



FLORIDA RBCA PLANNING STUDY
IMPACT OF RBCA POLICY OPTIONS ON
LUST SITE REMEDIATION COSTS



Prepared For
FLORIDA PARTNERS IN RBCA
IMPLEMENTATION (PIRI)

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1.0 EXECUTIVE SUMMARY

1.1 Project Objectives

As requested by the Florida Partners in RBCA Implementation (PIRI), Groundwater Services, Inc. (GSI), has conducted a technical evaluation of the impact of risk-based corrective action (RBCA) policy issues on the cost of corrective measures at leaking underground storage tanks (LUST) sites in the state of Florida. Technical information regarding environmental site conditions, remediation requirements, and related costs can greatly facilitate development of appropriate and cost-effective risk management policies. To this end, this study was undertaken to provide the Florida Department of Environmental Protection (FDEP) and other concerned parties with quantitative information related to implementation of RBCA policies for the storage tank cleanup program, as required by the recent legislative amendments (Chapter 96-277 Florida Statutes, CS for HB1127).

This project was commenced in January 1996, and preliminary findings were reviewed with representatives of FDEP and the Dade County Department of Environmental Resource Management (DERM) in June 1996. The study was modified thereafter to incorporate recommendations regarding addition/modification of policy issues and model sensitivity analyses, and a draft report was issued in October 1996. This final report has been modified to address written comments received from both the FDEP and the U.S. EPA Office of Underground Storage Tanks (OUST) on the draft report (see Attachment B). Throughout the course of this investigation, the findings have been used for technical guidance on various issues. The procedures and results of this policy study are summarized below.

1.2 RBCA Policy Options

The overall goal of Florida's Petroleum Contamination Site Cleanup Program is to establish cost-effective procedures for remediation and closure of LUST sites in a manner which is protective of public health and the environment. The degree of active site remediation and associated fund expenditures required under this corrective action program will depend upon the risk management policies defined by the Florida DEP. To support development of a cost-effective risk management program, this planning study has analyzed site remediation requirements and costs under several RBCA policy options (see Table 1). Key issues discussed with the FDEP prior to and during the rule-making process include the following:

- *Temporary Point of Compliance:* The point of application of state water quality standards (e.g., directly beneath tank, at property line, across roadway, or at nearest existing well).
- *Temporary Exceedance Period:* Time allowed to achieve cleanup via natural attenuation processes (e.g., 2, 10, or 25 years).
- *Soil Removal:* Need for removal of affected soils in order to protect/remediate underlying groundwater.
- *Site Classification:* Performance of Florida Site Priority Scoring System in predicting groundwater cleanup requirements.

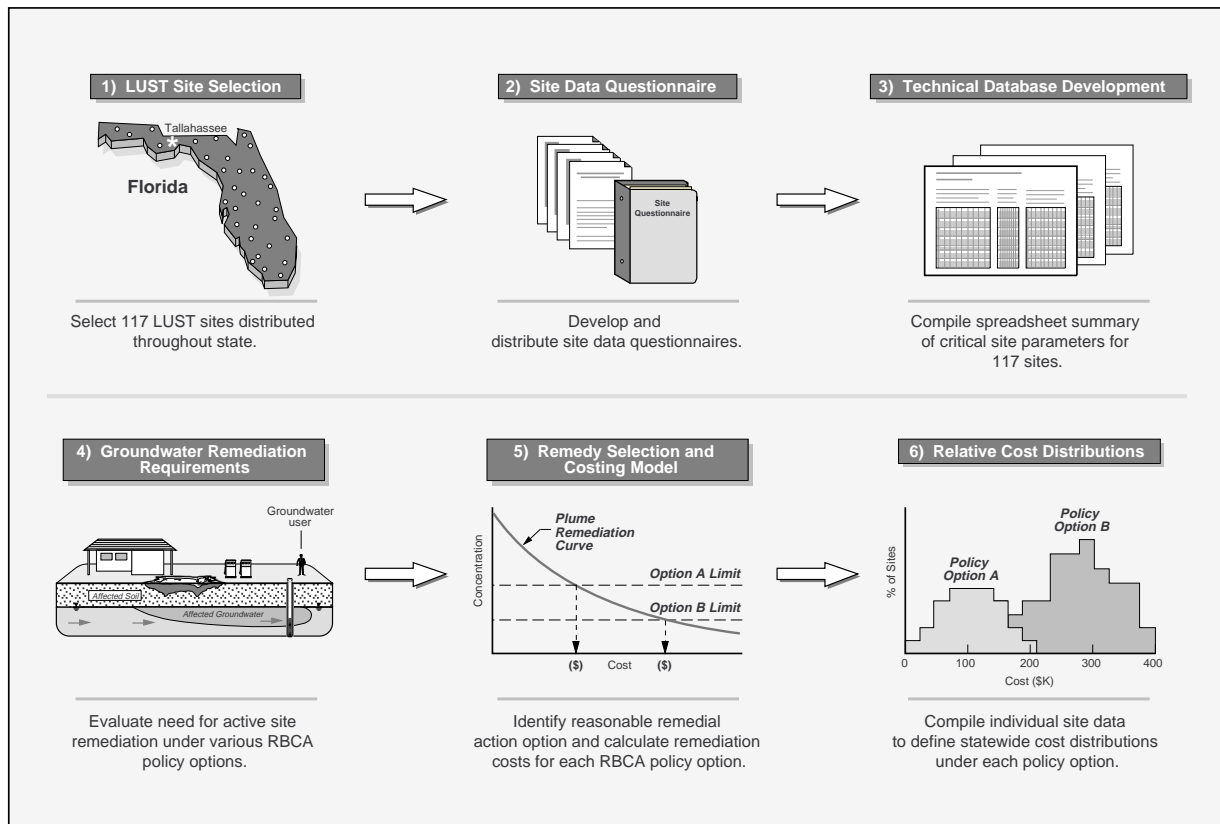


FIGURE 1: PROCEDURES FOR EVALUATION OF COST IMPACT OF RBCA POLICY ISSUES

Site evaluation, remedy selection, and costing procedures employed in this study reflect technical input received from Florida PIRI group members and representatives of the Florida DEP and the Dade County DERM. Detailed discussion of modeling assumptions and cost estimation methods is provided in Section 2.0 of this report. Key assumptions and procedures incorporated in this study include the following:

- **Type of Release:** The study is directed toward remediation of groundwater impacts associated with *gasoline* fuel releases, as this is the principal type of petroleum release encountered at Florida LUST sites.
- **Soil Remediation:** Costs associated with remediation of affected soils were not addressed in this study due to the absence of analytical soil test results for LUST sites in Florida. Affected soils are recognized as a risk management concern; however, data were not available to support quantitative evaluation of relevant policy options.
- **Critical Constituents:** Groundwater remediation requirements were calculated on the basis of benzene removal only, assuming that the other BTEX constituents would not significantly affect cleanup costs. To evaluate the impact of the MTBE standard (50 ppb) on groundwater remediation costs, a second set of runs addressed remediation of benzene/MTBE combined. Please note, however, that these benzene/MTBE remediation costs are based upon unproven remedial technologies and approximate MTBE cost multipliers and may therefore prove a less reliable indicator of RBCA policy impacts than the benzene-only cost values.



- **Remedy Selection:** For costing purposes the study employed a remedy selection decision tree (see Figure 4), matched to current management practices by tank owners in Florida. These remedial measures are not intended to represent optimal remedial strategies, but only to provide a reasonable and simple basis for cost comparisons under various policy options. The study is not intended to advocate use of the specific remedial technologies identified in the remedy selection matrix.
- **Cost Assumptions:** Groundwater remediation costs have been estimated on the basis of a unit price cost model, based on simplifying assumptions regarding capital costs, typical operating periods, and annual monitoring expense for each of the remedial technologies identified in the remedy selection matrix. Cost assumptions are summarized on Table 7.
- **Remediation by Natural Attenuation:** In this study, groundwater remediation by natural attenuation (RNA) was assumed to be a viable remedial measure only for low-concentration plumes or sites where other active remediation measures were previously implemented. For costing purposes, RNA was assumed to entail site assessment, routine groundwater monitoring, and data evaluation to ensure adequate plume remediation by natural attenuation processes.

1.4 Summary of Key Findings

Table 2 summarizes the average site remediation costs and percent cost savings calculated under each policy option relative to the conservative base case. Sensitivity runs conducted for key input parameters show these results to be consistent over a broad range of input values (see Table 8). Results of a separate case study analysis comparing alternative methods for derivation of soil cleanup standards are summarized on Table 3. These data support the following conclusions regarding the significance of RBCA policy options with respect to groundwater remediation of benzene at LUST sites in Florida:

1) *Target Risk Limits/Exposure Factors (Runs 1-3)*

Under Florida's Petroleum Contamination Site Cleanup Program, the current statutory water quality standards will be retained as the applicable exposure limits for groundwater ingestion. As indicated on Table 2, these existing standards (Run 1) are more stringent than application of a 10^{-6} carcinogenic risk limit with reasonable maximum exposure (RME) factors (see Run 2, 3% cost savings relative to Run 1). Use of MLE exposure factors would reduce costs by 14% relative to current standards.

Key Finding: *The current Florida water quality standards provide a relatively conservative basis for protection of groundwater resources.*

2) *Temporary Point of Compliance (Runs 4-6)*

Under this policy option, a site would be eligible for remediation by natural attenuation (RNA) once groundwater plume concentrations had been reduced to applicable water quality criteria at a specified *temporary point of compliance* (TPOC) location. As shown on Table 2, moving the groundwater TPOC from the source point (i.e., tank vault) to the downgradient property line or across the adjoining right-of-way reduces total groundwater remediation costs by 12% to 27% for this database (see Runs 4 and 5). If remediation requirements were based on actual downgradient receptors (or a maximum hypothetical well distance of 750 ft), current program costs would be reduced by 64% (see Run 6).



TABLE 2: REMEDIATION REQUIREMENTS AND RELATIVE COST SAVINGS UNDER RBCA POLICY OPTIONS

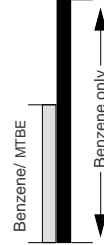
RBCA POLICY ISSUE	POLICY OPTION RUN / DESCRIPTION	AVERAGE GW REMEDIATION COST		REMEDIAL ACTION (%RNA)		COST SAVINGS RELATIVE TO BASE CASE (Run 1)	
		BENZENE/ MTBE	BENZENE ONLY	BENZENE/ MTBE	BENZENE ONLY	BENZENE/ MTBE	BENZENE ONLY
A) Target Risk Limits/ Exposure Factors	1 Exp. Limit = Existing Stds.	\$218K	\$193K	9%	9%	0%	0%
	2 Exp. Limit = TR: 10 ⁻⁶ , RME	\$212K	\$186K	12%	13%	3%	3%
	3 Exp. Limit = TR: 10 ⁻⁶ , MLE	\$189K	\$166K	24%	26%	13%	14%
B) Point of Compliance (POC)	4 POC = Property line	\$206K	\$169K	16%	23%	6%	12%
	5 POC = Across road	\$188K	\$141K	26%	38%	14%	14%
	6 POC = Nearest existing well	\$131K	\$ 69K	56%	79%	40%	64%
C) Temporary Exceedance Period (TEP)	7a TEP = 2 yrs, POC = source	\$203K	\$183K	16%	16%	7%	5%
	8a TEP = 10 yrs, POC = source	\$183K	\$163K	26%	27%	16%	16%
	9a TEP = 25 yrs, POC = source	\$163K	\$147K	37%	37%	25%	24%
D) Effect of Soil Removal	7b TEP = 2 yrs, POC = prop. line	\$189K	\$157K	24%	30%	13%	19%
	8b TEP = 10 yrs, POC = prop. line	\$169K	\$139K	34%	41%	23%	28%
	9b TEP = 25 yrs, POC = prop. line	\$151K	\$127K	44%	48%	31%	34%
D) Effect of Soil Removal	12a Remove soils, POC = source	\$218K	\$193K	9%	9%	0%	0%
	12b Remove soils, POC = prop. line	\$206K	\$169K	16%	23%	6%	12%
	12c Remove soils, POC = prop. line, TEP = 10 yrs.	\$160K	\$134K	39%	44%	27%	31%

NOTE:

1) Groundwater remediation requirements and relative costs under various RBCA policy options calculated for 117 LUST sites in Florida, using RBCA spreadsheet system and custom cost model. Relative cost savings represent reduction in average site remediation cost relative to Base Case (Run 1). See Table 1 for detailed description of policy options.

