EVALUATION OF RISK SCREENING VERSUS OKLAHOMA RISK-BASED CORRECTIVE ACTION FOR THE WELLHEAD PROTECTION AREAS

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CHAPTER I

INTRODUCTION

Background

Public Water Systems (PWSs) provide water for communities, and many derive their source of water supply from ground water (Bedient et al., 1981). Consequently, the quality of the resource is significant to the economy and welfare of these areas, which also defines and directs their growth and development (Christenson and Parkhurst, 1987). Furthermore, safe drinking water is essential to the quality of community life because it correlates with the public health (EPA, 1997).

Problems in ground water contamination have become major issues (Bedient et al., 1981). To assist local communities in protecting their ground water as their source of water supply, the state of Oklahoma has developed the Wellhead Protection (WHP) program under Section 1428 of the Safe Drinking Water Act Amendments of 1986. Within the program, states are required to complete assessments of all Public Water Systems (PWSs). The elements of assessment include wellhead protection area (WHPA) delineation, inventories of potential contaminant sources within WHPAs, and determination of susceptibility of the PWSs to contamination (EPA, 1997).

Previously, EPA had set the maximum contaminant levels (MCL) for specific contaminants to protect drinking water quality (Freeze and Cherry, 1979; EPA, 1998). The MCLs serve as standards for drinking water quality. If the concentration of specified contaminants in drinking water exceeds the MCLs, risk to the public health and their environment is judged as unacceptable (Freeze and Cherry, 1979; Crowe, 1993).

The risk is especially associated with chemical exposure that can be incurred primarily through ingestion of the drinking water (McBean et al., 1990). Nevertheless, the public's understanding and recognition of risk relates to their general knowledge concerning its riskiness. Hence, their acceptance of risk depends on their experience and familiarity with the potential threat, as well as the immediacy of effect (Rogers, 1987).

Previous studies of ground water quality assessments examined the relationships and effects of land use and hydrogeology on the quality of ground water. Other studies involved the assessment of aquifer vulnerability to potential sources that would pose a risk of contaminating the ground water supply. Risk assessments are often performed at specific sites, therefore, require remedial action. Other assessment methodologies investigate pollution prevention of risks posed by potential sources of contamination.

Several methods can be applied to assess risk within a WHPA (EPA, 1994), but few methods were documented. In this study, the methods selected are 'Priority Setting Approach' (PSA) developed by EPA for risk screening and the 'Oklahoma Risk-Based Corrective Action' (ORBCA) approach, which was developed by the Oklahoma Corporation Commission based on the America Society for Testing Materials (ASTM) standards E1739.

Purpose and Objectives

The purpose of this study is to evaluate the methods and procedures for risk assessment using the 'Priority Setting Approach" and comparing these results against those obtained by applying ORBCA approach.

The 'Priority Setting Approach' is described by EPA as a risk screening tool developed for pollution prevention within a WHPA. This method was selected because it is a simplified form of risk assessment that allows users to conduct an assessment with limited information. The manual provides default values for the concentration, toxicity, and characteristics of chemicals that are generally released from a specific site.

The ORBCA procedure is a process that combines elements of site assessment, risk assessment, remediation, and risk management into a system that develops site-specific cleanup goals that are protective of human health, safety, and the environment. This approach was chosen because it is a risk-based decision making method. Furthermore, ORBCA is an extensive procedure with tiered approaches for site-specific conditions and risks. The Tier 2 process, which requires site-specific information, was selected to quantify the current risk or potential threats.

The scope of this study includes applications of the methods, assumptions taken into consideration, and a discussion of the limitations of each method. In addition, information concerning the study area - Calvin, Oklahoma - is compiled. These data included the hydrology, ground water observations, and types of land-use within the delineation areas.

The town of Calvin, in Hughes County, Oklahoma, was selected because it is one of the targeted areas for the development of WHP program from which water quality data were readily available. Another reason is that bromoform, chloroform, dichloromethane, and tetrachloroethylene (PCE) were found in the PWS wells.

The objectives of this study are to: (1) determine which method is best suited for use for risk assessment within the WHPA, (2) compare the risk assessments from the

‘Priority Setting Approach’ with ORBCA risk assessment, considering only the exposure pathway involving the ingestion of ground water, and (3) determine the risk of contamination by bromoform, chloroform, dichlorobromomethane, and tetrachloroethylene using ORBCA.

CHAPTER II

LITERATURE REVIEW

Ground Water

Ground Water Definition

Groundwater is frequently used as a source of water supply and is defined as subsurface water that occurs beneath the water table where the soils and geologic formations are fully saturated (Freeze & Cherry, 1979). Hence, the occurrence of groundwater is related to its geologic setting, and the chemical composition is related to the precipitation and the solubility of aquifer constituents (Boulding, 1995).

Ground Water Contamination

The quality of ground water can be altered by contaminants (Christenson 1987). Freeze & Cherry (1979) define contaminant as "solutes that are introduced into the hydrologic environment, regardless of whether or not the concentrations reach levels that may cause significant degradation of water quality."

The contamination of ground water could be caused by many point or non-point sources (Barton et al., 1987). Point sources are considered as "any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding unacceptable risk to human health or the environment (Crowe, 1993, Freeze & Cherry, 1979).

The maximum contaminant levels, MCL, (permissible concentration limits in drinking water) are defined as the National Primary Drinking Water Regulations (NPDWR) or primary standards (Freeze & Cherry, 1979). MCLs are set by EPA and are enforceable at PWSs: " a system for the provision to the public of water for human consumption through pipes or other constructed conveyances, if such system has at least fifteen service connections or regularly serves at least twenty-five individuals" (EPA, 1998).

The primary standards protect drinking water quality by setting the limits of specific contaminants that are considered to have significant potential harm to human health at concentrations above the specified limits (Freeze & Cheery, 1979; EPA, 1998).

The Wellhead Protection (WHP) Program

Wellhead Protection Program Overview

The WHP program is a pollution prevention program designed to protect ground water-based sources of drinking water and to preserve them from threats that could degrade water quality. Under Section 1428 of the Safe Drinking Water Act Amendments of 1986, each State is required to develop and implement a Wellhead Protection Program (EPA 1994). Wellhead Protection (WHP) is a focused, community-based approach for the protection of ground water that supplies public water and wellfields. The WHP program consists of six components: (1) delineation of Wellhead Protection Areas, (2) inventory of potential pollution sources, (3) development of source control strategies, (4) contingency planning, (5) ground water monitoring, and (6) public education (EPA, 1995).

The overall goal of the program is to delineate Wellhead Protection Areas (WHPA), "a surface and subsurface area surrounding a water well or wellfield, supplying a public water system through which contaminants are likely to move toward and reach such well or wellfield" (EPA, 1995).

Wellhead Delineation Model (WHPA)

The US EPA has listed several criteria as technical base to delineate protection areas. These criteria include distance, drawdown, time-of-travel (TOT), flow boundaries and assimilative capacity. The ODEQ delineates the WHPAs based on the TOT criteria. Therefore, to assist local technical staff with the delineation, the WHPA ground water model was used. The WHPA model is a time-related, semi-analytical ground water flow model developed by Hydrogeologic Inc. for the U.S. EPA Office of Ground Water (ODEQ 1994). The model simulates the groundwater flow conditions and determines the boundary of the protection areas based on the TOT, which is the time required for a ground water contaminant to reach a well (Blanford and Huyakorn, 1991; ODEQ, 1994).

As described in the U.S. EPA WHPA's user guide (EPA, 1991), the model contains four major computational modules: RESSQC, MWCAP, GPTRAC, and MONTEC. The RESSQC can be used to delineate time-related capture zones for a system of one or more pumping/injection wells that penetrates a homogeneous aquifer. The ground water flow in the aquifer is analyzed in three dimensions, and is assumed to be steady. The aquifer may be confined or unconfined and well interference effects are considered.

The Multiple Well Capture Zone Module (MWCAP) delineates steady-state, time-related, and hybrid capture zones for one or more pumping wells in homogenous aquifers. The ground water flow is assumed to be steady and uniform. The module assumes that the wells operate independently and physical processes such as increased drawdown due to well interference effects are ignored.

The GPTRAC (General Particle Tracking Module) consists of two options: semi-analytical and numerical. The semi-analytical option delineates time-related capture zones for pumping wells in the homogenous aquifers with steady and uniform ambient ground water flow. The aquifer may be confined, unconfined or unconfined with recharge area. The extent of the aquifer may be infinite or bounded by one or two streams and/or boundaries. The numerical option delineates time-related capture zones of pumping wells for steady ground water flow fields. This option uses numerical ground water flow modeling, types of boundary, as well as aquifer heterogeneity.

The MONTEC module performs uncertainty analysis for time-related capture zones for a single pumping well in homogenous aquifers of infinite areal extent. The aquifer may be confined or semi-confined.

The Oklahoma Department of Environmental Quality (ODEQ) used the semi analytical option within GPTRAC to determine the WHPAs in Calvin, Oklahoma. This option delineates time-related capture zones for pumping wells in homogenous unconfined aquifers with steady and uniform ambient groundwater flow. ODEQ integrates the technical data into a map to provide information about the boundaries. At each well location, a time-of -travel of 10 years was used to map vulnerability areas (ODEQ 1994).

Risk Assessment

Concept

Risk assessment is a science-based process that estimates human health and environmental risks associated with exposure to chemical(s) of concern present in the environment (ASTM, 1996).

EPA (1990) defines human health risk as "the likelihood (or probability) that a given chemical exposure or series of exposures may damage the health of exposed individuals." Risks can be assessed by determining the probability of exposure and the acceptability of the negative impacts to specific individuals and the public (Shih & Riojas 1990).

Risk assessment involves the analysis of chemical exposures, the adverse health effects that could occur. The process of risk assessment includes four major components: hazard identification, dose-response assessment, human exposure assessment, and risk characterization (EPA, 1990).

Hazard identification determines whether toxic effects observed in one situation are likely to occur in another condition. In this process, the data on the types of health injury or disease that may be produced by a chemical, and reports on the conditions of exposure under which injury or disease is produced, are necessary (EPA, 1990).

Dose-response assessment describes the relationship between the amount of exposure to a substance and the extent of toxic injury or disease. This assessment characterizes the relationship between the amount of exposure (dose) and the magnitude of the adverse health effect (response) in a human population (Walsh, 1990). In many cases, dose-response relationships are estimated from studies in animals (EPA, 1990).

Assessment of human exposure requires estimation of the number of people exposed and the magnitude, duration and timing of exposures. This assessment could include past exposures, current exposures, and exposures anticipated in the future (EPA 1990). Exposure estimation usually uses '95th percentile' assumptions of the amount and duration of the exposure to the chemical or substance (Walsh, 1990).

Risk is generally characterized as carcinogenic and non-carcinogenic. Risk characterization combines the information accumulated and analyse performed during hazard identification, dose-response assessment, and human exposure assessment. The end result of the risk assessment is a quantitative risk for a given assumed exposure (Walsh, 1990). Quantification of non-carcinogenic effects (Hazard Quotient or HQ) is evaluated by comparing the estimated dose with the Reference Dose (RfD). Acceptable risk is $HQ < 1$. If $HQ > 1$, further evaluation is required (ASTM, 1996).

$$\textbf{Hazard Quotient} = \frac{\textbf{Dose}}{\textbf{RfD}} \tag{1}$$

Carcinogenic effects are quantified as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogens (Walsh, 1990; ASTM, 1996).

$$\textbf{Risk (R) = Slope Factor (SF) * Dose} \tag{2}$$

SF is the carcinogenic potency factor.

$$\textbf{Dose (mg/kg-day)} = \frac{\textbf{(CW) (IR) (EF) (ED)}}{\textbf{(BW) (AT)}} \tag{3}$$

CW = Concentration in water of chemical of concern (mg/L)
IR = Ingestion rate (L/day)
EF = Exposure frequency (days/yr)
ED = Exposure duration (yr)
BW = Body weight (kg)
AT = Averaging Time - period over which exposure is averaged (days)
AT noncarcinogen = ED (30 years) * 365 days per year;
AT carcinogen = Lifetime (70 years) * 365 days per year

Risk Assessment in Other WHPAs

Research regarding risk assessments on a WHPA in other states was done prior to the determination of the methods used herein. I contacted EPA Region VI to what types of risk assessment that has been done, and the processes or procedures applied, as well as where was the method applied.

Risk assessments within a WHPA use a risk ranking procedure to map potential contamination and aquifer vulnerability. For high risk of potential contaminant sources, more comprehensive risk assessment approaches are required (EPA, 1994). EPA has developed a risk screening tool to assist states in assessing risk within a WHPA. The manual was developed in 1991, and new version or edition has not yet been published (EPA Region VI Department of Documentation, 1998; Bechdol, 1998; Williams, 1998). A comprehensive human health risk assessment, is not a mandatory procedure in the WHP program. The program is a pollution prevention program and not a remediation program, thus, the methods available are generally simple risk screening (Bechdol, 1998; Williams, 1998). States usually develop their own procedures by adapting other methods. One example is the application of GIS-based screening analysis on watersheds developed in Texas. This method uses Cumulative Risk Index Analysis (CRIA) that was incorporated for a watershed delineation protection. However, in general, most procedures for risk assessment in WHPA generally adopt the same concept of risk ranking (Williams, 1998).

Methods for Risk Assessments

There are a number of methods to evaluate the risk posed by potential contaminant sources within the WHPA. The methods range from the simple ranking of risks by classifying sources as high, moderate, and low risk to a comprehensive risk assessment processes in which fate and transport of chemicals of concerns are modeled to quantify exposure and risk to people or the ecosystems (EPA, 1995).

Priority Setting Approach (PSA)

This method (EPA, 1991) can be used as a risk-screening tool to enable the assessment of risks posed by specific potential sources of contamination, with limited data to produce a relative expression of risk. It determines a risk score for each potential source of contamination. The established risk scores allow the user to rank the sources to assess whether one source poses a greater risk than another source and screen sources to determine whether a given source poses too high a risk. An overview of this process is shown in Figure 1.

PSA is based on a simplified conventional human health risk assessment that generally addresses two basic questions: (1) What is the frequency/duration of the exposure to a substance? and (2) What is the degree of toxicity of the substance? For the purpose of PSA, these questions correlate to (1) What is the likelihood that something will go wrong? and (2) What are the consequences in the event something does go wrong? (EPA, 1991).

Task I	Characterization of WHPA	→	• WHPA map boundaries • WHPA hydrogeology characteristics	Wellhead Datasheet	→	Master Scoresheet
Task II	Identification & Characterization of Potential Sources of contaminants	→	• Identify and locate all sources • List sources and categorize • Determine contaminants/mixture present • Determine the chemicals characteristics, concentration, mobility, persistence, and Toxicity (T) scores.	Source Datasheet	→	
Task III	Perform Source Calculation	→	• Assess the likelihood of contaminant releases from the source (L1) • Compute Quantity score (Q) → Q = concentration score + Volume or Area score	Source Worksheet	→	
Task IV	Perform Transport Calculations	→	• Assess contaminant transport • Determine the likelihood of contaminants reaching the wells in the unsaturated zone (Lu) & saturated zone (Ls) • Compute the likelihood of reaching the well (L2) → L2 = Lu + Ls • Determine the Attenuation due to transport in the unsaturated (Au) and saturated (As) zone Compute the Attenuation due to transport score (A) → A = Au + As	Transport Worksheet	→	
Task V	Estimate risks and rank sources	→	• Determine the contaminant specific risk scores (R) → R = L+S L = L1+L2, S = Q+A+T • Determine the source specific overall risk scores		→	

Figure 1. Overview of the 'Priority Setting Approach'

PSA considers two components of risk. The sum of the two components is the estimation of risk score.

$$\mathbf{R = L + S} \tag{4}$$

The first component of the risk score is the likelihood of well contamination score; i.e. the likelihood that the contaminant will be released from a source and will reach the well within a specified period of time. The second component is the severity of well contamination, i.e. the potential health hazard from drinking water drawn from the and dispersion between the source and the wellhead. The overall risk score for a source of potential contamination is the highest of the risk scores associated with each contaminant or contaminant mixture present at the source (EPA, 1991).

The scoring is based on logarithmic conversion of natural units of measurement of each risk parameter and is considered to have equal importance in terms of its contribution to the final risk scores (EPA, 1991).

Risk assessment determines risk by multiplying the several individual parameters mentioned earlier. PSA assumes a conversion of the derived risk values using the decimal logarithmic function, resulting summation of individual parameters rather than multiplication to obtain risk scores (EPA, 1991).

