International Symposium on Hydroscience and Engineering. Washington, DC. 1845-1852.

Wright, L. 1996. "It's a Dirty Job." *Los Angeles Times*, Sept. 29, pp. 1, 6, 7, and 8.