2) TR = Target risk for carcinogens
 RME = Reasonable maximum exposure factors
 MLE = Most likely exposure factors
 POC = Point of Compliance
 TEP = Temporary Exceedance Period

LEGEND





Key Finding: *The assumed TPOC location is the single most significant policy decision with respect to groundwater remediation requirements and costs. In this study, remedial actions based on assumed exposure at actual well locations (or 1500 ft, whichever is less) provided a high level of protection for well users and were found to reduce costs significantly (64%). (Note that this finding relates to groundwater remediation only, the TPOC location could prove less significant with respect to total soil and groundwater remediation costs.)*

3) Temporary Exceedance Period (Runs 7-9)

Under these options, sites for which plume concentrations at the designated TPOC are less than the relevant exposure limit (i.e., 0.001 mg/L benzene, 0.05 mg/L MTBE) after a *temporary exceedance period* would not require active groundwater remediation. To evaluate the impact of this parameter on groundwater remediation requirements, a broad range of time periods were analyzed (i.e., 2, 10, and 25 years). As indicated by Runs 7a through 9a (see Table 2), if groundwater cleanup limits must be achieved at the tank vault, temporary exceedance periods of 10 to 25 years would achieve cost savings of 16% to 24% relative to the base case. A two-year period (Run 7a) provides only a 5% cost savings in this case, indicating this timeframe to be insufficient for natural attenuation at most sites. If the point of application for the groundwater quality standard is moved from the source zone to the downgradient property line, temporary exceedance periods of 2, 10, or 25 yrs (Runs 7b - 9b) provide additional cost savings of 7%, 16%, and 22% relative to a no-exceedance period case (Run 4).

Key Finding: *Temporary exceedance periods of 10 years or more are required to achieve significant reductions in site remediation costs. Cost savings are greater in conjunction with TPOC locations away from the source.*

4) Effect of Soil Removal (Runs 12a - 12b)

Remedial actions at LUST sites often involve excavation of affected soils in an effort to reduce source mass and thereby facilitate groundwater cleanup by either active measures or natural attenuation. In this study, soil removal actions were reported to have occurred at 28 of 117 sites, in some cases as part of the tank replacement effort. At these 28 sites, the median groundwater source mass was 34% smaller than at those sites where no soils had been removed. These data suggest that, while soil removal actions had served to reduce source mass, a significant percentage of the groundwater contaminant source (66%) remained in place within the saturated water-bearing unit.

To evaluate the impact of such soil removal actions on groundwater remediation costs, Runs 1, 4, and 8b were repeated with the source terms of all sites adjusted to reflect the effect of soil removal (i.e., source mass was reduced proportionally at all sites to match the observed 34% reduction at those sites where soils had been previously removed). Comparison of Runs 12a, 12b, and 12c (soil removed at all sites) to the prior results for Runs 1, 4, and 8b (soil removed at only 28 of 117 sites) indicates that soil removal would not significantly affect groundwater remediation requirements. As indicated on Table 2, net cost reductions relative to the prior no-removal runs range from 0%, if existing Florida water quality standards are applied at the source zone or the property line (Run 1 vs. Run 12a and Run 4 vs. Run 12b), to only 3% if these standards are applied at the property line after a 10-year temporary exceedance period (Run 8b vs. Run 12c).

Key Finding: *Comparison of sites where affected soils have previously been removed to sites where soils have not been removed indicates that these prior soil removal actions provided no significant benefit with regard to groundwater remediation requirements or costs. These results suggest that, to prove effective, source removal may require excavation of a large volume of affected soils from above and below*



the water table. When conducted, such actions must be targeted toward the principal groundwater source mass (e.g., hydrocarbons in smear zone) and the associated costs weighed against potential benefits.

TABLE 3: COMPARISON OF ALTERNATE METHODS FOR EVALUATION OF SOIL CLEANUP STANDARDS

CALCULATION OPTION	ASSUMED TPOC LOCATION	SOIL BENZENE LIMIT
1) FDEP Equation		
Soil limit based on equilibrium soil-leachate concentration with default groundwater dilution factor of 20X.	Source area	0.007 mg/kg
2) EPA SSL Equation		
Soil limit based on equilibrium soil-leachate concentration with default groundwater dilution factor of 20X.	Source area	0.007 mg/kg
3) ASTM RBCA Tier 1		
Soil limit based on equilibrium soil-leachate concentration. (Dilution factor based on Infiltration = 10% of annual rainfall.)	Source area	0.007 mg/kg
4) ASTM RBCA Tier 2		
Soil limit based on equilibrium soil-leachate concentration, site-specific leachate-groundwater dilution factor with Infiltration = 10% of Annual Rainfall, and lateral groundwater attenuation factor to TPOC (across road).	Across road	0.18 mg/kg
NOTES:		
1) For each alternate calculation method, soil benzene limit represents the maximum allowable benzene concentration in unsaturated zone soil to prevent exceedance of Florida water quality standard (0.001 mg/L for benzene) in groundwater at temporary point of compliance (TPOC). All calculations conducted using Florida default values, where specified (Ruddell, Sept. 1995). Benzene $K_{oc} = 58.9$ L/Kg per EPA Soil Screening Guidance.		
2) References: • FDEP Equation: Ruddell, Sept. 1995 • ASTM RBCA Tier 1: ASTM, 1995 • EPA SSL Equation: U.S. EPA, 1996 • ASTM RBCA Tier 2: Connor et al, 1995		

5) Soil-Leachate Protection Standards (Case 2)

Under Florida’s Petroleum Contamination Site Cleanup Program, soil concentration limits will be established such that future soil-to-groundwater leachate release will not contaminate underlying groundwater at levels exceeding applicable water quality standards. For purpose of comparison, soil concentration limits protective of the Florida water quality standard for benzene (0.001 mg/L) were calculated by each of four optional methods, as listed on Table 3.

For each case, site default parameters were matched to the values specified in Florida DEP guidelines, where applicable. The three methods based on protection of groundwater immediately beneath the affected soil zone (Florida DEP, EPA SSL, RBCA Tier 1) were found to provide identical results for a benzene soil concentration limit (i.e., 0.007 mg/kg). Under a Tier 2 approach, to protect a hypothetical off-site well located immediately across the right-of-way, a median benzene soil cleanup standard of 0.18 mg/kg would apply for the 117 sites included in this study.

Key Finding: The optional methods for derivation of Tier 1 soil-leachate protection standards for on-site receptors were found to be equivalent based on Florida default parameters.

6) Site Priority Ranking System (Case 3)

As shown on Figure 2, comparison of risk-based action levels to Florida DEP Site Priority Ranking System scores for the 117 LUST sites in this study did not evidence a positive



correlation. Risk-based site evaluations indicated the need for active remediation at both high and low-score sites, with no clear trend between remediation requirements and site score (see Figure 2). These findings may reflect: i) incorrect priority ranking figures, ii) a change in site conditions since the initial scores were calculated, or iii) a failure of the ranking system to indicate relative site risk.

Key Finding: *The Florida DEP should review the current scores on all sites to ensure that the priority ranking system has been correctly applied and based upon up-to-date information.*

7) Significance of MTBE (Runs 1 - 12)

As indicated on Tables 2 and 4, groundwater remediation costs based on remediation of both methyl *tert*-butyl ether (MTBE) and benzene were predicted to be significantly higher than costs for remediation of benzene alone. This cost differential is related to the additional expense associated with MTBE removal and treatment, as incorporated in the cost model employed in this study. At 34 of 117 sites, reduction of current MTBE concentrations (i.e., >1 mg/L) to the 50 ppb standard will involve additional capital and operating expense. As shown on Table 4, remediation of MTBE will generally reduce the cost savings associated with the various RBCA policy options. However, it should be noted that these MTBE remediation estimates have been based on unproven remedial technologies and cost multipliers and may therefore provide a less reliable indicator of policy impacts than the benzene-only figures.

Key Finding: *Based on available information regarding groundwater treatment methods and costs, MTBE remediation is predicted to increase average site remediation costs.*

TABLE 4: EFFECT OF MTBE STANDARD ON GROUNDWATER REMEDIATION COSTS

RBCA POLICY	RUN	RELATIVE GROUNDWATER REMEDIATION COST	
		BENZENE ONLY	BENZENE/MTBE
Pre-RBCA Florida Standards	1	1.00	1.17
Temporary Point of Compliance (TPOC) at Property Line	4	0.88	1.10
Temporary Point of Compliance (TPOC) at Actual Receptor	6	0.35	0.68
NOTE: Relative groundwater remediation cost represents average per site cost divided by base case (Run1) cost for benzene only (i.e., \$193K). See Table 2 for detailed results.			

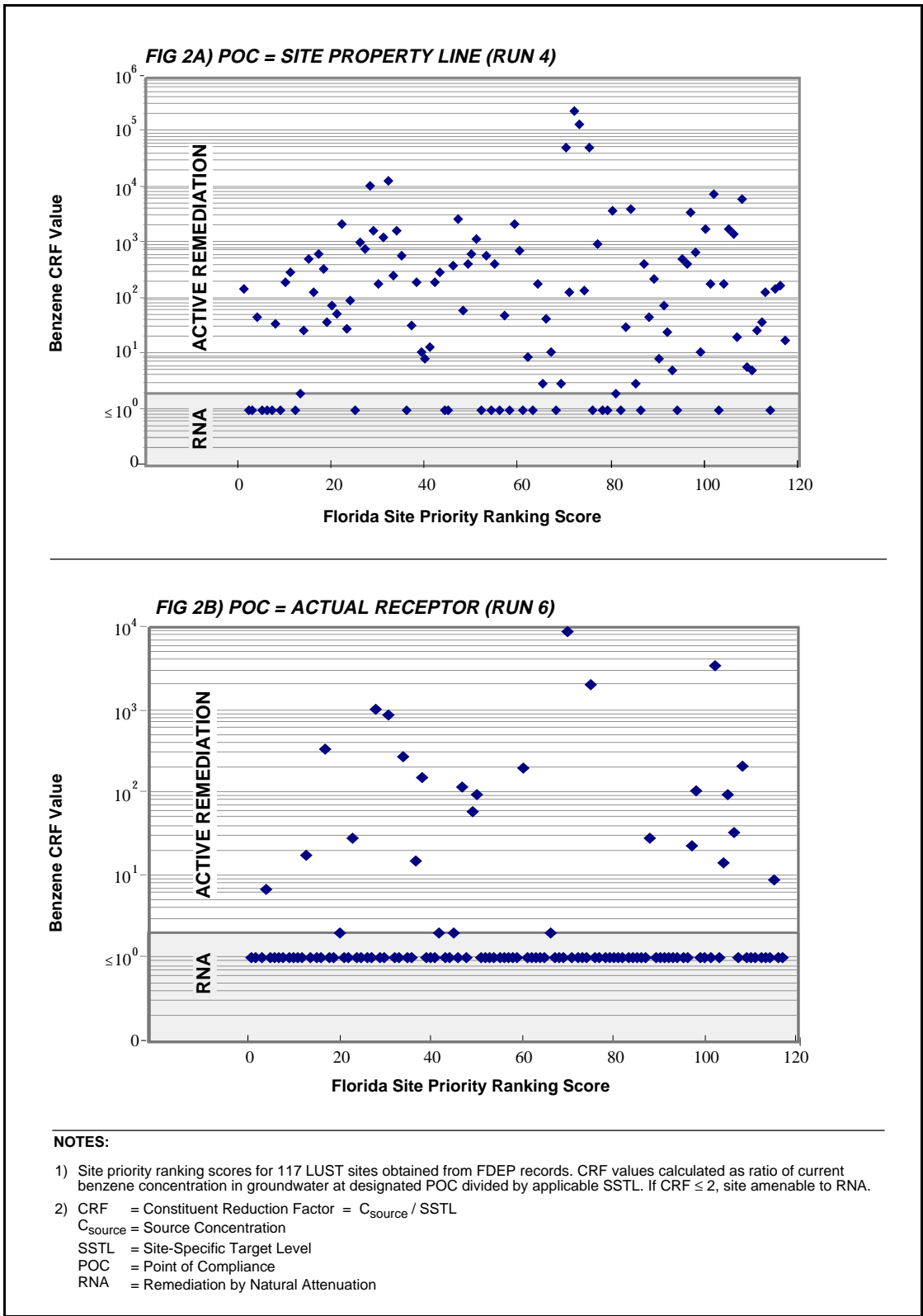


FIGURE 2: CORRELATION OF SITE PRIORITY SCORES TO REMEDIATION REQUIREMENTS



2.0 RISK-BASED SITE EVALUATION AND COSTING PROCEDURES

2.1 Technical Database Development

To evaluate the impact of RBCA policies on actual LUST sites, detailed technical information was compiled on over 100 LUST sites located in 30 separate counties in Florida (see Table 5). In March - April 1996, GSI distributed electronic data questionnaires to environmental consultants for 119 LUST sites owned or operated by PIRI members. The data questionnaire addressed all of the site-specific input required for RBCA Tier 1 and Tier 2 analyses, including land use and receptor data, soil and groundwater source concentrations, and relevant groundwater transport parameters.

