CUMULATIVE RISK ASSESSMENT OF
PETROLEUM RELEASES AT
TWO ADJACENT SITES
IN OKLAHOMA

By

BRYAN RAY MORRIS

Bachelor of Science

Oklahoma State University

Stillwater, Oklahoma

1995

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
December, 1999

CUMULATIVE RISK ASSESSMENT OF

PETROLEUM RELEASES AT

TWO ADJACENT SITES

IN OKLAHOMA

Thesis Approved:

William J. Fisher
Thesis Adviser

William F. McTernan

Gary F. Stewart

Wayne B. Powell
Dean of the Graduate College

ACKNOWLEDGEMENTS

I am very grateful to several people for the preparation of this thesis. I would like to express my gratitude to the following: Dr. Will Focht, chair and research advisor, Dr. Bill McTernan, and Dr. Gary Stewart for their guidance, cooperation and friendship while I was in graduate school. I would like to thank Wesley Hill and SUMMIT Environmental Services for access to their site-specific data, modeling advice and helpful suggestions.

Moreover, I would like to thank my co-workers at the Oklahoma Corporation Commission for their guidance, helpful suggestions and access to APIDSS.

I would also like to give my special appreciation to the following: my parents, Floyd and Ernestine Morris; and the rest of my family for their support and encouragement.

TABLE OF CONTENTS

CHAPTER I: INTRODUCTION

CHAPTER II: METHODOLOGY

CHAPTER III: METHODOLOGY

CHAPTER IV: NATURE OF THE RELEASES

CHAPTER V: SITE STRATIGRAPHY AND HYDROGEOLOGY

CHAPTER VI: EXPOSURE ASSESSMENT

CHAPTER VII: TOXICITY ASSESSMENT

CHAPTER VIII: INPUT PARAMETERS/MODELING

CHAPTER IX: FINDINGS AND CONCLUSIONS

LIST OF TABLES

LIST OF ACRONYMS

AS	Air Sparge
ASTM	American Society for Testing and Materials
AT-123D	Analytical Transport in 1, 2 and 3 Dimensions
BTEX	Benzene, Toluene, Ethylbenzene, Xylene
CASRN	Chemical Abstracts Registry Number
CEPA	California Environmental Protection Agency
cm	Centimeter
COC	Chemical of Concern
EPA	Environmental Protection Agency
FP	Free Product
HHE	Human Health and the Environment
HQ	Hazard Quotient
IELCR	Individual Excess Lifetime Cancer Risk
IRIS	Integrated Risk Information System
ISC	Initial Site Characterization
ISGC	Investigation for Soil and Groundwater Cleanup
kg	Kilogram
l	Liter
L	Low
LOAEL	Lowest Observed Adverse Effects Level
LUST	Leaking Underground Storage Tank
M	Medium
m	Meter
mg	Milligram
MF	Modifying Factor
MLE	Most Likely Exposure
MW	Monitoring Well
NA	Not Applicable
OCC	Oklahoma Corporation Commission
O/O	Owner/Operator
ORBCA	Oklahoma Risk Based Corrective Action
POE	Point of Exposure
RAGS	Risk Assessment Guidance for Superfund
RBCA	Risk Based Corrective Action
RBSL	Risk Based Screening Level
RBTL	Risk Based Target Level
RfD	Reference Dose
RfC	Reference Concentration
RME	Reasonable Maximum Exposure

SB	Soil Boring
SCEM	Site Conceptual Exposure Model
SF	Slope Factor
SSTL	Site-Specific Target Level
SVE	Soil Vapor Extraction
TPH	Total Petroleum Hydrocarbon
UF	Uncertainty Factor
UST	Underground Storage Tank

CHAPTER 1: INTRODUCTION

1. Introduction

In response to the need for cost-effective cleanup levels, the Oklahoma Corporation Commission (OCC) has adopted a risk-based corrective action (RBCA) program for the management of regulated leaking underground storage tank (LUST) sites. Oklahoma's version of this program is known as Oklahoma Risk-Based Corrective Action (ORBCA) and it was derived from Risk-Based Corrective Action Applied at Petroleum Release Sites Standard E1739-95.

Risk-based cleanup levels are known as Risk-Based Target Levels (RBTLs). RBTLs are further defined as Risk-Based Screening Levels (RBSLs)-for Tier I/IA analysis and Site-Specific Target Levels (SSTLs)-for Tier II analysis. Tier I/IA evaluation is the simplest level of risk evaluation and involves the comparison of on-site contaminant concentrations with Tier I/IA RBSLs developed by the OCC (ORBCA 1996:5-1). In some cases, SSTLs resulting from a Tier II analysis are required for comparison to on-site contaminant concentrations. On-site contaminant concentrations may be representative of soil and/or groundwater.

2. RBSLs and SSTLs

The OCC has conveniently precalculated all RBSLs and has tabulated them by region (western, central, and eastern counties), land use (current and future), route of exposure (ingestion, inhalation, etc.), receptor (adult, child, etc.), chemical (benzene, toluene, etc.), and distance to the point of exposure (POE) (50 feet down-gradient from each source was selected for this study).

In order for petroleum release sites to close under Tier I/IA, groundwater and/or soil concentrations cannot exceed the RBSLs at any potential point of exposure within a single plume (ORBCA 1996:1-9, 3-2, and 3-10).

3. Tier I/IA Analysis

Tier I/IA analysis requires the following steps:

- Development of a site conceptual exposure model (SCEM).
- Selection of relevant target levels from the look-up tables for the chemicals of concern (COC).
- Comparison of the target levels with site-specific concentrations.

The SCEM identifies the matrix of complete pathways and routes of exposure and it must be developed for current and potential future site conditions. SCEMs are qualitative evaluations that attempt to identify the mechanisms by which chemicals of concern will move from a source to the point at which a receptor comes in contact with the chemical(s). The final product of a SCEM is the organization of all relevant environmental media, all chemical sources, all routes of exposure, and all potential receptors. Less critical source-pathway-receptor-route combinations are screened out. For example, if an adult male is exposed to ingestion, inhalation, and dermal contact from contaminated shower water, ORBCA believes it is reasonable not to quantify the risks from inhalation and dermal contact, because the risk of ingestion will almost always be greater than the risks of inhalation and dermal contact. In cases where the route of exposure is not clear, ORBCA policy requires the assessor to choose groundwater ingestion because it is believed to be the most critical route. This qualitative approach of choosing the most critical route of exposure among other potential routes ultimately decides RBTL concentrations. Tier I/IA RBSLs for several chemicals, pathways, routes of exposure, and receptors are organized into the Tier I/IA look-up table presented in Table 5.1 of the ORBCA Guidance Document. RBSLs are pre-calculated from ORBCA risk models using conservative exposure values, default fate and transport parameters and chemical-specific properties (i.e., toxicity properties) found in Appendix I.

If all representative site concentrations (i.e., both soil and water) are lower than the Tier I/IA RBSLs and no nuisance conditions exist at the site, the OCC may grant site closure without any further activity (ORBCA 1996:5-13). However, if site concentrations exceed Tier I/IA RBSLs at any point within the plume, then three alternatives are available.

- Alternative 1: For localized exceedances where site concentrations exceed Tier I/IA levels in a small portion of the site, interim remediation/removal action may be implemented to meet Tier I/IA levels for site closure. For example, a small volume of soil near a recent release that exceeds Tier I/IA RBSLs may be sufficiently removed in order to receive case closure based on a Tier I/IA analyses.

- Alternative 2: Selection of Tier II analysis in cases where the magnitude of contamination is so great that the cost of achieving Tier I/IA RBSLs would be inefficient.
- Alternative 3: Remediate to Tier I/IA levels by monitoring for closure through natural attenuation. This alternative could be used in cases where a large portion of the site minimally exceeds RBSLs.

4. Tier II Analysis

Tier II analysis is conducted when Tier I/IA RBSLs are exceeded and the cost of attaining Tier I/IA RBSLs is too high. The objective of a Tier II evaluation is to collect additional site-specific data to be used in lieu of conservative assumptions and default input parameters for calculating cleanup levels. Tier II cleanup levels are called Site-Specific Target Levels (SSTLs) and they are derived from the same ORBCA risk models as RBSLs. Tier II analysis requires the following steps:

- Development of a SCEM.
- Inclusion of site-specific data in lieu of conservative assumptions and default input parameters into the ORBCA risk models.
- Comparison of SSTLs with site-specific concentrations.

The SCEM for Tier II will be very similar if not exactly the same as Tier I/IA, however, only those pathways and routes of exposure that exceed the Tier I/IA levels will be evaluated under Tier II (ORBCA 1996:6-1).

Site-specific physical data and fate and transport parameters should be used in lieu of conservative assumptions and reasonable maximum exposure (RME) factors for Tier II analysis. When data are not available for certain parameters, then RME factors and Tier I/IA default values should be used. Exposure data are never collected on a site-specific basis, therefore, the OCC allows the use of RME values.

Tier II analysis can be conducted in the forward (i.e., estimates individual excess lifetime cancer risk (IELCR)) mode or the backward (i.e., estimates the concentration that is representative of the IELCR)) mode. Generally, SSTLs are less stringent cleanup levels than RBSLs, therefore, they are economically easier to attain.

If the representative site contaminant concentrations are lower than the Tier II levels and no nuisance conditions exist at the site, the OCC may grant site closure without any further activity at the site. However, if any site concentration exceeds the Tier II SSTLs at any point within the plume, then two alternatives are available.

- Alternative 1: For localized exceedances where site concentrations exceed the Tier II levels in a small portion of the site, interim remediation/removal action may be implemented to meet Tier II levels for site closure. For example, a small volume of soil near a recent release that exceeds Tier II levels may be sufficiently removed in order to receive case closure based on a Tier II analysis.

- Alternative 2: Remediate to Tier II levels by monitoring for closure through natural attenuation. This alternative could be used in cases where a large portion of the site minimally exceeds the SSTLs.

The OCC does not require Tier III analyses, although the concept of Tier III is briefly mentioned in the ORBCA Guidance Document. This is just one of many examples of how ORBCA policy is not completely derived from the ORBCA guidance document. In fact, a substantial portion of ORBCA policy has been derived from in-house details and problems discovered after ORBCA policy was first introduced on October 1, 1996.

5. Purpose and Scope of This Study

This study is designed to evaluate whether a credible risk-based decision making process has been derived for Oklahoma. Currently, ORBCA calculates cleanup levels based on the most critical receptor, route of exposure, pathway, etc., thereby ignoring the additive effects from less critical receptors, routes of exposure, pathways etc. Therefore, a cumulative methodology has been derived in order to illustrate how cumulative health risks can exceed the acceptable risk level representative of RBSLs-for Tier I/IA analysis and SSTLs-for Tier II analysis. Furthermore, cumulative risk of groundwater ingestion is modeled and summed for two sites based on ten-year pulse releases for each site. These cumulative estimates are compared to future, residual, site-specific estimates in order to evaluate premises #2 and #3 in the ORBCA guidance document.

CHAPTER 2: IMPLEMENTATION

1. Introduction

This study assesses the current and future cumulative risks (scenarios #1 and #2) representative of two adjacent petroleum release sites and compares these results to site-specific, residual, current and future risk estimates derived in accordance with the OCC's ORBCA policy.

In addition, the cumulative risk of groundwater ingestion for two separate scenarios is modeled and summed over a ten-year period for comparison to future Tier II estimates i.e., future SSTLs derived from Table's 27 and 28. These two scenarios are further described in Chapter 8 and collectively, the four test scenarios are distinguished as premises #1, #2 and #3, respectively.

2. The Research Problem

Confirmed hydrocarbon releases from two adjacent sites with leaking underground storage tanks (LUSTs) have been documented over the last four years. Numerous reports required by the OCC concerning these particular sites have been produced by different consulting firms. However, no documentation of any report attempts to justify the claims mentioned in the direct quotes taken from the ORBCA Guidance Document. Four test scenarios (i.e., hypotheses) are tested and evaluated to validate the three premises taken from the ORBCA Guidance Document.

3. Premise #1

The crux of this thesis evolved from the following paragraph quoted from the ORBCA Guidance Document:

> "Since the number of chemicals of concern at most regulated underground storage tank impacted sites are few, and the OCC has generally adopted reasonably conservative values, the OCC will not consider the additive effects of different chemicals or routes of exposure. Thus, the risk and hazard quotient from different chemicals will not be added (ORBCA 1996:4-9)."

The above quotation (i.e., premise) contains one implicit assumption from which two test scenarios for the assessment of cumulative risk have been developed. The assumption is that current and future cumulative health effects from numerous sources, chemicals, pathways and routes of exposure are irrelevant and need not be considered.

The failure to consider cumulative risk cannot guarantee that the residual risk will be acceptable for the following reasons:

- The selection of only a few chemicals of concern (COCs) and conservative assumptions are inadequate to defending a non-cumulative approach in calculating cleanup levels (ORBCA 1996:4-9).
- Cleanup levels are decided only for the most critical route of exposure, therefore, less critical routes are ignored (ORBCA 4-14).
- ORBCA considers only one groundwater route of exposure (i.e., ingestion from deep groundwater, more than 10 feet below ground surface), thereby eliminating other viable routes such as shower inhalation and dermal exposure (ORBCA 1996:5-3).

- ORBCA does not consider the additive effects of multiple sources, pathways, chemicals, or routes of exposure in calculating cleanup levels (ORBCA 1996:4-14).

4. Cumulative Effects

Cumulative effects include four dimensions: multiple sources, multiple chemicals of concern, multiple exposure pathways, and multiple routes of exposure. Chemicals of concern and routes of exposure are the only two dimensions of cumulative risk ORBCA considers (see premise #1). The cumulative effects' scenarios are described with a metaphor that illustrates how multiple effects can increase an adult male's chance for adverse health effects (see page 48). For scenarios #2 and #3, cumulative effects refers to the summation of ingestion concentrations/risks modeled at 661 feet and at the property boundary over a ten-year period.

5. Conservative Assumptions

Appendix I presents the default input parameters (the ORBCA conservative assumptions) used in calculating current and future Tier I/IA RBSLs (ORBCA 1996:5-2) for scenarios #1 and #2. These same conservative assumptions may also be used in Tier II calculations when site-specific data are not available. Most of these assumptions were taken from the American Society for Testing and Materials (ASTM) RBCA policy and are based on 90^{th} percentile confidence levels. They are used to decide the Tier I/IA current and future

RBSLs that are compared with current and future Tier I/IA cumulative risk estimates. [1]Tier I/IA cumulative systemic risk estimates are found in Tables 1-4 and cumulative cancer risk estimates are found in Tables 9-12.