Likelihood of well contamination score (L) is the score of probability that a source contaminant will reach the well within a user-specified time period (planning period). L is calculated as the sum of the likelihood of release at the source score (L1) and the likelihood that the contaminant will reach the well score (L2).

$$\mathbf{L = L1 + L2} \qquad \mathbf{(5)}$$

L1 reflects the likelihood of contaminant released from a source. It is a function of the source type and is based on engineering failure analyses that account for the type of contamination source, design characteristics and operating status (EPA, 1991).

L2 reflects the probability that the contaminant will reach the well within the planning period, assuming that the contaminant is released from the source starting from day one in the source's lifetime. L2 is the sum of scores of the likelihood that a contaminant will reach the well in the unsaturated zone (Lu) and unsaturated zone (Ls) (EPA, 1991).

$$L2 = Lu + Ls \quad (6)$$

The Lu score is based on the contaminant's time of travel (TOT) through the unsaturated zone in comparison to the planning period. The TOT is given by Darcy's Law as a function of the depth to the aquifer, the hydraulic conductivity of the unsaturated zone, and the contaminant's mobility. Correspondingly, the Ls score is based on the contaminant's time of travel through the saturated zone to the well in comparison to the planning period. The TOT in the saturated zone is a function of the distance from the source to the well, ground water velocity, and the contaminant's mobility (EPA, 1991).

The decimal logarithm of the well contamination probability will result in the value of the likelihood of well contamination score less than or equal to 0. The higher the value of L, the higher the likelihood that the contaminant will be released and reach the well within the specified planning period (EPA, 1991).

Severity of well contamination reflects the potential health hazard from drinking water from a well that has been polluted by a contaminant. The severity of well contamination score (S) is the sum of three partial risk scores: the quantity score (Q) of contaminant released annually at the source, attenuation score (A) due to transport from the source to the well, and the toxicity score (T) of the contaminant (EPA, 1991).

$$S = Q + A + T \quad (7)$$

The quantity released at the source score (Q) is the expected mass of contaminant or contaminant mixture released annually from a source of potential contamination. Contaminants released are expressed as mass released per unit of time (kg/yr), while contaminant concentrations are measured as mass unit per unit volume of water (kg/m^3).

The expected quantity of contaminants released annually (in kg/yr) is equal to the product of the annual expected volume of waste released (m^3/yr) times the contaminant's concentration in the waste (kg/m^3). By applying logarithmic conversion, the Q score (in $\log_{10}$ (kg/yr) can be computed by adding the volume score (volume of water released in $\log_{10}$ (m^3/yr)) and the concentration score (contaminant concentration in waste, in $\log_{10}$ (kg/m^3)). This concept is applicable for most sources included in PSA, except for agrichemical application, where the volume score is in $\log_{10}$ (hectares) and the concentration score is in $\log_{10}$ (kg/hectare/yr) (EPA, 1991).

The volume score is a function of input parameters such as facility type and size. If the concentration of the contaminant is known, the concentration score can be determined form the graph provided in the Approach as a function of contaminant concentration. The contaminant concentration scoring graph provided converts the contaminant concentration from kg/m^3 to a concentration score in decimal logarithm. However, if the concentration is not known, a separate default value of contaminant specific concentration score applicable to the source is provided. The resulting scores generally range from –1 to 5, where 5 represents the largest theoretical contaminant mass release (EPA, 1991).

Attenuation due to transport score (A) reflects the dilution and decay of the contaminant released due to transport from the source to the well. Attenuation is defined as the contaminant concentration at the wellhead per unit of contaminant released annually at the source. Accordingly, A has units of $\log_{10}$ ((mg/l)/(kg/yr)). The higher the A value, the less the dilution and decay of the contaminant. The attenuation score (A) is calculated as the sum of attenuations in the unsaturated zone (Au) and saturated zone (As).

$$\mathbf{A = Au + As} \tag{8}$$

The Au score is a function of the unadjusted unsaturated zone hydraulic conductivity score, the contaminant's persistence and mobility, and the depth to the aquifer. It measures the ratio of the quantity of contaminant leaving the unsaturated zone to enter the saturated zone divided by the quantity of contaminant leaving the unsaturated zoned after being released from the source. Thus, Au has units of $\log_{10}$ ((kg/yr)/(kg/yr) and is dimensionless. The As score is a function of ground water velocity, the contaminant's persistence and mobility, the type of material in the saturated zone, and the distance from the source to the well, hence the provided As score is in $\log_{10}$ ((mg/l)/(kg/yr). The resulting attenuation score is generally less than 0; higher values indicate higher contamination at the well per unit of mass released at the source (EPA, 1991).

The toxicity of the contaminant score (T) indicates the potential health hazard posed by ingesting the contaminant. Toxicity scores are based on established dose-response relationships obtained from EPA's IRIS database. Using the dose-response relationship, PSA defines the oral reference dose for non-carcinogens as the "critical dose" for each contaminant, and the dose corresponding to an excess lifetime risk of 10^{-5} (1 in 100,000) for carcinogens. The approach converts the critical doses into critical concentrations (in mg/l of drinking water) using the EPA's standard assumptions of two liters consumed per day over a 70-year lifetime exposure period. The toxicity score of the contaminant is defined as the decimal logarithm of the inverse of the critical concentration in mg/L. Thus, T has units of $\log_{10}$ $(mg/l)^{-1}$.

$$\textbf{Toxicity (T)} = \log_{10} (CC)^{-1} \qquad (9)$$

For carcinogens, it is generally assumed that no threshold level of adverse health effect exists; any exposure can cause cancer. Therefore, the critical dose is defined as the dose that increases the risk of cancer by 10^{-5} over background levels. CC is determined as the contaminant concentration in drinking water equivalent to a 10^{-5} individual health lifetime cancer risk (assuming 70 kg body weight and 2 L/d average water consumption):

$$CC\ (mg/L) = \frac{1x\ 10^{-5} * 70\ kg}{q\ (mg/kg\text{-}d)\text{-}1 * 2\ L/d} \qquad (10)$$

q = carcinogenic slope factor

The toxicity scores published for chemicals listed in PSA ranges from –2.4 to 3.8, where higher scores indicate higher toxicity (EPA, 1991).

The risk score (R) posed by a contaminant is equal to the sum of the likelihood of well contamination score (L) and severity of well contamination score (S). The risk of well contamination posed by a given contaminant is the product of the probability of well contamination multiplied by the severity of well contamination. However, in natural log, the overall risk score of well contamination posed by a given source is equal to the highest R of well contamination posed by individual contaminant mixtures present at the source. The risk level posed by a potential source of contamination can also be categorized into low, medium or high as a function of its overall risk score. If the overall risk score is greater than 0, then the source poses a high risk. Between 0 to –4, the risk is medium, less than –4,the risk is low. In the case that a contaminant has a risk score of -1, then this contaminant is expected to contaminate the well at a concentration equal to one tenth its critical concentration in drinking water (EPA, 1991).

To proceed assessment with this approach, information of the study area is required. This information includes a map showing the wellhead protection area delineation, the location of potential contamination sources, the hydrogeology setting, aquifer characteristics and material (e.g., sand or gravel). Source-specific information includes basic design features (e.g. landfill liner), distance from well, and contaminants present (defaults provided) (EPA, 1991).

The procedure relies on the general principles of risk assessment, but requires less data and analysis than a comprehensive risk assessment. It integrates information from several EPA databases and models. The Integrated Risk Information System (IRIS) is used for toxicity information. The RCRA risk-cost analysis model (or WET model), the Liner Location Model, and Hazardous Waste Tank Failure model are used to estimate the potential for contaminant release (EPA, 1991).

The program incorporates many assumptions and evaluates the hydrogeologic setting, including confined and unconfined aquifers. The hydrogeologic characteristics in the WHPA are presumed to be relatively homogenous and isotropic (e.g., the thickness and flow rates in the unsaturated and saturated zones are constant). The theoretical basis of transport components includes Darcy's Law to describe the movement of contaminants from the source to the aquifer through the unsaturated zone. The approach provides a default value for hydraulic conductivity as a function of the type of material (assuming no variation between the saturated and unsaturated zones). Default flow velocities are based upon a unit hydraulic gradient and an average porosity of 0.3. This requires that the effect of the drawdown near the well in an unconfined aquifer be relatively small compared to the saturated thickness. Consequently, it is assumed that pumping rates do not dewater even a fine-grained aquifer (EPA, 1991).

The approach assumes that the zone of contribution is within the delineation of the WHPA and that contaminants released from each source inside the WHPA can reach the well. However, there may be contaminants that are not located inside the WHPA; these should be evaluated in also (EPA, 1991).

The physical and chemical characteristics of the potential contaminants are considered to be in aqueous solution, have the same density and viscosity as water and their concentrations do not vary with time. The transport model considers each source as a point source and assumes that concentrations do not vary in the vertical dimension. Retardation coefficients and biodegradation rates are also assumed to be constant -not affected by concentration or by mixture with other constituents. Leakage from a contamination source is presumed to influence neither the shape of the water table nor the prevailing groundwater velocity, and contamination at the wellhead is not diluted from capture of "clean water" during pumping (EPA, 1991).

Assumptions for the toxicity score of a contaminant is based on the established dose-response relationships obtained from EPA's IRIS database.

The mobility score is based on a "retardation factor". Values greater than 1,000 are categorized as low, between 10 to 1,000 as medium, and less than 10 as high. The persistence score is based on the "degradation rate". Degradation rate greater than 19 years is categorized as low, between 0.0069 to 19 years as medium, and less than 19 years as high (EPA, 1991).

The methods to define health risks posed by carcinogens and non-carcinogens are very different. Many users prefer to treat these risks separately. However, PSA allows the screening and ranking of risks together. The model equates a 10^{-5} (1 in 100,000) lifetime cancer risk with a lifetime exposure to the reference dose for non-carcinogens. Human exposure is considered only through the consumption of contaminated drinking water. Other pathways such as inhalation or dermal contact are not taken into account. The range that has been set by EPA as acceptable is between 1 in 10^{-4} (10,000) to 1 in 10^{-6} (1,000,000). To alter the assumption from 1 in 10^{-5} to 1 in 10^{-6}, add 1 to the risk score for carcinogenic contaminants computed in Task V. For assumptions of 1 in 10^{-4}, subtract 1 from the risk score for carcinogenic contaminants (EPA, 1991).

Dense non-aqueous phase liquids (DNAPLs) and light non-aqueous phase liquids (LNAPLs) are ground water contaminants that are relatively insoluble in water. DNAPLs have greater densities in water and tend to sink whereas LNAPLs have lower densities than water and therefore tend to float on water. Due to their densities and limited solubility in water, assessment concerning DNAPLs can be overestimated and LNAPLs can be underestimated (EPA, 1991).

Oklahoma Risk Based Corrective Action (ORBCA)

Oklahoma Risk-Based Corrective Action is a process of assessment adapted from Risk-Based Corrective Action (RBCA). RBCA can be used for evaluating current and future potential risks to human health and the environment due to contamination from petroleum underground storage tanks. RBCA was developed by the American Society of Testing Materials (ASTM) to assist in development about cleanup and site management to ensure that risks will be reduced to acceptable levels (ASTM, 1996).

Accordingly, to assess risk at a contaminated site, additional reports are needed. These include the nature of release and the types of contaminants that exist, the magnitudes of the releases, the extent of contamination into the ground, through the soil or ground water, from on-site or off-site. Chemical data such as the contaminant toxicity and exposure assessment through inhalation, ingestion, or direct contact are also essential (RBCA, 1996).

A conceptual site model (CSM) is a summary that covers identification of the potential sources of contamination and their location. This model is necessary to determine the three elements of risk. The first element includes the sources of risk, the specific contaminants that are present, and the environmental media in which they are contained. The second element includes the pathways considered as the likely routes of contaminant migration to a receptor. The third includes the receptors, who are likely to become exposed to the chemicals, and should be identified according to current and future land and ground water uses (ORBCA, 1996).

In ORBCA, a tiered process is used to set the cleanup levels for a site. Each tier requires source, pathway and receptor data. Tier 1, Risk-Based Screening Level (RSBL), requires the least amount of site-specific information. It instead sets generic cleanup level that may be more conservative than necessary for some sites. Tier 2 requires more information, thereby increasing site investigation costs but can lower cleanup levels. Tier 3 requires the most information and would be used for the most complex and heavily contaminated sites (RBCA, 1996). For the purpose of this study, only Tier 1 (Risk-Based Screening Levels) and Tier 2 (Site Specific Target Levels) particularly exposure pathways through ingestion of ground water will be discussed.

Site assessment data for the application of Tier 1 may contain historical records of site activities and past releases, and regional hydrogeologic and geological characteristics. Additional data required includes identification of chemicals of concern and their locations, and the position of human and the environmental receptors as points of exposure (POE). Further information is the identification of potential significant transport and exposure pathways, as well as determination of current and future land uses of the site and surrounding areas (ASTM, 1996).

ORBCA provides a Tier 1 RBSL 'Look-Up Table' for petroleum chemicals of concern as a tabulation for potential exposure pathways, media (soil, water, and air), a range of carcinogenic risk levels of 10E-4 to 10E-6, and systemic risk of one. If the COC is not available, the user is responsible for developing a Look-Up Table. The RBSLs are determined by using general, non-specific site values for exposure parameters and physical parameters for media suggested by the USEPA. For indirect pathways, fate and transport models can be used to predict RBSLs at a source that corresponds to exposure point concentrations (ASTM, 1996).

The Tier 2 process requires additional site-specific information about hydrogeologic and geologic characteristics, determination of extent of COCs relative to the RSBL or SSTL, changes of concentration over time, and measurements at POEs. The Tier 2 process involves the development of SSTLs based on the attenuation of the COCs away from the source area(s).

The ORBCA Tier 2 can be analyzed in the forward or backward mode. The forward mode results in the estimation of individual excess lifetime cancer risk and hazard quotient, where the backward mode calculates the target levels of RBSL SSTL.

Estimation of individual excess lifetime cancer risk and hazard quotient:

$$C_{\text{Tier 2}} = \frac{\underline{TR\ [THQ]}}{CR\ [CHQ]} \times C \qquad (11)$$

C_{Tier2} = Tier 2 target concentration (mg/l or mg/kg)
TR = Target or acceptable risk level (--)
THQ = Target hazard quotient (--)
CR = Site-specific risk estimated using the forward mode (--)
CHQ = Site-specific hazard quotient using the forward mode (--)
C = Concentration used to calculate risk in the forward mode (mg/l or mg/kg)

The backward mode calculates the target levels of RBSL or SSTL:

$$\text{RBSLw (SSTL)} = \frac{\underline{TR * BW * AT * 365}}{IR * ED * EF * SF} \qquad (12)$$

RBSLw = Risk-based screening level (or SSTLs) in water at POE
TR = Target or acceptable risk level (unitless)

$$\text{RBSLw (SSTL)} = \frac{\underline{THI * BW * AT * 365 * RfD}}{IR * ED * EF} \qquad (13)$$

THI = Target hazard index (unitless)

Tier results should be evaluated by comparing the target levels (RBSL or SSTL) to the concentrations of COCs at the point of compliance. If the concentration of the COCs exceed the target levels at the point of compliance, then remedial action, interim remedial action or further tier evaluation should be conducted (ASTM, 1996).

Risk-based decision making requires specific acceptable risk levels for carcinogenic and non-carcinogenic adverse health effects. For carcinogenic effects, the maximum allowable risk is considered to be 1 x 10-6. For non-carcinogenic effects, the acceptable risk level is a systemic risk of one at point of exposure.

To perform the Tier analysis, a qualitative evaluation of the site conceptual exposure model (CEM) is required. The CEM evaluates the identification of the sources of release, the sources of chemicals, the media of concern, and potential receptors. The evaluation results in the determination of exposure pathways and potential human routes of exposures.

Risk Assessment of a Public Water System in Calvin, Oklahoma

Description of the Study Area

Information of the study of the area is obtained from previous investigations conducted by ODEQ, and USGS. The town of Calvin is located in the central Hughes County, Oklahoma, approximately 30 miles from Ada.