TABLE 5: LOCATIONS OF LUST SITES USED FOR RBCA PLANNING STUDY

Florida County Name	Total UST Site Population		LUST Database for Planning Study		Difference in Site Distribution
	Quantity	% of State Total	Quantity	% of Study Total	
Alachua	604	1.5	3	2.6	+1.1%
Brevard	1086	2.7	7	6	+3.3%
Broward	2197	5.4	12	10.3	+4.9%
Charlotte	283	0.7	1	0.9	+0.2%
Collier	598	1.5	2	1.7	+0.2%
Dade	3293	8.2	27	23.1	+14.9%
Duval	2049	5.1	5	4.3	-0.8%
Escambia	937	2.3	1	0.9	-1.4%
Hillsborough	2773	6.9	2	1.7	-5.2%
Indian River	372	0.9	1	0.9	0
Lake	705	1.7	1	0.9	-0.8%
Lee	1006	2.5	3	2.6	+0.1%
Leon	617	1.5	1	0.9	-0.6%
Manatee	760	1.9	2	1.7	-0.2%
Marion	935	2.3	2	1.7	-0.6%
Martin	485	1.2	1	0.9	-0.3%
Monroe	442	1.1	1	0.9	-0.2%
Nassau	197	0.5	1	0.9	+0.4%
Okaloosa	490	1.2	1	0.9	-0.3%
Orange	2145	5.3	7	6	+0.7%
Osceola	407	1	3	2.6	+1.6%
Palm Beach	2379	5.9	15	12.8	+6.9%
Pasco	727	1.8	1	0.9	-0.9%
Pinellas	1832	4.5	3	2.6	-1.9%
Polk	2043	5.1	1	0.9	-4.2%
St. Lucie	630	1.6	1	0.9	-0.7%
Sarasota	743	1.8	4	3.4	+1.6%

cont'd



TABLE 5: LOCATIONS OF LUST SITES USED FOR RBCA PLANNING STUDY *cont'*

Florida County Name	Total UST Site Population		LUST Database for Planning Study		Difference in Site Distribution
	Quantity	% of State Total	Quantity	% of Study Total	
Seminole	593	1.5	1	0.9	-0.6%
Sumter	138	0.3	1	0.9	+0.6%
Volusia	1058	2.6	6	5.1	+2.5%
TOTAL:	32524	80.5%	117	100%	-----
NOTE: For RBCA planning study, data was obtained for 117 LUST sites in 30 counties in Florida. Information on total UST population in these counties (including opened, abandoned, and closed USTs) was based on August 1996 inventory by Florida DEP. These 30 counties account for 80.5% of the total UST population in state.					

Upon receipt by GSI, each questionnaire was reviewed for completeness and consistency, and the consultant was contacted as necessary to resolve apparent discrepancies. Table 5 shows the geographical distribution of this site database to be in reasonable agreement with the LUST site populations in the 30 counties included in the study. Consequently, the site database should prove representative of the range of hydrogeologic conditions encountered at LUST sites across the state.

For sites for which available information was insufficient to complete all data entries, reasonable parameter estimates were made on the basis of engineering judgment or statistical analysis of data from the other completed questionnaires. Table 6 itemizes these database assumptions and identifies the number of sites for which such estimates were required. Of the 119 site questionnaires distributed for the purpose of this planning study, sufficient data were compiled for a total of 117 LUST sites. Figures 3A and 3B provide statistical summaries of key site parameters, as reported for these 117 sites.

2.2 Evaluation of Groundwater Remediation Requirements

For the purpose of this planning study, the state-wide database has been analyzed to define the degree of active site remediation required under each RBCA policy option (see Table 1). It is presently anticipated that the Florida RBCA program will require compliance with the existing Florida water quality criteria. However, policies regarding the timeframe and location at which such compliance must be achieved will dictate the applicability of *active remedies* vs *natural attenuation* at many sites. Remediation by natural attenuation (RNA) can be effectively employed to meet groundwater cleanup goals given appropriate site conditions and adequate time. Sites not amenable to RNA will require active remedies, such as groundwater treatment and/or engineering control measures. For each site and each policy option, a customized groundwater fate and transport model has been used to quantify the upper concentration limit amenable to natural attenuation, known as the Site-Specific Target Level (SSTL). Calculated SSTL values were then compared to actual measured site concentrations to define the number of sites requiring active remediation under each policy option. In this study, remediation requirements were evaluated for both benzene and MTBE, the two critical constituents for most LUST site remediation efforts. Please note that, due to the absence of analytical data on site soils, evaluation of site remediation requirements has been limited to affected groundwater only.



TABLE 6: ASSUMED INPUT PARAMETERS FOR LUST SITE DATA GAPS

Data Gap	Assumed Value	No. of Sites with Data Gap	
		No.	Percent
Receptor Data			
• Distance to property line	5 ft	4/117	3%
• Distance to nearest downgradient water supply well	750 ft	5/117	4%
Source Zone Characteristics			
• Groundwater plume source	30 ft	4/117	3%
-Width:	6.6 ft	36/117	31%
-Thickness:	(0.5 x reported width) ²	37/117	32%
-Area:			
• Smear zone thickness	1 ft	3/117	3%
Groundwater Transport Parameters			
• Saturated thickness of water-bearing unit	100 ft	1/117	1%
• Hydraulic conductivity of water-bearing unit	6.6 x 10 ⁻³ cm/sec*	5/117	4%
• Groundwater seepage velocity	44 ft/yr*	3/117	3%
NOTE:			
1) For sites for which site-specific measurements were unavailable, the assumed values shown above were used to address data gaps. For all other cases, model inputs were matched to site-specific measurements. See Table A.1 in Attachment A for detailed list of modeling assumptions.			
2) * = Parameter matched to median value reported for sites for which site-specific measurements were available.			

For the purpose of this study, GSI developed a customized version of the RBCA Spreadsheet System (Connor et al, 1995) to assess the need for active remedial measures at each site under the various policy options listed on Table 1. The RBCA Spreadsheet employs the Domenico analytical groundwater solute transport model to predict steady-state (maximum chronic) plume concentrations downstream of a contaminant source zone (see Figures A.1 and A.2 in Attachment A), based on consideration of hydrodynamic dispersion, retardation, and biodegradation effects. In all runs except Runs 7 - 9, the model employed a constant source term and a first-order decay rate assumption for solute biodegradation.

To assess the effect of a "temporary exceedance period" (as required for Runs 7 - 9), the Domenico model was augmented with the diminishing source term feature of the BIOSCREEN Natural Attenuation Decision Support System (Newell et al, 1996), developed for the U.S. Air Force Center for Environmental Excellence (AFCEE). The BIOSCREEN model estimates the source term concentration vs. time using a simple mass balance approach based upon the mass of dissolvable hydrocarbons in the source zone and the rate of hydrocarbons leaving the source via dissolution into the passing, uncontaminated groundwater stream (Newell et al, 1996). An effective source mass half-life is then calculated based on the estimated rate of contaminant dissolution at the source-groundwater interface. Table A.1 in Attachment A summarizes key modeling assumptions incorporated in this study.

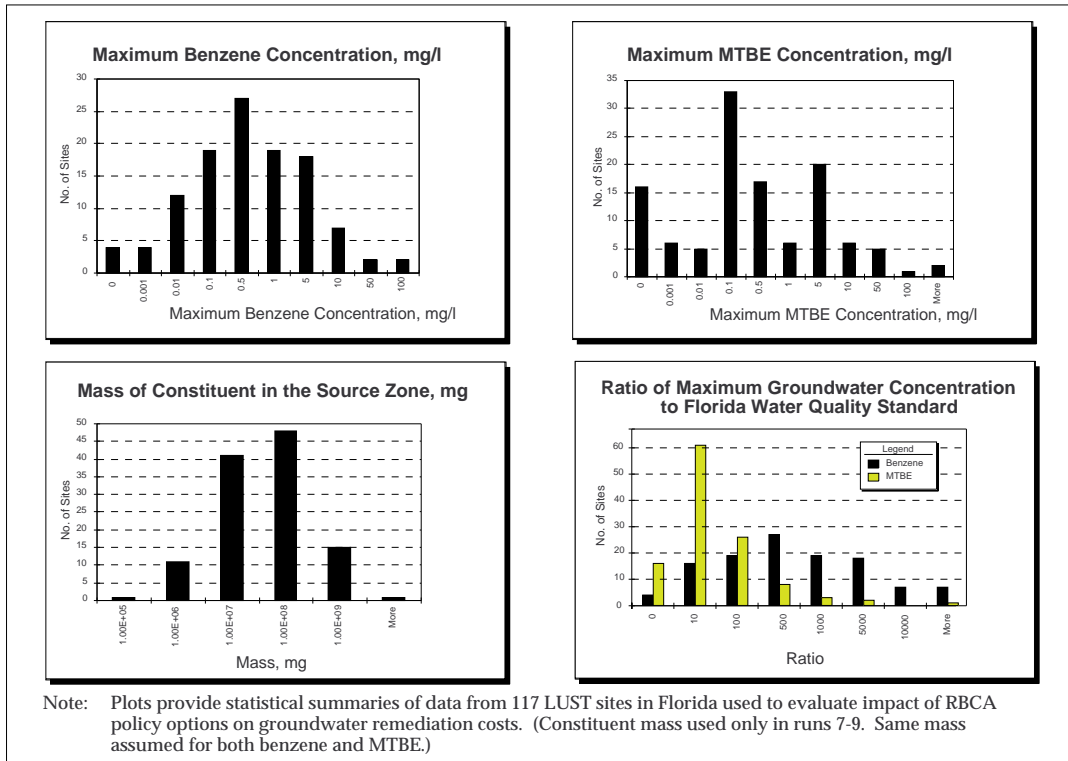


FIGURE 3A: STATISTICAL SUMMARY OF SELECTED SITE PARAMETERS: *PLUME CHARACTERISTICS*

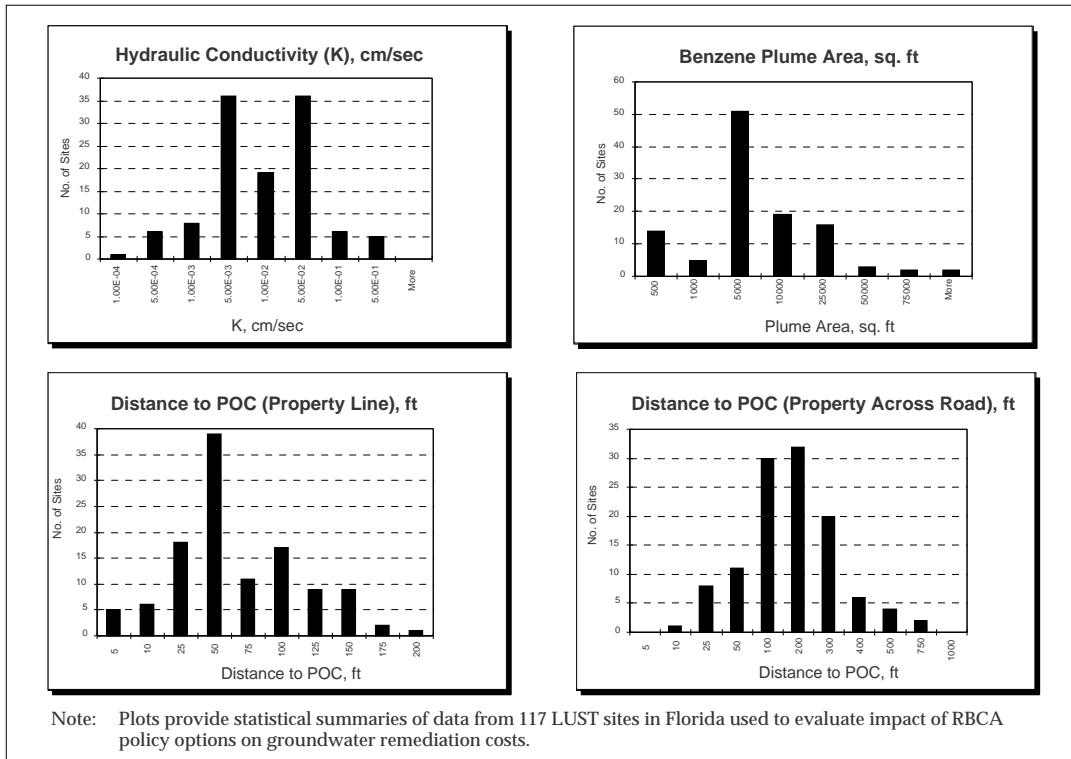


FIGURE 3B: STATISTICAL SUMMARY OF SELECTED SITE PARAMETERS: *PHYSICAL SITE CHARACTERISTICS*



For this project, a "baseline" run was first conducted to determine groundwater remediation requirements and associated costs for the full site database, under a relatively conservative set of RBCA program policies (Run 1). To assess the cost significance of possible policy options, the database analysis was then re-run for each of the 14 additional conditions listed on Table 1 (see Run 2 - 12), and the cost impact of each defined in terms of the relative decrease (or increase) in total remediation costs. To evaluate the impact of key parameter estimates on model results, sensitivity runs were conducted for both hydraulic conductivity and contaminant decay half-life (Runs 13 and 14). For each of Runs 1 - 14, groundwater remediation requirements and associated costs were calculated for each of the 117 sites under two separate criteria: i) remediation of benzene-only and ii) remediation of both benzene and MTBE to applicable exposure limits. This evaluation involved a total of over 4440 individual risk-based site analyses, using the customized RBCA data processing software developed by GSI. Modeling and cost estimation procedures are described in further detail in Sections 2.3 and 2.4 below.

In addition to these cost analyses, separate case studies have been completed to i) compare alternative methods for derivation of soil cleanup standards and ii) correlate risk-based remediation requirements with the Florida DEP site priority scores reported for each site. Results of these analyses are provided in Section 3.0 of this report.