Scenario #2 will compare future Tier I/IA RBSLs and Tier II SSTLs with the same current and future cumulative systemic/cancer risk estimates used in scenario #1. SSTLs, unlike RBSLs will be calculated using site-specific physical data and therefore represent a more certain cleanup level. The Tier II cumulative systemic risk estimates are found in Tables 5-8 and Tier II cumulative cancer risk estimates are found in Tables 13-16.

6. <u>Discussion of Tables 1-4</u>

Table's 1-4 have been designed to illustrate the breakdown and derivation of Tier I/IA cumulative systemic risk estimates for multiple sources, chemicals, pathways and routes of exposure. In particular, the reader should notice how chemical-specific systemic risk estimates have been derived and subsequently summed in order to obtain the total systemic risk of 12 for current and future conditions. Total pathway-specific systemic risks of 2 result from each exposure pathway. Three could not be used because Xylene's critical effect (target organ) is not liver and kidneys (i.e., synergistic effects cannot be summed). The site-specific, subtotal systemic risk of 6 resulted from the summation of 2 for each exposure pathway. Lastly, the total systemic risk of 12 accounts for the additive effects from two sites. Also, chemical-specific reference doses (RfDs),

[1] Highly quantitative statistical uncertainty analyses is not practical in this study due to the absence of site-specific exposure data that can be presented as valid probability distributions.

confidence levels, and critical effects have been included for further clarification as to the origin and derivation of these systemic risk estimates.

7. Discussion of Table's 9-12

Table's 9-12 have been designed to illustrate the breakdown and derivation of Tier I/IA cumulative cancer risk estimates for multiple sources, chemicals, pathways, and routes of exposure. In particular, the reader should notice how chemical-specific cancer risk estimates have been derived and summed in order to obtain total cancer risks of 6.0 E-6 for current conditions and 6.0 E-4 for future conditions and how these estimates exceed the acceptable risk levels of 1.0 E-6 and 1.0 E-4. Because only one carcinogenic chemical having the same toxicological endpoint exists, all chemical-specific cancer risks are summed in order to derive the total pathway cancer risk of 3.0 E-6. Lastly, the total cancer risk of 6.0 E-6 accounts for the additive effects from two sites. Also, chemical-specific slope factors (SFs), weight of evidence, and toxicological endpoints have been included for further clarification as to the origin and derivation of these cancer risk estimates.

8. Discussion of Table's 17-20

Table's 17-18 somewhat reiterate Table's 1-4, however, they are the backbone for illustrating how cumulative effects have been derived. Note that ingestion, inhalation, and dermal concentrations representative of the systemic/cancer risk estimates have been organized for illustration. Maximum site-specific ground water concentrations are included as well as artificially increased/decreased inhalation and dermal concentrations. Most important, concentrations/risk levels for all three Tier I/IA routes of exposure are representative of the acceptable risk level. Ingestion concentrations representative of a 50-foot point of exposure (POE) were taken directly from the Tier I/IA look-up tables. Inhalation and dermal concentrations were not available in the look-up tables, therefore, artificial concentrations were used. These artificial concentrations have been back-calculated from the acceptable risk level and represent the maximum concentration an adult male can intake and yet be safe from adverse health effects. Likewise, Table's 19-20 reiterate Table's 9-12, however, they are representative of Tier II cumulative SSTLs.

9. Discussion of Table's 5-8

Table's 5-8 have been designed to illustrate the breakdown and derivation of Tier II cumulative systemic risk estimates for multiple sources, chemicals, pathways, and routes of exposure. In particular, the reader should notice how chemical-specific systemic risk estimates have been derived and subsequently summed in order to obtain the total systemic risks of 11.78 and 9.89 for current and future conditions. For Tier II, all three ingestion routes of exposure were calculated using site-specific data, and ORBCA risk models. The three inhalation and dermal concentrations, like the Tier I/IA inhalation and dermal concentrations are assumed to be representative of the acceptable risk level. Chemical-specific

RfDs, confidence levels, and critical effects have been included for further clarification as to the origin and derivation of these systemic risk estimates.

10. Discussion of Table's 13-16

Table's 13-16 have been designed to illustrate the breakdown and derivation of Tier II cumulative cancer risk estimates for multiple sources, chemicals, pathways, and routes of exposure. In particular the reader should notice how chemical-specific cancer risk estimates have been derived and subsequently summed in order to obtain the subtotal cancer risk estimates of 1.42 E-5 and 4.0 E-4 for current and future conditions and how these estimates exceed the acceptable cancer risk of 1.0 E-6 and 1.0 E-4. Also, chemical-specific slope factors, weight of evidence, and toxicological endpoints have been included for further classification as to the origin and derivation of these cancer risk estimates.

11. Discussion of Table's 21-28

Table's 21-28 have been calculated to illustrate the ORBCA derived residual risk estimates that are supposedly representative of a safe cleanup level. For Tier I/IA, RBSLs representative of 50 feet from each release were selected. RBSLs for current and future conditions are pre-calculated and can be found in the ORBCA guidance document. For Tier II current conditions, physical groundwater contaminant concentrations are available for cancer/systemic risk from calculations. However, no such data existed for future conditions, therefore,

Table 1: Cumulative Systemic Risk Estimates

Chemical	RfD (mg*kg/day)	Confidence Level	Critical Effect	RfD/RfC Source	Hazard Quotient	Pathway-Specific Systemic Risk	Site-Specific Subtotal Systemic Risk	Total Systemic Risk
Johnson Grocery:Tier I/IA Current Conditions								
Exposure Pathway: Ingestion from groundwater.								
Toluene	2 E-1	M	Liver and Kidneys	IRIS	1			
Ethylbenzene	1 E-1	L	Liver and Kidneys	IRIS	1			
Xylene	2 E+0	M	Hyperactivity	IRIS	1			
						2		
Exposure Pathway: Inhalation of chemicals from groundwater while showering.								
Toluene	1.1 E-1	M	Neurolog-ical Effects	IRIS	1			
Ethylbenzene	2.9 E-1	L	Develop-mental Toxicity	IRIS	1			
Xylene	8.6 E-2	M	Hyperactivity	IRIS	1			
						2		
Exposure Pathway: Dermal contact with groundwater while showering.								
Toluene	2 E-1	M	Liver and Kidneys	IRIS	1			
Ethylbenzene	1 E-1	L	Liver and Kidneys	IRIS	1			
Xylene	2 E+0	M	Hyperactivity	IRIS	1			
						2		
							6	12
Total Systemic Risk.								**Next page**

Table 2: Cumulative Systemic Risk Estimates

Chemical	RfD (mg*kg/day)	Confidence Level	Critical Effect	RfD/RfC Source	Hazard Quotient	Pathway-Specific Systemic Risk	Site-Specific Subtotal Systemic Risk	Total Systemic Risk
Hahn's Cleaners:Tier I/IA Current Conditions								
Exposure Pathway: Ingestion from groundwater.								
Toluene	2 E-1	M	Liver and Kidneys	IRIS	1			
Ethylbenzene	1 E-1	L	Liver and Kidneys	IRIS	1			
Xylene	2 E+0	M	Hyperactivity	IRIS	1			
						2		
Exposure Pathway: Inhalation of chemicals from groundwater while showering.								
Toluene	1.1 E-1	M	Neurolog-ical Effects	IRIS	1			
Ethylbenzene	2.9 E-1	L	Develop-mental Toxicity	IRIS	1			
Xylene	8.6 E-2	M	Hyperactivity	IRIS	1			
						2		
Exposure Pathway: Dermal contact with groundwater while showering.								
Toluene	2 E-1	M	Liver and Kidneys	IRIS	1			
Ethylbenzene	1 E-1	L	Liver and Kidneys	IRIS	1			
Xylene	2 E+0	M	Hyperactivity	IRIS	1			
						2		
							6	
Total Systemic Risk.								**12**

Table 3: Cumulative Systemic Risk Estimates

Chemical	RfD (mg*kg/day)	Confidence Level	Critical Effect	RfD/RfC Source	Hazard Quotient	Pathway-Specific Systemic Risk	Site-Specific Subtotal Systemic Risk	Total Systemic Risk
Johnson Grocery:Tier I/IA Future Conditions								
Exposure Pathway: Ingestion from groundwater.								
Toluene	2 E-1	M	Liver and Kidneys	IRIS	1			
Ethylbenzene	1 E-1	L	Liver and Kidneys	IRIS	1			
Xylene	2 E+0	M	Hyperactivity	IRIS	1			
						2		
Exposure Pathway: Inhalation of chemicals from groundwater while showering.								
Toluene	1.1 E-1	M	Neurolog-ical Effects	IRIS	1			
Ethylbenzene	2.9 E-1	L	Develop-mental Toxicity	IRIS	1			
Xylene	8.6 E-2	M	Hyperactivity	IRIS	1			
						2		
Exposure Pathway: Dermal contact with groundwater while showering.								
Toluene	2 E-1	M	Liver and Kidneys	IRIS	1			
Ethylbenzene	1 E-1	L	Liver and Kidneys	IRIS	1			
Xylene	2 E+0	M	Hyperactivity	IRIS	1			
						2		
							6	
Total Systemic Risk.								**Next page**

Table 4: Cumulative Systemic Risk Estimates

Chemical	RfD (mg*kg/day)	Confidence Level	Critical Effect	RfD/RfC Source	Hazard Quotient	Pathway-Specific Systemic Risk	Site-Specific Subtotal Systemic Risk	Total Systemic Risk
Hahn's Cleaners:Tier I/IA Future Conditions								
Exposure Pathway: Ingestion from groundwater.								
Toluene	2 E-1	M	Liver and	IRIS	1			
			Kidneys					
Ethylbenzene	1 E-1	L	Liver and	IRIS	1			
			Kidneys					
Xylene	2 E+0	M	Hyperactivity	IRIS	1			
						2		
Exposure Pathway: Inhalation of chemicals from groundwater while showering.								
Toluene	1.1 E -1	M	Neurolog-	IRIS	1			
			ical Effects					
Ethylbenzene	2.9 E -1	L	Develop- mental Toxicity	IRIS	1			
Xylene	8.6 E-2	M	Hyperactivity	IRIS	1			
						2		
Exposure Pathway: Dermal contact with groundwater while showering.								
Toluene	2 E-1	M	Liver and	IRIS	1			
			Kidneys					
Ethylbenzene	1 E-1	L	Liver and	IRIS	1			
			Kidneys					
Xylene	2 E+0	M	Hyperactivity	IRIS	1			
						2		
							6	
Total Systemic Risk.								**12**

Table 5: Cumulative Systemic Risk Estimates

Chemical	RfD (mg*kg/day)	Confidence Level	Critical Effect	RfD/RfC Source	Hazard Quotient	Pathway-Specific Systemic Risk	Site-Specific Subtotal Systemic Risk	Total Systemic Risk
Johnson Grocery:Tier II Current Conditions								
Exposure Pathway: Ingestion from groundwater.								
Toluene	2 E-1	M	Liver and Kidneys	IRIS	0.96			
Ethylbenzene	1 E-1	L	Liver and Kidneys	IRIS	0.93			
Xylene	2 E+0	M	Hyperactivity	IRIS	0.96			
						1.89		
Exposure Pathway: Inhalation of chemicals from groundwater while showering.								
Toluene	1.1 E-1	M	Neurolog-ical Effects	IRIS	1			
Ethylbenzene	2.9 E-1	L	Develop-mental Toxicity	IRIS	1			
Xylene	8.6 E-2	M	Hyperactivity	IRIS	1			
						2		
Exposure Pathway: Dermal contact with groundwater while showering.								
Toluene	2 E-1	M	Liver and Kidneys	IRIS	1			
Ethylbenzene	1 E-1	L	Liver and Kidneys	IRIS	1			
Xylene	2 E+0	M	Hyperactivity	IRIS	1			
						2		
							5.89	
Total Systemic Risk.								**Next page**

18

Table 6: Cumulative Systemic Risk Estimates

Chemical	RfD (mg*kg/day)	Confidence Level	Critical Effect	RfD/RfC Source	Hazard Quotient	Pathway-Specific Systemic Risk	Site-Specific Subtotal Exposure	Total Systemic Risk
Hahn's Cleaners:Tier II Current Conditions								
Exposure Pathway: Ingestion from groundwater.								
Toluene	2 E-1	M	Liver and Kidneys	IRIS	0.96			
Ethylbenzene	1 E-1	L	Liver and Kidneys	IRIS	0.93			
Xylene	2 E+0	M	Hyperactivity	IRIS	0.96			
						1.89		
Exposure Pathway: Inhalation of chemicals from groundwater while showering.								
Toluene	1.1 E-1	M	Neurolog-ical Effects	IRIS	1			
Ethylbenzene	2.9 E-1	L	Develop-mental Toxicity	IRIS	1			
Xylene	8.6 E-2	M	Hyperactivity	IRIS	1			
						2		
Exposure Pathway: Dermal contact with groundwater while showering.								
Toluene	2 E-1	M	Liver and Kidneys	IRIS	1			
Ethylbenzene	1 E-1	L	Liver and Kidneys	IRIS	1			
Xylene	2 E+0	M	Hyperactivity	IRIS	1			
						2		
							5.89	
Total Systemic Risk.								**11.78**

Table 7: Cumulative Systemic Risk Estimates

Chemical	RfD (mg*kg/day)	Confidence Level	Critical Effect	RfD/RfC Source	Hazard Quotient	Pathway-Specific Systemic Risk	Site-Specific Subtotal Systemic Risk	Total Systemic Risk
Johnson Grocery:Tier II Future Conditions								
Exposure Pathway: Ingestion from groundwater.								
Toluene	2 E-1	M	Liver and Kidneys	IRIS	2.7 E-7			
Ethylbenzene	1 E-1	L	Liver and Kidneys	IRIS	1.61 E-6			
Xylene	2 E+0	M	Hyperactivity	IRIS	5.66 E-6			
						7.54 E-6		
Exposure Pathway: Inhalation of chemicals from groundwater while showering.								
Toluene	1.1 E-1	M	Neurolog-ical Effects	IRIS	1			
Ethylbenzene	2.9 E-1	L	Develop-mental Toxicity	IRIS	1			
Xylene	8.6 E-2	M	Hyperactivity	IRIS	1			
						2		
Exposure Pathway: Dermal contact with groundwater while showering.								
Toluene	2 E-1	M	Liver and Kidneys	IRIS	1			
Ethylbenzene	1 E-1	L	Liver and Kidneys	IRIS	1			
Xylene	2 E+0	M	Hyperactivity	IRIS	1			
						2		
							5.89	
Total Systemic Risk:								**Next page**