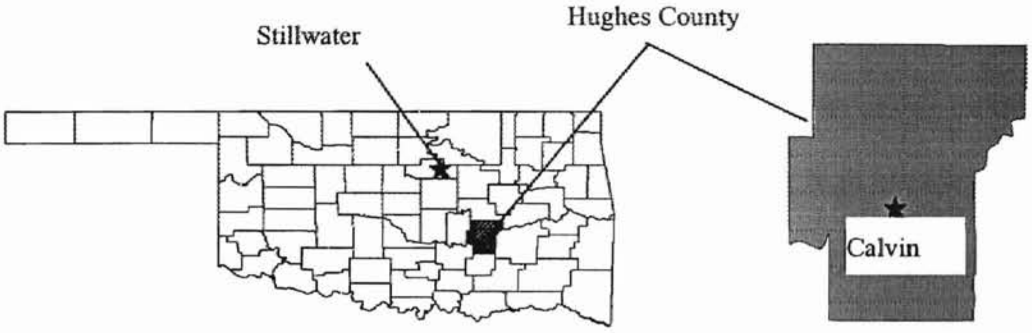

Figure 2. Calvin, Hughes County, Oklahoma

The population of the town in 1990 was approximately 251 (Tiger Files, 1990). The topography of the area is characterized by a series of northeast trending cuestas, land elevations with a gentle slope on one side and a cliff on the other (ODEQ, 1992). Resistant sandstones, siltstones, or conglomerates that are underlain by softer shales, agrillaceous siltstones, and thin limestones of Pennsylvanian age overlay these cuestas (Weaver 1954, ODEQ 1994).

Calvin has a warm, humid climate region, with long hot summers and mild, brief winters. The average annual temperature is 61 degrees F. The humidity is moderate, ranging from 60 to 70 percent with an average annual rainfall of approximately 38 inches (Weaver 1954, ODEQ 1994). These ridges or escarpments overlook broad shale valleys to the southeast and slope gently to the northwest about 1 degree. The consolidated beds are covered locally by alluvial deposit of present streams or by Quartenary terrace deposits (Weaver 1954, ODEQ 1994).

Alluvium is the last deposited material in geologic columns in the Calvin area. The alluvium consists of sand, silt, and clay on the flood plains of the present streams. The terrace deposits are gravel, sand, silt, clay and volcanic ash. The central and eastern part of the county are drained by the Canadian River and its tributaries. Little River is the most important tributary of the Canadian River drains the west-central part of the county. Both of these rivers have broad, oversized floodplains punctuated with high terrace deposits. The gradient of the Canadian River in Hughes County is approximately 3.1 feet per mile. There are three distinct stream terraces along the Canadian River in Hughes County (Weaver 1954, ODEQ 1994).

The North Canadian River, a wide alluvial flood plain, is a stream that flows in a southeastern direction through the northeast corner of the town. The stream originates in northern New Mexico and flows in a southeastern direction through Oklahoma to its confluence with the Canadian River near Eufala, Oklahoma (FEMA, 1987).

Water in the North Canadian River has a lower quality as compared to water in the adjoining alluvial and terrace aquifer. This is due to the extensive of sediments that has been eroded, transported and then deposited by the streams (Christenson & Parkhurst, 1987). Periods of low to moderate flow in the river where the head of the river is higher than the head of the aquifer can cause the surface water entering the aquifer effecting degradation of the quality. The water from this river also recharges the underlying aquifer, the Garber-Wellington, which is in hydraulic continuity with the N. Canadian alluvium and terrace where the water level is the same (Havens, 1989).

The town of Calvin consumes water from the unconfined Quartenary Terrace Deposits of the Canadian River. The water is derived from 2 wells (Well #1 and Well#2). Well #1 is found to be contaminated with bromoform, chloroform, and dichlorobromomethane, although the concentrations of each constituent are below the MCL. Well #2 has recently been shut down due to contamination of tetrachloroethylene that was reported to exceed the MCL. To support the town's need of water, Well #4 has been built to replace the closed well, yet it is still not operative. Despite of the activity of well #4, delineation of the wellhead, as well as identifying the potential sources within the area has been done. The procedure was applied as though the well was in operation to consider its potential sources of contaminants and to determine the potential threats to the well.

The Oklahoma Geologic Survey and OSDH produced hydrologic parameters for the Canadian River alluvium and terrace basins. The hydraulic conductivity was reported to be 1000 gpd/ft sq., the porosity is 0.15, the gradient is 0.003, specific yield of 0.15, and the transmissivity of 199.45 sq. ft/day for Well #1 and 289.82 sq ft/day for Well #2. The areal recharge rate is 3.3 inches per year (0.27 ft/d) (USGS, 1989).

Chemicals of Concern

Bromoform

Bromoform, is a colorless to pale yellow liquid with a sweetish odor. The chemical formula is CBR3H and the molecular weight is 252.75 g/mol. The vapor pressure is 5 mm Hg at 20 °C, an octanol/water partition coefficient (log Kow) of 2.38, slightly soluble in water and is nonflammable. The half life of this compound in ground water is 1 year (Howard et al., 1991). Bromoform is used as a fluid for mineral ore separation in geological tests, as a laboratory reagent, and in the electronics industry relating quality assurance programs. The compound was formerly used as a solvent for waxes, greases, and oils as an ingredient in fire-resistant chemicals and in fluid gauges. It has also been used as an intermediate in chemical synthesis, as a sedative, and as a cough suppression agent (ASTDR 1990, EPA OAQPS, 1998).

The Oral Reference Dose is 2E-2 mg/kg-day, with uncertainty factor of 1000, modifying factor of 1, and slope factor of 7.9 E-3 (mg/kg)/day. The uncertainty factor of 1000 resulted from employing factors of 10 each for use of subchronic assay, for extrapolation from animal data, and for protection of sensitive human subpopulation.

Bromoform is classified as a B2 carcinogenicity, which is a probable human carcinogen. The principle route of entry is considered to be from ingestion of drinking water that has been disinfected with bromine or bromine compounds. Other exposure of concern can be through inhalation (ASTDR 1990, EPA OAQPS, 1998, IRIS, 1998).

Chloroform

Chloroform with major synonyms of trichloromethane or methyl tetrachloride, is a colorless liquid with a pleasant, nonirritating odor and a slightly sweet taste. The chemical formula is CHCl3, has a molecular weight of 119.38 g/mol. The vapor pressure is 159 mm Hg at 20 °C, and has a log octanol/water partition coefficient (Log Kow) of 1.97. The boiling and melting points are 61 °C (142 °F) and –64°C (-83°F) respectively. The specific gravity is 1.48, solubility in water between 0.1 to 1%, evaporation rate of 0.09 (EPA OAQPS, 1998) and half life of 5 years (Howard et al., 1991). In the past, chloroform was used as an inhaled anesthetic during surgery, as an extraction solvent for fats, oil greases, and other products, as a dry cleaning spot remover, and as a fumigant in fire extinguishers. Now, it is used to make other chemicals such as fluorocarbon, and can also be formed in small amounts when chlorine is added to water (ASTDR 1990, EPA OAQPS, 1998). Chloroform evaporates easily into the air when it enters the environment. Most of the chloroform in air breaks down eventually in a slow process, with a final product of phosgene and hydrogen chloride, which are both toxic. Chloroform does not stick to soil very well and can travel through soil to ground water and lasts a long time. The substance dissolves easily in water, which some can break down to other chemicals (ASTDR 1990, EPA OAQPS, 1998).

The Oral Reference Dose is 2E-2 mg/kg-day, with uncertainty factor of 1000, modifying factor of 1, and slope factor of 6.1 E-3 per (mg/kg)/day. The uncertainty factor of 1000 results from employing factors of 10 each for use of a subchronic assay, for extrapolation from animal data, and for protection of sensitive human subpopulation (IRIS, 1998).

Chloroform is classified as a B2 carcinogenicity, which is a probable human carcinogen. Routes of entry are considered to be from inhalation, ingestion, skin and eye contact. Inhalation and ingestion of this substance are harmful and may be fatal.

Exposure of inhalation may cause headache, nausea, vomiting, dizziness, drowsiness, irritation of respiratory tract, and loss of consciousness. Ingestion may cause nausea, vomiting, gastrointestinal irritation and burns to mouth and throat. Contact with skin may cause irritation and leading to dermatitis if prolonged. Eye contact may result in temporary corneal damage. Chronic effects of overexposure may include kidney and/or liver damage (IRIS, 1998). The EPA drinking water limit for total trihalomethanes, a class of chemicals that includes chloroform, is 100 micrograms per liter (100 μg/L) of water (ASTDR 1990, EPA OAQPS, 1998).

Dichlorobromomethane

Dichlorobromomethane or Bromodichloromethane is a colorless liquid used as a chemical intermediate, solvent and fire extinguisher fluid ingredient (TRIFacts, 1989, EPA OAQPS, 1998). The half life of this substance in ground water is 6 months. The Oral Reference Dose is 2E-2 mg/kg-day, with uncertainty factor of 1000, modifying factor of 1, and slope factor of 6.2 E-2. The uncertainty factor of 1000 resulted from employing a factor of 100 for extrapolation from animal data and for protection of sensitive human subpopulations. An additional factor of 10 was used because the RfD was based on a LOAEL (Lowest observed adverse effect level) due to account for database deficiencies (no reproductive studies).

Dichlorobromomethane is classified as a B2 carcinogenicity, which is a probable human carcinogen with critical effects of renal cymatomegaly. Routes of entry are considered to be from inhalation, ingestion of drinking water, and dermal contact (IRIS, 1998).

Tetrachloroethylene

Tetrachloroethylene has a major synonyms as perchloroethylene (PERC or PCE), is a colorless liquid with a pleasant, nonirritating odor and a slightly sweet taste. The chemical formula is C2Cl4, has a molecular weight of 165.83 g/mol. The vapor pressure is 14 mm Hg at 20 C, and has a log octanol/water partition coefficient (Log Kow) of 3.4. The boiling and melting points are 121°C and –19°C (-83°F) respectively. The specific gravity is 1.6227, solubility in water is 150 mg/L (ASTDR 1990, EPA OAQPS, 1998, EPA OGWDW, 1998), and half life of 2 years (Howard et al., 1991).

This compound can be used as solvent for greases, waxes, rubbers, gums and caffeine from coffee. It is also used in dry cleaning industry, in degreasing metals, as an anthelmintic against hookworms (Ancylostoma and Necator), intestinal flukes (Heterophyes), nematodes and trematodes. It could also be utilized in the manufacture of trichloroacetic acid and fluorocarbons, in textile finishing, in cold cleaning of metals, as a fumigant for insects and rodents, as a drying medium in copying machines, in the manufacture of paint removers, in printing inks and removing soot from industrial boilers (ASTDR 1990, EPA OAQPS, 1998).

The Oral Reference Dose is 1E-2 mg/kg-day, with uncertainty factor of 1000, and modifying factor of 1. The uncertainty factor of 1000 results from multiplying factors of 10 account for intraspecies variability, interspecies variability and extrapolation of a subchronic effect level to its chronic equivalent (IRIS, 1998).

Trichloroethylene is classified as a B2 carcinogenicity, which is a probable human carcinogen (ASTDR, 1998). However, the carcinogenity data is not available through IRIS, database. Routes of entry are considered to be from inhalation, ingestion, skin and eye contact. Exposure to this compound can cause irritations, headaches, nausea, vomiting, liver and kidney damage, mental confusion, respiratory failure, cardiac failure, epigastric pain, and several others (ASTDR 1990, EPA OAQPS, 1998).

CHAPTER III

METHODOLOGY

The quality of groundwater in this study is emphasized on the occurrence of chemical constituents caused by natural hydrogeologic and anthropogenic sources related to types of land use.

Priority Setting Approach

A Priority Setting Approach document was used as a risk-screening tool to help assess and rank the relative threats to groundwater caused by potential contamination sources in the WHPA. The tasks are (1) determination of the location of the WHPA; (2) identification of potential sources of contaminants; (3) assessment of the release of contaminants from its sources; (4) assessment of the contaminants transport; and (5) estimation of the risks or potential threats posed by contamination.

Task I: Delineation of Wellhead Protection Area

The data and information of the study area were provided from previous research conducted by ODEQ (1994). They determined the locations of the 2 public wells (Well #1 and #2) by using the Trimble Navigational Positioning System (Basic Pathfinder Unit), which utilizes satellite technology to determine positional data. Based on the location of the wells, the characteristics and the setting of the hydrogelogy, these data were used by ODEQ as parameters for the WHPA delineation. Well #4 had not been built at the time of site investigation by ODEQ. Therefore, the location of well 4 and the potential sources of contaminants were identified using the global positioning system (Magellan GPS[1]2000) during the field visitation of this study

To delineate the WHPA for Well #4, parameters used by ODEQ were input into the WHPA-GPTRAC model. The map showing the location and delineation of all the wells were then reproduced by using GIS[2] to include well #4 (Figure 2), and input parameters used for GPTRAC are shown in Appendix 1.

The characteristics of the WHPA, including its hydrogeologic settings were then used and recorded in the Wellhead Data sheet.

Task II: Identification and characterization of potential sources of contaminants

Since potential sources of contaminants are site specific, a field visitation was necessary. Based on the boundaries defined, potential sources of contaminants were identified. To recognize the potential sources of contaminants, an inventory list was developed based on the US EPA's Guide for Conducting Contamination Source Inventories for Public Drinking Water Supply Protection Programs (1991) (Appendix 2).

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[1] GPS (Global positioning System) is a configuration of navigation satellites that orbit the earth. The Magellan GPS 2000 receives information from GPS satellites to compute a value that describes the position in the earth with an accuracy of about 25 meters (Magellan System Corporation, 1995).

[2] GIS (Geographic Information Systems) are tools that allow the processing of special data into information in the form of maps (DeMers, 1997).

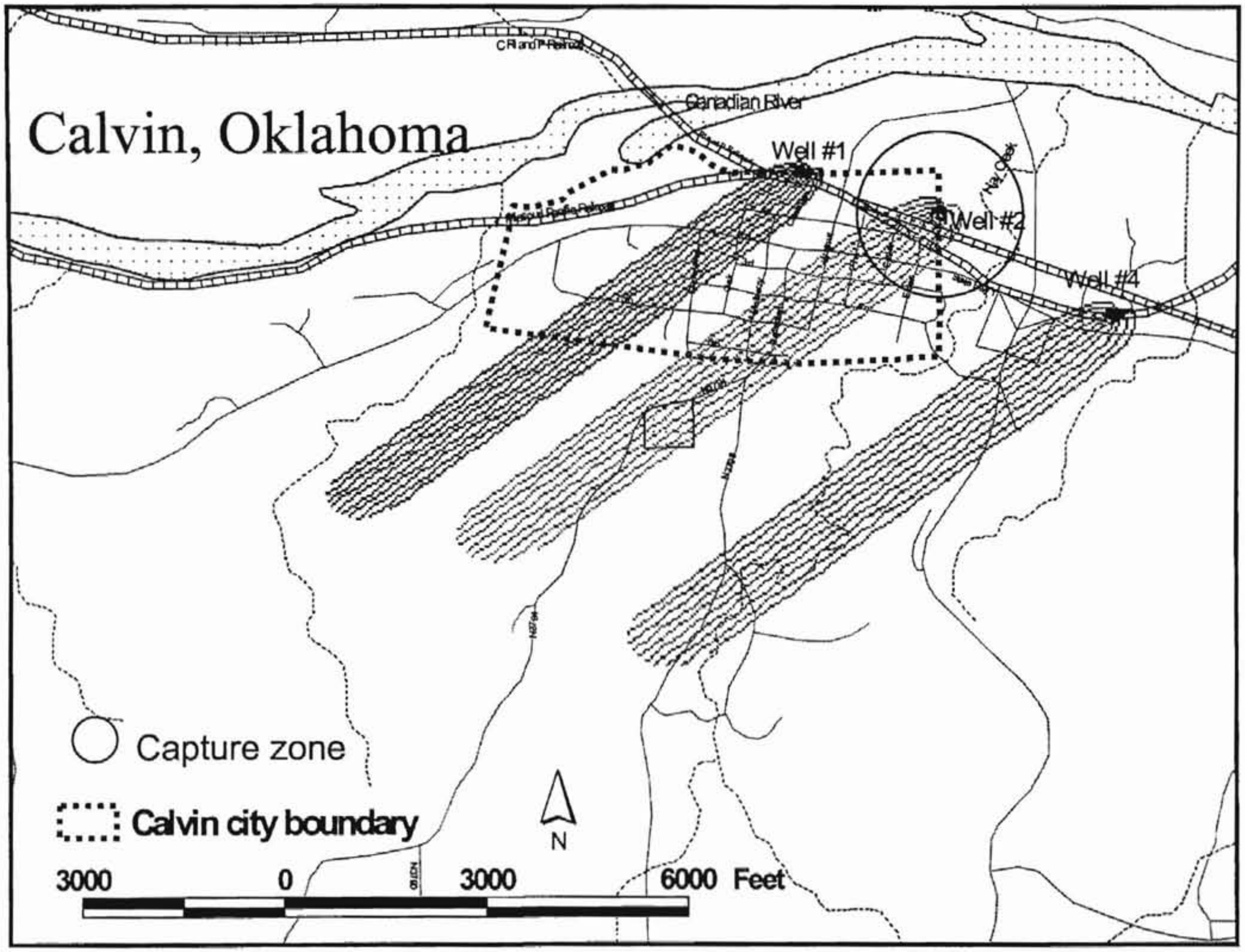

Figure 3. Delineation of Wellhead Protection Areas (10 years Time-of-Travel)

The information was then recorded on the Source Datasheet and used to analyze the chemicals' characteristics and obtain default values on their persistence, mobility, toxicity and concentration. If the concentrations of contaminants or contaminant mixtures present are known, the concentration can be derived from the Contaminant Scoring Graph. The contaminant scoring graph converts the concentration value in ppm or mg/l for other sources except agricultural. For agrichemical sources, application rate in kg/hectare-yr is used. If the concentration of the contaminants is not known, default scores are provided to obtain the characteristics, persistence, mobility, toxicity, and concentration by source category and subcategory.