2.3 Technology Selection and Cost Model

Based on the site remediation requirements determined as described above, the cost significance of each policy option was defined in terms of the relative (Base Case, Run 1) groundwater remediation costs for the full site database. For this purpose, a simple remedy selection and costing model was used to i) identify an appropriate remediation strategy for each site and ii) estimate associated capital and operating expenses. Under each option, individual site remediation costs were summed and divided by 117 to define the average cost among the full site database. The cost-significance of each policy option was then calculated as a percent savings in the average site remediation costs relative to a conservative baseline standard. Details regarding this modeling and costing effort are provided below. Results of each policy option analysis are summarized on Table 2 and Figure 5. Sensitivity analyses conducted on key input parameters are presented on Table 8.

For the purpose of this study, technology selection procedures were matched to current site management practices in Florida, as determined from interviews with PIRI participants and their consultants. The technology selection flowchart provided on Figure 4 summarizes the logic used to match groundwater remedial measures to site conditions and remediation requirements. As indicated on Figure 4, the best-match remediation approach for each site under each policy option is based on four selection criteria: i) the presence or absence of free product, ii) the permeability of the water-bearing unit, iii) the constituent reduction factor (CRF) required to reduce current source concentrations to the calculated SSTL value, and iv) the magnitude of the current source concentration. As shown, if groundwater source concentrations were found to exceed applicable SSTL values (i.e., $CRF > 2$), active groundwater remediation was determined to be necessary for the site. In such case, a total of five separate remediation technologies were considered:

- **Long-Term Containment:** Groundwater pump-and-treat recovery well system to prevent free-product migration in low permeability water-bearing units (i.e., $K < 1.0 \text{ E-4 cm/sec}$), for 10-year operating period. Followed by a 4 or 8-year period of RNA monitoring, depending on source concentration.

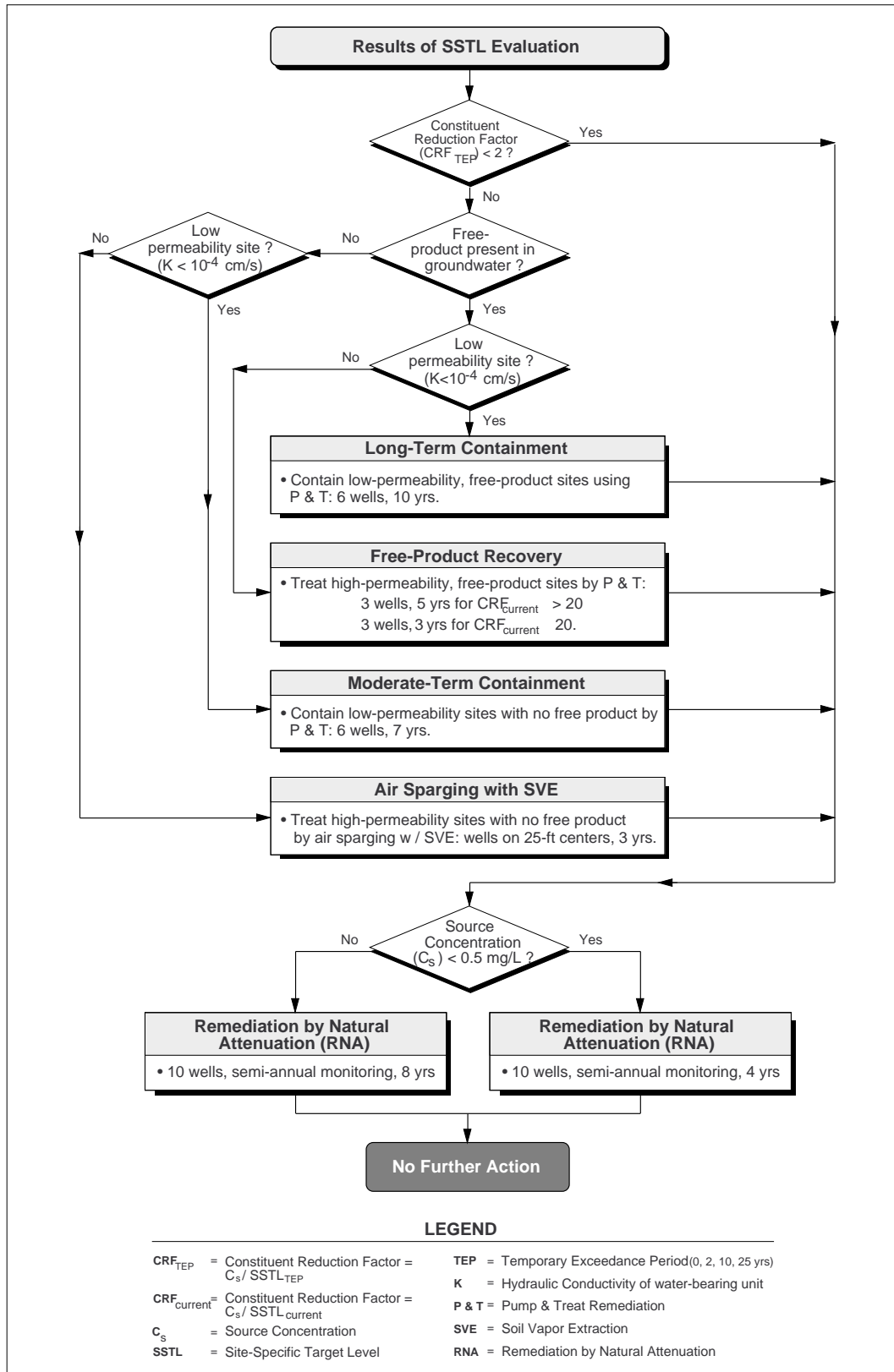


FIGURE 4: SELECTION OF GROUNDWATER REMEDIATION TECHNOLOGIES



- **Free-Product Recovery:** Groundwater pump-and-treat system to withdraw free-product layer from high-permeability units (i.e., $K \geq 1.0 \text{ E-4 cm/sec}$) for 3 to 5-year operating period. Followed by a 4 or 8-year period of RNA monitoring, depending on source concentration.
- **Moderate-Term Containment:** Groundwater pump-and-treat system to withdraw dissolved plume from low-permeability units for 7-year operating period. Followed by a 4 or 8-year period of RNA monitoring, depending on source concentration.
- **Air Sparging with Soil Vapor Extraction (SVE):** System of air sparging points on 25-foot centers to treat dissolved plume in high-permeability unit for 3-year operating period. Followed by a 4 or 8-year period of RNA monitoring, depending on source concentration.
- **Remediation by Natural Attenuation (RNA):** Semi-annual groundwater monitoring program to track natural attenuation of plume constituents in groundwater system for 4 to 8-year period, depending on source concentration. Followed by site closure.

Please note that these remedial measures are not intended to represent the optimal remediation strategy for each site. Rather, the goal of this technology selection effort is to match typical remediation scenarios to each site so as to provide a reasonable basis for comparison of remediation costs under the various RBCA policy options.

For each site, capital and operating costs associated with application of the selected remedial measure(s) were calculated on the basis of the unit prices listed on Table 7. Assumed operating durations for each treatment train are specified on Figure 4. To define the cost significance of each policy option, the average site remediation cost for the full site database was calculated for each option, and cost impact calculated as a percent savings relative to the conservative baseline standard (Run 1). Note that remediation costs were adjusted to reflect the relative difficulty of remediating MTBE-contaminated groundwater compared to BTEX plumes. For sites reporting MTBE groundwater concentrations in excess of 10 mg/L (8 sites out of 117), capital and operating costs were increased by factors of 1.5x and 2.5x, respectively, for groundwater pump-and-treat systems. Air sparging costs were similarly adjusted by a factor of 1.5x if MTBE levels exceeded 1 mg/L. (Please note that air sparging is not presently a proven remediation technology for MTBE; however, in this study, it has been assumed that air sparging or some other technology of comparable cost could be applied.

Actual remediation costs for these sites may differ significantly from the values predicted in this study, based on consideration of additional site information or use of other remediation technologies. However, for planning purposes, the procedures employed in this study should provide comparative cost estimates of sufficient accuracy for use in development of effective risk management policies.



TABLE 7: ASSUMED UNIT COSTS FOR GROUNDWATER REMEDIATION

GROUNDWATER REMEDIATION TECHNOLOGY	CAPITAL EXPENSE		ANNUAL O & M COST		ASSUMED ** DURATION
	Benzene Site	MTBE Site	Benzene Site	MTBE Site	
Remediation by Natural Attenuation (RNA)	0	0	\$5K	\$5K	4 - 8 yrs
Air Sparging	\$60K + 2K/well	\$90K + 2K/well	Yr 1: \$30K Yrs 2-3: \$22K	Yr 1: \$45K Yrs 2-3: \$33K	3 yrs
Groundwater Pump -and- Treat	\$80K + 2.5K/well	\$120K + 2.5K/well	\$30K	\$75K	5 - 10 yrs

NOTE:

- 1) For each site, estimated costs of groundwater remediation efforts based on unit prices shown above. Basis for selection of appropriate remediation technology and assumed operating period shown on Figure 4.
- 2) Benzene Site = LUST site for which benzene is controlling constituent for site remediation (i.e., max CRF).
MTBE Site = LUST site for which MTBE is controlling constituent for site remediation (i.e., max CRF). MTBE site costs applied only if MTBE groundwater concentration exceeded relevant threshold levels, i.e., 10 mg/L for groundwater pump-and-treat and 1 mg/L for air sparging.
- 3) * = Air sparging wells assumed to be located on 25-ft centers. Required number of sparging wells (n) for benzene site estimated as: $n = A / (12.5 \text{ ft})^2 \pi$, where A = total plume area in ft².
**= See Figure 4 for specific durations assigned to each remediation technology.



3.0 ANALYSIS OF RBCA POLICY OPTIONS

In accordance with the modeling procedures described above, groundwater remediation requirements were evaluated for each LUST site under each of the various policy options identified on Table 1 (i.e., Runs 1 - 14 and Cases 2 and 3). Tables 2, 3, and 8 and Figures 5 - 6 summarize the results of these analyses. The objectives and results of each policy option analysis are described in further detail below. Please note that, due to the greater reliability of the benzene remediation cost estimates developed in this study, the cost savings figures cited below refer to the benzene-only case rather than benzene/MTBE combined. Cost data for both groundwater remediation criteria are reported on Table 2.

1) Target Risk Limits / Exposure Factors (Runs 1 - 3)

- *Objective:* Evaluate impact of alternate exposure limits on site remediation requirements. Under these options, the site would qualify for closure once plume concentrations had been reduced to specified exposure limits in the source area and all points downstream.
- *Methodology:* For the base case (Run 1), allowable constituent concentrations in the groundwater at the relevant temporary point of compliance (TPOC) were matched to current state water quality standards. For Runs 2 and 3, carcinogenic risk limit and hazard quotient values were matched to the same criteria used in the development of the state standards (i.e., $TR = 10^{-6}$, $HQ = 1$), as specified in the recent tank bill (Chapter 96-277 Florida Statutes, HB1127). However, applicable exposure factors were varied from EPA Reasonable Maximum Exposure (RME) values in Run 2 to Most Likely Exposure (MLE) values in Run 3 to evaluate the impact of these options on cleanup requirements and costs. For each run, the applicable exposure limits for groundwater at the TPOC (i.e., source area in this case) were as follows:

Run	Applicable Standard	Exposure Limit (mg/L)			
		Benzene		MTBE	
		Residential	Commercial	Residential	Commercial
1	Florida Water Quality Stds.	0.001	0.001	0.050	0.050
2	RME Limits	0.003	0.010	0.18	0.61
3	MLE Limits	0.016	0.054	0.98	3.3