Table 8: Cumulative Systemic Risk Estimates

Chemical	RfD (mg*kg/day)	Confidence Level	Critical Effect	RfD/RfC Source	Hazard Quotient	Pathway-Specific Systemic Risk	Site-Specific Subtotal Systemic Risk	Total Systemic Risk
Hahn's Cleaners: Tier II Future Conditions								
Exposure Pathway: Ingestion from groundwater.								
Toluene	2 E-1	M	Liver and Kidneys	IRIS	3.22 E-8			
Ethylbenzene	1 E-1	L	Liver and Kidneys	IRIS	1.24 E-7			
Xylene	2 E+0	M	Hyperactivity	IRIS	1.09 E-6			
						1.24 E-6		
Exposure Pathway: Inhalation of chemicals from groundwater while showering.								
Toluene	1.1 E-1	M	Neurological Effects	IRIS	1			
Ethylbenzene	2.9 E-1	L	Developmental Toxicity	IRIS	1			
Xylene	8.6 E-2	M	Hyperactivity	IRIS	1			
						2		
Exposure Pathway: Dermal contact with groundwater while showering.								
Toluene	2 E-1	M	Liver and Kidneys	IRIS	1			
Ethylbenzene	1 E-1	L	Liver and Kidneys	IRIS	1			
Xylene	2 E+0	M	Hyperactivity	IRIS	1			
						2		
							4	
Total Systemic Risk.								**9.89**

Table 9: Cumulative Cancer Risk Estimates

Chemical	SF $(mg*kg/day)^{-1}$	Weight of Evidence	Type of Cancer (Endpoint)	SF Source	Chemical Specific Cancer Risk	Total Pathway Cancer Risk	Total Cancer Risk
Johnson Grocery: Tier I/IA Current Conditions							
Exposure Pathway: Ingestion of chemicals from groundwater.							
Benzene	2.9 E–2	A*	Leukemia	IRIS	1.0 E-6		
Exposure Pathway: Inhalation of chemicals from groundwater while showering.							
Benzene	2.9 E–2	A*	Leukemia	IRIS	1.0 E-6		
Exposure Pathway: Dermal contact with groundwater while showering.							
Benzene	2.9 E–2	A*	Leukemia	IRIS	1.0 E-6		
						3.0 E-6	
Total Cancer Risk.							Next page

Table 10: Cumulative Cancer Risk Estimates

Chemical	SF $(mg*kg/day)^{-1}$	Weight of Evidence	Type of Cancer (Endpoint)	SF Source	Chemical Specific Cancer Risk	Total Pathway Cancer Risk	Total Cancer Risk
Hahn's Cleaners: Tier I/IA Current Conditions							
Exposure Pathway: Ingestion of chemicals from groundwater.							
Benzene	2.9 E–2	A*	Leukemia	IRIS	1.0 E-6		
Exposure Pathway: Inhalation of chemicals from groundwater while showering.							
Benzene	2.9 E–2	A*	Leukemia	IRIS	1.0 E-6		
Exposure Pathway: Dermal contact with groundwater while showering.							
Benzene	2.9 E–2	A*	Leukemia	IRIS	1.0 E-6		
						3.0 E-6	
Total Cancer Risk.							**6.0 E-6**

Table 11: Cumulative Cancer Risk Estimates

Chemical	SF $(mg*kg/day)^{-1}$	Weight of Evidence	Type of Cancer (Endpoint)	SF Source	Chemical Specific Cancer Risk	Total Pathway Cancer Risk	Total Cancer Risk
Johnson Grocery: Tier I/IA Future Conditions							
Exposure Pathway: Ingestion of chemicals from groundwater.							
Benzene	2.9 E–2	A*	Leukemia	IRIS	1.0 E-4		
Exposure Pathway: Inhalation of chemicals from groundwater while showering.							
Benzene	2.9 E–2	A*	Leukemia	IRIS	1.0 E-4		
Exposure Pathway: Dermal contact with groundwater while showering.							
Benzene	2.9 E–2	A*	Leukemia	IRIS	1.0 E-4		
Total Cancer Risk:						3.0 E-4	Next page

Table 12: Cumulative Cancer Risk Estimates

Chemical	SF (mg*kg/day)$^{-1}$	Weight of Evidence	Type of Cancer (Endpoint)	SF Source	Chemical Specific Cancer Risk	Total Pathway Cancer Risk	Total Cancer Risk
Hahn's Cleaners: Tier I/IA Future Conditions							
Exposure Pathway: Ingestion of chemicals from groundwater.							
Benzene	2.9 E–2	A*	Leukemia	IRIS	1.0 E-4		
Exposure Pathway: Inhalation of chemicals from groundwater while showering.							
Benzene	2.9 E–2	A*	Leukemia	IRIS	1.0 E-4		
Exposure Pathway: Dermal contact with groundwater while showering.							
Benzene	2.9 E–2	A*	Leukemia	IRIS	1.0 E-4	1.0 E-4	
Total Cancer Risk:							**6.0 E-4**

Table 13: Cumulative Cancer Risk Estimates

Chemical	SF (mg*kg/day)$^{-1}$	Weight of Evidence	Type of Cancer (Endpoint)	SF Source	Chemical Specific Cancer Risk	Total Pathway Cancer Risk	Total Cancer Risk
Johnson Grocery: Tier II Current Conditions							
Exposure Pathway: Ingestion of chemicals from groundwater.							
Benzene	2.9 E–2	A*	Leukemia	IRIS	3.4 E-6		
Exposure Pathway: Inhalation of chemicals from groundwater while showering.							
Benzene	2.9 E–2	A*	Leukemia	IRIS	1.0 E-6		
Exposure Pathway: Dermal contact with groundwater while showering.							
Benzene	2.9 E–2	A*	Leukemia	IRIS	1.0 E-6		
Total Cancer Risk:						5.4 E-6	Next page

Table 14: Cumulative Cancer Risk Estimates

Chemical	SF (mg*kg/day)$^{-1}$	Weight of Evidence	Type of Cancer (Endpoint)	SF Source	Chemical Specific Cancer Risk	Total Pathway Cancer Risk	Total Cancer Risk
Hahn's Cleaners: Tier II Current Conditions							
Exposure Pathway: Ingestion of chemicals from groundwater.							
Benzene	2.9 E–2	A*	Leukemia	IRIS	6.8 E-6		
Exposure Pathway: Inhalation of chemicals from groundwater while showering.							
Benzene	2.9 E–2	A*	Leukemia	IRIS	1.0 E-6		
Exposure Pathway: Dermal contact with groundwater while showering.							
Benzene	2.9 E–2	A*	Leukemia	IRIS	1.0 E-6		
						8.8 E-6	
Total Cancer Risk:							**1.42 E-5**

Table 15: Cumulative Cancer Risk Estimates

Chemical	SF $(mg*kg/day)^{-1}$	Weight of Evidence	Type of Cancer (Endpoint)	SF Source	Chemical Specific Cancer Risk	Total Pathway Cancer Risk	Total Cancer Risk
Johnson Grocery: Tier II Future Conditions							
Exposure Pathway: Ingestion of chemicals from groundwater.							
Benzene	2.9 E–2	A*	Leukemia	IRIS	2.21 E-8		
Exposure Pathway: Inhalation of chemicals from groundwater while showering.							
Benzene	2.9 E–2	A*	Leukemia	IRIS	1.0 E-4		
Exposure Pathway: Dermal contact with groundwater while showering.							
Benzene	2.9 E–2	A*	Leukemia	IRIS	1.0 E-4		
Total Cancer Risk:						2.0 E-4	Next page

Table 16: Cumulative Cancer Risk Estimates

Chemical	SF (mg*kg/day)$^{-1}$	Weight of Evidence	Type of Cancer (Endpoint)	SF Source	Chemical Specific Cancer Risk	Total Pathway Cancer Risk	Total Cancer Risk
Hahn's Cleaners: Tier II Future Conditions							
Exposure Pathway: Ingestion of chemicals from groundwater.							
Benzene	2.9 E–2	A*	Leukemia	IRIS	3.0 E-7		
Exposure Pathway: Inhalation of chemicals from groundwater while showering.							
Benzene	2.9 E–2	A*	Leukemia	IRIS	1.0 E-4		
Exposure Pathway: Dermal contact with groundwater while showering.							
Benzene	2.9 E–2	A*	Leukemia	IRIS	1.0 E-4		
						2.0 E-4	
Total Cancer Risk:							4.0 E-4

Table 17

TIER I/IA CUMULATIVE RBSLs BASED ON INGESTION, INHALATION AND DERMAL CONTACT

Current Conditions

Receptor	Pathway	Route of Exposure	Tier I Levels			
			Benzene	Toluene	Ethylbenzene	Xylene
Resident Adult	Deep Ground-water	Ingestion (mg/l)	0.0064	15.85	7.92	158.48
		Cancer/Systemic Risk	1.0 E-6	1	1	1
		Inhalation (mg/m^3)	0.00632	8.65	22.8	6.76
		Cancer/Systemic Risk	1.0 E-6	1	1	1
		Dermal (mg/cm^3)	0.26	299	91.4	72.5
		Cancer/Systemic Risk	1.0 E-6	1	1	1
Cumulative cancer risk (see Table)			3.0 E-6	NA		NA
Cumulative systemic risk (see Table)			NA	6		3
Maximum On-Site Groundwater Concentrations (mg/l)			37.1	30.8	3.4	12.8
Artificially Increased/Decreased Groundwater Concentrations (mg/l)			NA	NA	NA	NA
Artificial Inhalation RBSL (mg/m^3)			0.00632	8.65	22.8	6.76
Artificial Dermal RBSL (mg/cm^3)			0.26	29900	9140	72.5

Point of Exposure for Groundwater (Refer Tables 5-10 (a) through 5-12 (c) of the Guidance Document): NA ft County: West

- Ingestion concentrations were taken from RBSL Look-up Tables.
- Inhalation and dermal exposure modeling are beyond the scope of this study. Therefore, these artificial concentrations are assumed to be equal to the acceptable risk level.
- The systemic effects of Toluene and Ethylbenzene effect the kidneys –therefore these effects are additive.
- NA: not applicable.

Table 18

TIER I/IA CUMULATIVE RBSLs BASED ON INGESTION, INHALATION AND DERMAL CONTACT

Future Conditions

Receptor	Pathway	Route of Exposure	Tier I Levels			
			Benzene	Toluene	Ethylbenzene	Xylene
Resident Adult	Deep Ground-water	Ingestion (mg/l)	0.64	15.85	7.92	158.48
		Cancer/Systemic Risk	1.0 E-4	1	1	1
		Inhalation (mg/m^3)	0.632	8.65	22.8	6.76
		Cancer/Systemic Risk	1.0 E-4	1	1	1
		Dermal (mg/cm^3)	26	299	91.4	72.5
		Cancer/Systemic Risk	1.0 E-4	1	1	1
Cumulative cancer risk (see Table)			3.0 E-4	NA		NA
Cumulative systemic Risk(see Table)			NA	6		3
Maximum On-Site Groundwater Concentrations (mg/l)			37.1	30.8	3.4	12.8
Artificially Increased/Decreased Groundwater Concentrations (mg/l)			NA	NA	NA	NA
Artificial Inhalation RBSL (mg/m^3)			0.00632	8.65	22.8	6.76
Artificial Dermal RBSL (mg/cm^3)			0.26	299	91.4	72.5

Point of Exposure for Groundwater (Refer Tables 5-10 (a) through 5-12 (c) of the Guidance Document): NA ft County: West

- Ingestion concentrations were taken from RBSL Look-up Tables.
- Inhalation and dermal exposure modeling are beyond the scope of this study. Therefore, these artificial concentrations are assumed to be equal to the acceptable risk level.
- The systemic effects of Toluene and Ethylbenzene effect the kidneys-therefore these effects are additive.
- NA: not applicable.

Table 19

TIER II CUMULATIVE SSTLs BASED ON INGESTION, INHALATION AND DERMAL CONTACT

Current Conditions

Receptor	Pathway	Route of Exposure	Tier II Levels			
			Benzene	Toluene	Ethylbenzene	Xylene
Resident Adult	Deep Ground-water	Ingestion (mg/l)	0.02	7	3.4	70
		Cancer/Systemic Risk	6.8 E-6	0.96	0.93	0.96
		Inhalation (mg/m^3)	0.00632	8.65	22.8	6.76
		Cancer/Systemic Risk	1.0 E-6	1	1	1
		Dermal (mg/cm^3)	0.26	299	91.4	72.5
		Cancer/Systemic Risk	1.0 E-6	1	1	1
Cumulative cancer risk (see Table)			2.0 E-6	NA		NA
Cumulative systemic risk (see Table)			NA	5.89		2.96
Maximum On-Site Groundwater Concentrations (mg/l)			37.1	30.8	3.4	12.8
Artificially Increased/Decreased Groundwater Concentrations (mg/l)			NA	NA	NA	NA
Artificial Inhalation SSTL (mg/m^3)			0.00632	8.65	22.8	6.76
Artificial Dermal SSTL (mg/cm^3)			0.26	299	91.4	72.5

Point of Exposure for Groundwater (Refer Tables 5-10 (a) through 5-12 (c) of the Guidance Document): NA ft   County: West

- Ingestion concentrations were derived from the ORBCA ingestion, risk model.
- Inhalation and dermal exposure modeling are beyond the scope of this study. Therefore, these artificial concentrations are assumed to be equal to the acceptable risk level.
- The systemic effects of Toluene and Ethylbenzene effect the kidneys-therefore these effects are additive.
- NA: not applicable.

Table 20

TIER II CUMULATIVE SSTLs BASED ON INGESTION, INHALATION AND DERMAL CONTACT

Future Conditions

Receptor	Pathway	Route of Exposure	Tier I Levels			
			Benzene	Toluene	Ethylbenzene	Xylene
Resident Adult	Deep Ground-water	Ingestion (mg/l)	6.5 E-4	1.97 E-6	5.876 E-6	4.13 E-4
		Cancer/Systemic Risk	2.21 E-8	2.7 E-7	1.61 E-6	5.66 E-6
		Inhalation (mg/m^3)	0.632	8.65	22.8	6.76
		Cancer/Systemic Risk	1.0 E-4	1	1	01
		Dermal (mg/cm^3)	0.26	29900	9140	7250
		Cancer/Systemic Risk	1.0 E-4	1	1	1
Cumulative cancer risk (see Table)			2.0 E-4	NA		NA
Cumulative systemic risk (see Table)			NA	4		2
Maximum On-Site Groundwater Concentrations (mg/l)			37.1	30.8	3.4	12.8
Artificially Increased/Decreased Groundwater Concentrations (mg/l)			NA	NA	NA	NA
Artificial Inhalation SSTL (mg/m^3)						
Artificial Dermal SSTL (mg/cm^3)			NA	NA	NA	NA

Point of Exposure for Groundwater (Refer Tables 5-10 (a) through 5-12 (c) of the Guidance Document): NA ft County: West

- Ingestion concentrations were derived from the ORBCA ingestion risk model.
- Inhalation and dermal exposure modeling are beyond the scope of this study. Therefore these artificial concentrations are assumed to be equal to the acceptable risk level.
- The systemic effects of toluene and ethylbenzene effect the kidneys-therefore these effects are additive.
- NA: not applicable.