Task III: Perform Source Calculations

The two source elements of risks, likelihood of release at the source (L1), and quantity released at the source (Q) were estimated. Each source has only one L1, because L1 does not depend on the contaminant or contaminant mixture at the source.

Task IV: Perform Transport Calculation

Using data from the Wellhead Datasheet, contaminant transport is assessed. Two transport-related elements of risk for each contaminant or contaminant mixture are estimated. The two elements are likelihood of reaching the well score (L2), and attenuation due to transport score (A).

Task V: Estimate Risk and Rank Source

The risk score for each contaminant or contaminant mixture at each source is computed ($R = L + S$). The risk score is the sum of the likelihood of well contamination ($L=L1 + L2$) and the severity of well contamination ($S= Q+ T+A$).

Carcinogenic or noncarcinogenic risks may be ranked together or separately, thereby producing different ranking scores for each risk. The overall risk score is then determined by selecting the maximum contaminant specific risk score obtained from each source. Based on the overall risk score, the risk level can be determined. A score of less than –4 is considered low, between –4 and 0 is medium, and greater than 0 is high.

Oklahoma Risk-Based Corrective Action (ORBCA)

The principal tasks associated with the ORBCA process include (1) the development of a site conceptual exposure model (CEM), (2) identification and collection of site-specific data, (3) development of Tier 2 Site Specific Target Levels and estimations of risk, and (4) decision making using Tier 2 results.

Step 1: Development of Site Conceptual Exposure Model

The first step is to develop the site CEM that includes the identification of the completed routes and pathways. For the purpose of this study, the only pathway considered is through ingestion of ground water.

Step 2: Identification and Collection of Additional Data as Appropriate.

The objective of this task is to collect any additional data necessary to complete the Tier 2 evaluation. The information includes preliminary planning, review of existing facility information, and a receptor survey. Preliminary planning involves the determination of receptors, exposure pathways, current and future land uses, transport mechanisms, contaminant source area(s), and the maximum degree of contamination in affected media. Review of existing facility information includes regional geology and hydrogeology that identifies the soil and bedrock types, depth to ground water, aquifer characteristics, ground water gradient, and ground water flow direction. A receptor survey is performed to establish the basis for site prioritization and determination of target cleanup levels. The site and chemical specific fate and transport parameters, as well as toxicity values, are required. If the data for certain parameters are not available, the Tier 1 default values should be used.

Step 3: Development of Tier 2 SSTLs and Estimation of Risk

The Tier 2 analysis can be conducted in the forward or backward mode. The end result of the forward mode will be the estimated individual excess lifetime cancer risk and systemic risk. The calculations for input parameters are the representative site chemical concentrations. In the backward mode, the end result is the site specific target levels (SSTLs).

Step 4: Decision Making Using Tier 2 Results

The estimated risk calculated should be compared with the target risk of 1 x 10-6 or hazard quotient of 1. If the resulting risk and/or the hazard index does not exceed these values, no further action is required and the site may be closed. If the risk exceeds the acceptable level, a Tier 3 analysis should be conducted or Tier 2 cleanup level should be developed. The procedure of Tier 2 cleanup level and Tier 3 analysis are beyond the scope of this discussion.

CHAPTER IV

RESULTS AND DISCUSSION

Priority Setting Approach

The delineation of the WHPAs was used as a boundary to conduct an inventory of the potential sources of contamination. However, as mentioned in the WHPA manual, the model should only be used as guidance. Therefore, other potential sources found nearby the delineation areas were also examined. These sources were identified and categorized (Table 1), and plotted on the map shown in Figure 4.

Table 1. List of Potential Sources of Contamination

No.	Category	Sources	Other Potential Sources
	Well 1		
1	Shallow wells	Dry cleaner	
	Well 2		
2	Agrichemical Application	Peanut crop field	Old chemical burial (15)
3	Container storage & Material Transport	Peanut Plant	Abandoned well (16)
4	Deep Injection Wells	Gas station 1	Cemetery (17)
5	Tanks	Gas station 1	Storage bin (old) (18)
6	Shallow wells	Salvage 3	
	Well 2 - (Hay Creek)		
7	Deep Injection Wells	Gas station 2 (old)	
8	Tank	Gas station 2 (old)	
9	Shallow wells	Salvage 2 (old)	
10	Shallow wells	Laundromat (old)	
11	Shallow wells	Oil well (old)	
	Well 4		
12	Shallow wells	Salvage 1	Abandoned Well (Well 3) (19)
13	Landfill	Municipal waste (old)	Horse stable (20)
14	Container Storage & Material Transfer	County Barn	

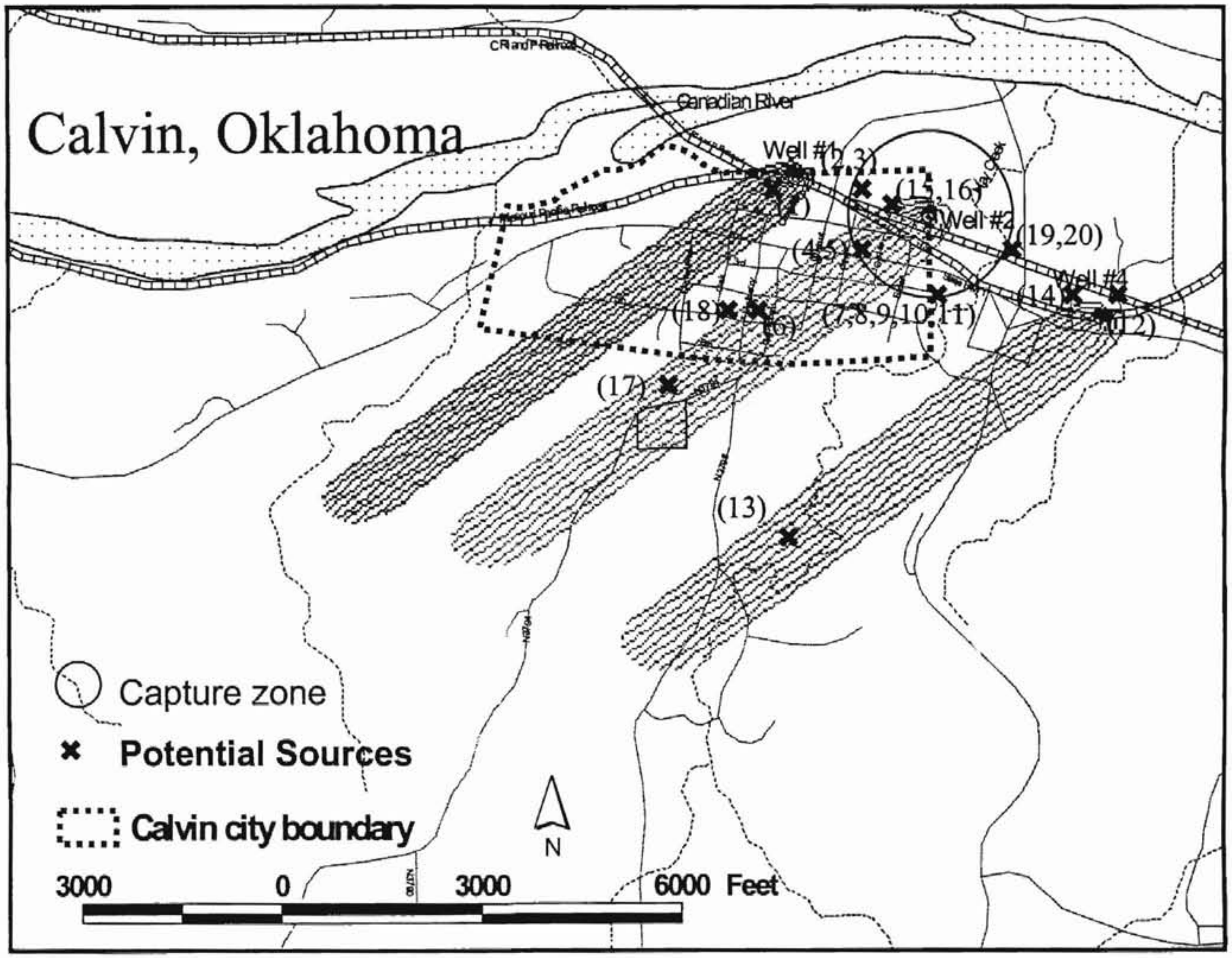

Figure 4. Map of Potential Sources of Contamination

The sources listed as other potential sources were identified as possible sources. However, these sources were not evaluated due to the incapability of assessment using the approach, and lack of data regarding abandoned wells, the contents of the storage bin, and the old chemical burial. Though the horse stable did not seem to be a confined feeding area; its location, so close to an abandoned well, required that it be considered.

The gas station 2 (old), salvage 2 (old), oil well (old), and laundromat (old) are located close to Hay Creek. They are considered to be possible sources of contaminants to Well #2 because it was assumed that the water from the creek flows near the well.

Table 2 shows the results of the risk assessment, the risk level, and a risk ranking for all wells and all sources. The results are also summarized in the Master score sheet shown in Appendix 3. Calculations and parameters that were used are included in Appendix 4.

Table 2. Result of Risk Score, Risk Level, and Risk Ranking

#	Category	Name	Possible Contaminants	C/ NC	Risk Score	Risk Level	Risk Ranking
	Well 1						
1	Shallow well	Dry cleaner	Tetrachloroethene	NC	-103	L	1
	Well 2						
2	Agrichemical Application	Peanut cropfield	Trifluralin	C			
			Other Pesticides	NC			
			Nitrate-nitrogen	NC	-3	M	4
3	Container Storage	Peanut Plant	Acetic acid	NC	1.2	H	1
			Chloroform	C			
			Carbon tetrachloride	C			
			1,1,1-trichloroethane	NC			
4	Shallow wells	Salvage1	Arsenic	C	-2.6	M	3
			Chromium	NC			
			Chromium+Barium	NC			
5	Deep Injection Wells	Oil Well	Arsenic	C	-3.4	M	6
			Benzene	C			
			Boron	NC			
6	Deep Injection Wells	Gas station 1	Arsenic	C	-0.55	M	2
			Benzene	C			
			Boron	NC			
7	Underground Storage Tanks	Gas station 1	Benzene	C	-94.6	L	7
			Xylene+Toluene	NC			
	Well 2 - Hay Creek						
8	Shallow wells	Gas station2 (old)	Arsenic	C	-3	M	4
9	Shallow wells	Salvage2 (old)	Chromium	NC			
			Chromium+Barium	NC			
10	Shallow wells	Laundromat (old)	Tetrachloroethene	NC			
11	Tanks	Gas station2 (old)	Benzene	C	-94.9	L	8
			Xylene+Toluene	NC			
	Well 4						
12	Shallow wells	Salvage3	Arsenic	C	-0.2	M	1
			Chromium	NC			
			Chromium+Barium	NC			
13	Container & Storage	County barn	Acetic acid	NC	-2.3	M	3
			Chloroform	C			
			Carbon tetrachloride	C			
			1,1,1-trichloroethane	NC			
14	Landfill	Municipal Waste	Arsenic	C	-2.2	M	2
			Chromium & cyanide	C			
			Other metals	NC			

The dry cleaner within the Well #1 delineation area seems to be the only potential source to the well, and is examined to be a low risk level. The low risk level was assigned because it has not operated since 1940. The risk calculated is an estimate due to the lack of data regarding its past activities and chemical releases. However, this source was taken into consideration because of its past activity where the chemicals released can leach into the ground water. The default list of contaminants by type of source determines that chemicals released from dry cleaners include only tetrachloroethylene (PCE), not bromoform, chloroform or dichlorobromomethane.

Bromoform, chloroform and dichlorobromomethane were also detected, but the source is unknown. Bromoform is an unusual and relatively expensive material used as a solvent for waxes, greases and oils, as an ingredient in fire-resistant chemicals and in fluid gases. It has also been used as an intermediate in chemical synthesis, as a sedative, and as a cough suppression agent. Today, the substance is used as a laboratory reagent in the electronics industry in quality assurance (EPA OAQPS, 1998). The half-life of this substance is 1 year (Howard et al., 1991), indicating that a release is not from past activities, unless bromoform is a breakdown from other constituents that were released into the ground water long ago.

Chloroform is a fairly common material that was used as an inhaled anesthetic during surgery, but now is used as an additive to make other chemicals. Its half-life in ground water is 5 years (Howard et al., 1991) causing it to accumulate in the soil and ground water. Dichlorobromomethane is used as a chemical intermediate, solvent, and fire extinguisher fluid ingredient with a half-life of 6 months.

Bromoform, chloroform, and dichlorobromomethane are considered trihalomethanes, by products of chlorine. These compounds are formed from the reaction of chlorine, a disinfection substance usually added in PWSs, with organic matter in the water, such as humus, fulvic acids, and amides (EPA, 1990).

PCE and its byproducts (trichloroethylene, dichloroethylene, vinyl chloride, and ethylene) were not found in well #1 (detection level 0.0005 mg/L). PCE with a half-life of 2 years in ground water could have been degraded, considering that the dry cleaner has not been present since 1940. The half-lives of trichloroethylene (4.5 years), dichloroethylene (4 months), vinyl chloride (8 years) and ethylene (56 days), could also be found below the detection limit. Therefore, the low risk score obtained for this source can be assumed to be acceptable.

There are eight possible sources found within and around the Well #2 delineation area, including sources that are close to the Hay Creek. Of these sources, two are classified as low risk level, five as medium risk level, and one as high risk level. The low risk level are associated with sources of contaminants from the old and active gas station tanks (risk scores of -94.9 and -94.6, respectively). Low risk is probably due to the design or the construction of the tanks, underground with concrete. Moreover, the old gas station no longer exists and thus, there is no activity. As for the active gas station, there is only one underground tank, and the size is relatively small (<5,000 gallons). The medium sources are from peanut crop field (risk score = -3), salvage 1 (risk score = -2.6), old oil well (risk score = -3.4), gas station deep injection wells (risk score = -0.55) and shallow wells from a combined old Laundromat, old salvage 2, and old gas station (risk score = -3).

For shallow wells from the old oil well, old Laundromat, old salvage 2 and gas station 2 (old), the reason for medium risk could be because it is located approximately 1,500-2,000 feet from the well, although these activities no longer exist. For gas station and salvage, the distance is about 1,200 feet or less, therefore giving it a higher score. The chemical of concern, that is likely to be released from these sources, is arsenic - a carcinogenic substance that produces the overall risk score. This constituent is not detected in well #2 today. If in the future a leakage plume reaches the ground water, there is a possibility that it can get into Well #2.

The peanut plant and crop field are approximately 800-1000 ft from Well #2, but is not found within the delineation of WHPA. Because the Priority Setting Approach takes distance into consideration and does not consider shape, it can not differentiate the risk posed by sources that are found within or outside the delineation of the WHPAs. The peanut crop field has a medium risk level (risk score = -3) for release of nitrate-nitrogen. The high risk level is from the peanut plant (risk score = -1.2), the highest score of all the sources from the possible release of chloroform. This high risk level is probably due to the location of the facility and the design of the storage area (unpadded). However, chloroform is not found in Well 2; therefore, further study of the chemicals released from the plant is needed. Table 3 shows the risk ranking for potential sources for Well 2.

Table 3. Risk Rank of Sources in Well #2

No.	Source	Risk Rank
2	Peanut crop field	4
3	Peanut plant	1
4	Gas station (wells)	2
5	Gas station (tanks)	7
6	Salvage 3	3
7	Gas station 2 (well)	4
8	Gas station 2 (tank)	8
9	Salvage 2	4
10	Laundromat	4
11	Oil well	6

Many sources can contribute contaminants to the well although most of the activities in the area are no longer in existence. These sources were considered because chemicals may have been released in the past with enough time to reach the well and the mobility of some of the chemicals are high. Other potential sources that can not be assessed with this approach could also contribute pollution to the well, such as the tributary of Hay creek that is also not found anymore.