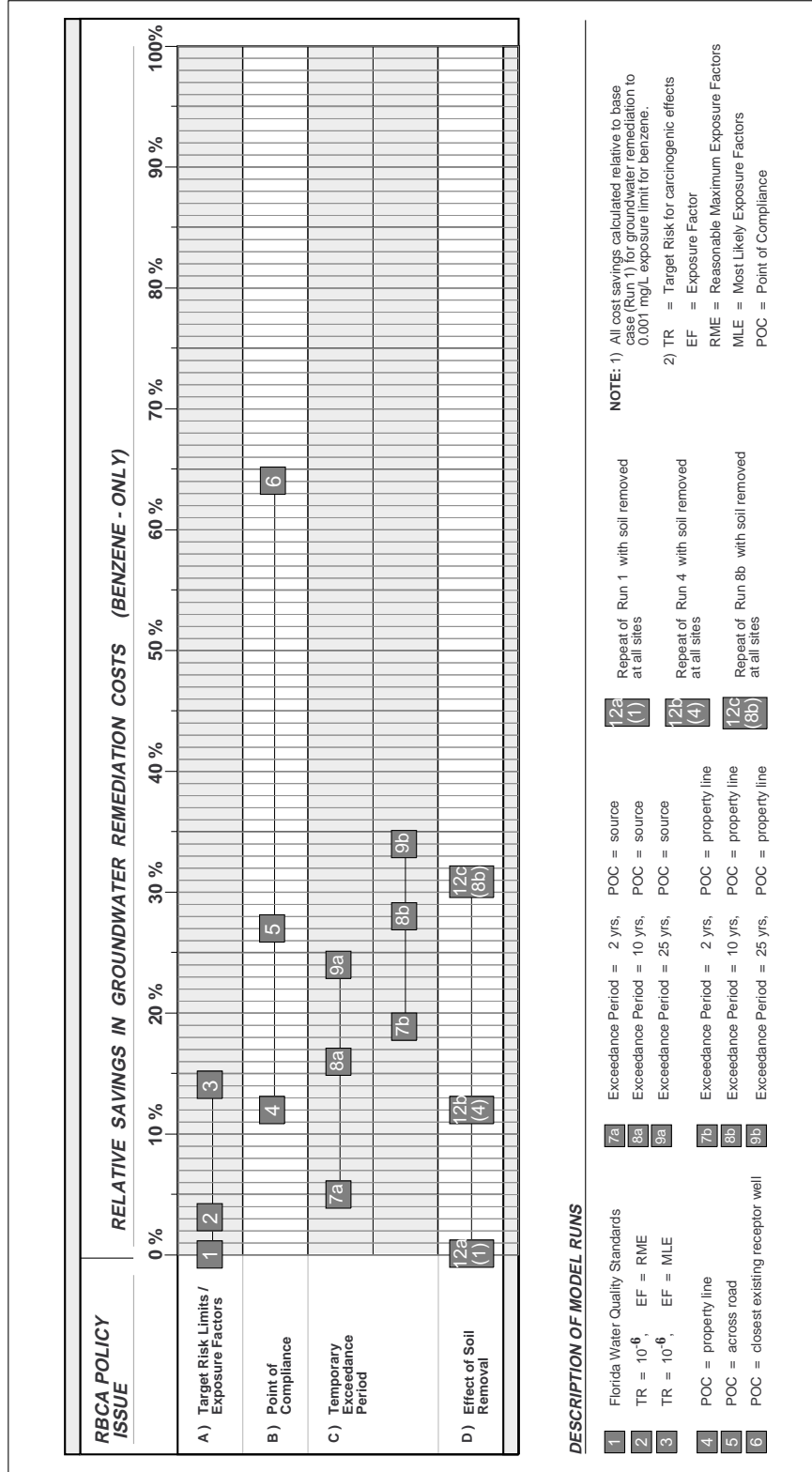
- *Results:* As shown on Table 2 and Figure 5, use of a 10^{-6} carcinogenic risk limit in conjunction with RME values provides an outcome very similar to the current Florida remediation standards (only a 3% cost reduction relative to base case for benzene). Use of MLE exposure factors (Run 3) would more significantly affect groundwater remediation costs, achieving a net savings of 14% for the 117-site database.

2) Temporary Point of Compliance (Runs 4 - 6)

- *Objective:* Evaluate impact of TPOC location on remediation requirements. Under these policy options, the site would be eligible for remediation by natural attenuation when plume concentrations are reduced to applicable water quality criteria at the specified TPOC location.
- *Methodology:* Under the base case (Run 1), the point of application of the allowable exposure concentration is the source zone. In Runs 4, 5, and 6, the assumed temporary point of compliance is located at increasing distances downgradient of the source zone, including:



FIGURE 5: COST SIGNIFICANCE OF KEY POLICY ISSUES





i) the downgradient site property line, ii) the first potential well location beyond the property line and across the bordering roadway (if present), and iii) the first actual existing water supply well location (or 1500 ft, if no actual wells within 1500 ft, or 750 ft, if no value is given). These alternate runs incorporate the effects of natural attenuation during plume transport from the source zone to the receptor.

- **Results:** The assumed TPOC location was found to be the most significant policy decision with respect to groundwater remediation requirements and costs. Moving the groundwater TPOC from the source point to the downgradient property line reduces total groundwater remediation costs by 12% for this database (see Table 2 and Figure 5). Relocating the TPOC across the downgradient right-of-way increases the net cost savings to 27% of the base case expense for benzene. If remediation requirements were based on actual downgradient receptors (or assumed receptors at 750 ft or 1500 ft, as above), current program costs would be reduced by 64%. These results indicate that remediation requirements based on an assumed TPOC well at the property line or across the road would be highly conservative with respect to protection of existing groundwater users in the vicinity of these sites. Remedial actions based on actual well locations achieved a high level of protection at significantly lower cost.

3) Temporary Exceedance Period (Runs 7 - 9)

- **Objective:** Evaluate impact of temporary exceedance period on feasibility of RNA remedies. Under these options, sites for which plume concentrations at the designated TPOC are less than relevant exposure limits (i.e., 0.001 mg/L for benzene and 0.05 mg/L for MTBE) after a *temporary exceedance period* would not require active groundwater remediation.
- **Methodology:** For the base case (Run 1), remedial action is required if groundwater constituent concentrations are found to exceed allowable limits at the TPOC at the present time. However in Runs 7, 8, and 9, a temporary exceedance period is allowed to facilitate further reduction of plume concentrations by natural attenuation processes prior to implementation of an active, engineered remedy. A broad range of allowable waiting periods (2, 10, and 25 years) were evaluated to establish the potential effect of natural attenuation on cleanup requirements. For each of Runs 7 - 9, remediation requirements were assessed for two TPOC assumptions. Runs 7a, 8a, and 9a assume a TPOC at the source, while Runs 7b, 8b, and 9b assume a TPOC at the property line.

To evaluate the time-rate of natural attenuation effects, the BIOSCREEN diminishing source term equation was incorporated in the customized RBCA Spreadsheet for these runs. In addition to Runs 7 - 9, the BIOSCREEN model was also used to predict the time required for *total* plume attenuation by RNA at each site (see Figure 6). For planning purposes, these predicted attenuation rates should be considered order-of-magnitude estimates. Key modeling assumptions are summarized on Table A.1.

- **Results:** Runs 7a - 9a are comparable to Run 1 (base case) with 2, 10, or 25 years of natural attenuation allowed prior to assessment of active remediation requirements. As indicated on Table 2 and Figure 5, a 2-year temporary exceedance period (Run 7a) reduces remediation costs by only 5% relative to the base case. Cost savings of 16% and 24%, respectively, are associated with exceedance periods of 10 and 25 years (Runs 8a and 9a). If the point of application for the groundwater quality standard is moved from the source zone to the downgradient property line, temporary exceedance periods of 2, 10, or 25 years (Runs 7b through 9b) provide additional cost savings of 7%, 16%, and 22% relative to the no-exceedance-period case (Run 4).

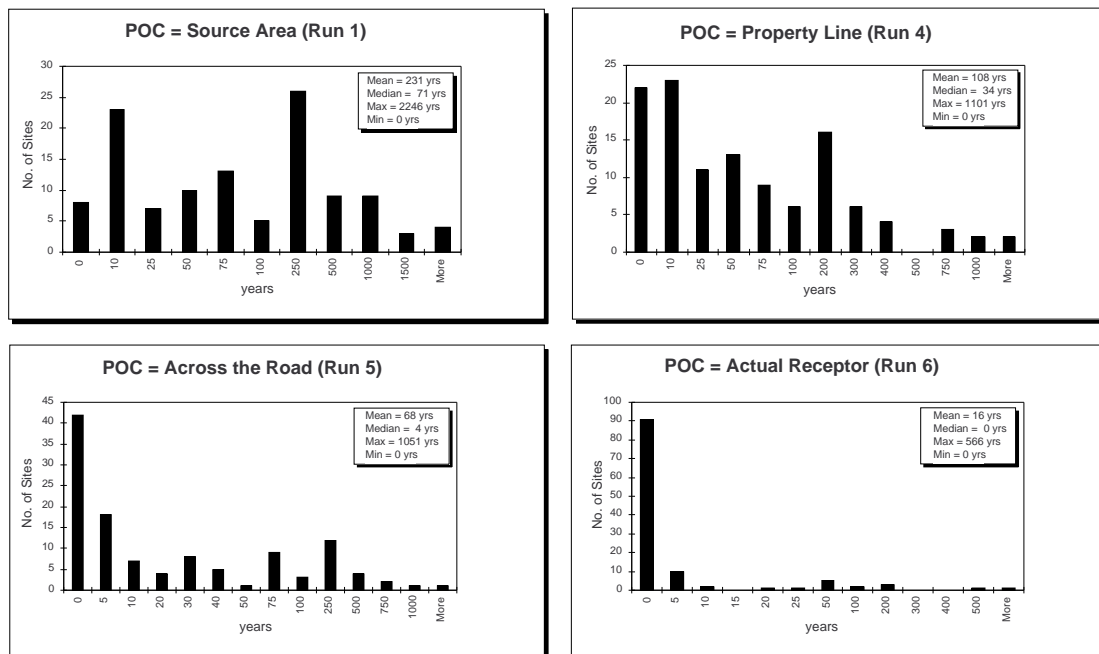


FIGURE 6: TIME REQUIRED FOR GROUNDWATER REMEDIATION BY NATURAL ATTENUATION

4) Effect of Soil Removal (Runs 12a - 12c)

- **Objective:** Evaluate impact of proposed soil removal requirement on groundwater remediation costs. Under a proposed policy, FDEP may require treatment/excavation of affected soils to prevent leaching to underlying groundwater and minimize potential groundwater quality impacts.
- **Methodology:** Of the 117 sites included in this study, affected soils have been previously removed at 28 sites. For these 28 sites, the estimated median groundwater source mass is approximately 34% lower than the median groundwater source mass for sites where overlying affected soils have *not* yet been removed. These data suggest that, while the soil removal actions have served to reduce groundwater impacts, a significant percentage of the contaminant source (66%) remains in place in the saturated water-bearing unit. To evaluate the impact of soil removal on groundwater remediation costs, Runs 1, 4, and 8b were repeated with the source terms of all sites adjusted to reflect the effect of soil removal (i.e., reduce source mass by 34% if affected soil not previously excavated).
- **Results:** Comparison of Runs 12a, 12b, and 12c (soil removed at all sites) to the prior results for Runs 1, 4, and 8b (soil removed at only 28 sites) indicates that soil removal would not significantly affect groundwater remediation requirements (see Figure 5). Net cost reductions for the prior runs range from 0%, if existing Florida water quality standards are applied at the source zone or the property line (Run 1 vs. Run 12a and Run 4 vs. Run 12b), to only 3% if these standards are applied at the property line after a 10-year temporary exceedance period (Run 8b vs. Run 12c).



TABLE 8: RESULTS OF PARAMETER SENSITIVITY ANALYSES

Key Input Parameter	Selected Values	Estimated Groundwater Remediation Costs		
		Run No.	Predicted Savings	Net Change
Hydraulic Conductivity of Water-Bearing Unit				
• Best Estimate	Reported Site K	Run 5	27%	-----
• High-Range Case (10x)	Reported Site K • 10	Run 13a	27%	0%
• Low-Range Case (0.1x)	Reported Site K/10	Run 13b	24%	-3%
First-Order Decay Rate for Benzene				
• Best Estimate	Half Life = 730 days	Run 5	27%	-----
• High-Range Case (0.5x)	Half Life = 365 days	Run 14a	35%	+8%
• Low-Range Case (2x)	Half Life = 1460 days	Run 14b	20%	-7%
Biodegradation Model				
• Base Case: First-Order Decay	Domenico: First-order	Run 4	12%	-----
• Option: Electron-Acceptor Superposition (EAS)	Domenico: EAS	Run 10	15%	+3%
Statistical Methods				
• Base-Case: Maximum Source Concentration	Maximum benzene concentration	Run 1	0%	-----
• Option: Mean Source Concentration	Mean benzene concentration	Run 11	3%	+3%
NOTE:				
1) For purpose of sensitivity analysis, model methods and input parameters varied as shown and groundwater remediation requirements and costs recalculated for 117 LUST sites to determine affect on predicted cost savings.				
2) Predicted Savings = Percent reduction in groundwater remediation costs relative to base case (Run 1).				
3) Net Change = Effect of modification on predicted cost savings.				
4) K = Hydraulic conductivity of affected water-bearing unit. Half-Life = First-order decay half-life for benzene in groundwater.				

5) Cost Study Sensitivity Analyses (Runs 10, 11, 13, and 14)

- **Objective:** Assess impact of key modeling assumptions and parameter values on results of groundwater remediation cost estimates.
- **Methodology:** To evaluate the stability of the cost savings figures generated in this modeling effort, sensitivity runs were conducted with regard to the following modeling criteria (see Table 8):
 - i) **Groundwater Biodecay Algorithm (Run 10):** For the base case (Run 1) and all other runs except Run 10, dissolved constituent biodegradation in the groundwater flow system was calculated using the Domenico analytical transport model with a first-order decay algorithm. Model runs were conducted for both benzene and MTBE, with the first-order decay half-lives for these constituents matched to the maximum (slowest) values reported in the literature (i.e., benzene: 730 days, MTBE: infinite). As an alternative approach for characterization of natural attenuation effects, Run 10 substitutes an electron-acceptor superposition algorithm for the first-order decay equation. The superposition algorithm simulates the actual stoichiometric rates of biodegradation processes by accounting for the rate of plume mixing with electron acceptors within the groundwater system and can, in some cases, provide a more



accurate prediction of the rate and degree of plume attenuation (see Connor et al, 1994, and Connor et al, 1995).