Table 21

TIER I/IA RBSLs BASED ON DEEP GROUNDWATER INGESTION
Current Conditions – Johnson Grocery

Receptor	Pathway	Route of Exposure	Tier I Levels			
			Benzene	Toluene	Ethylbenzene	Xylene
Resident Adult	Deep Ground-water	Ingestion (mg/l)	.0064	15.85	7.92	158.48
		Cancer/Systemic Risk	1.0 E-6	1	1	1
		Inhalation (mg/m³)	0	0	0	0
		Cancer/Systemic Risk	0	0	0	0
		Dermal	0	0	0	0
		Cancer/Systemic Risk	0	0	0	0
Residual cancer risk (see Table)			NA	1	1	1
Residual systemic risk (see Table)			1.0 E-6	NA	NA	NA
Maximum On-Site Groundwater Concentrations (mg/l)			42.3	11.5	0.69	5.36
Artificially Increased/Decreased Groundwater Concentrations (mg/l)			NA	NA	NA	NA
Tier I Screening Levels (RBSLs) – current conditions			.0064	15.85	7.92	158.48

Point of Exposure for Groundwater (Refer Tables 5-10 (a) through 5-12 (c) of the Guidance Document): 50 ft County: West

- Ingestion concentrations were taken from RBSL Look-up Tables.
- NA: not applicable.

Table 22						
TIER I/IA RBSLs BASED ON DEEP GROUNDWATER INGESTION Current Conditions – Hahn's Cleaners						
Receptor	**Pathway**	**Route of Exposure**	Tier I Levels			
			Benzene	Toluene	Ethylbenzene	Xylene
Resident Adult	Deep Ground-water	Ingestion (mg/l)	0.0064	15.85	7.92	158.48
		Cancer/Systemic Risk	1.0 E-6	1	1	1
		Inhalation (mg/m^3)	0	0	0	0
		Cancer/Systemic Risk	0	0	0	0
		Dermal (mg/cm^3)	0	0	0	0
		Cancer/Systemic Risk	0	0	0	0
Residual cancer risk (see Table)			NA	1	1	1
Residual systemic risk (see Table)			1.0 E-6	NA	NA	NA
Maximum On-Site Groundwater Concentrations (mg/l)			37.1	30.8	3.4	12.8
Artificially Increased/Decreased Groundwater Concentrations (mg/l)			NA	NA	NA	NA
Tier I Screening Levels (RBSLs) – current conditions			.0064	15.85	7.92	158.48

Point of Exposure for Groundwater (Refer Tables 5-10 (a) through 5-12 (c) of the Guidance Document): 50 ft County: West

- Ingestion concentrations were taken from RBSL Look-up Tables.
- NA: not applicable.

Table 23						
TIER I/IA RBSLs BASED ON DEEP GROUNDWATER INGESTION **Future Conditions – Johnson Grocery**						
Receptor	**Pathway**	**Route of Exposure**	Tier I Levels			
			Benzene	Toluene	Ethylbenzene	Xylene
Resident Adult	Deep Ground-water	Ingestion (mg/l)	0.64	15.85	7.92	158.48
		Cancer/Systemic Risk	1.0 E-4	1	1	1
		Inhalation (mg/m^3)	0	0	0	0
		Cancer/Systemic Risk	0	0	0	0
		Dermal (mg/cm^3)	0	0	0	0
		Cancer/Systemic Risk	0	0	0	0
Residual cancer risk (see Table)			NA	1	1	1
Residual systemic risk (see Table)			1.0 E-4	NA	NA	NA
Maximum On-Site Groundwater Concentrations (mg/l)			42.3	11.5	0.69	5.36
Artificially Increased/Decreased Groundwater Concentrations (mg/l)			NA	NA	NA	NA
Tier I Screening Levels (RBSLs) – future conditions			0.64	15.85	7.92	158.48

Point of Exposure for Groundwater (Refer Tables 5-10 (a) through 5-12 (c) of the Guidance Document): 50 ft County: West

- Ingestion concentrations were taken from RBSL Look-up Tables.
- NA: not applicable.

Table 24

TIER I/IA RBSLs BASED ON DEEP GROUNDWATER INGESTION
Future Conditions – Hahn's Cleaners

Receptor	Pathway	Route of Exposure	Tier I Levels			
			Benzene	Toluene	Ethylbenzene	Xylene
Resident Adult	Deep Ground-water	Ingestion (mg/l)	0.64	15.85	7.92	158.48
		Cancer/Systemic Risk	1.0 E-4	1	1	1
		Inhalation (mg/m^3)	0	0	0	0
		Cancer/Systemic Risk	0	0	0	0
		Dermal (mg/cm^3)	0	0	0	0
		Cancer/Systemic Risk	0	0	0	0
Residual cancer risk (see Table)			NA	1	1	1
Residual systemic risk (see Table)			1.0 E-6	NA	NA	NA
Maximum On-Site Groundwater Concentrations (mg/l)			37.1	30.8	3.4	12.8
Artificially Increased/Decreased Groundwater Concentrations (mg/l)			NA	NA	NA	NA
Tier I Screening Levels (RBSLs) – current conditions			0.64	15.85	7.92	158.48

Point of Exposure for Groundwater (Refer Tables 5-10 (a) through 5-12 (c) of the Guidance Document): 50 ft County: West

- Ingestion concentrations were taken from RBSL Look-up Tables.
- NA: not applicable.

Table 25 TIER II SSTLs BASED ON DEEP GROUNDWATER INGESTION Current Conditions – Johnson Grocery						
Receptor	**Pathway**	**Route of Exposure**	Tier I Levels			
			Benzene	Toluene	Ethylbenzene	Xylene
Resident Adult	Deep Ground-water	Ingestion (mg/l)	0.01	7	3.4	70
		Cancer/Systemic Risk	3.4 E-6	0.96	0.93	0.96
		Inhalation (mg/m^3)	0	0	0	0
		Cancer/Systemic Risk	0	0	0	0
		Dermal (mg/cm^3)	0	0	0	0
		Cancer/Systemic Risk	0	0	0	0
Residual cancer risk (see Table)			3.4 E-6	NA	NA	NA
Residual systemic risk (see Table)			NA	0.96	0.93	0.96
Maximum On-Site Groundwater Concentrations (mg/l)			42.3	11.5	0.69	5.36
Artificially Increased/Decreased Groundwater Concentrations (mg/l)			0.01	7	3.4	70
Tier II Screening Levels (SSTLs) – current Conditions (mg/l)			0.01	7	3.4	70

Point of Exposure for Groundwater (Refer Tables 5-10 (a) through 5-12 (c) of the Guidance Document): NA   County: West

- Cancer/systemic risks were calculated with ORBCA risk models.
- NA: not applicable.

Table 26

TIER II SSTLs BASED ON DEEP GROUNDWATER INGESTION

Current Conditions – Hahn's Cleaners

Receptor	**Pathway**	**Route of Exposure**	Tier I Levels			
			Benzene	Toluene	Ethylbenzene	Xylene
Resident Adult	Deep Ground-water	Ingestion (mg/l)	0.02	7	3.4	70
		Cancer/Systemic Risk	6.8 E-6	0.96	0.93	0.96
		Inhalation (mg/m^3)	0	0	0	0
		Cancer/Systemic Risk	0	0	0	0
		Dermal (mg/cm^3)	0	0	0	0
		Cancer/Systemic Risk	0	0	0	0
Residual cancer risk (see Table)			6.8 E-6	NA	NA	NA
Residual systemic risk (see Table)			NA	0.96	0.93	0.96
Maximum On-Site Groundwater Concentrations (mg/l)			37.1	30.8	3.4	12.8
Artificially Increased/Decreased Groundwater Concentrations (mg/l)			0.02	7	3.4	70
Tier II Screening Levels (SSTLs) – current Conditions (mg/l)			0.02	7	3.4	70

Point of Exposure for Groundwater (Refer Tables 5-10 (a) through 5-12 (c) of the Guidance Document): NA ft County: West

- Cancer/systemic risks were calculated using ORBCA risk models.
- NA: not applicable.

Table 27						
TIER II SSTLs BASED ON DEEP GROUNDWATER INGESTION **Future Conditions – Johnson Grocery**						
Receptor	**Pathway**	**Route of Exposure**	Tier I Levels			
			Benzene	Toluene	Ethylbenzene	Xylene
Resident Adult	Deep Ground-water	Ingestion (mg/l)	9.32 E-4	2.65 E-4	2.83 E-5	1.0 E-2
		Cancer/Systemic Risk	7.7 E-7	3.9 E-5	2.1 E-5	1.42 E-4
		Inhalation (mg/m^3)	0	0	0	0
		Cancer/Systemic Risk	0	0	0	0
		Dermal (mg/cm^3)	0	0	0	0
		Cancer/Systemic Risk	0	0	0	0
Residual cancer risk (see Table 31)			7.7 E-7	NA	NA	NA
Residual systemic risk (see Table 31)			NA	3.9 E-5	2.1 E-5	1.42 E-4
Maximum On-Site Groundwater Concentrations (mg/l)			NA	NA	NA	NA
Artificially Increased/Decreased Groundwater Concentrations (mg/l)			NA	NA	NA	NA
AT-123D modeled groundwater concentrations (mg/l)			9.32 E-4	2.65 E-4	2.83 E-5	1.0 E-2
Tier II Screening Levels (SSTLs) – future conditions			NA	NA	NA	NA

Point of Exposure for Groundwater (Refer Tables 5-10 (a) through 5-12 (c) of the Guidance Document): NA County: West

- Ingestion concentrations were modeled using AT-123D.
- NA: not applicable.

Table 28

TIER II SSTLs BASED ON DEEP GROUNDWATER INGESTION
Future Conditions – Hahn's Cleaners

Receptor	Pathway	Route of Exposure	Tier I Levels			
			Benzene	Toluene	Ethylbenzene	Xylene
Resident Adult	Deep Ground-water	Ingestion (mg/l)	1.9 E-4	5.65 E-4	7.21 E-5	1.79 E-2
		Cancer/Systemic Risk	1.57 E-4	8.1 E-5	2.1 E-5	2.4 E-4
		Inhalation (mg/m^3)	0	0	0	0
		Cancer/Systemic Risk	0	0	0	0
		Dermal	0	0	0	0
		Cancer/Systemic Risk	0	0	0	0
Residual cancer risk (see Table 32)			1.57 E-4	NA	NA	NA
Residual systemic risk (see Table 32)			NA	8.1 E-5	2.1 E-5	2.4 E-4
Maximum On-Site Groundwater Concentrations (mg/l)			NA	NA	NA	NA
Artificially Increased/Decreased Groundwater Concentrations (mg/l)			NA	NA	NA	NA
AT-123D modeled groundwater concentrations (mg/l)			1.9 E-4	5.65 E-4	7.21 E-5	1.79 E-2
Tier II Screening Levels (SSTLs) – future conditions			NA	NA	NA	NA

Point of Exposure for Groundwater (Refer Tables 5-10 (a) through 5-12 (c) of the Guidance Document): NA County: West

- Ingestion concentrations were modeled using AT-123D.
- NA: not applicable.

future groundwater concentrations were modeled for each site ten years into the future. Table's 27-28 illustrate these results which will be used in test scenarios #2 and #3 for comparison to modeled estimates that are summed over a ten-year period.

12. Premise #2

The second premise that is evaluated is the following ORBCA provision:

> "For human health risk assessment the receptors to be considered include persons who live within 660 feet of the site. A distance of 660 feet is selected because historic data indicates that plumes for leaking UST sites and the COC being considered generally do not exceed 660 feet (ORBCA 1996:4-6)."

This quotation implicitly assumes that the risk is acceptable at any point greater than 660 feet from any site regardless of the magnitude of residual risk. Ten years from now, the residual cancer/systemic risk estimates for BTEX (Benzene, Toluene, Ethylbenzene, and Xylene) will be 1.57 E-4, 8.1 E-5, 2.1 E-5, and 2.4 E-4, respectively as per AT-123D (see Table 28). Test scenario #3 will validate this assumption by comparing ten-year cumulative modeled risk estimates with Tier II, future, residual systemic/cancer risk estimates found in Table 28. As per ORBCA, the estimates in Table 28 represent safe cleanup levels for each site. If the cumulative risk estimates modeled over a ten year period are less than or equal to these residual estimates, then this paragraph is valid, at least in this case.

As the leading edge of the plume impacts the hypothetical point of exposure (POE) located 661 feet away, the receptor will begin to be exposed to

BTEX. Theoretically, in five years the receptor will be exposed to the bulk of the plume and will receive the maximum amount of contamination and in ten years, the receptor will be exposed to the back edge of the plume. Concentrations and risks over the residual risk and illustrate that a person located 660 feet away from a plume may not be as safe as previously thought. AT-123D was used to model the concentrations/risks for this ten-year time period and the output files for this scenario have been included in Appendix II.

13. Premise #3

The third and final ORBCA premise that should be evaluated is:

> "For the groundwater pathway, the nearest current and reasonable potential future location of a drinking water well (i.e., the exposure point) is determined based on site-specific conditions. As an example, if the site is surrounded by residential areas where there is a potential to drill and use the groundwater, the potential drinking water well should be located at the property boundary (ORBCA 1996:4-16)."

This premise implicitly assumes that a future receptor who chooses to relocate on-site will be considered safe from groundwater exposure if the risk is acceptable at the property boundary. Ten years from now, the residual cancer/systemic risk estimates for BTEX will be 3.0 E-7, 3.22 E-8, 1.24 E-7, and 1.09 E-6, respectively as per AT-123D (see Table 33). Test scenario #4 will validate this assumption by comparing ten-year cumulative, modeled, systemic/cancer risk estimates with Tier II, future, residual systemic/cancer risk estimates found in Table 33. If the cumulative risk estimates modeled over a ten-year period are less than or equal to these residual estimates, then this paragraph is valid, at least in this case. Though the likelihood of a future resident relocating on either study site is unlikely, the pertinent question is: would such a receptor be safe from deep groundwater exposure at the property boundary? Again, AT-123D was used to model site-specific groundwater concentrations/risks at each property boundary and for the cumulative ten-year time period.

14. <u>Purposes of the Study</u>

The purposes and goals of this study are these:

- Illustrate how the additive effects of numerous sources, pathways, chemicals, and routes of exposure can increase the cancer and systemic risks.
- Illustrate that commingled groundwater plumes from adjacent petroleum release sites considered safe under current ORBCA methodology are not safe when evaluated for cumulative risk under both current and future conditions.
- Model future site-specific groundwater concentrations 661 feet down-gradient from each site and at each property boundary and calculate the cumulative systemic/cancer risk over a ten-year time frame for comparison with future, residual SSTLs.
- Evaluate and draw conclusions from the results of four test scenarios.