Another important aspect to take into consideration is the radius of influence of the well. The zone of influence or radius of influence (R) of the well can be obtained from the default value calculated by WHPA, by calculating R as the square root of ($Q/\pi/N$). Q is the discharge (16365 ft3/d), and N is the areal recharge rate (0.00075 ft/d); therefore, R is 2636 ft. Within the radius of influence of well 2, the peanut plant, peanut crop field and old Laundromat, old gas station, old oil well and old salvage yard have the potential to contribute to the well. However, to justify its inclusion, more studies are needed and more sophisticated ground water modeling is required.

Within the Well #4 delineation area, all of the sources considered as possible contaminants pose medium risk. These sources are the old salvage 1 (risk score = -0.2), country barn (risk score =-2.3), and old municipal waste (risk score = -2.2). The salvage 3 no longer exists, and the county barn, is located close to the well. The municipal waste is located between 3,000 to 4,000 feet and is no longer present. Although the distance is relatively far, this is considered to be a medium risk. The risk posed was probably caused by the time of travel allowing the contaminants to reach the well. Other factors considered are the unpadded area (prior to 1976), and that a tributary to the Hay Creek that was once found on the landfill site. The risk ranking for the delineation area is shown in Table 4.

Table 4. Risk Ranking of Sources in Well #4

No	Sources	Risk Rank
1	Salvage 1	1
2	Municipal Waste	2
3	County Barn (storage)	3

The possible contaminant and mixtures released from these potential sources were obtained as default constituents provided in the approach based on the category of the sources and are only approximate. The concentration and toxicity determined were based on 95th percentile scenario of critical concentration (or action level in RBCA). The approximation of default chemicals, concentration, and toxicity causes many uncertainties in the result. Other factors that affect the uncertainties are because of the incomplete information and data (especially the release of chemicals), identification of locations using GPS, application of the delineation program, and selection of the module for delineation. The lack of information and data not provided or available makes it difficult to minimize the uncertainties. Identifying these locations by using GPS could also be a source of uncertainties, although points of each location were taken twice and the average value was used to determine the positions by approximately 25 meters. When integrated into GIS, these approximate locations are shown as a point. Some of these sources are not identified exactly at the point due to difficulties and obstacles in reading their positions. Some other sources are not in the form of one point but an area, which was also difficult in determining their boundaries. These difficulties and obstacles contribute to the uncertainties. Other uncertainties that should also be considered are caused by the parameters and the selected module used for the delineation program where ground water movement is a complex phenomenon. The WHPA model delineates an area based on time of travel and does not consider dispersion. To minimize the uncertainties from delineation, dispersion should also be considered. This is shown by the delineation of Well #2, where potential sources that are not located within the WHPA poses the medium and high risk to the well, and contributes to the pollution of the well. In fact, based on the observation, the sources that release tetrachloroethylene to the well are not known and can not be determined.

Oklahoma Risk-Based Corrective Action (ORBCA)

The results of assessment of risk and hazard quotient of these constituents are shown in Table 5, and calculations are presented in Appendix 5. The risk to adults from drinking the water from Well #1 is still within the acceptable risk range recommended by EPA: 10E-4 to 10E-6. The concentrations of bromoform, chloroform, dichlorobromomethane at point of exposure are lower than the SSTL (site specific target level) concentration. Thus, according to RBCA, remediation is not required.

The evaluation of systemic risk caused by tetrachloroethylene is 0.46, which is less than the limit set by EPA (1.0). Although the concentration of the substance (0.1623mg/L) is found to be above the MCL level (0.005mg/L), remediation is not required because the site specific target level is 0.35 mg/L. Even if this concentration was found to be higher than the SSTL level requiring a remedial action, remediation would be complicated by the fact that the source of this contamination is not known.

Table 5. Risk and Hazard Quotient

Chemicals	Oral RfD (mg/kg-d)	SF (mg/kg-d)$^{-1}$	Concentration in water (mg/L)	Intake (mg/kg-d)	Risk or HQ	SSTL	MCL (mg/L)
Bromoform	2.00E-2	6.20E-2	0.0006	7.34E-05	4.55E-06	0.0131	0.005
Chloroform	2.00E-2	6.10E-2	0.0017	2.08E-05	1.27E-06	0.0133	0.005
Dichlorobromomethane	2.00E-2	7.90E-2	0.0024	2.90E-05	2.29E-06	0.0103	0.005
Tetrachloroethylene *	1.00E-2	-	0.1623	4.64E-03	0.4637	0.3500	0.005

* = noncarcinogen

To determine the concentration of a solute at the well down gradient from the source, the solute transport equation was used, based on parameters such as advection and attenuation, which includes dispersion, retardation and biodegradation. To obtain the values needed, a combination of Darcy's equation, advection and dispersion were used. These values were then used as an input to the ECOPLUS model (Hounslow and Goff, 1995) to simplify the process (calculations and parameters used are included in Appendix 6). The model computes the concentration from one point of source to a receptor without considering the geologic matrix of the plume released. Various loading rates and distances were plotted to see the differences of concentrations produced at the well. Figure 4 and 5 shows the estimated concentration and distance that would produce the observed concentration with and without biodegradation.

The result shows that with an estimated chemical loading of 0.2 lb/d, 0.15 lb/d, 0.1 lb/d, and 0.05 lb/d for the past 20 years, will produce the concentration of PCE at the well today from any distance between 1000 to 5000 feet if biodegradation is not taken into consideration (Figure 5). If biodegradation of these chemicals is taken into consideration, the concentration of PCE produced at the well (0.16 mg/L) released for the past 20 years with a loading concentration of 0.2 lb/d, 0.15 lb/d, 0.1 lb/d, and 0.05 lb/d could have been released from distances between 1000 feet and 3500 feet (Figure 6).

Nonetheless, the by-products of tetrachloroethylene were not found at the well or at the point of exposure, or the concentration is less than the detection level. The half lives of these constituents are two years, four and one half years, four months, eight years, and 56 days, respectively. The longest biodegradation rate belongs to vinyl chloride (eight years) and the concentration of this substance was not detected in the well. Since these byproducts are not detected, it is likely that the PCE found in the well is not caused by past activities but from recent activity from a source that is not known.

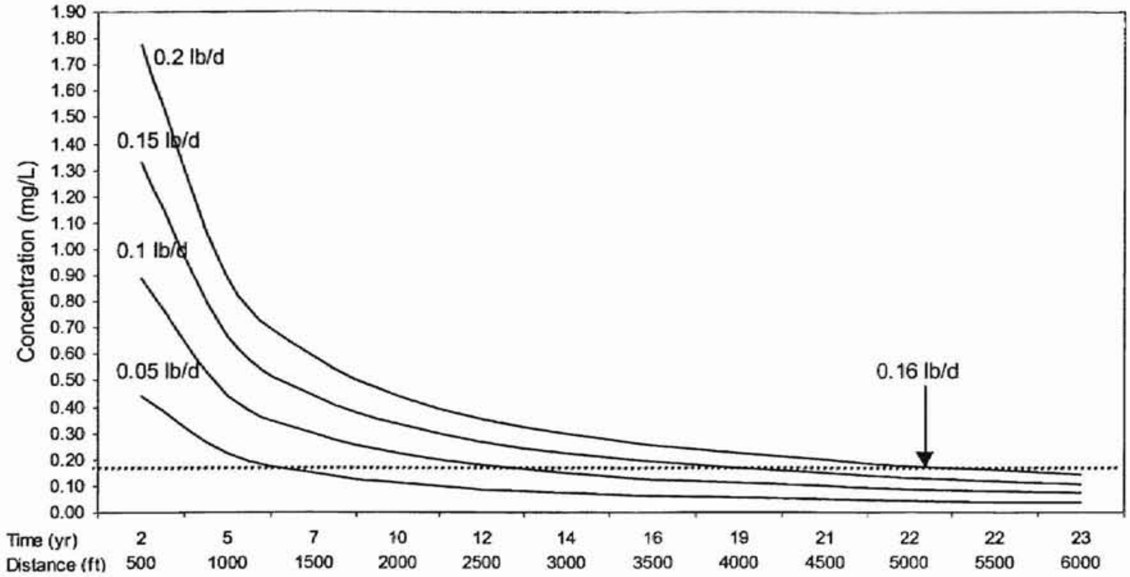

Figure 5. Maximum Concentration at Well (without biodegradation)

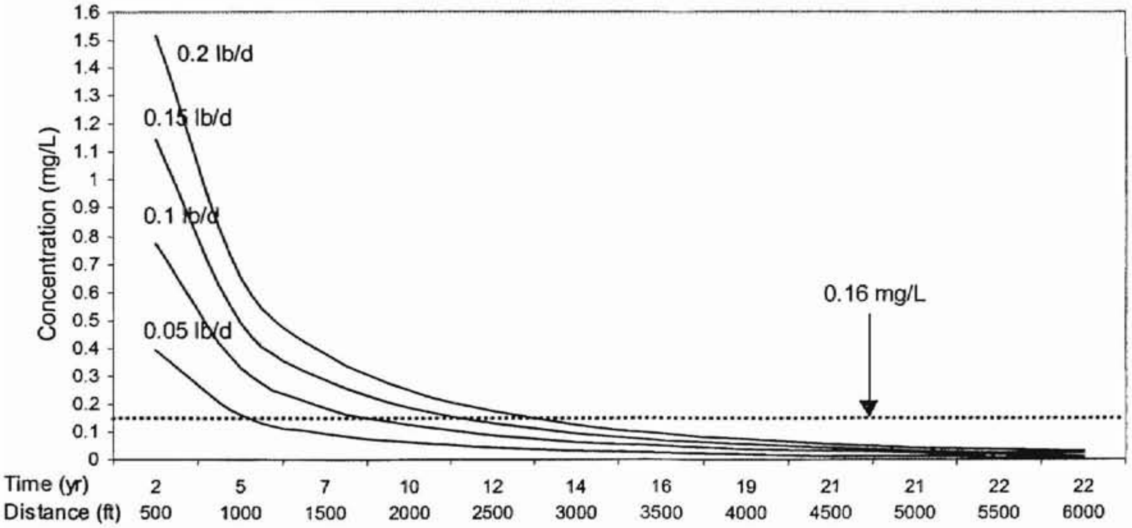

Figure 6. Maximum Concentration at Well (with biodegradation)

Tetrachloroethylene experiences slow biodegradation under anaerobic conditions once the microorganisms have become acclimated (EPA OGWDW, 1998). The breakdown of this contaminant will result in ethylene as its final product (Figure 7).

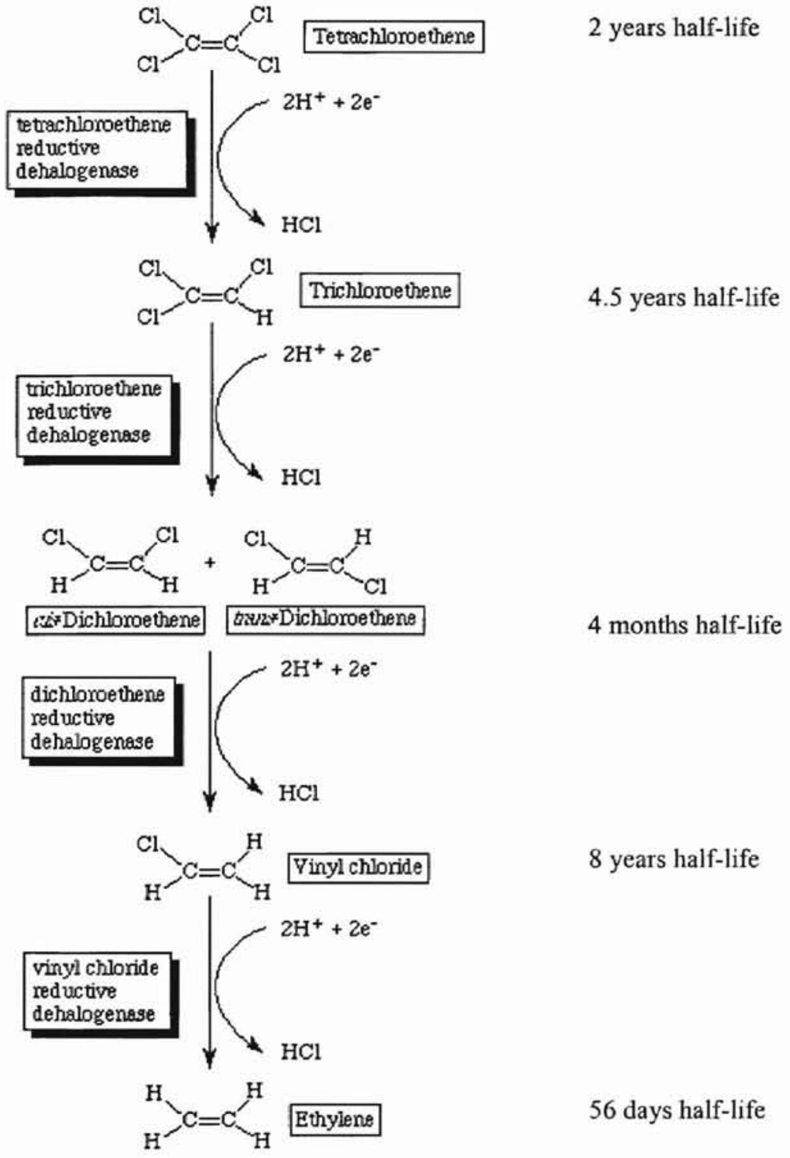

Figure 7. Anaerobic Tetrachloroethene Graphic Pathway Map (Ellis, 1998)

The potential source identified within the WHPA delineation of well 2 with higher risk level is the salvage yard. Tetrachloroethylene could have been used extensively as a cleaning or degreasing reagent for metals (EPA OGWDW, 1998) in the past. However, the Priority Setting Approach does not indicate PCE as one of the chemicals released from a salvage yard and the chemical is known to be used mostly for dry cleaning purposes. Therefore, the use of this substance or management of its release should be taken into consideration in the future.

The comparison of the two methods shows that the SSTL concentration of tetrachloroehtylene in the ORBCA process is the same as the critical concentration in the Priority Setting Approach (0.35 mg/L). The calculation of the tetrachloroethylene site specific target level concentration in RBCA and critical concentration in the priority setting approach are both based on HQ* RfD*BW*AT/IR*EF*ED. Therefore, the Priority Setting Approach could be considered to be sufficient. However, there are other parameters used in PSA that needs to be evaluated as well. This could be done when more information and data are available, such as a definite release is known from a particular source.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The risk screening process was developed for a pollution prevention program and is restricted to an estimation or prediction of a risk posed by possible sources of contamination. The procedure is not technically demanding making it easy for local managers to conduct an assessment without prior extensive training; and it is not costly. Accordingly, this procedure is adequate for the WHP program, especially where the estimated risk levels can be used to educate and involve the community and to promote implementation of BMPs. However, the procedure is not adequate to do a cumulative and comprehensive risk assessment due to the many uncertainties. On the other hand, RBCA is a method to be used for a cleanup of contaminated sites. The assessment results serve to establish cleanup target levels based on adverse impacts to human health. Although uncertainties occur in most risk assessments, the uncertainties in ORBCA is minimized as compared to PSA. Nonetheless, application of ORBCA in the WHPA is difficult, where most of the sources of the contaminants released are not known. Moreover, the procedure is relatively technical and costly, requiring risk professionals to perform the assessments, making it difficult to be used in a pollution prevention program.

The risks and adverse health effect caused by the contaminants are 4.55E-6 (bromoform), 1.276E-6 (chloroform), 2.29E-6 (dichlorobromomethane), and HQ = 0.46

(tetrachloroethylene). These risks are within the acceptable risk range set by EPA; 10E-4 to 10E-6 for carcinogens, and Hazard Quotient = 1 for systemic toxicants.

The site specific target level (SSTL) concentration of tetrachloroethylene calculated in ORBCA is the same as the critical concentration used in the PSA. This is because PSA uses the same 95th percentile scenario to estimate its level of chemical concentration or action level, therefore could be used in the wellhead protection areas. However, more parameters should be compared to justify use of the procedure. This can be done when more information and data are available, such as a particular release from a source.

Recommendations for Future Studies

Recommendations for future studies include: (1) evaluation of the cone of depression caused by pumping rate of a well and the geologic matrix of plume released and (2) use of a more sophisticated ground water modeling program to determine the movement of the plume. If the WHPA ground water model is to be used, the well radius of influence should also be considered to minimize the uncertainties in assessing risk.