- ii) **Statistical Procedures (Run 11):** In the base case (Run 1) and all other runs except Run 11, the SSTL calculated for each of the LUST sites was compared to the maximum recent benzene or MTBE concentration measured in the source area. As an alternative, in Run 11, for those sites for which multiple measurements have been conducted in the plume source zone, the cleanup goal was compared to the mean benzene or MTBE value measured in source area wells. Note that, in this application, the mean concentration does *not* represent the average concentration measured in the *full* plume area. Rather, the mean source level corresponds to the average concentration measured inside the defined groundwater source zone (i.e., 1 mg/L benzene contour), for those sites for which multiple measurements are available for this area.
 - iii) **Key Parameter Values (Runs 13 and 14):** To evaluate the sensitivity of the modeling results to key input parameters, Run 5 was repeated using modified input values for groundwater hydraulic conductivity and constituent first-order decay rates. In Runs 13a and 13b, the reported hydraulic conductivity values for each site were in turn multiplied and divided by a factor of 10X. For Runs 14a and 14b, the first-order decay half-life assumed for benzene in groundwater (i.e., 730 days) was multiplied by factors of 0.5X and 2X, respectively.
- **Results:** Results of these sensitivity analyses are summarized on Table 8. Key findings are as follows:
 - i) **Groundwater Biodecay Algorithm (Run 10):** The results of Run 10 show the selection of the biodegradation algorithm has no significant affect on groundwater remediation requirements. Remediation costs for benzene under Run 10 (electron-acceptor superposition) are 3% lower than those estimated for Run 4 (first-order decay model).
 - ii) **Statistical Procedures (Run 11):** Results of this analysis suggest that use of mean source concentrations (Run 11) in place of maximum measured concentrations would have little impact on site remediation requirements (i.e., only a 3% reduction in estimated costs for benzene). Mean source values were reported for 68 of the 117 sites in this database; however, reported mean values did not vary sufficiently from maximum concentration to significantly affect the outcome of the cost model.
 - iii) **Key Parameter Values (Runs 13 and 14):** As shown on Table 8, comparison of Runs 13a and 13b to Run 5 indicates that varying hydraulic conductivity values by a factor of 10X only slightly affects the predicted savings for benzene (0% savings for $K \times 10$; -3% savings for $K/10$). Similarly, modifying the assumed benzene half-life by a factor of 2X did not dramatically alter Run 5 results (+8% savings for increased decay rate, -7% savings for reduced decay rate).

In sum, the results of these sensitivity analyses show the results of these cost analyses to be relatively consistent over a broad range of input values. To a large degree, this outcome is a function of the remedy selection criteria employed in this study (see Figure 4). For example, under current standards of practice, air sparging is applied to sites exhibiting a broad range of hydraulic conductivities (i.e., $K > 1.0 \text{ E-4 cm/sec}$). Consequently, varying the reported site K values by a factor of 10x would not alter the selected remedy in most cases and therefore has no significant effect on estimated remediation costs.



6) Soil-to-Groundwater Protection Standard (Case 2)

- **Objective:** Compare optional methods for calculation of soil cleanup standard for protection of underlying groundwater resources. For this purpose, the maximum constituent concentration for surface soils is determined such that future soil-to-groundwater leachate release will not cause an exceedance of the applicable groundwater standards in the underlying groundwater unit.
- **Methodology:** For purpose of comparison, soil concentrations limits protective of the Florida water quality standard for benzene (0.001 mg/L) were calculated by each of four optional methods:
 - i) Proposed Florida DEP Equation (Ruddell, Sept. 1995)
 - ii) EPA SSL Equation (U.S. EPA, 1996)
 - iii) Tier 1 RBCA Equation (ASTM, 1995)
 - iv) Tier 2 RBCA Evaluation (Connor et al, 1995)

For each case, site default parameters and chemical-specific properties were matched to the values specified in Florida DEP guidelines (Ruddell, Sept. 1995). For site parameters not addressed by the DEP, ASTM defaults (groundwater flow, source dimensions, etc.) or reasonable parameter estimates (infiltration = 10% of annual Florida rainfall) were employed.

- **Results:** Soil concentration limits for benzene, calculated using the four options listed above, are detailed on Table A.2 in Attachment A and presented in summary form on Table 3. As shown, the three methods based on protection of groundwater immediately beneath the affected soil zone (Florida DEP, EPA SSL, RBCA Tier 1) give identical results for the benzene soil concentration limit (0.007 mg/kg). Under a Tier 2 approach, to protect a hypothetical off-site well located immediately across the right-of-way, a median benzene soil cleanup standard of 0.18 mg/kg would apply for the 117 sites included in this study.

7) Site Classification System (Case 3)

- **Objective:** Evaluate correlation of Florida DEP Site Priority Ranking System to risk-based groundwater remediation requirements.
- **Methodology:** To assess the consistency of DEP site priority scores with the risk-based groundwater remediation requirements derived for the 117 sites in this study, reported DEP site scores have been correlated with the *constituent reduction factors* (CRFs) calculated for each site, as discussed above. For this analysis, Run 4 (TPOC at property line) and Run 6 (Actual TPOC well) were selected for purpose of comparison. For these runs, calculated CRF values for each site were plotted against reported site scores in order to define the range of site scores corresponding to i) conditions amenable to RNA (e.g., $CRF \leq 2$) and ii) conditions requiring active groundwater remediation ($CRF > 2$).
- **Results:** Figures 2a and 2b show plots of CRF values against FDEP site priority scores for Runs 4 and 6, respectively. As indicated on these plots, no clear relationship between risk-based site remediation requirements and site priority scores is discernible. Sites qualifying for RNA post scores ranging from 0 to 100, as do sites requiring active remediation. In addition, increasing CRF values (higher risk levels) do not correlate with higher site scores. These results suggest that i) site-ranking scores are either incorrectly reported or are out of date for many of these sites or ii) scoring criteria do not reflect relative risks posed by current site conditions.



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ATTACHMENT A
Background Information
On Data Evaluation Procedures

FLORIDA RBCA PLANNING STUDY

**IMPACT OF RBCA POLICY OPTIONS ON
LUST SITE REMEDIATION COSTS**

Table A.1:	<i>Summary of Groundwater Modeling Assumptions</i>
Table A.2:	<i>Comparison of Alternate Methods for Evaluation of Soil Cleanup Standards</i>
Figure A.1:	<i>Definition of Source Term for Groundwater Solute Transport Model</i>
Figure A.2:	<i>Typical Procedures for Development of Groundwater SSTL Value</i>



TABLE A.1: SUMMARY OF GROUNDWATER MODELING ASSUMPTIONS

PARAMETER	MODEL INPUT VALUE	BASIS FOR SELECTION
Groundwater Transport Parameters		
Groundwater Darcy Velocity, V_{gw}	$V_{gw} = K \times i$	• Matched to site data.
Hydraulic Conductivity, K	SS	• Matched to site data. (Sensitivity analysis: Run 13a = $K \cdot 10$, Run 13b = $K/10$)
Hydraulic Gradient, i	SS	• Matched to site data.
Effective Soil Porosity, η_e	SS	• Matched to site data or assumed $\eta_e=0.35$.
Groundwater Seepage Velocity, v_s	SS	• Matched to site data. Min = 1 ft/yr.
Distance to Receptor	SS	• Matched to site data.
Retardation Factor	Benzene: 1.6 MTBE: 1.0	• Average value for typical soil conditions.
Biodegradation Half-life	Benzene: 730 days MTBE: Infinite	• Slowest benzene decay rate reported in literature. (Sensitivity analysis: Run 14a = 365 days, Run 14b = 1460 days)
Longitudinal Dispersivity, α_x	Function of distance to receptor	• Xu and Eckstein relationship (1995)
Transverse Dispersivity, α_y	10% of α_x	• Newell et al (1996)
Vertical Dispersivity, α_z	If $S_d/b < 0.5$, $\alpha_z = 10\%$ of α_y If $S_d/b \geq 0.5$, $\alpha_z = 0$	• Newell et al (1996)
Diminishing Source Term Characteristics		
Source Mass, M_s	$M_s = V_s \times C_s$	• Newell et al (1996)
Source Volume, V_s	$V_s = A_s \times \delta_{sz}$ or $V_s = (S_w)^2 \times \delta_{sz}$	• Newell et al (1996)
Source Release Rate, M_{out}	$M_{out} = Q_s \times C_{eff}$	• Newell et al (1996)
Flowrate through source, Q_s	$Q_s = S_w \times S_d \times V_{gw}$	• Newell et al (1996)
Effective Source Concentration, C_{eff}	$C_{eff} = C_s + BC$	• Newell et al (1996)

cont'd



TABLE A.1: SUMMARY OF GROUNDWATER MODELING ASSUMPTIONS cont'd

PARAMETER	MODEL INPUT VALUE	BASIS FOR SELECTION
<i>Diminishing Source Term Characteristics continued</i>		
Source Half-Life, t_s	$t_s = 0.693 \left[\frac{M_s}{Q_s \times C_{eff}} \right]$	<ul style="list-style-type: none"> Newell et al (1996)
Effective Soil Porosity in Source Zone, η_{es}	0.35	<ul style="list-style-type: none"> Typical value for sandy soil.
Residual Saturation	10% of η_{es}	<ul style="list-style-type: none"> Upper-range value for hydrocarbon-affected soil.
Mass fraction of benzene in residual material	1%	<ul style="list-style-type: none"> Typical value for weathered gasoline.
NOTE:		
<p>1) Assumptions listed above incorporated in customized RBCA Spreadsheet model for estimation of groundwater plume transport and natural attenuation rates. Diminishing source term characteristics employed only to assess time-rate of biodegradation, as required for Runs 7 - 9 (see Newell et al, 1996). All other runs based on constant-source term.</p> <p>2)</p> <p>A_s = Source area, defined as area enclosed by 1 mg/L benzene plume contour.</p> <p>b = Saturated thickness of water-bearing unit.</p> <p>BC = Groundwater biodegradation capacity = 2.48 mg/L for benzene.</p> <p>C_s = Source benzene concentration at time $t = 0$.</p> <p>M_{out} = Rate of benzene mass release into groundwater flowing through source.</p> <p>M_s = Source mass at time $t = 0$.</p> <p>Q_s = Rate of groundwater flow through source area.</p> <p>S_d = Source zone thickness, defined as plume thickness at source location.</p> <p>S_w = Source zone width, defined as width of 1 mg/L benzene plume contour perpendicular to direction of groundwater flow. If no measurement of S_w reported, S_w assumed equal to 0.5 times the total plume width at this location.</p> <p>SS = Site-Specific measurement.</p> <p>V_{gw} = Groundwater Darcy Velocity.</p> <p>V_s = Source volume.</p> <p>δ_{sz} = Smear zone thickness (annual water table fluctuation).</p>		



TABLE A.2: COMPARISON OF ALTERNATE METHODS FOR EVALUATION OF SOIL CLEANUP STANDARDS

CALCULATION OPTION	SOIL CLEANUP LIMIT EQUATION	ASSUMED POE LOCATION	SOIL BENZENE LIMIT
1) FDEP Equation			
Soil limit based on equilibrium soil-leachate concentration with default groundwater dilution factor of 20x	$C_s = C_w \left[K_d + \frac{(\theta_w + \theta_a H')}{\rho_b} \right]$ $C_w = GW_{obj} \times 20$	Source area	0.007 mg/kg
2) EPA SSL Equation			
Soil limit based on equilibrium soil-leachate concentration with default groundwater dilution factor of 20x	$C_s = DF \cdot GW_{obj} \cdot \left[K_d + \frac{(\theta_w + \theta_a H')}{\rho_b} \right]$ $DF = 20$	Source area	0.007 mg/kg
3) ASTM RBCA Tier 1			
Soil limit based on equilibrium soil-leachate concentration. (Dilution factor based on I = 10% of annual rainfall.)	$C_s = DF \cdot GW_{obj} \cdot \left[K_d + \frac{(\theta_w + \theta_a H')}{\rho_b} \right]$ $DF = 1 + \frac{Vd}{IL}$	Source area	0.007 mg/kg
4) ASTM RBCA Tier 2			
Soil limit based on equilibrium soil-leachate concentration, site-specific leachate-groundwater dilution factor with I = 10% of annual rainfall, and lateral ground-water attenuation factor to POC (across road).	$(C_s) = (C_s \text{ for Tier 1}) \times DAF$ <p>where DAF = lateral groundwater dilution-attenuation factor for plume migration from source to POC, using Domenico 2D solute transport model (see Connor et al, 1995).</p>	Across road	0.18 mg/kg
NOTES:			
<p>1) For each alternate calculation method, soil benzene limit represents the maximum allowable benzene concentration in unsaturated zone soil to prevent exceedance of Florida water quality standard (0.001 mg/L for benzene) in groundwater at point of exposure (POE). All calculations conducted using Florida default values, where specified (Ruddell, Sept. 1995).</p> <p>2) References:</p> <ul style="list-style-type: none"> • FDEP Equation: Ruddell, Sept. 1995 • EPA SSL Equation: U.S. EPA, 1996 • ASTM RBCA Tier 1: ASTM, 1995 • ASTM RBCA Tier 2: Connor et al, 1995 			