Current ORBCA policy treats each groundwater plume separately in calculating systemic/cancer risks. California believes that potential health risks and potential liability disagreements posed by commingled groundwater plumes potential liability disagreements posed by commingled groundwater plumes are so great that the state has developed a commingled plume account to pay for these cleanups (CEPA 1997:4). Oklahoma does not have a commingled plume account designed to reimburse the cleanup cost of multiple plumes originating from adjacent sites.

15. Basis for the Additive Approach

Additivity may be addressed in Tier I/IA, II or III analyses but is usually avoided in Tier I/IA because of insufficient data (ASTM 1995:9). Although RBCA does not discourage additivity of risk, it lacks specific guidance. In fact, the only guidance available on cumulative risk from ORBCA and ASTM was stated in the crux of this thesis (i.e., premise #1). The last sentence in this paragraph suggests that additive techniques exist and are used to estimate the risk of exposure to contaminated surface soil. However, no cumulative risk methodology for the groundwater pathway is defined in ORBCA.

16. Modeling Requirements

For current receptor exposure scenarios, groundwater ingestion contaminant source concentrations are available for risk calculation while inhalation and dermal exposure concentrations are not available for risk calculation. For future receptor exposure scenarios, all three exposure concentrations are unavailable. Therefore, shower inhalation and dermal concentrations were back-calculated by using RBCA and ORBCA ASTM additive effects of multiple chemicals are important to consider, additive effects of other dimensions of cumulative risk should also be considered, including: multiple sources, multiple pathways, and multiple routes of exposure.

Only the deep groundwater migration pathway is considered in this study. Other viable pathways such as soil and air were not considered. The ignorance of ignoring cumulative risks by ORBCA can be illustrated with an 'ocean critter' metaphor[2]. To paraphrase the first ORBCA premise quoted on page 8 of this paper:

> "Since the number of 'ocean critters' in most oceans are few, and the 'ocean patrol' has generally adopted reasonable safety measures, the ocean patrol will not consider the additive chances of being attacked by numerous ocean critters or the direction from which they attack."

The paraphrased provision mentions only two dimensions of cumulative risk (numerous ocean critters and numerous directions of attack) that could lead to an adverse injury. Likewise ORBCA mentions only two dimensions of cumulative risk (multiple COCs and multiple roues of exposure) that could lead to an adverse injury. However, other dimensions could also increase the chances of adverse health effects. At least three additional dimensions of cumulative risk are prescribed from ocean critters:

- Dimension #1: Multiple critters (equivalent to multiple COCs)
- Dimension #2: Multiple routes of attack (equivalent to multiple routes of exposure)

[2] This metaphor is not intended to ridicule ORBCA but rather to further clarify the reader with the point of view adopted in this paper.

additive effects of multiple chemicals are important to consider, additive effects of other dimensions of cumulative risk should also be considered, including: multiple sources, multiple pathways, and multiple routes of exposure.

Only the deep groundwater migration pathway is considered in this study. Other viable pathways such as soil and air were not considered. The ignorance of ignoring cumulative risks by ORBCA can be illustrated with an 'ocean critter' metaphor[2]. To paraphrase the first ORBCA premise quoted on page 8 of this paper:

> "Since the number of 'ocean critters' in most oceans are few, and the 'ocean patrol' has generally adopted reasonable safety measures, the ocean patrol will not consider the additive chances of being attacked by numerous ocean critters or the direction from which they attack."

The paraphrased provision mentions only two dimensions of cumulative risk (numerous ocean critters and numerous directions of attack) that could lead to an adverse injury. Likewise ORBCA mentions only two dimensions of cumulative risk (multiple COCs and multiple roues of exposure) that could lead to an adverse injury. However, other dimensions could also increase the chances of adverse health effects. At least three additional dimensions of cumulative risk are prescribed from ocean critters:

- Dimension #1: Multiple critters (equivalent to multiple COCs)
- Dimension #2: Multiple routes of attack (equivalent to multiple routes of exposure)

[2] This metaphor is not intended to ridicule ORBCA but rather to further clarify the reader with the point of view adopted in this paper.

- Dimension #2: Multiple routes of attack (equivalent to multiple routes of exposure)
- Dimension #3: Multiple effects from being attacked (equivalent to multiple adverse health effects)

For every critter (benzene, toluene etc.), there can be multiple routes of attack (ingestion, shower inhalation, and dermal contact), and for every route of attack, there could be multiple health effects (leukemia, kidney damage etc.). Cumulative effects is illustrated in the following table and discussion.

Table 29: Ocean-Critter Metaphor

Dimension #1 Multiple Critters	Dimension #2 Multiple Routes Of Exposure	Dimension #3 Multiple Adverse Effects	Risk Estimate	Total Risk
Great-white Shark	From below	100 stitches	3.1 E-7	
Great-white Shark	From below	50 stitches	3.3 E-6	
Great-white Shark	From above	100 stitches	3.1 E-7	
Great-white Shark	From above	50 stitches	3.3 E-6	
				7.2 E-6
Hammerhead Shark	From below	100 stitches	1.8 E-10	
Hammerhead Shark	From below	50 stitches	1.0 E-11	
Hammerhead Shark	From above	100 stitches	1.8 E-10	
Hammerhead Shark	From above	50 stitches	1.0 E-11	
				3.8 E-10
Tiger-shark	From below	100 stitches	2.1E -7	
Tiger-shark	From below	50 stitches	2.2 E-6	
Tiger-shark	From above	100 stitches	2.1E -7	
Tiger-shark	From above	50 stitches	2.2 E-6	

One limitation of this metaphor is that the risk calculations are hypothetical and were chosen strictly for illustrative purposes. For this study, risk values will be calculated using systemic/cancer risk models available in RBCA and ORBCA.

Two important relationships between the ocean critter metaphor and this study are:

- The risk posed by each individual critter is acceptable.
- The combined risk posed by all three critters (i.e., the cumulative risk) is unacceptable.

This metaphor helps demonstrate that the ORBCA definition of safety based on few COCs and conservative assumptions cannot guarantee acceptable risk in a cumulative risk scenario.

Though current ORBCA policy may be protective of single COCs (e.g., one great white shark) resulting from a single route of exposure (e.g., attacking from below) that produces a single health effect (e.g., stitches), it ignores the potential cumulative risk from other chemicals, routes of exposure, and health effects for current and future conditions. ORBCA believes that by protecting the public from few COCs and routes of exposure with conservative assumptions, adverse health effects will not develop. In other words, the ocean patrol has determined, based on the most critical route of exposure and conservative assumptions, that the risk of being harmed by few critters (e.g., great white shark or a hammerhead shark) is acceptable. This ignores the risks of attack by other potentially harmful critters (e.g., tiger sharks, sea snakes, sea urchins, jellyfishes, etc.) attacking from multiple directions (e.g., from below, above, etc.) resulting in numerous health effects (e.g., stitches, amputations, etc).

18. <u>Brief Site Description</u>

The research sites are in Enid, Oklahoma. In most cases, multiple plumes are separated, in this case, two plumes are commingled. The plumes are impacting the Enid Terrace Aquifer which is a current and potential future source of municipal drinking. Characteristics of these two sites are ideal to test the hypotheses, based on the following facts:

- Site-specific analytical data are from near-simultaneous sampling events, which provide excellent time correlation between the two sites.
- There exist multiple sources, chemicals of concern, pathways, and routes of exposure which can contribute to a cumulative risk study.
- Several domestic wells (> 10 feet below ground surface) are in the vicinity of these sites, therefore, the deep groundwater pathway is the major current and most likely future route of exposure.
- The Enid Terrace Aquifer underlies these sites and is the source of Enid's water supply. This aquifer consists of silt, sand, and gravel from which modeled groundwater concentrations over a ten year period could be high enough to exceed future residual SSTLs found in Table's 28 and 33.

CHAPTER 3: METHODOLOGY

1. Introduction

To demonstrate how current and future cumulative risk estimates and future modeled risk estimates can exceed ORBCA's RBTLs, the following tasks must be accomplished.

- Calculate site-specific residual systemic/cancer risk estimates (i.e., Tier I/IA RBSLs and Tier II SSTLs for current and future conditions) and compare them to cumulative estimates, encompassing four dimensions of cumulative risk calculated for the first two scenarios.

1. Dimension #1 – Multiple sources. Two petroleum releases (one from each site).
2. Dimension #2 – Multiple chemicals. Four chemicals of concern exist for each release, totaling up to eight chemicals of concern.
3. Dimension #3 – Multiple exposure pathways. Pathways other than groundwater, such as soil and air, are not considered, though they would be expected to increase cumulative risk to an even greater magnitude.
4. Dimension #4 – Multiple routes of exposure. For each chemical, three routes of exposure are considered: groundwater ingestion, shower inhalation, and dermal contact, resulting in up to twenty-four routes.

- Using AT-123D, model and sum future risk calculations over a ten-year period and compare them with future, residual Tier II SSTLs for the last two scenarios.

2. Expected Findings

Current and future cumulative risk estimates are expected to exceed ORBCA RBTLs for at least one of the first two test scenarios. Moreover, cumulative ten-year modeled estimates are expected to exceed future, residual site-specific ORBCA SSTLs for at least one of the last two scenarios. Finally, current and future cumulative risk test scenarios (hypothesis #1 and #2) are expected to contribute the greatest increase in risk, followed by future modeling scenarios (hypotheses #3 and #4).

To disprove the premises contained in this thesis, unacceptable risk to a current or future adult male from at least one of the four test scenarios must be demonstrated. This demonstration would show how the cumulative effects would exceed the residual effects derived from ORBCA policy. In other words, at least one hypothesis, at least in this case, must be supported.

To validate the premises contained in this thesis, all cumulative risk estimates and modeled risk estimates must be less than the RBTLs, which they are compared to. This outcome would demonstrate that ORBCA's conservative risk estimates, deterministic risk models and premises #1, #2 and #3 are adequate for providing an acceptable level of safety to human health and the environment (HHE), at least in this case.

3. Methodology Implementation

Tables 30-31 are important because they compare tier-specific residual RBTLs based on one source, one chemical, one pathway and one route of exposure with cumulative RBTLs based on multiple sources, chemicals, pathways and routes of exposure for premise #1 (i.e., scenarios #1 and #2).

Two sets of systemic risk (Table's 1-8 and 17-20) and cancer risk (Table's 9-16 and 17-20) table's were necessary to illustrate the cumulative systemic risk estimates (Table's 1-8) and cumulative cancer risk estimates (Table's 9-16) that have been combined with residual estimates (Table's 21-28) and simultaneously placed into Table's 30 and 31, the Risk Comparison Table's.

Table's 32 and 33 present the results of the two modeling scenarios. These tables illustrate and compare future cumulative site-specific risks based on a ten-year pulse release with future, residual, site-specific Tier II SSTLs.

CHAPTER 4: NATURE OF THE RELEASES

1. Introduction

The OCC is responsible for the cleanup of all regulated petroleum underground storage tank (UST) releases including, but not limited to the following products: gasoline, kerosene, fuel oil, diesel, jet fuel and used oil. Unfortunately, their chemical composition varies in the raw product form as well with respect to age, temperature, and other factors. The OCC focuses on a limited set of key components that pose the most risk for each product (ORBCA 1996:3-18).

2. Source of Releases

Johnson Grocery is a currently operating facility that maintains three registered gasoline USTs, each having a capacity of 6,000 gallons. These tanks were installed on April 1, 1981. The amount of released gasoline is unknown. The source of the release is from the piping ancillary equipment and was discovered by the failure of a system tightness test in March 1993. Since then, the source has been eliminated but not before impacting groundwater and soil, both on and off-site. Free product (FP) removal was initiated in 1993 in response to the presence of 0.83 feet of FP in monitor wells (MWs) 1 and 2. By 1995, all measurable FP had been removed.

Hahn's Cleaners maintained three registered gasoline USTs, having capacities of 1,000, 2,000, and 3,000 gallons. The installation date and the quantities of releases are unknown. The releases were discovered on March 27, 1996, when high BTEX concentrations were discovered in background monitoring wells of Johnson Grocery. The only logical explanation for up-gradient Johnson Grocery wells to be contaminated was the presence of an up-gradient release. Further investigation revealed that Hahn's Cleaners also had a release of gasoline. Since that time, the source – located near the former UST system, has been eliminated but not before impacting groundwater and soil both on and off-site. Though free product has been found at this site, the Hahn's Cleaners contaminant plume was significantly larger than the Johnson Grocery plume.

3. Site Descriptions

The Johnson Grocery facility is overlaid with asphalt to the north, west and south, 60% of which is paved and is qualitatively represented by a moderate degree of cracking. The east side has a recently back-filled gravel alley that was excavated to install remediation equipment such as soil vapor extraction (SVE) and air sparge (AS) devices. On-site utilities consist of a sanitary sewer line, gas line, telephone lines, and water lines at depths of ten feet to forty inches (Bach 1997:WS#2).

Immediate land uses adjacent to this site include a dry cleaner, O.K. Garriott Street, and a residential area to the north; an apartment complex and park to the south; Johnson Street and Indian Hills Shopping Center to the west and a medical building and fast food restaurant to the east. Local surface drainage is to the south/southeast at a gradient of 0.022 ft/ft; which discharges into an unnamed tributary of Boggy Creek approximately 200 feet downgradient of the site.

Hahn's Cleaners is surrounded by moderately cracked concrete to the north, west and south side. To the east, a small grassy strip separates the facility from a State Farm Insurance Agency. On-site utilities consist of a sanitary sewer line, gas line, telephone lines, and water lines at depths of ten feet to forty inches (Hill 1996:WS#2).

Immediate land uses adjacent to this site include: O.K. Garriott Street and a family business to the north, Johnson Grocery to the south, Johnson Street and Indian Hills Shopping Center to the west, and a State Farm Insurance Agency to the east. Local surface drainage is to the south/southeast at a gradient of 0.002 ft/ft which discharges into an unnamed tributary of Boggy Creek approximately 500 feet downgradient of the site.

4. Site History of Johnson Grocery

Johnson Grocery, located on the southeast corner of O.K. Garriott and Johnson Street, has been assigned a site prioritization index number of 2.3, which indicates that this site is not an emergency but requires remediation. Previous names include The Grocery Store #2, Circle K No. 941, and the Seven-Eleven Quick Shop. The site is located in NE4, NE4, NW4, Sec 13, T22N, R7W, Garfield County.

The release history of the site can be traced back to January 1993 when the dispensers malfunctioned and further investigation revealed a possible release of gasoline. Since that time, at least sixteen release investigation events have occurred (Bach 1997:WS#5). A few of these are described below.