Additional studies such as (1) inventory of releases of the chemicals, (2) the determination of the source of contaminants, (3) the amount of release, and (4) the treatment or disposal system of the chemicals used, are necessary. With such available information, local managers will be able to take further action to implement best management practices.

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APPENDICES

Appendix 1. Input Parameters for WHPA Delineation

The input parameters used for the WHPA ground water model flow, GPTRAC, semi analytical option are listed below. The parameters for well 1 and 2 are obtained from ODEQ, for well 4 are from the water superintendent in the town of Calvin Oklahoma.

Units for current problem		:	1	(feet and days)
Aquifer type selection		:	2	Unconfined
Perform hydraulic head calculation		:	0	No
STUDY AREA BOUNDARIES AND STEP LENGTH				
Minimum x-coordinate		:	0	(ft)
Maximum x-coordinate		:	15000.0	(ft)
Minimum y-coordinate		:	0	(ft)
Maximum y-coordinate		:	15000.0	(ft)
Maximum spatial step length		:	250	(ft)
NUMBER OF PUPING WELLS & AQUIFER PARAMETERS				
Number of pumping wells in the study area		:	3	
(Recharge wells are not permitted for unconfined aquifer case)		:		
		:		
Transmissivity		:	3208	(ft2/d)
Saturated thickness prior to pumping		:	24	(ft)
Aquifer porosity		:	0.15	(dimensionless)
Hydraulic gradient		:	0.003	(dimensionless)
Angel of ambient flow		:	45	(degrees)
Areal recharge rate		:	0.000750	(ft/d)
TIME AND BOUNDARY PARAMETERS				
Time limit for simulation		:	3650	Days
Time value for capture zones		:	3650	Days
Input boundary condition type		:	1	One stream boundary
Input boundary location		:	4	Right
PUMPING WELL PARAMETERS				
Pumping well #1, #2, #3				
x-coordinate	1	:	7800	(ft)
	2	:	10500	(ft)
	3	:	13700	(ft)
y-coordinate	1	:	12400	(ft)
	2	:	11500	(ft)
	3	:	9750	(ft)
Discharge	1	:	12514	(ft3/d)
	2	:	16365	(ft3/d)
	3	:	16000	(ft3/d)
Well radius	1	:	0.4	(ft)
	2	:	0.4	(ft)
	3	:	0.4	(ft)
Radius of influence of the well	1	:	2304.6	(ft)
	2	:	2635	(ft)
	3	:	2605.9	(ft)
Delineate capture zone for wells		:	Yes	
Number of path lines desired		:	10	
COORDINATES OF STARTING PARTICLE LOCATIONS				
Number of forward pathlines		:	0	
Number of reverese pathlines		:	0	

Appendix 2. Inventory List Form

INVENTORY LIST OF POTENTIAL CONTAMINATION SOURCES

Location : ______________________________
Public Well # : ______________________________

Nature of Property:

- ☐ Residential
- ☐ Agricultural
- ☐ Commercial
- ☐ Industrial
- ☐ City/ State Government Site
- ☐ Others

Potential Sources

- ☐ Abandoned water well
  - ○ Plugged
  - ○ Not plugged
  - ○ How ______________
  - ○ How many? ______________
- ☐ Above ground storage tank
  - ○ Content
  - ○ Size
  - ○ Describe
- ☐ Airport
- ☐ Animal Feedlot
- ☐ Artificial recharge
- ☐ Auto Salvage yard
- ☐ Cemetery
- ☐ Cesspool
- ☐ Chemical Storage Facility
  - ○ Chemical use (lawn or garden)
  - ○ Fertilizers/Pesticide Application
  - ○ Pesticide
- ☐ Drainage well/canal
- ☐ Dump
- ☐ Fertilizer/pesticide application
- ☐ Golf course
- ☐ Grain Storage Bin
- ☐ Highway
- ☐ Holding Pond/Lagoon
- ☐ Injection well
- ☐ Landfill
- ☐ Mine
- ☐ Municipal sewage line
- ☐ Oil/Gas well
- ☐ Quarry
- ☐ Railroad
- ☐ Septic tank
  - ○ Drain field size ______________
  - ○ Drain field location ______________
  - ○ Depth ______________
  - ○ Last pumped ______________
- ☐ Service station disposal well
- ☐ Sewage plant sludge disposal
- ☐ Stream (lake, river, creek)
- ☐ Underground storage tank
  - ○ Size ______________
  - ○ Contents ______________
- ☐ Water well
- ☐ Other
  - ○ Livestock
  - ○ Heating/fuel oil storage
  - ○ Floor drains that do not connect to the city sewer system

Remarks: ______________________________
____
____

AGRICULTURAL/RESIDENTIAL

Total acreage : ____________________

Type of agricultural practice:

☐ Crops

○ Type : ____________________
○ Acreage : ____________________

Chemical application
○ Yes
○ No

Describe chemicals used (# of years, volume - kg/hectare/yr).

Describe storage procedure.

Describe chemical mixing practices.

Describe irrigation and chemigation practices.

Describe container disposal.

☐ Livestock

○ Type ____________________
○ How many ____________________

☐ Feedlot

Describe age and design.

Describe any manure storage on property and how.

Appendix 3. Master Scoresheet

Block I			Block II							Block III					
TASK II				TASK III			TASK IV			TASK V					
Identify Sources				Source Elements			Transport Elements			Estimates Risks and Rank Sources					
#	Category	Name	Contaminant/ Mixture	C/ NC	L1	Q	T	L2	A	L	S	R	Overall Risk	Risk Level	Risk Rank
	Well 1														
1	Shallow well	Dry cleaner	Tetrachloroethene	NC	0	3.1	0.5	-103	-3.6	-103	0.0	-103.0	-103	L	1
	Well 2														
2	Agrichemical Application	Peanut cropfield	Trifluralin	C	0	-0.2	1.3	-200	-132	-200	-131.1	-331.1			
			Other Pesticides	NC	0	0.5	-0.2	-1.2	-11.5	-1.2	-11.2	-12.4			
			Nitrate-nitrogen	NC	0	0.2	-1.5	0	-1.7	0	-3.0	-3.0	-3	M	4
3	Container Storage	Peanut Plant	Acetic acid	NC	-0.2	2.6	-1.5	0	-48.2	-0.2	-47.1	-47.3			
			Chloroform	C	-0.2	2.2	1.2	0	-2	-0.2	1.4	1.2	*1.2*	H	1*
			Carbon tetrachloride	C	-0.2	2.2	2.5	-1.2	-201	-1.4	-196.3	-197.7			
			1,1,1-trichloroethane	NC	-0.2	2.5	-0.2	-1.2	-11.5	-1.4	-9.2	-10.6			
4	Shallow wells	Salvage3	Arsenic	C	0	-1.4	3.7	-3	-1.9	-3	0.4	-2.6	*-2.6*	M	3*
			Chromium	NC	0	-0.8	0.7	-3	-1.9	-3	-2.0	-5.0			
			Chrom.+Barium	NC	0	1.1	1.3	-103	-1.7	-103	0.7	-102.3			
5	Deep Injection Wells	Oil Well	Arsenic	C	-2.4	-2.7	3.7	-0.3	-1.7	-2.7	-0.7	-3.4	*-3.4*	M	6*
			Benzene	C	-2.4	-1.3	2	-103	-201	-105	-200.3	-305.7			
			Boron	NC	-2.4	0	-0.5	-103	-0.6	-105	-1.1	-106.5			
6		Gas station	Arsenic	C	-1.15	-1.5	3.7	0	-1.6	-1.15	0.6	-0.6	*-0.6*	M	2*
			Benzene	C	0	-0.1	2	-100	-201	-100	-199.1	-299.4			
			Boron	NC	0	1.2	-0.5	-100	-0.1	-100	0.6	-99.7			
7	Underground Storage Tanks	Gas station	Benzene	C	0	1.3	2	-100	-201	-100	-197.7	-298.0			
			Xylene+Toluene	NC	0	-0.2	-0.4	0	-94	0	-94.6	-94.6	-94.6	L	7
	Well 2 - Hay Creek														
8	Shallow wells	Gas station (old)	Arsenic	C	0	-2	3.7	-3	-1.7	-3	0.0	-3.0	-3	M	4*
9		Salvage2 (old)	Chromium	NC	0	-1.4	0.7	-3	-1.7	-3	-2.4	-5.4			
10		Laundry mat (old)	Chrom.+Barium	NC	0	0.5	1.3	-103	-0.6	-103	1.2	-101.8			
			tetrachloroethene	NC	0	0.5	1.3	-103	-0.6	-103	1.2	-101.8			
11	Tanks	Gas station (old)	Benzene	C	0	1.3	2	-103	-201	-103	-197.7	-300.7			
			Xylene+Toluene	NC	0	-0.2	-0.4	-0.3	-94	-0.3	-94.6	-94.9	-94.9	L	8
	Well 4														
12	Shallow wells	Salvage1	Arsenic	C	0	-2	3.7	-0.3	-1.6	-0.3	0.1	-0.2	*-0.2*	M	1*
			Chromium	NC	0	-1.4	0.7	-0.3	-1.6	-0.3	-2.3	-2.6			
			Chrom.+Barium	NC	0	0.5	1.3	-3.3	-0.1	-3.3	1.7	-1.6			
13	Container & Storage	Country barn	Acetic acid	NC	-2.8	1.7	-1.5	0	-48.2	-2.8	-48.0	-50.8			
			Chloroform	C	-2.8	1.3	1.2	0	-2	-2.8	0.5	-2.3	-2.3	M	3*
			Carbon tetrachloride	C	-2.8	1.3	2.5	-1.2	-201	-4	-197.2	-201.2			
			1,1,1-trichloroethane	NC	-2.8	1.6	-0.2	-1.2	-11.5	-4	-10.1	-14.1			
14	Landfill	Municipal Waste	Arsenic	C	-0.2	-0.8	3.7	-3	-1.9	-3.2	1.0	-2.2	-2.2	M	2*
			Chromium & Cyanide	C	-0.2	-3.4	0.8	-3	-1.9	-3.2	-4.5	-7.7			
			Other metals	NC	-0.2	1.6	1.4	-103	-1.7	-103	1.3	-101.9			

* = carcinogenic chemicals

Appendix 4. Priority Setting Approach Calculations

Category	No.	Source	Well
Shallow wells	(1)	Dry Cleaner	1
	(4)	Salvage 3	2
	(9,10)	Salvage 2 and Laundromat	2
	(12)	Salvage 1	4
Deep wells	(5)	Oil well (old)	2
	(6)	Gas station 1 (active)	2
	(8)	Gas station 2 (old)	2
Tanks	(7)	Gas station 1 (active)	2
	(11)	Gas station 2 (old)	2
Agrichemical application	(2)	Peanut crop field	2
Storage	(3)	Peanut plant	2
	(13)	Country barn	4
Landfill	(14)	Municipal waste	4

WELLHEAD DATASHEET

Parameter		
WD1 Planning Period	Enter the number of years of which you are concerned with the possibility of contamination	10
WD2 Depth to aquifer score	Concert the depth to the aquifer in the WHPA into a Depth to Aquifer score Depth to aquifer: 19'10" - 23'6" Depth to aquifer Score = 1.0 (Table W1)	1
WD3 Aquifer Thickness score	Convert the thickness of the aquifer in the WHPA into an Aquifer thickness score. Aquifer thickness: 20'-50' = 30'-40'=1	1
WD4 Net infiltration	Annual net infiltration in inches for the WHPA (Figure 1)	10
WD5 Unsaturated zone Hydraulic score	Determine the unsaturated zone conductivity score (Table W2 - cm/s) Hydrauluc conductivity = 1000 unsaturatedzone material = sand	3
WD6 Saturated zone material	[Silt/sand/gravel/Karst] Terrace deposits= sand, gravel, silt	sand
WD7 Ground water velocity score	Determine the ground water velocity score if the ground water velocity is known (Table W4). If the ground water velocity is not known, determine the ground water scoree as a function of the type of material in the saturated zone (Table W5) For 'sand material', score depends on the pumping rate at the wellhead. Pumping rate Well #1= 65 gpm = 65 g/m * 24hr/1d * 60 m/1hr = 93600 g/d Pumping rate Well #2= 85 gpm = 85 g/m * 24hr/1d * 60 m/1hr = 122400 g/d Pump rate is < 45 million gpd, therefore, ground water velocity score is 3 (3.3 101 to 3.3 103 ft/yr)	3

SOURCE DATASHEET - Shallow Wells

Parameters		(1)	(4)	(9,10)	(12)
SD1 Well Age (years)		0	0	0	0
SD2 Throughput rate	Determine the amount of liquid injected or drained into well anually (million gallons per year) Default volume score: L=0.6 million gallons/year	2.6 (mg/y)	0 (mg/y)	0.1 (mg/y)	0.1 (mg/y
SD3 Distance score	Determine the Distance score as a function of the shortest distance to from the area of injection well to the well (or to an abandoned well if one exists between the injection well and the well (Use Table) (635-1320 ft)	1	4	3	2
SD4 Source discharge	Does the source discharge directly to a conduit system that could tranport contaminants directly to a well	no	no	no	no

SD5 Contaminant data

No.	Source	Contaminants (Mixture)	**Toxicity Score**	Concentration Score	Mobility Score	Persistence score	Cancer/ Noncancer
1	(1)	Tetrachloroethe	**0.5**	-1.3	M	M	NC
2	(4)	Arsenic	**3.7**	-4.0	H	H	C
3	(4)	Chromium	**0.7**	-3.4	H	H	NC
4	(4)	Chrom.+Barium	**1.3**	-1.5	M	H	NC
5	(9)	Arsenic	**3.7**	-4.0	H	H	C
6	(9)	Chromium	**0.7**	-3.4	H	H	NC
7	(9)	Chrom.+Barium	**1.3**	-1.5	M	H	NC
8	(10)	Tetrachloroethe	**0.5**	-1.3	M	M	NC
9	(12)	Arsenic	**3.7**	-4.0	H	H	C
10	(12)	Chromium	**0.7**	-3.4	H	H	NC
11	(12)	Chrom.+Barium	**1.3**	-1.5	M	H	NC

SOURCE WORKSHEET - Shallow Wells

Step			(1)	(4)	(9,10)	(12)
1	Likelihood of Release **(L1)**	Determined the likelihood of release score. L1=0 for all shallow wells	**0**	**0**	**0**	**0**
2	Volume score	Determine the Volume score (Graph) as a function of the Throughput rate (SD2) -- default value provided	4.4	3	2	2
3	Quantity (Q)	Compute the Quantity score for each contaminant Q = Concentration score (SD5) + Area score (Step2)				

	Source	Contaminant (Mixture)	Concentration Score	Volume Score	**Quantity (Q)**
1	(1)	Tetrachloroethene	-1.3	4.4	**3.1**
2	(4)	Arsenic	-4.0	2.6	**-1.4**
3	(4)	Chromium	-3.4	2.6	**-0.8**
4	(4)	Chrom.+Barium	-1.5	2.6	**1.1**
5	(9)	Arsenic	-4.0	2.0	**-2.0**
6	(9)	Chromium	-3.4	2.0	**-1.4**
7	(9)	Chrom.+Barium	-1.5	2.0	**0.5**
8	(10)	Tetrachloroethene	-1.3	2.0	**0.7**
9	(12)	Arsenic	-4.0	2.0	**-2.0**
10	(12)	Chromium	-3.4	2.0	**-1.4**
11	(12)	Chrom.+Barium	-3.4	2.0	**-1.4**

TRANSPORT WORKSHEET - Shallow Wells: salvage1

Step			(1)	(6)	(9,10)	(12)
1	Time Frame	Compute Time Frame (years) TF = Age of source (SD) + Planning Period (WD1)	10	10	10	10

2 Hydraulic Conductivity

Determine the Hydraulic Conductivity and Velocity Adjusted score (use Table)
Hydraulic conductivity score as a function of:
contaminant mobility (SD) and unsaturated zone hydraulic conductivity score (WD5)
Velocity score as a function of
contaminant mobility (SD) and groundwater velocity score (WD7)

	Source	Contaminant (Mixture)	Unsat. HC	Hydraulic Conductivity	CM	GW velocity	Velocity score
1	(1)	Tetrachloroethene	3	2	M	3	2
2	(4)	Arsenic	3	3	H	3	3
3	(4)	Chromium	3	3	H	3	3
4	(4)	Chrom.+Barium	3	2	M	3	2
5	(9)	Arsenic	3	3	H	3	3
6	(9)	Chromium	3	3	H	3	3
7	(9)	Chrom.+Barium	3	2	M	3	2
8	(10)	Tetrachloroethene	3	2	M	3	2
9	(12)	Arsenic	3	3	H	3	3
10	(12)	Chromium	3	3	H	3	3
11	(12)	Chrom.+Barium	3	2	M	3	2