cont'd



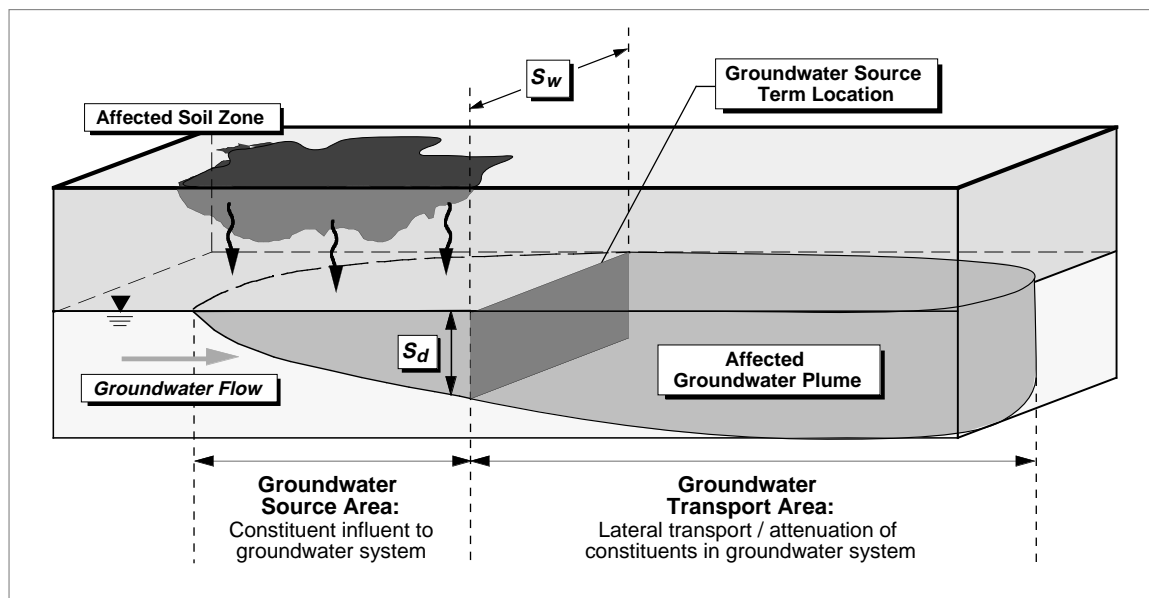
TABLE A.2: COMPARISON OF ALTERNATE METHODS FOR EVALUATION OF SOIL CLEANUP STANDARDS
cont'd

3) **Parameter Definitions**

Variable	Definition	Assumed Value
C_w	target soil leachate concentration (mg/L)	Calculated
k_d	soil-water partition coefficient (cm ³ /g)	$K_{oc} \times f_{oc}$ (benzene: 0.118)
k_{oc}	organic carbon partition coefficient (cm ³ /g)	benzene: 58.9
f_{oc}	organic carbon content of soil (g/g)	0.002 (0.2%)
H'	dimensionless Henry's Law constant	benzene: 0.22
V	Darcy's velocity of groundwater unit (m/yr)	2.5
d	groundwater-leachate mixing zone depth (m)	2
I	rainfall infiltration rate (m/yr)	0.14 (10% of annual rainfall)
L	soil source length parallel to groundwater flow (m)	15
GW_{obj}	groundwater protection standard (mg/L)	benzene: 0.001 mg/L
DF	Dilution factor for leachate mixing with groundwater	see above
θ_w	water-filled soil porosity (L_{water}/L_{soil})	0.3
θ_a	air-filled soil porosity (L_{air}/L_{soil})	0.13
ρ_b	dry soil bulk density (kg/L)	1.5

4) All "assumed values" matched to values used in Ruddell, Sept. 1995, where available.

FIGURE A.1 : DEFINITION OF SOURCE TERM FOR GROUNDWATER SOLUTE TRANSPORT MODEL



SELECTION OF GROUNDWATER MODEL INPUT PARAMETERS

For use of Domenico groundwater solute transport model (see Equation LT-1, Connor et al., 1995), select source term location and dimensions are selected as follows:

1) Groundwater Source Term Location

The source term corresponds to a vertical source plane, normal to the direction of groundwater flow, located at the downgradient limit of the area serving as the principal source of constituent release to groundwater (e.g., overlying affected soils, NAPL plume, land disposal unit, spill area, etc.). For the Florida planning study, the source zone was defined as the groundwater area enclosed by the 1.0 mg/L benzene contour. Distances to downgradient points of exposure (POEs) were then measured from this location along the principal direction of groundwater flow.

2) Groundwater Source Term Width, S_w

The width of the source term was matched to one of the following:

- i) the reported width of the 1.0 mg/L benzene or MTBE contour, or
- ii) 0.5 times the total plume width, if the 1.0 mg/L benzene or MTBE contour width was not reported.
- iii) a default value of 30 ft if no other data available.

3) Groundwater Source Term Thickness, S_d

The thickness of the source term was matched to:

- i) the reported smear zone thickness (water table fluctuation) at the source location, or
- ii) a default value of 1 ft, if no measurement provided.

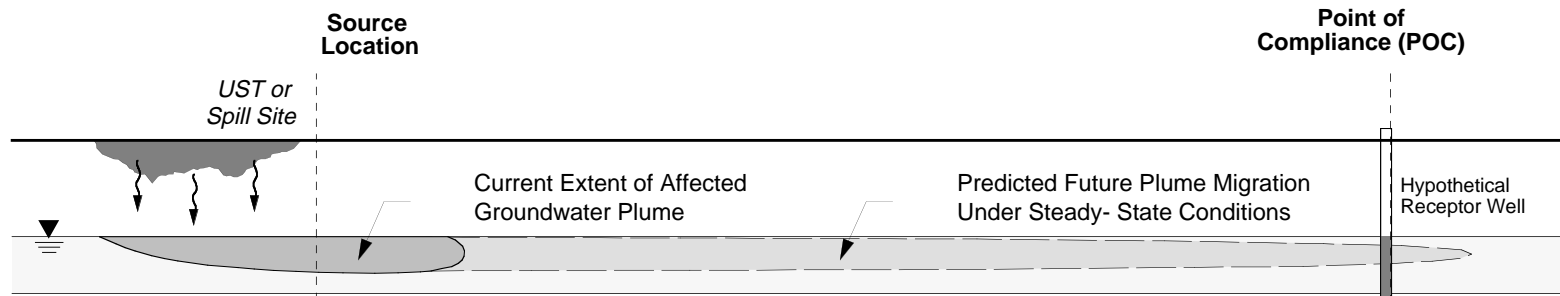
4) Groundwater Source Term Mass

The mass of the source term was characterized using two optional methods:

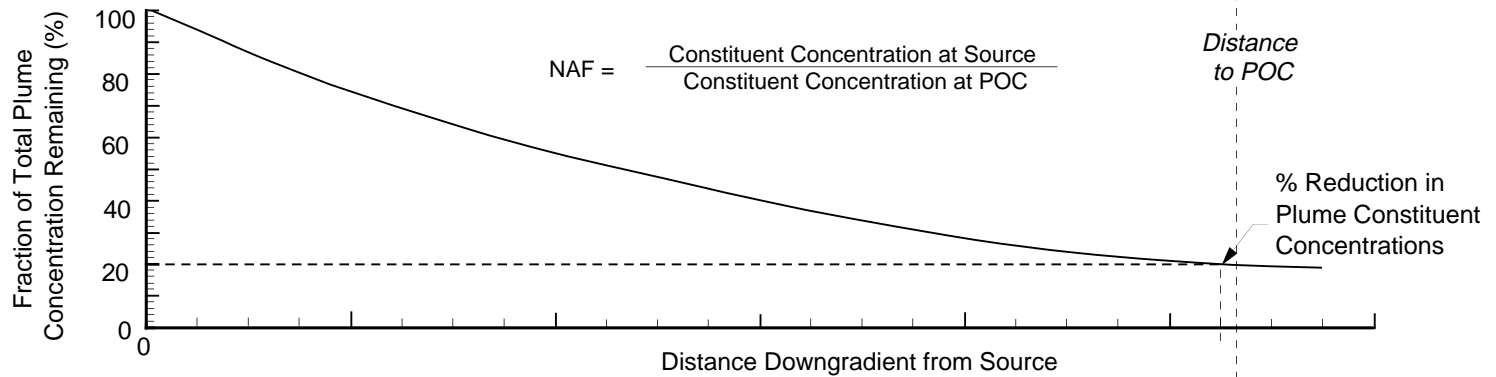
- i) *Infinite Source Term* (All Runs except 7-9): Source characterized as continuous flux equivalent to maximum or mean (Run 11 only) benzene or MTBE concentration measured at source location.
- ii) *Diminishing Source Term* (Runs 7,8,9, and 12c only): To simulate natural attenuation effects, benzene or MTBE source mass assumed to diminish over time per BIOSCREEN model (see Table A.1).

1) Groundwater Plume Model

Run steady-state solute transport model to predict maximum chronic plume concentrations at Point of Compliance (POC).

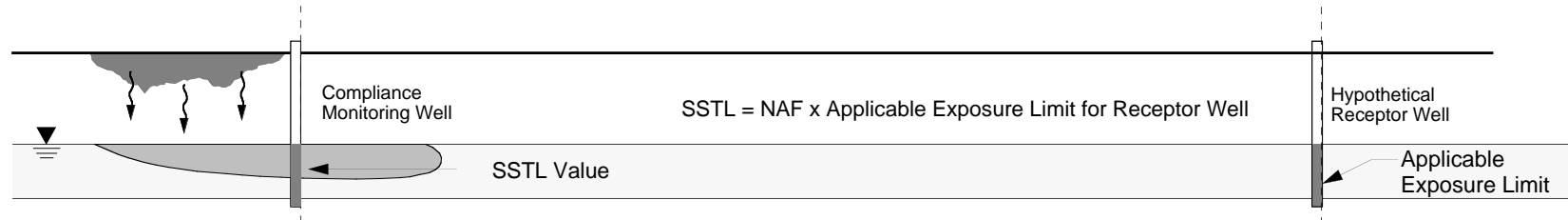


2) Natural-Attenuation Factor (NAF)



3) Site-Specific Target Level (SSTL)

Calculate source-area SSTL limit required to prevent exceedance of applicable exposure limit at downgradient POC location. SSTL corresponds to the upperbound concentration amenable to natural attenuation, for a given POC and exposure limit.



GSI Job No.	G-1805	Drawn By:	DLB
Issued:	2/13/97	Chk'd By:	JAC
Revised:		Apr'd By:	JAC
Scale:	Not to Scale	FIGURE A.2	

TYPICAL PROCEDURES FOR DEVELOPMENT OF GROUNDWATER SSTL VALUE
Florida RBCA Planning Study



ATTACHMENT B

Comments from Florida DEP and U.S. EPA OUST on Draft Report (10/96)

FLORIDA RBCA PLANNING STUDY

IMPACT OF RBCA POLICY OPTIONS ON LUST SITE REMEDIATION COSTS

-
- Attachment B.1:** *"Comments on Draft Florida RBCA Planning Study," Ms. Dana Tulis, Acting Director, Implementation Division, U.S. EPA Office of Underground Storage Tanks (OUST), December 1996.*
- Attachment B.2:** *Response to EPA OUST Comments on Draft Florida RBCA Planning Study*
- Attachment B.3:** *Correspondence from Mr. Michael Sole, Chief, Bureau of Petroleum Storage Systems, Division of Waste Management, Florida Department of Environmental Protection (FDEP), January 9, 1997.*
- Attachment B.4:** *Response to Florida DEP Comments on Draft Florida RBCA Planning Study.*



ATTACHMENT B.1

Comments on Draft Florida RBCA Planning Study, Ms. Dana Tulis, Acting Director, Implementation Division, U.S. EPA Office of Underground Storage Tanks (OUST), December 1996

FLORIDA RBCA PLANNING STUDY

**IMPACT OF RBCA POLICY OPTIONS ON
LUST SITE REMEDIATION COSTS**



ATTACHMENT B.2

**Response to Comments from U.S. EPA OUST
on Draft Florida RBCA Planning Study (October 1996)**

FLORIDA RBCA PLANNING STUDY

**IMPACT OF RBCA POLICY OPTIONS ON
LUST SITE REMEDIATION COSTS**



Attachment B.2: Response to Comments from U.S. EPA OUST on Draft Florida RBCA Planning Study (October 1996)

Reference: "Comments on Draft Florida RBCA Planning Study,"
Ms. Dana Tulis, Acting Director, Implementation Division, U.S. EPA
Office of Underground Storage Tanks (OUST), December 1996.

INTRODUCTION

In December 1996, representatives of the U.S. EPA Office of Underground Storage Tanks (OUST) provided technical comments on the Draft Florida RBCA Planning Study previously issued by Groundwater Services, Inc. (GSI), on October 29, 1996. These comments have been considered in preparation of the final draft of this report, issued February 1997. Specific responses to the EPA OUST comments, including associated text modifications or clarifications, are itemized below.