On November 3, 1993 the OCC issued a Notice of Confirmed Release to the owner/operator of the site who responded by retaining TRUST Environmental Services. TRUST conducted the initial site characterization (ISC) that resulted in the discovery of FP in soil borings SB-1 and SB-2. SB-1 was later converted to a monitoring well (MW-1) and subsequently bailed to remove FP. Investigations for Soil and Groundwater Cleanup (ISGCs) began on July 16, 1993, and continued through December 21, 1993. This investigation warranted two monitoring well installations on July 16, 1993 and December 21, 1993. Further monitoring well installations took place on September 13, 1995, and November 21, 1995.

SUMMIT Environmental Services was retained by the owner/operator to provide additional consulting services. On May 21, 1996 and December 11, 1996, Tier I/IA analysis began. Additional analyses including Tier II analyses were initiated on March 12, 1996.

5. Site History of Hahn's Cleaners

Hahn's Cleaners, has been assigned a site prioritization index number of 2.3, which indicates that this site is not an emergency but should be remediated. Previous names include Westside Texaco, Youngs Texaco, and Young and Kiely Texaco. The site is located in NE4, NW4, Sec 13, T22N, R7W, Garfield County.

A release history of this site can be traced back to March 3, 1996, when the OCC issued a letter of suspected release. Since that time, approximately thirteen release investigation events have occurred (Hill 1997:WS#5). A few of these are mentioned below.

After the March 3, 1996, Letter of Suspected Release, further initial site activities by TRUST Environmental Services confirmed the presence of a release, resulting in a Notice of Confirmed Release on April 4, 1996.

SUMMIT Environmental Services was retained by Hahn's Cleaners to provide additional consulting services that involved additional monitoring well installations and a 660 ft foot-search for groundwater supply wells.

CHAPTER 5: SITE STRATIGRAPHY AND HYDROGEOLOGY

1. Local Stratigraphy

The Unified Classification System is currently used for the soil classification portion of ORBCA analyses. Even though the two sites are in close proximity, they possess completely different soil stratigraphies and soil types. For illustration of the local stratigraphy and soil type of each site, see the following table's taken from (Bach 1996:43).

Table 34: Johnson Grocery Soil Stratigraphy

Depth	Unified Soil Classification	Type of Soil
1 to 2.5 feet	CL	Silty clay
2.5 to 5 feet	ML	Clayey silt
5 to 8 feet	ML	Clayey silt-increasing silt with depth
8 to 15 feet	ML	Silt-some clay
15 to 20 feet	ML	Silt-little clay, sand with depth
Predominant soil texture: Silt and clayey silts. Increasing sand towards south of site.		

Table 35: Johnson Grocery Soil Types

Depth	Type of Bedrock & Geologic Formation
0 to 5 feet	Moderately coarse clayey loam, slightly plastic,

	Shellabarger/Carwile series.
5 to 10 feet	Finer, less compacted, less plastic silty loam, Shellabarger/Carwile series.
10 to 25 feet	Sandy loam horizon, Shellabarger/Carwile series.
Predominant soil: Typical Shellabarger/Carwile series.	

Table 36: Hahn's Cleaners Soil Stratigraphy

Depth	Unified Soil Classification	Type of Soil
0 to 8 feet	ML/CL	Silty clay to clayey silt
8 to 11 feet	SM/CL/ML	Variations of silt, sand, and clay
11 to 16 feet	ML/SM	Silty sand to clayey silt
16 to 25 feet	SM/ML/SP	Mostly sand with some silt
Predominant soil texture: Clayey silt.		

Table 37: Hahn's Cleaners Soil Types

Depth	Type of Bedrock & Geologic Formation
0 to 35 feet	Enid Terrace Aquifer – clay, silt and fine grained sand
35 to 400 feet	Permian redbed shale

Predominant soil: Terrace and alluvium deposits

2. Local Hydrogeology

The local hydrogeology is similar for each site. The study area is underlain by the sand, silt, and clay of the Enid Terrace Aquifer. This aquifer has a maximum thickness of 75 feet and the yield ranges from 50 to 150 gpm (Key 1995:4). Other characteristics were taken from (Bach 1996:23) and are located in the following tables.

Table 38: Hydrogeologic Properties of the Johnson Grocery Site

Property	Units	Value	Estimated/Measured
Average depth at which groundwater is first encountered.	ft	9.53	measured
Shallowest depth to water table	ft	6.52	measured
Flow direction	---	S-SE	measured
Hydraulic gradient (I)	ft/ft	0.022	measured
Estimated porosity	cm^3/cm^3	.35	estimated
Water content	cm^3/cm^3	.2	estimated
Dry bulk density	g/cm^3	1.8	estimated
Hydraulic conductivity (K)	ft/day	1.42 E0	measured
Flow velocity (ki/2)	ft/day	8.93 E-2	measured
Estimated aquifer volume	(ft^3)	11 E-10	estimated

Groundwater level fluctuations	ft	2.83	measured

Table 39: Hydrogeologic properties of the Hahn's Cleaners Site

Property	Units	Value	Estimated/Measured
Average depth at which groundwater is first encountered.	ft	12.06	Measured
Shallowest depth to water table	ft	10.46	Measured
Flow direction	---	S	Measured
Hydraulic gradient (I)	ft/ft	0.022	Measured
Estimated porosity	cm^3/cm^3	0.32	Measured
Water content	cm^3/cm^3	0.163	Measured
Dry bulk density	g/cm^3	1.848	Measured
Hydraulic conductivity (K)	ft/day	1.42 E0	Measured
Flow velocity (ki/2)	ft/day	9.76 E-2	Measured

There are numerous domestic water supply wells located down-gradient of the releases and the potential for future use of this supply was determined to be high.

CHAPTER 6: EXPOSURE ASSESSMENT

1. Introduction

The purpose of this chapter is to estimate the type and magnitude of exposures to the chemicals of concern that are present at or migrating from the sites (EPA 1989:6-1). Exposure assessment is the estimation (qualitative and quantitative) of the magnitude, frequency, duration, and routes of exposure. Exposure assessments (i.e., site conceptual exposure models) and risk estimates (i.e., RBTLs) for current and future adult receptors have been completed for both sites.

2. Exposure Setting Characterization

In this step, the exposure setting with respect to the general physical characteristics that influence the exposed population for current and future land uses is evaluated. A residential exposure scenario was chosen because it is most conservative and is appropriate in this setting.

3. Identification of Exposure Pathways

Routes of exposure associated with the deep groundwater pathway only (i.e., ingestion, inhalation and dermal contact) were identified. This eliminates other pathways, such as inhalation from shallow soil and soil ingestion, that could cause adverse health effects. Exposure pathways link the sources, locations, and types of environmental releases with population locations and activity patterns and consist of four elements: (1) a source and mechanism of chemical release, (2) a retention or transport medium, (3) a point of potential human contact with the contaminated medium, and (4) an intake route (e.g., ingestion) at the receptor (EPA1989:6-8).

Table 40 lists all current and future possible exposure routes for adults and documents their selection or exclusion from this study. Table 40 illustrates how the additive adverse health effects for an adult male could be increased from eight separate routes of exposure for current and future conditions. However, only three routes of exposure have been selected from which to sum numerous routes of exposure. Also, the additive effects of numerous COCs could have been included for all eight routes of exposure. This would increase the IELCR above the acceptable risk level even more!

Table 40: Summary of Complete Exposure Pathways

Potentially Exposed Population	Exposure Route, Medium, and Exposure Point	Pathway Selected for Evaluation?	Reason for Selection or Exclusion
Current Land Use			
Resident (adult)	Ingestion of deep groundwater from local wells down-gradient of the site.	Yes	Residents could use groundwater from local wells as drinking water.
Resident (adult)	Inhalation of chemicals volatilized from groundwater during showering.	Yes	Residents could inhale volatilizing COCs while showering.

Resident (adult)	Ingestion of surface water from the downgradient creek.	No	No surface water models are available in APIDSS.
Resident (adult)	Dermal contact of groundwater while showering.	Yes	Residents could use groundwater from local wells for bathing.
Resident (adult)	Ingestion and Inhalation of soil (surficial and sub-surface).	No	Irrelevant for this study which considers the groundwater pathway only.
Resident (adult)	Inhalation of chemicals volatilized from groundwater.	No	Assuming that volatiles in the deep groundwater never reach the receptor.
Resident (adult)	Dermal contact with chemicals in soil.	No	Irrelevant for this study which considers the groundwater pathway only.
Resident (adult)	Dermal contact with surface water while swimming.	No	No surface water models are available in APIDSS.

Future Land Use			
Resident (adult)	Ingestion of deep groundwater from local wells down-gradient of the site.	Yes	Residents could use groundwater from local wells as drinking water.
Resident (adult)	Inhalation of chemicals volatilized from groundwater during showering.	Yes	Residents could inhale volatilizing COCs while showering.
Resident (adult)	Ingestion of surface water from the down-gradient creek.	No	No surface water models are availabale in APIDSS.
Resident (adult)	Dermal contact of groundwater while showering.	Yes	Residents could use groundwater from local wells for bathing.
Resident (adult)	Ingestion and inhalation of soil (surficial and sub-surface).	No	Irrelevant for this study which considers the groundwater pathway only.
Resident (adult)	Inhalation of chemicals volatilized from	No	Assuming that volatiles in the deep

	groundwater.		groundwater never reach the receptor.
Resident (adult)	Dermal contact with chemicals in soil.	No	Irrelevant for this study which considers the groundwater pathway only.
Resident (adult)	Dermal contact with surface water while swimming.	No	No surface water models are available in APIDSS.

CHAPTER 7: TOXICITY ASSESSMENT

1. Introduction

Toxicity assessment evaluates available evidence of the potential for particular contaminants to cause adverse effects in exposed individuals and provides, where possible, an estimate of the relationship between the extent of exposure to a chemical and the increased likelihood of adverse health effects. Toxicological profiles and the Integrated Risk Information System (IRIS) database are valuable data sources for such estimates.

Toxicity values for different chemicals are estimated for carcinogenic (cancer causing) and non-carcinogenic (systemic) effects. Classification between the two is determined by EPA's Classification System for Carcinogenicity (EPA 1989:7-11) and from chemical-specific Slope Factors (SFs) and Reference Doses (RfDs).

EPA Weight-of-Evidence Classification

System For Carcinogenicity

Group	Description
A	Human carcinogen
B1 or B2	Probable human carcinogen B1 indicates that limited human data are available

	B2 indicates sufficient evidence in animals and inadequate or no evidence in humans
C	Possible human carcinogen
D	Not classifiable as to human carcinogenicity
E	Evidence of noncarcinogenicity for humans

Carcinogenic effects are assumed to result from a small number of molecular events which can lead to uncontrolled cellular proliferation, i.e., cancer. This mechanism is described as "non-threshold" because there is believed to be no level of exposure that does not pose a finite probability, however small, of generating a carcinogenic response (EPA 1989:7-10). The slope factor (SF), is the toxicity value used for evaluating carcinogenic effects resulting from exposure to carcinogens such as Benzene.

Unlike carcinogens, protective mechanisms are believed to exist for noncarcinogens that must be overcome before an adverse effect is manifested. This mechanism is decribed as "threshold" because a level of exposure that is not detrimental to human health and the environment (HHE) is believed to exist. A reference dose (RfD) is the toxicity value used for evaluating non-carcinogenic (systemic) effects resulting from exposure to Toluene, Ethylbenzene, and Xylene. Also, uncertainty factors (UFs) and modifying factors (MFs) are used to calculate RfDs. UFs and MFs compensate for areas of inherent uncertainty in the following way:

- UF of 10 is used to account for variation in the general population.
- UF of 10 is used to account for extrapolation from animals to humans.
- UF of 10 is used to account for interspecies variation.
- MFs range from >0 to 10 and are included to reflect a qualitative professional assessment of additional uncertainties in the critical study area.

2. Toxicological Properties of Benzene

Benzene, CASRN 71-43-2, has been assigned a weight-of-evidence cancer classification of A: known human carcinogen. This conclusion is based on several studies of increased incidence of nonlymphocytic leukemia from occupational exposure, increased incidence of neoplasia in rats and mice exposed by inhalation and gavage, and other supporting evidence (IRIS 1997:2). Information as to the noncarcinogenicity of Benzene is unavailable.

3. Toxicological Properties of Toluene

Toluene, CASRN 108-88-3, has been assigned a weight-of-evidence cancer classification of D: not classifiable as a human carcinogen. This conclusion is based on the fact that no human and inadequate animal cancer data exist. Also, Toluene does not produce positive results in the majority of genotoxic assays (IRIS 1997:15). However, this chemical is a known non-carcinogen (systemic toxicant) and much data are available as to the origin of oral reference doses (RfDs) and inhalation reference concentrations (RfCs).

The oral RfD for Toluene is 2.0 E-1 mg/kg*day and is based on liver and kidney weight changes in male rats. There is medium confidence in this RfD based on a sufficient number of animals per sex being tested in each dose group and a lack of reproductive studies. 2.0 E-1 was derived from the experimental dose of 233 mg*kg/day and an uncertainty factor of 1,000 (which accounts 10 for inter/intraspecies extrapolations, 10 for sub-chronic-to-chronic extrapolation, and 10 for limited reproductive and developmental toxicity data (IRIS 1997:3).

The inhalation RfC is 4.0 E-1 mg/m^3 and is based on neurological effects. There is medium confidence in the RfC based on a study by Foo et al. (1990), which studied adverse neurological effects of Toluene in a small worker population. The RfC was derived from the lowest observed adverse effects level (LOAEL) of 437 mg/m^3 and an uncertainty factor of 10 to account for intraspecies variability and for use of a LOAEL. An additional modifying factor of 3 was applied for data base deficiencies such as lack of data and well-characterized laboratory animal exposures evaluating neurotoxicity (IRIS 1997:7).

4. Toxicological Properties of Ethylbenzene

Ethylbenzene, CASRN 100-41-4, has been assigned a weight-of-evidence cancer classification of D: not classifiable as a human carcinogen. This conclusion is based on the lack of animal bioassays and human studies. However, Ethylbenzene is a known systemic toxicant.

The oral RfD is 1.0 E-1 mg/kg*day and is based on the critical effect of liver and kidney toxicity. There is low confidence in this RfD for multiple reasons such as unisex testing and no data on chronic exposures. The RfD was derived from the experimental dose of 97.1 mg/kg*day and an uncertainty factor of 1,000 which accounts 10 for both intraspecies and interspecies toxicity variability and 10 for extrapolation of a subchronic effect level to its chronic equivalent (IRIS 1997:2).

The inhalation RfC is 1.0 E+0 mg/kg*day and is based on the critical effect of developmental toxicity. There is low confidence in this RfC because there are no chronic studies or multi-generation developmental studies (IRIS 1997:11). 1.0 E+0 was derived from the experimental exposure of 434 mg/m^3 and an uncertainty factor of 300 which accounts for 10 to protect sensitive individuals, 3 to adjust for interspecies conversion, and 10 to adjust for the absence of reproductive and chronic studies (IRIS 1997:6).