3 Unsaturated and saturated zone TOT category

Determine the Unsaturated zone Time of Travel category (use Table)
Unsat TOT = function of Depth to Aquifer score (WD2) and the adjusted Hydraulic Conductivity score (step 2)
Sat TOT = function of Disctance score (SD) and adjusted velocity score (step 2)

	Source	Contaminant (Mixture)	WD2	Unsaturated TOT	HCS	Saturated TOT	DS	VS
1	(1)	Tetrachloroethene	1	C	2	D	1	2
2	(4)	Arsenic	1	A	3	C	4	3
3	(4)	Chromium	1	A	3	C	4	3
4	(4)	Chrom.+Barium	1	A	2	C	4	2
5	(9)	Arsenic	1	A	3	C	3	3
6	(9)	Chromium	1	A	3	C	3	3
7	(9)	Chrom.+Barium	1	C	2	E	3	2
8	(10)	Tetrachloroethene	1	C	2	E	3	2
9	(12)	Arsenic	1	A	3	B	2	3
10	(12)	Chromium	1	A	3	B	2	3
11	(12)	Chrom.+Barium	1	C	2	B	2	2

4 Unsaturated zone and Saturated zone Likelihoods

Determine the Unsaturated zone (Lu) and
Saturated zone (Ls) likelihoods of reaching the well (use Table)
Lu as a function of the Unsat. zone TOT category (step 3) and Time Frame (step 1)
Ls as a function of the Saturated zone TOT category (step 3) and Time Frame (step 1)

	Source	Contaminant (Mixture)	TF	Unsaturated TOT	Lu	Saturated TOT	Ls
1	(1)	Tetrachloroethene	10	C	-3	D	-100
2	(4)	Arsenic	10	A	0	C	-3
3	(4)	Chromium	10	A	0	C	-3
4	(4)	Chrom.+Barium	10	A	-3	C	-100
5	(9)	Arsenic	10	A	0	C	-3
6	(9)	Chromium	10	A	0	C	-3
7	(9)	Chrom.+Barium	10	C	-3	E	-100
8	(10)	Tetrachloroethene	10	C	-3	E	-100
9	(12)	Arsenic	10	A	0	B	-0.3
10	(12)	Chromium	10	A	0	B	-0.3
11	(12)	Chrom.+Barium	10	C	-3	B	-0.3

5 Likelihood of Reaching the well

Compute the Likelihood of reaching the well L2= Lu (step 4) + Ls (step 5)

	Source	Contaminant / Mixture	**L2**	Lu	Ls	**L=L1+L2**
1	(1)	Tetrachloroethene	**-103**	-3	-100	-103
2	(4)	Arsenic	**-3**	0	-3	-3
3	(4)	Chromium	**-3**	0	-3	-3
4	(4)	Chrom.+Barium	**-103**	-3	-100	-103
5	(9)	Arsenic	**-3**	0	-3	-3
6	(9)	Chromium	**-3**	0	-3	-3
7	(9)	Chrom.+Barium	**-103**	-3	-100	-103
8	(10)	Tetrachloroethene	**-103**	-3	-100	-103
9	(12)	Arsenic	**-0.3**	0	-0.3	-0.3
10	(12)	Chromium	**-0.3**	0	-0.3	-0.3
11	(12)	Chrom.+Barium	**-3.3**	-3	-0.3	-3.3

6 Unsaturated zone Attenuation (Au)

Determine the unsaturated zone Attenuation
Au as a function of the Depth to the Aquifer score (WD2), adjusted Hydraulic conductivity score (step 2), Contaminant Persistence (SD)

	Source	Contaminant (Mixture)	WD2	Hydraulic Conductivity	CP	Au
1	(1)	Tetrachloroethene	1	2	M	-0.3
2	(4)	Arsenic	1	3	H	0
3	(4)	Chromium	1	3	H	0
4	(4)	Chrom.+Barium	1	2	H	0
5	(9)	Arsenic	1	3	H	0
6	(9)	Chromium	1	3	H	0
7	(9)	Chrom.+Barium	1	2	H	0
8	(10)	Tetrachloroethene	1	2	M	0
9	(12)	Arsenic	1	3	H	0
10	(12)	Chromium	1	3	H	0
11	(12)	Chrom.+Barium	1	2	H	0

7 Saturated zone Attenuation (As)

Determine the saturated zone Attenuation
As = Unadjusted saturated zone attenuation score (from Table) - Aquifer thickness (WD3)
Unadjusted saturated zone attenuation score as a function of the saturated zone material (
Distance score (SD), adjusted velocity score (step 2), contaminant persistence (S

	Source	Contaminant (Mixture)	WD6	Distance score	VS	CP	Unadj. sat. score
1	(1)	Tetrachloroethene	sand	1	2	M	-2.3
2	(4)	Arsenic	sand	4	3	H	-0.9
3	(4)	Chromium	sand	4	3	H	-0.9
4	(4)	Chrom.+Barium	sand	4	2	H	-0.7
5	(9)	Arsenic	sand	3	3	H	-0.7
6	(9)	Chromium	sand	3	3	H	-0.7
7	(9)	Chrom.+Barium	sand	3	2	H	0.4
8	(10)	Tetrachloroethene	sand	3	2	M	0.4
9	(12)	Arsenic	sand	2	3	H	-0.6
10	(12)	Chromium	sand	2	3	H	-0.6
11	(12)	Chrom.+Barium	sand	2	2	H	0.9

	Source	Contaminant / Mixture	Unadj. Sat	WD3	As
1	(1)	Tetrachloroethene	-2.3	1	-3.3
2	(4)	Arsenic	-0.9	1	-1.9
3	(4)	Chromium	-0.9	1	-1.9
4	(4)	Chrom.+Barium	-0.7	1	-1.7
5	(9)	Arsenic	-0.7	1	-1.7
6	(9)	Chromium	-0.7	1	-1.7
7	(9)	Chrom.+Barium	0.4	1	-0.6
8	(10)	Tetrachloroethene	0.4	1	-0.6
9	(12)	Arsenic	-0.6	1	-1.6
10	(12)	Chromium	-0.6	1	-1.6
11	(12)	Chrom.+Barium	0.9	1	-0.1

8 Attenuation due to transport (Compute Attenuation due to transport A = Au (step 6) + As (step 7)

	Source	Contaminant / Mixture	Au	As	A	S=(Q+A+T)
1	(1)	Tetrachloroethene	-0.3	-3.3	**-3.6**	**0.0**
2	(4)	Arsenic	0	-1.9	**-1.9**	**0.4**
3	(4)	Chromium	0	-1.9	**-1.9**	**-2.0**
4	(4)	Chrom.+Barium	0	-1.7	**-1.7**	**0.7**
5	(9)	Arsenic	0	-1.7	**-1.7**	**0.0**
6	(9)	Chromium	0	-1.7	**-1.7**	**-2.4**
7	(9)	Chrom.+Barium	0	-0.6	**-0.6**	**1.2**
8	(10)	Tetrachloroethene	0	-0.6	**-0.6**	**0.6**
9	(12)	Arsenic	0	-1.6	**-1.6**	**0.1**
10	(12)	Chromium	0	-1.6	**-1.6**	**-2.3**
11	(12)	Chrom.+Barium	0	-0.1	**-0.1**	**-0.2**

SOURCE DATASHEET - Deep Injection Wells: Gas Station & Oil Well

Parameters		(6)	(8)
SD1 Well Age (years)		20	0
SD2 Throughput rate	Determine the amount of liquid injected into well anually (million gallons per year) Default values: Class I=20.7mg/y, Class II=5.3 mg/y, Class III=19.4 mg/y	5.3 (mg/y)	5.3
SD3 Distance score	Determine the Distance score as a function of the shortest distance to from the area of agrichemical application to the well (or abandoned well if one exists between the area of agrichemical application and the well) (refer to table)	3	3
SD4 Source discharge	Does the source discharge directly to a conduit system that could tranport contaminants directly to a well	no	no

SD5 Contaminant data

No.	Contaminants (Mixture)	**Toxicity Score**	Concentration Score	Mobility Score	Persistence score	Cancer/ Noncancer
(6)						
1	Arsenic	**3.7**	-4.7	H	H	C
2	Benzene	**2.0**	-3.3	M	L	C
3	Boron	**-0.5**	-2.0	M	H	NC
(8)						
4	Arsenic	**3.7**	-4.7	H	H	C
5	Benzene	**2.0**	-3.3	M	L	C
6	Boron	**-0.5**	-2.0	M	H	NC

SOURCE WORKSHEET - Deep Injection Wells: Gas Station-Class II

Step			(6)	(8)
1	Likelihood of Release **(L1)**	Determined the likelihood of release score. L1= as a funtion of well age (graph)	**-1.15**	**-2.4**
2	Volume score	Determine the Volume score (Graph) Volume score as a function of the Throughput rate (SD2) - (default value)	3.2	2.0
3	Quantity (Q)	Compute the Quantity score for each contaminant Q = Concentration score (SD5) + Area score (Step2)		

	Contaminant (Mixture)	Concentration Score	Volume Score	**Quantity (Q)**
(6)				
1	Arsenic	-4.7	3.2	**-1.5**
2	Benzene	-3.3	3.2	**-0.1**
3	Boron	-2.0	3.2	**1.2**
(8)				
4	Arsenic	-4.7	2.0	**-2.7**
5	Benzene	-3.3	2.0	**-1.3**
6	Boron	-2.0	2.0	**0.0**

TRANSPORT WORKSHEET - Deep Injection Wells: Gas Station

Step				
1	Time Frame	Compute Time Frame (years) TF = Age of source (SD) + Planning Period (WD1)	30	10
2	Hydraulic Conductivity Velocity	Determine the Hydraulic Conductivity and Velocity Adjusted score (use Table) Hydraulic conductivity score as a function of contaminant mobility (SD) and unsaturated zone hydraulic conductivity score (WD5) Velocity score as a function of contaminant mobility (SD) and ground water velocity score (WD7)		

	Contaminant (Mixture)	Unsat. HC	Hydraulic Conductivity	CM	GW velocity	Velocity score
(6)						
1	Arsenic	3	3	H	3	3
2	Benzene	3	2	M	3	2
3	Boron	3	2	M	3	2
(8)						
4	Arsenic	3	3	H	3	3
5	Benzene	3	2	M	3	2
6	Boron	3	2	M	3	2

3 Unsaturated zone anc Determine the Unsaturated zone Time of Travel
Saturated zone TOT category (use Table)
Category Unsat TOT = function of Depth to Aquifer score (WD2) and the
adjusted Hydraulic conductivity score (step2)
Sat TOT = function of Disctance score (SD) and
adjusted velocity score (step 2)

	Contaminant (Mixture)	WD2	Unsaturated TOT	HCS	Saturated TOT	DS	VS
(6)							
1	Arsenic	1	A	3	B	3	3
2	Benzene	1	C	2	E	3	2
3	Boron	1	A	2	B	3	2
(8)							
4	Arsenic	1	A	3	B	3	3
5	Benzene	1	C	2	E	3	2
6	Boron	1	A	2	E	3	2

4 Unsaturated zone anc Determine the Unsaturated zone (Lu) and
Saturated zone Saturated zone (Ls) likelihoods of reaching the well
Likelihoods (use Table)
Lu as a function of the Unsaturated zone TOT category (step3) and
Time Frame (step 1)
Ls as a function of the Saturated zone TOT category (step 3) and
Time Frame (step 1)

	Contaminant (Mixture)	TF	Unsaturated TOT	Lu	Saturated TOT	Ls
(6)						
1	Arsenic	30	A	0	B	0
2	Benzene	30	C	-0.3	E	-100
3	Boron	30	A	-0.3	B	-100
(8)						
4	Arsenic	30	A	0	B	-0.3
5	Benzene	30	C	-3	E	-100
6	Boron	30	A	-3	E	-100

5 Likelihood of Reachin Compute the Likelihood of reaching the well.
the Well **(L2)** L2 = Lu (step 4) + Ls (step 5)

	Contaminant / Mixture	**L2**	Lu	Ls	**L= (L1+L2)**
(6)					
1	Arsenic	**0**	0	0	**-1.15**
2	Benzene	**-100.3**	-0.3	-100	**-101.45**
3	Boron	**-100.3**	-0.3	-100	**-101.45**
(8)					
4	Arsenic	**-0.3**	0	-0.3	**-2.70**
5	Benzene	**-103**	-3	-100	**-105.40**
6	Boron	**-103**	-3	-100	**-105.40**

6 Unsaturated zone Attenuation (Au)

Determine the unsaturated zone Attenuation
Au as a function of the Depth to the Aquifer score (WD2), Hydrauliic conductivity score (step 2), contaminant persistence (SD)

	Contaminant (Mixture)	WD2	Hydraulic Conductivity	CP	Au
(6)					
1	Arsenic	1	3	H	0
2	Benzene	1	2	L	-100
3	Boron	1	2	H	0
(8)					
4	Arsenic	1	3	H	0
5	Benzene	1	2	L	-100
6	Boron	1	2	H	0

7 Saturated zone Attenuation (As)

Determine the saturated zone Attenuation
As = Unadjusted saturated zone attenuation score from Table) - Aquifer Thickness (WD3)
Unadjusted saturated zone attenuation score as a function of the saturated zone material (WD6), distance score (SD), velocity score (step 2), contaminant persistence (SD)

	Contaminant (Mixture)	WD6	Distance score	VS	CP	Unadj. sat. score
(6)						
1	Arsenic	sand	3	3	H	-0.6
2	Benzene	sand	3	2	L	-100
3	Boron	sand	3	2	H	0.9
(8)						
4	Arsenic	sand	3	3	H	-0.7
5	Benzene	sand	3	2	L	-100
6	Boron	sand	3	2	H	0.4

	Contaminant / Mixture	Unadj. Sat	WD3	As
(6)				
1	Arsenic	-0.6	1	-1.6
2	Benzene	-100	1	-101
3	Boron	0.9	1	-0.1
(8)				
4	Arsenic	-0.7	1	-1.7
5	Benzene	-100	1	-101
6	Boron	0.4	1	-0.6

8 Attenuation due to transport **(A)**

Compute Attenuation due to transport
A = Au (step 6) + As (step 7)

	Contaminant / Mixture	Au	As	**A**	**S=(Q+A+T)**
(6)					
1	Arsenic	0	-1.6	**-1.6**	**0.6**
2	Benzene	-100	-101	**-201**	**-199.1**
3	Boron	0	-0.1	**-0.1**	**0.6**
(8)					
4	Arsenic	0	-1.7	**-1.7**	**-0.7**
5	Benzene	-100	-101	**-201**	**-200.3**
6	Boron	0	-0.6	**-0.6**	**-1.1**

SOURCE DATASHEET - Tanks: Gas station - underground storage tank

Parameters			(7) active	(11) old
SD1	Number of tanks		1	1
SD2	Tank size	Enter Small, Medium or High for the size of each tank group (L=<5000 gallons each, M=5000-30000 gallons each, H=>30000 gallons each	small	small
SD3	Tank design	Enter the tank design number according to the tank design (3= inground concrete tank with an open top at the ground - use Table)	3	3
SD4	Tank age	Enter the age of the tank or the average age of the tanks in group	20 (years)	0 (years)
SD5	Distance score	Determine the Distance score as a function of the shortest distance to from the container storage area to the well (or abandoned well if one exists between the well and the source (use Table)	3	3
SD6	Source discharge	Does the source discharge directly to a conduit system that could tranport contaminants directly to a well	no	no

SD7 Contaminant data

No.	Contaminants (Mixture)	**Toxicity Score**	Concentration Score	Mobility Score	Persistence score	Cancer/ Noncancer
1	Benzene	**2.0**	2.0	M	L	C
2	Xylene+Toluene	**-0.4**	0.5	H	L	NC
3	Benzene	**2.0**	2.0	M	L	C
4	Xylene+Toluene	**-0.4**	0.5	H	L	NC

SOURCE WORKSHEET - Tanks: Gas station-underground storage tank

Step				
1	Likelihood of Release **(L1)**	Determine the likelihood of release score. L1 score as a function of the Tank design (SD3) and Tank age (SD4) - (use graph)	0	0
2	Volume Score	Determine the Volume score (Use Graph) Volume score as a function of the number of tanks (SD1), Tank size (SD2), and Tank design (SD3) (Number of tanks=1, tank size=small, tank design=3)	-0.7	-0.7
3	Quantity (Q)	Compute the Quantity score for each contaminant Q = Concentration score (SD5) + Area score (Step2)		