RESPONSE TO COMMENTS IN EPA MEMORANDUM

- **EPA Memorandum, Paragraph 1:** The EPA comment requests additional information regarding key assumptions employed in this study. These assumptions are identified in the final report text and a cover letter has been added identifying the key factors affecting the outcome of this study.
- **EPA Memorandum, Paragraph 2:** The EPA comment requests further information regarding hydrogeologic data, types of fuel releases, and soil remediation costs. Response to each point is provided below.
 - i) *Hydrogeologic Data:* As the basis for this planning study, detailed hydrogeologic data inventories have been compiled on each of 117 sites in Florida. For purpose of brevity, these data inventories have not been enclosed with the report; however, general information regarding site characteristics is provided.
 - ii) *Fuel Releases:* The planning study is directed to costs associated with management of *gasoline* releases only, as this is the type of fuel release encountered at the vast majority of Florida LUST sites.
 - iii) *Chemicals of Concern:* Experience with remediation of gasoline releases in Florida and other states has shown benzene to be the critical constituent with regard to both risk and remediation costs. Toluene, ethylbenzene, and xylene (TEX), typically drive remediation requirements only in the absence of benzene. However, historically, the Florida LUST site management program has not required individual TEX analyses; therefore, data were not available to support risk-based evaluation of these compounds in this planning study. MTBE cost impacts have been addressed in this study; however, as noted in the final report text, in the absence of detailed information regarding applicable remediation technologies and related costs, these benzene/MTBE cost results are considered less reliable than the benzene-only cost analyses.
- **EPA Memorandum, Paragraph 3:** The EPA comments note that the EPA LUST program does not advocate use of one cleanup technology over another. Rather, technology selection



is to be conducted on a site-specific basis. In the Florida RBCA Planning Study, selection of applicable groundwater remediation technologies has been based upon the specific characteristics of each LUST site. For costing purposes, a remedy selection decision tree (see Figure 4 of final report), matched to current management practices by site owners in Florida, was used to identify a reasonable approach to groundwater remediation at each site. These remedial measures are not intended to represent optimal remediation strategies, but only to provide a reasonable basis for cost comparisons under various policy options. Remediation by natural attenuation (RNA), as considered in this remedy selection matrix, entails active site monitoring and data evaluation to confirm adequate control of constituent transport and associated exposures.

RESPONSE TO COMMENTS IN EPA ATTACHMENT 1

- **Assumed Values:** The EPA comments request clarification regarding selection of specific parameter values used in this study. The basis for those parameter selections is as follows:
 - i) *Temporary Exceedance Period:* In the initial phase of the rule-making effort, the Florida DEP was considering placing a time limit (termed a *temporary exceedance period*) on groundwater remediation by natural attenuation (RNA). Exceedance periods of 2, 10, and 25 years were selected based on discussions with Florida DEP representatives. This broad range of time values was used only to establish the relationship between the temporary exceedance period and the percentage of sites qualifying for remediation by natural attenuation. The actual value used in the Florida RBCA program could incorporate other considerations.
 - ii) *Point of Compliance:* The site database questionnaires issued for this project required information on water supply wells located within 1500 ft of the LUST site property, per Florida guidelines. If no existing wells were reported, an existing well location 750 ft downgradient of the site was assumed for conservative evaluation of the "actual receptor" case (Run 6).
 - iii) *Assumed Values on Table 5:* The "assumed values" shown on Table 5 (renumbered as Table 6 in final report) were used in the modeling analyses if site-specific values were not provided on the LUST site questionnaire. In each case, these "assumed values" were matched to either i) median values reported for sites for which site-specific measurements were available (hydraulic conductivity and groundwater seepage velocity), ii) ASTM Tier 1 default values (source zone dimensions), or iii) conservative exposure assumptions (receptor data).
- **Receptors:** The EPA comments note that the Florida RBCA Planning Study addressed only the groundwater ingestion exposure pathway, although other pathways (including soil exposure mechanisms) can pose a concern at some LUST sites. The proposed Florida RBCA program recognizes the presence of such soil-related pathways and imposes very conservative Tier 1 soil screening levels based on soil vapor exposure. However, in the past, the Florida DEP has not required constituent-specific analyses of affected soil samples. Consequently, at the time of this planning study, no data were available to support risk-based evaluation of soil remediation requirements. Analysis of remedial action requirements and costs was therefore restricted to groundwater remediation at the 117 LUST sites included in this study.
- **Policy Options:** The EPA comments request that the wording of the "soil removal" policy option be clarified in the text and notes that soil removal alone does not comply with guidelines for free product removal. The final text incorporates the requested wording



correction. In addition, the remedy selection matrix used in this study does require free product recovery, per EPA guidelines. A minimum free product recovery effort of 3 to 5-years duration has been assumed for costing purposes.

- **Study Scope:** The EPA comment requests clarification on the degree to which the 117 LUST sites used in this study are representative of hydrogeologic conditions throughout the state. In development of this database, effort was made to obtain site data from a broad geographic distribution. As noted in the final report, the site database covers 30 separate counties and closely patterns the total UST site population in Florida. Consequently, it is assumed that these 117 sites provide a reasonable representation of the various hydrogeologic settings across the state.
- **Appropriate Technologies:** The EPA comment states that the remedy selection process used in this study appears to "default to remediation by natural attenuation," without considering the active measures associated with this remedy. This is an incorrect characterization of the assumptions incorporated in the Florida RBCA Planning Study. Under the simple remedy selection process used in this study, remediation by natural attenuation (RNA) is applied as a first-step remedial measure only if groundwater plume concentrations are within a multiple of 2x of the site-specific source remediation goal. If plume concentrations exceed this level, active plume containment or removal technologies must be applied *prior* to a 4 to 8-year RNA monitoring period. Assumed remedial action periods range from 4 to 18 years, depending on site-specific conditions, with *no* sites closed without a minimum 4-year monitoring and data evaluation program. This remedy selection process was intended as a simple, yet conservative basis for estimation of groundwater remediation costs associated with different policy scenarios. Under this costing model, natural attenuation was not considered a "no-action" approach but was assumed to involve data collection, evaluation, and reporting at an average cost of \$5000 per year per site.
- **Point of Compliance:** The EPA comments note that the impact of the point of compliance (POC) location on remediation costs may be less significant if soil remediation had been considered in the study. This has been noted in the final report.
- **Temporary Exceedance Period:** The EPA comments request clarification regarding the selection of temporary exceedance periods (TEP) and note that shorter timeframes could be applied if active remedies were employed. The basis for the TEP values used in the study is discussed above. For the purpose of this study, the TEP was considered to be a timeframe for application of RNA measures. If RNA proved insufficient to achieve groundwater remediation standards in this timeframe, active removal/treatment measures would be required thereafter. Consequently, application of active groundwater remediation measures does not affect the TEP policy.
- **Effect of Soil Removal:** The EPA comments pose questions regarding the mechanisms of leachate release from affected soils. These issues are beyond the scope of the current study. However, the final report has been amended to clarify the significance of the findings regarding soil removal actions.
- **Technical Database Development:** The EPA comments request detailed information regarding the site database used in this study. For purpose of brevity, the report summarizes general information regarding this database. Detailed records are available for review upon approval of the project sponsors, the Florida Partners in RBCA Implementation (PIRI).



ATTACHMENT B.3

**Correspondence from Mr. Michael Sole, Chief, Bureau of Petroleum Storage
Systems, Division of Waste Management, Florida Department of
Environmental Protection (FDEP), January 9, 1997**

FLORIDA RBCA PLANNING STUDY

**IMPACT OF RBCA POLICY OPTIONS ON
LUST SITE REMEDIATION COSTS**



ATTACHMENT B.4

**Response to Florida DEP Comments
on Draft RBCA Planning Study (October 1996)**

FLORIDA RBCA PLANNING STUDY

**IMPACT OF RBCA POLICY OPTIONS ON
LUST SITE REMEDIATION COSTS**



Attachment B.4: Response to Florida DEP Comments on Draft RBCA Planning Study (October 1996)

Reference: Correspondence from Michael W. Sole, Chief, Bureau of Petroleum Storage Systems, Division of Waste Management, Florida Department of Environmental Protection (FDEP), January 9, 1997.

RESPONSE TO FLORIDA DEP COMMENTS

In January 1997, representatives of the Florida Department of Environmental Protection (FDEP) provided technical comments on the Draft Florida RBCA Planning Study previously issued by Groundwater Services, Inc. (GSI), on October 29, 1996. These comments have been considered in preparation of the final draft of this report, issued February 1997. Specific responses to the FDEP comments are itemized below.

RESPONSE TO COMMENTS IN FDEP COVER LETTER (1/9/97)

- 1) **Timing of Study:** The FDEP comment notes that the RBCA rule-making effort has been nearly completed; consequently, the timing of the Florida RBCA Planning Study report is of questionable value. The Florida RBCA Planning Study was commenced in January 1996 and preliminary results were provided to FDEP representatives in June 1996 at the beginning of the rule-making process. The scope of the study was modified thereafter to address key issues identified by the FDEP. Over the course of the past year, data generated by the RBCA Planning Study have formed the basis of technical comments submitted by concerned parties. The draft project report was issued in October 1996 and has been reissued in final form in February 1997 to incorporate FDEP and U.S. EPA comments. This final report documents information regarding environmental site conditions, remediation requirements and associated costs which are critically relevant to the continued development and implementation of a cost-effective RBCA regulatory program for Florida.
- 2) **Temporary Exceedance Period:** The FDEP comments note that the temporary exceedance period provision was not incorporated in the final draft rule; consequently, findings regarding this policy option are not relevant to the Florida RBCA program. In the early stages of the rule-making effort, the FDEP had proposed placing time limits, termed "temporary exceedance periods," on the use of natural attenuation as a groundwater remediation technology. The initial timeframe under consideration was 2 to 5 years. This policy option was therefore addressed in the Florida RBCA Planning Study based on consultation with FDEP representatives. The results of this analysis indicate that, were such a time limit to be considered, time periods of 10 years or more would typically be required in order to achieve significant economic benefit from the use of natural attenuation remedies.
- 3) **Soil Removal:** The FDEP comments state that findings regarding soil removal are counter-intuitive; removal of the affected soil mass should have a clear benefit with regard to reduced groundwater remediation requirements. The text of the final report has been revised to clarify the discussion of this policy issue. At the 28 of 117 LUST sites where



affected soils had been removed, the median groundwater source mass was 34% lower than at sites where no removal actions were undertaken. The degree of soil removal achieved at these sites was not reported. However, these data indicate that, while these soil removal actions had served to reduce source mass, a significant percentage of the groundwater source (66%) remained in place within the saturated water-bearing unit. Consequently, to prove effective, these prior source removal efforts may have required excavation of a larger volume of affected soils from above and below the water table. When conducted, such actions must be targeted toward the principal groundwater source mass (e.g., smear zone), and the associated costs weighed against potential benefits.

RESPONSE TO COMMENTS IN FDEP MEMORANDUM (12/13/96)

- 1) **Natural Attenuation Time Periods:** The FDEP comment notes a discrepancy between the relatively long time periods predicted for groundwater remediation by natural attenuation (RNA) in the modeling analyses and the relatively short time periods (4 to 8 years) assumed for RNA monitoring costs. In the modeling analyses, in the absence of site-specific decay measurements, a conservative first-order decay half-life value (i.e., 730 days for benzene) was used so as not to overestimate the effects of biodegradation. This approach is generally consistent with recommended modeling practices, but likely contributed to an upper-range estimate of the time required for RNA at each site. In the remedy selection matrix employed in this study, RNA was applied only to low concentration plumes or sites where other active remediation measures had previously been implemented. Consequently, timeframes required for RNA monitoring at these low concentration sites were matched to lower-range values (e.g., 4 to 8 years). These values are therefore not contradictory, but are intended to provide a reasonable costing basis for those sites where RNA could be applied. If a less conservative half-life values had been assumed in this study, the number of sites qualifying for RNA may have been higher, contributing to higher predicted cost savings under RBCA.
- 2) **Source Removal Analyses:** The FDEP memorandum again notes that findings regarding soil removal appear counter-intuitive and posits that this outcome may be related to natural attenuation modeling assumptions. Clarification of the study conclusions regarding soil removal actions is provided above (see FDEP Cover Letter, Comment 3). Evaluation of the impact of soil removal actions on groundwater remediation costs was not highly dependent on natural attenuation assumptions. Rather, the analysis was based upon observed groundwater source reductions at sites where soil removal actions had been completed. As noted previously, these results suggest that prior soil excavation efforts may have failed to remove hydrocarbon source materials located below the water table.
- 3) **Point of Compliance:** The FDEP comment requests that the term *Point of Compliance* be amended to *Temporary Point of Compliance* or (*TPOC*), for consistency with the RBCA legislation. This change has been incorporated in the final report.
- 4) **Wording Correction:** The FDEP comment identifies incorrect wording for "Soil Removal". This correction has been made in the final report.
- 5) **Wording Correction:** The FDEP comment notes that the MTBE standard is not "proposed" but final. This correction has been made on the final report.



- 6) **Wording Correction:** The FDEP comment requests that the base case run not be described as the "current FDEP corrective action program", as RBCA principles have since been implemented. This clarification has been incorporated in the final report.

- 7) **RNA Monitoring Periods:** The FDEP comments states that the RNA timeframes used for costing purposes should be matched to the values predicted by the modeling analyses. This issue is addressed above (see FDEP Memorandum, Comment 1).