5. Toxicological Properties of Xylene

Xylene, CASRN 1330-20-7, has been assigned a weight-of-evidence cancer classification of D: not classifiable as a human carcinogen. This conclusion is based on the fact that orally administered Xylene mixtures did not produce tumor responses in rats or mice of both sexes. However, Xylene is a known systemic toxicant.

The oral RfD is 2.0 E+0 mg/kg*day and is based on the critical effect of hyperactivity and decreased body weight in male rats. There is medium confidence in this RfD because of a lack of well-designed studies that tested adequately sized groups of two species over a substantial portion of their lifespan (IRIS 1997:3).

Human data, animal data, and other supporting data are the most popular sources for toxicological studies aimed at linking positive associations between chemicals and a disease. Well-conducted epidemiologic studies that show a positive association between an agent and a disease are accepted as the most convincing evidence of human risk (RAGS 1989:7-3). However, such evidence is scarce and is only available for a few chemicals. In cases such as these, the potential for some adverse health effect is inferred from animals such as rats, mice and hamsters. The inference that humans and animals (mammals) are similar, on average, in intrinsic susceptibility to toxic chemicals and that data from animals can in many cases be used as a surrogate for data from humans is the basic premise of modern toxicology (RAGS 1989:7-5). Other data sources that support 'causation' conclusions include metabolic and pharmacokinetic studies, cell culture studies, and structure-activity studies.

CHAPTER 7: INPUT PARAMETERS/MODELING

1. Input Parameters

Site-specific input parameter output files for all three modeling scenarios are represented in Table 41.

Table 41: Input Parameters

Parameter	At 661 feet		At the property boundary		At the source	
Site Location	J.G.	H.C.	J.G.	H.C.	J.G.	H.C.
Model Control Parameters						
Infinite Aquifer	Yes	Yes	Yes	Yes	Yes	Yes
Infinite in depth	No	No	No	No	No	No
Type of source	Pulse	Pulse	Pulse	Pulse	Pulse	Pulse
Simulation time (yrs)	10	10	10	10	10	10
Media Specific Parameters						
Effective porosity	0.35	0.32	0.35	0.32	0.35	0.32
Hydraulic conductivity (m/yr)	92	92	92	92	92	92
Hydraulic gradient	0.022	0.022	0.022	0.028	0.022	0.022
Longitudinal dispersivity (m)	22	22	3	3.7	0	0
Transverse dispersivity (m)	7.3	0.66	0.5	0.62	0	0
Vertical dispersivity (m)	1.08	1.08	0.075	0.09	0	0
Dry weight soil bulk density	1.8	1.8	1.8	1.8	1.8	1.8
Fraction organic carbon	0.01	0.01	0.01	0.01	0.01	0.01
Thickness of the aquifer	10	10	10	10	10	10
Receptor well geometry						
X Coord – of well (m)	220	220	40	30	0	0
Y Coord – of well (m)	0	0	0	0	0	0
Z Coord – Top of screen (m)	1.6	1.6	1.6	1.6	1.6	1.6
Z Coord – Bottom of screen (m)	5	8.3	5	8.3	5	8.3
Source Geometry						
Length of source in x-direction (m)	30	30	30	30	30	30
Length of source in y-direction (m)	40	40	40	40	40	40
Thickness of source in z-direction (m)	0.8	0.8	0.8	0.8	0.8	0.8
Time duration for pulse (yr)	10	10	10	10	10	10
Constant Release Rate (during pulse) for each Chemical (kg/yr)						
Benzene	0.13	0.20	0.13	0.20	0.13	0.20
Ethylbenzene	3.1	0.46	3.1	0.46	3.1	0.46
Toluene	1.29	0.20	1.29	0.2	1.29	0.20

Xylene	30.9	5.6	30.9	5.6	30.9	5.6
Chemical Specific Parameters for each Chemical						
Benzene						
KOC (ug/gOC/ug/ml)	83	83	83	83	83	83
Degradation Rate Constant in Saturated Zone	0	0	0	0	0	0
Molecular Diffusion Coefficient (cm^2/sec)	1.1E-5	1.1E-5	1.1E-5	1.1E-5	1.1E-5	1.1E-5
Ethylbenzene						
KOC (ug/gOC/ug/ml)	1100	1100	1100	1100	1100	1100
Degradation Rate Constant in Saturated Zone	0	0	0	0	0	0
Molecular Diffusion Coefficient (cm^2/sec)	8.5E-6	8.5E-6	8.5E-6	8.5E-6	8.5E-6	8.5E-6
Toluene						
KOC (ug/gOC/ug/ml)	300	300	300	300	300	300
Degradation Rate Constant in Saturated Zone	0	0	0	0	0	0
Molecular Diffusion Coefficient (cm^2/sec)	9.4E-6	9.4E-6	9.4E-6	9.4E-6	9.4E-6	9.4E-6
Xylene						
KOC (ug/gOC/ug/ml)	240	240	240	240	240	240
Degradation Rate Constant in Saturated Zone	0	0	0	0	0	0
Molecular Diffusion Coefficient (cm^2/sec)	8.5E-6	8.5E-6	8.5E-6	8.5E-6	8.5E-6	8.5E-6
Body Weight and Lifetime-Deterministic						
Average weight (kg)	70	70	70	70	70	70
Lifetime (yrs)	70	70	70	70	70	70
Drinking water						
Exposure frequency (days/yr)	350	350	350	350	350	350
Exposure duration (yrs)	30	30	30	30	30	30
Ingestion rate (liters/day)	2	2	2	2	2	2
Drinking Water Chemical Specific Parameters						
Benzene						
Bioavailability	1	1	1	1	1	1
Ethylbenzene						
Bioavailability	1	1	1	1	1	1
Toluene						
Bioavailability	1	1	1	1	1	1
Xylene						
Bioavailability	1	1	1	1	1	1
Oral Dose						
Benzene						
Slope Factor (1/(mg/kg-day)	0.029	0.029	0.029	0.029	0.029	0.029
Reference Dose (mg/kg-day)	ND	ND	ND	ND	ND	ND
Ethylbenzene						
Slope Factor (1/(mg/kg-day)	NA	NA	NA	NA	NA	NA
Reference Dose (mg/kg-day)	0.1	0.1	0.1	0.1	0.1	0.1

produce tumor responses in rats or mice of both sexes. However, Xylene is a known systemic toxicant.

The oral RfD is 2.0 E+0 mg/kg*day and is based on the critical effect of hyperactivity and decreased body weight in male rats. There is medium confidence in this RfD because of a lack of well-designed studies that tested adequately sized groups of two species over a substantial portion of their lifespan (IRIS 1997:3).

Human data, animal data, and other supporting data are the most popular sources for toxicological studies aimed at linking positive associations between chemicals and a disease. Well-conducted epidemiologic studies that show a positive association between an agent and a disease are accepted as the most convincing evidence of human risk (RAGS 1989:7-3). However, such evidence is scarce and is only available for a few chemicals. In cases such as these, the potential for some adverse health effect is inferred from animals such as rats, mice and hamsters. The inference that humans and animals (mammals) are similar, on average, in intrinsic susceptibility to toxic chemicals and that data from animals can in many cases be used as a surrogate for data from humans is the basic premise of modern toxicology (RAGS 1989:7-5). Other data sources that support 'causation' conclusions include metabolic and pharmacokinetic studies, cell culture studies, and structure-activity studies.

3. Media Specific Factors

Effective porosity, hydraulic conductivity, hydraulic gradient, dry weight, soil bulk density, fraction organic carbon, and thickness of the aquifer have been determined by lab technicians working for SUMMIT Environmental Services. Longitudinal, transverse and vertical dispersivity values used in this study are ORBCA default values.

4. Receptor Well Geometry

These four parameters were all estimated from site-specific boring logs and graphic scales. The x-coordinate of the well represents the longitudinal distance to the receptor and the y-coordinate represents the distance normal to the x-axis. Both z-coordinates were estimated based on actual screened intervals of site-specific monitoring wells.

5. Source Geometry

Source geometry consists of four parameters: length of source in the x-direction, length of source in the y-direction, thickness of source in the z-direction, and the time duration for the pulse. Source dimensions have been estimated from headspace vapor readings taken in the unsaturated zone and recorded on soil boring logs. AT-123D models future groundwater in the saturated zone only, therefore, source dimensions can significantly impact the results. Source geometry estimates are probably the most difficult to estimate. AT-123D uses a Cartesian coordinate system to describe the source and location of monitoring points for eight different geometric source configurations (i.e., point sources, x-component line sources, y-component line sources, z-component line sources, x-component plane sources, y-component plane sources, z-component plane sources and volume sources).

6. Chemical Specific Parameters for Each Chemical

ORBCA default values were used for all chemical parameter inputs.

7. Body Weight and Lifetime

Average weight and lifetime are representative of EPA RME values. These values were taken from the APIDSS manual and are based on the 90th percentile.

8. Drinking Water

Exposure frequency, exposure duration, and ingestion rate are representative of EPA RME values. These values were taken from the ORBCA Guidance Document and are based on the 90th percentile.

9. Drinking Water Chemical-Specific Parameters

Bioavailability for each chemical of concern has been estimated/assumed to be one. This conservative estimate of bioavailability implies that all of the contaminant is available for receptor intake.

10. Oral Dose

All BTEX toxicity values for this route of exposure are representative of ORBCA default values.

CHAPTER 8: FINDINGS AND CONCLUSIONS

1. Introduction

This chapter is devoted to the Table's in Chapter 2 and the findings/results contained therein. These Table's illustrate the four test hypotheses' representative of Tier I/IA and Tier II results for current and future conditions, and modeling results indicative of 661 feet down-gradient and at each property boundary. Data contained in these table's are sufficient to illustrate the aforementioned deficiencies in ORBCA. Each test scenario will begin with a brief paraphrase of the ORBCA premises that are tested and followed with table from which the conclusions can be defended.

2. Test Scenario #1

Premise:

For current conditions, ORBCA policy is sufficient for protecting human health and the environment, regardless of the cumulative effects from multiple sources, pathways, chemicals of concern and routes of exposure.

Finding #1

Table 30 does not support this premise. This table illustrates that cumulative systemic/cancer risks exceed ORBCA-derived residual systemic/cancer risk estimates. For Tier I/IA, the cumulative cancer risk is 6.0 E-6, which is greater than 1.0 E-6-the acceptable cancer risk level. Cumulative systemic effects of 12 exceed the acceptable systemic risk level of 1.0 as well.

Moreover, Tier II cumulative systemic/cancer risk estimates of 11.78 and 1.42 E-5 exceed acceptable levels.

3. Test Scenario #2

Premise:

For future conditions, ORBCA policy is sufficient for protecting HHE, regardless of the cumulative effects from multiple sources, pathways, chemicals of concern and routes of exposure.

Finding #2

Table 31 does not support Premise #2. This table illustrates that cumulative systemic/cancer risks exceed ORBCA-derived residual systemic/cancer risk estimates. For Tier I/IA, the cumulative cancer risk is 6.0 E-4, which is greater than 1.0 E-4-the acceptable cancer risk level. Cumulative systemic effects of 12 exceed the acceptable systemic risk level of 1.0 as well. Moreover, Tier II systemic/cancer risk estimates of 11.78 and 4.0 E-4 exceed the acceptable systemic/cancer risk estimates as well.

4. Test Scenario #3

Premise:

At any point greater than 660 feet from any petroleum release, the IELCR is acceptable. This premise has been based on the assumption that petroleum plumes seldom migrate over 660 feet from any site.

Finding #3

Table 32 illustrates and compares future, residual, site–specific Tier II SSTLs with cumulative systemic/cancer risk estimates; both modeled at 661 feet down-gradient of each release. Cumulative risks for this scenario are representative of a ten-year pulse release whereby the concentrations over a ten-year period are summed. Furthermore, these sums are then used to calculate the associated BTEX systemic/cancer risks using ORBCA risk models (see Appendix II). Hence, the greater the number of years summed, the larger the cumulative risks will be. Ten was chosen, because it takes several years for the cumulative effects of insignificant concentrations to meet or exceed Tier II SSTLs which are representative of the acceptable cancer/systemic risk level. Table 28 contains BTEX SSTLs of 1.5 E-7, 8.1 E-5, 2.1 E-5, and 2.4 E-4. When compared to cumulative BTEX levels of 2.17 E-6, 2.80 E-4, 4.94 E-5, and 9.20 E-4 taken from Appendix II, the cumulative estimates are clearly greater. This means that an adult male who is exposed to ten years of BTEX at 661 feet will indeed be subjected to a greater amount of risk.

5. Test Scenario #4

Premise:

Future receptors who choose to relocate on a former UST release are safe if the systemic/cancer risk acceptable at the property boundary.

Finding #4

Table 33 illustrates and compares future, residual, site-specific Tier II SSTLs with cumulative estimates of systemic/cancer risks taken from Appendix

II; both modeled at each property boundary. Like scenario #3, cumulative risks for this scenario are representative of a ten-year pulse release whereby the concentrations over a ten-year period are summed. Furthermore, these sums are then used to calculate the associated BTEX systemic/cancer risks using ORBCA risk models (see Appendix II). Hence, the greater the number of years summed, the larger the cumulative risks will be. I chose ten, because it takes several years for the cumulative effects of insignificant concentrations to meet or exceed Tier II SSTLs which are representative of the acceptable cancer/systemic risk level. Table 33 contains BTEX levels of 3.0 E-7, 3.22 E-8, 1.24 E-7, and 1.09 E-6. When compared to cumulative BTEX levels of 1.59 E-3, 1.29 E-3, 1.53 E-4, and 5.48 E-3 taken from Appendix II, the cumulative estimates are clearly greater. This means that an adult male who is exposed to ten years of BTEX at the property boundary will indeed be subjected to a greater amount of risk.

6. Conclusions

Based on the findings illustrated in Table's 28 and 30-33, all three premises' cannot be validated. The policy that cumulative health effects should not be considered for calculating cleanup levels is ridiculus. In fact, the cumulative estimates probably would have exceeded acceptable levels even more had I included soil with numerous pathways or had included more COCs (e.g. Napthalene and Total Petroleum Hydrocarbon (TPH)).

Since findings for premise #1 and #2 illustrate how the magnitude of cumulative modeled estimates depends on the number of years an adult male is exposed to, this conclusion is subjective. However, I believe the ten-year period is valid and will suffice for this study.

Table 30: Risk Comparison Table for Scenario #1 Current Conditions				
Tier I				
	Benzene		**Toluene** / **Ethylbenzene** / **Xylene**	
	Residual risk	Cumulative risk	Residual risk	Cumulative risk
Cancer Risk	1.0 E-6	6.0 E-6	NA	NA
Systemic Risk	NA	NA	1	12
Tier II				
	Benzene		**Toluene** / **Ethylbenzene** / **Xylene**	
	Residual risk	Cumulative risk	Residual risk	Cumulative risk
Cancer Risk	1.0 E-6	1.42 E-5	NA	NA
Systemic Risk	NA	NA	1	11.78

Table 31: Risk Comparison Table for Scenario #2
Future Conditions

Tier I

	Benzene		**Toluene** **Ethylbenzene** **Xylene**	
	Residual risk	Cumulative risk	Residual risk	Cumulative risk
Cancer Risk	1.0 E-4	6.0 E-4	NA	NA
Systemic Risk	NA	NA	1	12

Tier II

	Benzene		**Toluene** **Ethylbenzene** **Xylene**	
	Residual risk	Cumulative risk	Residual risk	Cumulative risk
Cancer Risk	1.0 E-4	4.0 E-4	NA	NA
Systemic Risk	NA	NA	1	11.78

Table 32: Risk Comparison Table for Scenario #3
Future Conditions

Johnson Grocery at 661 feet

	Benzene		Toluene		Ethylbenzene		Xylene	
	J.G. Tier II future estimate	Modeled cumulative estimate	J.G. Tier II future estimate	Modeled cumulative estimate	J.G. Tier II future estimate	Modeled cumulative estimate	J.G. Tier II future estimate	Modeled cumulative estimate
Cancer Risk	7.70 E-7	2.17 E-6	NA	NA	NA	NA	NA	NA
Systemic Risk	NA	NA	3.90 E-5	2.80 E-4	8.10 E-3	4.94 E-5	1.42 E-4	9.20 E-4

Hahn's Cleaners at 661 feet

	Benzene		Toluene		Ethylbenzene		Xylene	
	H.C. Tier II future estimate	Modeled cumulative estimate	H.C. Tier II future estimate	Modeled cumulative estimate	H.C. Tier II future estimate	Modeled cumulative estimate	H.C. Tier II future estimate	Modeled cumulative estimate
Cancer Risk	1.57 E-7	9.54 E-5	NA	NA	NA	NA	NA	NA
Systemic Risk	NA	NA	8.10 E-5	1.52 E-5	2.10 E-5	1.47 E-7	2.40 E-4	1.33 E-4

Table 33: Risk Comparison Table for Scenario #4 Future Conditions								
At the Property Boundary								
	Benzene		**Toluene**		**Ethylbenzene**		**Xylene**	
	J.G. Tier II estimate	Modeled cumulative estimate	J.G. Tier II estimate	Modeled cumulative estimate	J.G. Tier II estimate	Modeled cumulative estimate	J.G. Tier II estimate	Modeled cumulative estimate
Cancer Risk	6.5 E-4	7.63 E-4	NA	NA	NA	NA	NA	NA
Systemic Risk	NA	NA	1.97 E-6	4.0 E-3	5.86 E-6	1.09 E-4	4.13 E-4	1.60 E-2
At the Property Boundary								
	Benzene		**Toluene**		**Ethylbenzene**		**Xylene**	
	H.C. Tier II estimate	Modeled cumulative estimate	H.C. Tier II estimate	Modeled cumulative estimate	H.C. Tier II estimate	Modeled cumulative estimate	H.C. Tier II estimate	Modeled cumulative estimate
Cancer Risk	3.0 E-7	1.59 E-3	NA	NA	NA	NA	NA	NA
Systemic Risk	NA	NA	3.22 E-8	1.29 E-3	1.24 E-7	1.53 E-4	1.09 E-6	5.48 E-3

REFERENCES

American Petroleum Institute. 1994. "American Petroleum Institute Decision Support System (APIDSS)." Dupont Environmental Remediation Services.

American Society for Testing and Materials (ASTM) 1996. "Standard Guide for RBCA Applied at Petroleum Release Sites", ASTM Publication E-1739-95.

California Environmental Protection Agency. 1997. "A Guide to California's Commingled Plume Account Program." State Water Resources Control Board.

Fetter, C.W. 1988. *"Applied Hydrogeology."* Macmillan College Publishing Company.

Gephart L.A., J.G. Tell, L.R. Triemer, 1994. *"Water Quality Data Analysis and Interpretation."* Lewis Publishers.

Hounslow, Arthur W. 1995. *"Water Quality Data Analysis and Interpretation."* Lewis Publishers.

Oklahoma Corporation Commission, Codified Rules and Regulations Governing Underground Storage Tanks in Oklahoma; Guidance Documents (ORBCA) and Checklists for Indemnity Fund Applications, July 1, 1995.

Summit Environmental Services. 1996. ORBCA Tier 1/1A, Bill's Westside Texaco.

Summit Environmental Services. 1996. ORBCA Tier 1/1A, Johnson Grocery.

U.S. Environmental Protection Agency. 1989. *"Risk Assessment Guidance for Superfund Volume I Human Health Evaluation Manual (Part A)."* Office of Emergency and Remedial Response U.S. Environmental Protection Agency Washington, DC 20450.

APPENDIX I

Tier I Default Fate and Transport Parameters		
	UNITS	Default value
Source parameters		
Depth to groundwater	cm	304.8
Depth to surficial soil sources	cm	30.48
Depth to subsurface soil sources	cm	304.8
Thickness of vadose zone	cm	295
Building parameters		
Height of the indoor space (Building)		
On/Off-site Resident (adult and child)	cm	300
On-site Commercial Worker	cm	300
Construction Worker	cm	300
Width of the indoor space (Building)	cm	1500
Length of the indoor space (Building)	cm	1500
Fraction of area exposed by cracks	--	0.01
Enclosed space air exchange rate		
On/Off-site Resident (adult)	L/day	12
On/Off-site Resident (child)	L/day	12
On/Off-site Commercial Worker	L/day	18
Averaging time for vapor flux		
On/Off-site Resident (adult)	Sec	9.46E+8
On/Off-site Resident (child)	Sec	1.89E+8
On/Off-site Commercial Worker	Sec	7.88E+8
Construction Worker	Sec	3.15E+7
Groundwater parameters		
Groundwater Darcy Velocity	Cm/year	2500
Groundwater mixing zone thickness (Source Thickness)	Cm	200
Source width parallel to flow direction	Cm	1500
Thickness of capillary fringe	Cm	5
Soil parameters		
Total Soil Porosity	Cc/cc	0.35
Volumetric water content in vadose zone soils	Cc/cc	0.20
Volumetric water content in vadose zone soils	Cc/cc	0.15
Soil bulk density	G/cc	1.7
Fractional organic carbon content in soil	g-C/g-soil	0.01
Other parameters		
Particulate emission rate	G/cm^2-s	6.90E-9
Wind speed above ground surface in mixing zone	Cm/sec	225
Width of source parallel to wind direction	Cm/yr	1500
Ambient air mixing zone height	Cm	200
Infiltration rate		
West Zone County	Cm/yr	7
Central Zone County	Cm/yr	10
East Zone County	Cm/yr	13

APPENDIX I

TIER I DEFAULT EXPOSURE FACTORS (RME VALUES)

	UNITS	Default values
Body Weight		
On/Off-site Resident (adult)	kg	70
On/Off-site Resident (child)	kg	15
On/Off-site Commercial Worker	kg	70
Construction Worker	kg	70
Exposure Duration		
On/Off-site Resident (adult)	yr	30
On/Off-site Resident (child)	yr	6
On/Off-site Commercial Worker	yr	25
Construction Worker	yr	0.083
Exposure Time for indoor inhalation, dermal contact, and soil ingestion		
On/Off-site Resident (adult)	Hrs/day	16
On/Off-site Resident (child)	Hrs/day	16
On/Off-site Commercial Worker	Hrs/day	8
Construction Worker	Hrs/day	8
Exposure Frequency		
On/Off-site Resident (adult and child)	Days/yr	350
On-site commercial worker	Days/yr	250
Construction Worker	Days/yr	250
Soil ingestion rate		
On/Off-site Resident (adult)	Mg/day	100
On/Off-site Resident (child)	Mg/day	200
On/Off-site Commercial Worker	Mg/day	50
Construction Worker	Mg/day	50
Daily Indoor Inhalation Rate		
On/Off-site Resident (adult)	M^3/hr	0.937
On/Off-site Resident (child)	M^3/hr	0.937
On/Off-site Commercial Worker	M^3/hr	2
Daily Outdoor Inhalation Rate		
Construction Worker	M^3/hr	2
Exposure Time for outdoor inhalation, dermal contact, and soil ingestion		
On/Off-site Resident (adult)	Hrs/day	16
On/Off-site Resident (child)	Hrs/day	16
On/Off-site Commercial Worker	Hrs/day	8
Construction Worker	Hrs/day	8
Daily Water Ingestion rate		
On/Off-site Resident (adult)	L/day	2
On/Off-site Resident (child)	L/day	1

On/Off-site Commercial Worker	L/day	1
Construction Worker	L/day	1
Skin surface area for dermal contact with soil		
On/Off-site Resident (adult)	Cm^2	3160
On/Off-site Resident (child)	Cm^2	3160
On/Off-site Commercial Worker	Cm^2	3160
Construction Worker	Cm^2	3160
Soil skin adherence factor	Mg/cm^2	0.5
Oral relative absorption factor	---	1
Dermal relative absorption factor (volatiles)	---	0.5
Dermal relative absorption factor (PAHs)	---	0.05
Target Risk and Hazard Quotient		
Target Hazard Quotient		
Current Conditions	---	1
Future Conditions	---	1
Target Excess Individual Lifetime Cancer Risk		
Current Conditions	---	1.0 E-6
Future Conditions	---	1.0 E-4

APPENDIX II

J.G. at 661 feet

x	benzene	toluene	ethylbenzene	xylene	
1	4.12E-06	7.17E-08	0.00E+01	9.01E-06	
2	2.53E-05	6.77E-06	0.00E+01	4.08E-04	
3	5.15E-05	3.58E-05	4.04E-08	1.67E-03	
4	7.69E-05	8.78E-05	5.11E-07	3.59E-03	
5	1.00E-04	1.55E-04	2.47E-06	5.86E-03	
6	1.14E-04	2.32E-04	7.31E-06	8.27E-03	
7	1.11E-04	3.04E-04	1.61E-05	1.02E-02	
8	1.02E-04	3.54E-04	2.97E-05	1.12E-02	
9	9.37E-05	3.83E-04	4.77E-05	1.16E-02	
10	8.57E-05	3.97E-04	6.91E-05	1.17E-02	
	7.64E-05	1.96E-03	1.73E-04	6.45E-02	cumulative concentrations
	2.17E-06	2.80E-04	4.94E-05	9.20E-04	**cumulative risk**

J.G. at Property Boundary

x	benzene	toluene	ethylbenzene	xylene	
1	3.50E-05	7.48E-08	0.00E+01	1.62E-05	
2	2.24E-04	1.05E-05	0.00E+01	8.97E-04	
3	7.92E-04	1.06E-04	3.93E-09	7.24E-03	
4	1.43E-03	4.41E-04	1.52E-07	2.48E-02	
5	2.23E-03	1.09E-03	1.34E-06	5.47E-02	
6	2.94E-03	2.10E-03	6.43E-06	9.65E-02	
7	3.73E-03	3.43E-03	2.07E-05	1.47E-01	
8	4.40E-03	5.04E-03	5.15E-05	2.06E-01	
9	5.14E-03	6.88E-03	1.07E-04	2.69E-01	
10	5.75E-03	8.90E-03	1.97E-04	3.36E-01	
	2.67E-02	2.80E-02	3.84E-04	1.14E-00	cumulative concentrations
	7.63E-04	4.00E-03	1.09E-04	1.60E-02	**cumulative risk**

H.C. at 661 feet

x	benzene	toluene	ethylbenzene	xylene
1	9.84E-07	0.00E+01	0.00E+01	0.00E+01
2	1.08E-05	0.00E+01	0.00E+01	1.73E-06
3	5.31E-05	7.26E-09	0.00E+01	2.21E-05
4	1.20E-04	2.03E-07	0.00E+01	1.09E-04
5	2.15E-04	1.27E-06	0.00E+01	3.01E-04
6	3.24E-04	4.17E-06	0.00E+01	6.24E-04
7	4.49E-04	9.62E-06	1.44E-08	1.08E-03
8	5.80E-04	1.80E-05	5.07E-08	1.66E-03
9	7.22E-04	2.96E-05	1.38E-07	2.37E-03
10	8.65E-04	4.44E-05	3.13E-07	3.20E-03

	benzene	toluene	ethylbenzene	xylene	
	3.34E-03	1.07E-04	5.16E-07	9.37E-03	cumulative concentrations
	9.54E-05	1.52E-05	1.47E-07	1.33E-04	**cumulative risk**

H.C. at Property Boundary

x	benzene	toluene	ethylbenzene	xylene	
1	0	1.69E-06	0.00E+01	1.58E-04	
2	9.75E-04	2.12E-05	1.44E-08	1.41E-03	
3	2.31E-03	1.13E-04	3.64E-07	6.40E-03	
4	3.63E-03	2.83E-04	2.63E-06	1.43E-02	
5	5.10E-03	5.36E-04	9.79E-06	2.54E-02	
6	6.36E-03	8.46E-04	2.50E-05	3.79E-02	
7	7.71E-03	1.20E-03	5.11E-05	5.22E-02	
8	8.83E-03	1.59E-03	9.03E-05	6.67E-02	
9	1.00E-02	2.01E-03	1.44E-04	8.22E-02	
10	1.10E-02	2.44E-03	2.13E-04	9.74E-02	
	5.59E-02	9.04E-03	5.36E-04	3.84E-01	cumulative concentrations
	1.59E-03	1.29E-03	1.53E-04	5.48E-03	**cumulative risk**

VITA

Bryan Morris

Candidate for the Degree of

Master of Science

Thesis: CUMULATIVE RISK ASSESSMENT OF PETROLEUM RELEASES AT TWO ADJACENT RELEASE SITES IN OKLAHOMA

Major Field: Geology

Biographical:

Personal Data: Born in Ponca City, Oklahoma, On November 13, 1970, the son of Floyd and Ernestine Morris.

Education: Graduated from Poteau High School, Poteau, Oklahoma in May 1989; received Bachelor of Science Degree in Geology from Oklahoma State University, Stillwater Oklahoma in December 1994, respectively. Completed the requirements for the Master of Science degree with a major in Geology at Oklahoma State University in December, 1999.

Experience: Raised on a farm near Cameron, Oklahoma; employed as a farm laborer while growing up; employed by Oklahoma State University, Department of Geology as a teaching assistant; Oklahoma State University, Department of Geology, 1995 to 1996.

Professional Memberships: National Association of Environmental Professionals, Gideon's International.