	Contaminant (Mixture)	Concentration Score	Volume Score	**Quantity (Q)**
1	Benzene	2.0	-0.7	**1.3**
2	Xylene+Toluene	0.5	-0.7	**-0.2**
3	Benzene	2.0	-0.7	**1.3**
4	Xylene+Toluene	0.5	-0.7	**-0.2**

TRANSPORT WORKSHEET -Tanks: Gas station-underground storage tank

Step				
1	Time Frame	Compute Time Frame (years) TF = Age of source (SD) + Planning Period (WD1)	30	10
2	Hydraulic Conductivity Velocity	Determine the Hydraulic Conductivity and Velocity Adjusted score (use Table) Hydraulic conductivity score as a function of contaminant mobility (SD) and unsat. zone hydraulic conductivity score (WD5) Velocity score as a function of contaminant mobility (SD) and ground water velocity score (WD7)		

	Contaminant (Mixture)	Unsat. HC	Hydraulic Conductivity	CM	GW velocity	Velocity score
1	Benzene	3	2	M	3	2
2	Xylene+Toluene	3	3	H	3	3
3	Benzene	3	2	M	3	2
4	Xylene+Toluene	3	3	H	3	3

3 Unsaturated zone and Saturated zone TOT Category

Determine the Unsaturated zone Time of Travel category (use Table)
Unsat TOT as a function of depth to aquifer score (WD2) and the adjusted hydraulic conductivity score (step 2)
Sat TOT as a function of distance score (SD) and adjusted velocity score (step 2)

	Contaminant (Mixture)	WD2	Unsaturated TOT	HCS	Saturated TOT	DS	VS
1	Benzene	1	C	2	E	3	2
2	Xylene+Toluene	1	A	3	B	3	3
3	Benzene	1	C	2	E	3	2
4	Xylene+Toluene	1	A	3	B	3	3

4 Unsat. and saturated zone Likelihoods

Determine the Unsaturated zone (Lu) and saturated zone (Ls) likelihoods of reaching the well (use Table)
Lu as a function of the Unsaturated zone TOT category (step 3) and Time Frame (step 1)
Ls as a function of the Saturated zone TOT category (step 3) and (time Frame (step 1)

	Contaminant (Mixture)	TF	Unsaturated TOT	Lu	Saturated TOT	Ls
1	Benzene	30	C	-0.3	E	-100
2	Xylene+Toluene	30	A	0	B	0
3	Benzene	10	C	-3	E	-100
4	Xylene+Toluene	10	A	0	B	-0.3

5 Likelihood of Reaching the Well **(L2)**

Compute the Likelihood of reaching the well.
L2 = Lu (step 4) + Ls (step 5)

	Contaminant / Mixture	L2	Lu	Ls	L= (L1+L2)
1	Benzene	**-100.3**	-0.3	-100	**-100.3**
2	Xylene+Toluene	**0**	0	0	**0**
3	Benzene	**-103**	-3	-100	**-103**
4	Xylene+Toluene	**-0.3**	0	-0.3	**-1**

6 Unsaturated zone Attenuation (Au)

Determine the unsaturated zone Attenuation
Au as a function of the Depth to the Aquifer score (WD2), Hydraulic conductivity (step 2) Contaminant Persistence (SD)

	Contaminant (Mixture)	WD2	Hydraulic Conductivity	CP	Au
1	Benzene	1	2	L	-100
2	Xylene+Toluene	1	3	L	-1.2
3	Benzene	1	2	L	-100
4	Xylene+Toluene	1	3	L	-1.2

7 Saturated zone Attenuation (As)

Determine the saturated zone Attenuation
As = Unadjusted saturated zone attenuation score (Table) - aquifer thickness (WD3)
Unadjusted saturated zone attenuation score as a function of the saturated zone material (WD6), Distance score (SD), velocity score (step 2), contaminant persistence (SD)

	Contaminant (Mixture)	WD6	Distance score	VS	CP	Unadj. sat. score
1	Benzene	sand	3	2	L	-100
2	Xylene+Toluene	sand	3	3	L	-91.8
3	Benzene	sand	3	2	L	-100
4	Xylene+Toluene	sand	3	3	L	-91.8

	Contaminant / Mixture	Unadj. Sat	WD3	As
1	Benzene	-100	1	-101
2	Xylene+Toluene	-91.8	1	-92.8
3	Benzene	-100	1	-101
4	Xylene+Toluene	-91.8	1	-92.8

8	Attenuation due to transport **(A)**	Compute Attenuation due to transport A = Au (step 6) + As (step 7)

	Contaminant / Mixture	Au	As	**A**	**S=(Q+A+T)**
1	Benzene	-100	-101	**-201**	**-197.7**
2	Xylene+Toluene	-1.2	-92.8	**-94**	**-94.6**
3	Benzene	-100	-101	**-201**	**-197.7**
4	Xylene+Toluene	-1.2	-92.8	**-94**	**-94.6**

SOURCE DATASHEET - Agrichemical Application: Peanut Cropfield

Parameters

SD1	Age of source	Indicate the number of years agrichemicals have been applied	20
SD2	Area Application	Indicate the number of acres within the WHPA to which agrichemicals have been applied.	5
SD3	Distance score	Determine the Distance score as a function of the shortest distance from the area of agrichemical application to the well (or abandoned well if one exists between the are of agrichemical application and the well) (refer to table)	2
SD4	Source discharge	Does the source discharge directly to a conduit system that could tranport contaminants directly to a well	no
SD5	Contaminant data		

No.	Contaminants (Mixture)	**Toxicity Score**	Concentration Score	Mobility Score	Persistence score	Cancer/ Noncancer
1	Trifluralin	**1.3**	-0.6	L	M	C
2	Other Pesticides	**-0.2**	0.1	M	M	NC
3	Nitrate-nitrogen	**-1.5**	-0.2	H	M	NC

SOURCE WORKSHEET : Agrichemical Application: Peanut Cropfield

Step			
1	Likelihood of Release (**L1**)	Determined the likelihood of release score. (For agrichemical application L1 = 0)	**0**
2	Area score	Determine the Area score (Graph) Area score as a function of the Area of Application (SD2)	0.4
3	Quantity (Q)	Compute the Quantity score for each contaminant Q = Concentration score (SD5) + Area score (Step2)	

	Contaminant (Mixture)	Concentration Score	Area Score	**Quantity (Q)**
1	Trifluralin	-0.6	0.4	**-0.2**
2	Other Pesticides	0.1	0.4	**0.5**
3	Nitrate-nitrogen	-0.2	0.4	**0.2**

TRANSPORT WORKSHEET - Agrichemical Application: Peanut Cropfield

Step			
1	Time Frame	Compute Time Frame (years) TF = Age of source (SD) + Planning Period (WD1)	30
2	Hydraulic Conductivity Velocity	Determine the Hydraulic Conductivity and Velocity Adjusted score (use Table) Hydraulic conductivity score as a function of contaminant mobility (SD) and unsaturated zone hydraulic conductivity score (WD5) Velocity score as a function of contaminant mobility (SD) and ground water velocity score (WD7)	

	Contaminant (Mixture)	Unsat. HC	Hydraulic Conductivity	CM	GW velocity	Velocity score
1	Trifluralin	3	1	L	3	1
2	Other Pesticides	3	2	M	3	2
3	Nitrate-nitrogen	3	3	H	3	3

3	Unsat.and sat. zone TOT Category	Determine the Unsaturated zone Time of Travel category (use Table) Unsat TOT = function of Depth to Aquifer score (WD2) and the adjusted Hydraulic conductivity score (step2) Sat TOT = function of distance score (SD) & adjusted velocity score (step 2)

SOURCE DATASHEET - Container Storage & Materials Transfer

Parameters			(3)	(13)
SD1	Throughput Category	Enter Number (1,2,3,4,or 5) to indicate the number of 55-gallon drums passing through the storage and/or transfer facilities in one year (1=1-10 drums, 2=11-100 drums, 3=101-500 drums 4= 501-1000 drums, 5=>1000 drums)	2	1
SD2	Duration of storage	Enter Low, Medium or High for the average duration of storage of the 55-gallon drums (L=<30 days, M=31 days-1 yr, H=+1 yr)	Medium	Low
SD3	Storage Area Design	Indicate whether the storage area is padded or padded	unpadded	padded
SD4	Container storage and/or material transfer age	Enter the number of years that hazardous materials have been stored and/or transferred within the WHPA	20 (yrs)	10 (yrs)
SD5	Distance score	Determine the Distance score as a function of the shortest distance to from the container storage area to the well (or abandoned well if one exists between the well and the source - use Table) (635-1320 ft)	2	2
SD6	Source discharge	Does the source discharge directly to a conduit system that could tranport contaminants directly to a well	no	no

SD7 Contaminant data

No.	Source	Contaminants (Mixture)	Toxicity Score	Concentration Score	Mobility Score	Persistence score	Cancer/ Noncancer
1	(1)	Acetic acid	-1.5	2.4	H	L	NC
2	(1)	Chloroform	1.2	2.0	H	M	C
3	(1)	Carbon tetrachloride	2.5	2.0	M	L	C
4*	(1)	1,1,1-Trichloroethane	-0.2	2.3	M	M	NC
5	(2)	Acetic acid	-1.5	2.4	H	L	NC
6	(2)	Chloroform	1.2	2.0	H	M	C
7	(2)	Carbon tetrachloride	2.5	2.0	M	L	C
8*	(2)	1,1,1-Trichloroethane	-0.2	2.3	M	M	NC

* from chemical / cleaning liquid

SOURCE WORKSHEET : Container Storage & Materials Transport

Step			(3)	(13)
1	Likelihood of Release **(L1)**	Determine the likelihood of release score. L1 score as a function of the Throughput category (SD1), Duration of storage (SD2) and Storage Area Design (SD3) - Use Table	**-0.2**	**-2.6**
2	Volume Score	Determine the Volume score (Use Table) Volume score as a function of the Area of the Throughput category (SD1) and Duration of storage (SD2)	0.2	-0.7
3	Quantity (Q)	Compute the Quantity score for each contaminant Q = Concentration score (SD5) + Area score (Step2)		

	Source	Contaminant (Mixture)	Concentration Score	Volume Score	Quantity (Q)
1	(1)	Acetic acid	2.4	0.2	**2.6**
2	(1)	Chloroform	2.0	0.2	**2.2**
3	(1)	Carbon tetrachloride	2.0	0.2	**2.2**
4*	(1)	1,1,1-Trichloroethane	2.3	0.2	**2.5**
5	(2)	Acetic acid	2.4	-0.7	**1.7**
6	(2)	Chloroform	2.0	-0.7	**1.3**
7	(2)	Carbon tetrachloride	2.0	-0.7	**1.3**
8*	(2)	1,1,1-Trichloroethane	2.3	-0.7	**1.6**

TRANSPORT WORKSHEET - Container Storage & Material Transfer

Step			(3)	(13)
1	Time Frame	Compute Time Frame (years) TF = Age of source (SD) + Planning Period (WD1)	30	20

2 Hydraulic Conductivity

Determine the Hydraulic Conductivity and Velocity Adjusted score - use Table
Hydraulic conductivity score as a function of contaminant mobility (SD) and unsaturated zone hydraulic conductivity score (WD5)
Velocity score as a function of contaminant mobility (SD) and groundwater velocity score (WD7)

	Source	Contaminant (Mixture)	Unsat. HC	Hydraulic Conductivity	CM	GW velocity	Velocity score
1	(1)	Acetic acid	3	3	H	3	3
2	(1)	Chloroform	3	3	H	3	3
3	(1)	Carbon tetrachloride	3	2	M	3	2
4*	(1)	1,1,1-Trichloroethane	3	2	M	3	2
5	(2)	Acetic acid	3	3	H	3	3
6	(2)	Chloroform	3	3	H	3	3
7	(2)	Carbon tetrachloride	3	2	M	3	2
8*	(2)	1,1,1-Trichloroethane	3	2	M	3	2

3 Unsaturated zone and Saturated zone TOT category

Determine the Unsaturated zone Time of Travel category (use Table)
Unsat TOT = funtion of Depth to Aquifer score (WD2) and the adjusted Hydraulic Conductivity score (step 2)
Sat TOT = function of Disctance score (SD) and adjusted velocity velocity score (step 2)

	Source	Contaminant (Mixture)	WD2	Unsaturated TOT	HCS	Saturated TOT	DS	VS
1	(1)	Acetic acid	1	A	3	B	2	3
2	(1)	Chloroform	1	A	3	B	2	3
3	(1)	Carbon tetrachloride	1	C	2	D	2	2
4*	(1)	1,1,1-Trichloroethane	1	C	2	D	2	2
5	(2)	Acetic acid	1	A	3	B	2	3
6	(2)	Chloroform	1	A	3	B	2	3
7	(2)	Carbon tetrachloride	1	C	2	D	2	2
8*	(2)	1,1,1-Trichloroethane	1	C	2	D	2	2

4 Unsaturated zone and Saturated zone

Determine the Unsaturated zone (Lu) and saturated zone (Ls) likelihoods of reaching the well (use Table)
Lu as a function of the Unsaturated zone TOT category (step 3) and Time Frame (step 1)
Ls as a function of the Saturated zone TOT category (step 3) and Time Frame (step 1)

	Source	Contaminant (Mixture)	TF	Unsaturated TOT	Lu	Saturated TOT	Ls
1	(1)	Acetic acid	30	A	0	B	0
2	(1)	Chloroform	30	A	0	B	0
3	(1)	Carbon tetrachloride	30	C	-0.3	D	-0.9
4*	(1)	1,1,1-Trichloroethane	30	C	-0.3	D	-0.9
5	(2)	Acetic acid	30	A	0	B	0
6	(2)	Chloroform	30	A	0	B	0
7	(2)	Carbon tetrachloride	30	C	-0.3	D	-0.9
8*	(2)	1,1,1-Trichloroethane	30	C	-0.3	D	-0.9

5 Likelihood of Reaching the Well **(L2)**

Compute the Likelihood of reaching the well.
L2 = Lu (step 4) + Ls (step 5)

	Source	Contaminant / Mixture	**L2**	Lu	Ls	**L= (L1+L2)**
1	(1)	Acetic acid	**0**	0	0	**-0.2**
2	(1)	Chloroform	**0**	0	0	**-0.2**
3	(1)	Carbon tetrachloride	**-1.2**	-0.3	-0.9	**-1.4**
4*	(1)	1,1,1-Trichloroethane	**-1.2**	-0.3	-0.9	**-1.4**
5	(2)	Acetic acid	**0**	0	0	**-0.2**
6	(2)	Chloroform	**0**	0	0	**-0.2**
7	(2)	Carbon tetrachloride	**-1.2**	-0.3	-0.9	**-1.4**
8*	(2)	1,1,1-Trichloroethane	**-1.2**	-0.3	-0.9	**-1.4**

6 Unsaturated zone Attenuation (Au)

Determine the unsaturated zone Attenuation
Au as a function of the Depth to the Aquifer score (WD2), Hydraulic conductivity score (step 2), contamina Hydraulic conductivity score (step 2),

	Source	Contaminant (Mixture)	WD2	Hydraulic Conductivity	CP	Au
1	(1)	Acetic acid	1	3	L	-1.2
2	(1)	Chloroform	1	3	M	-0.3
3	(1)	Carbon tetrachloride	1	2	L	-100
4*	(1)	1,1,1-Trichloroethane	1	2	M	-0.3
5	(2)	Acetic acid	1	0	L	-1.2
6	(2)	Chloroform	1	0	M	-0.3
7	(2)	Carbon tetrachloride	1	0	L	-100
8*	(2)	1,1,1-Trichloroethane	1	Unsat TOT =	M	-0.3

7 Saturated zone Attenuation (As)

Determine the saturated zone Attenuation
As = Unadjusted saturated zone attenuation score (from Table) - Aquifer Thickness (
Unadjusted saturated zone attenuation score as a function of the saturated zone mat
distance score (SD), velocity score (step 2), contaminant persistence (S

	Source	Contaminant (Mixture)	WD6	Distance score	VS	CP	Unadj. sat. score
1	(1)	Acetic acid	sand	2	3	L	-46
2	(1)	Chloroform	sand	2	3	M	-0.7
3	(1)	Carbon tetrachloride	sand	2	2	L	-100
4*	(1)	1,1,1-Trichloroethane	sand	2	2	M	-10.2
5	(2)	Acetic acid	sand	2	0	L	-46
6	(2)	Chloroform	sand	2	0	M	-0.7
7	(2)	Carbon tetrachloride	sand	2	0	L	-100
8*	(2)	1,1,1-Trichloroethane	sand	2	0	M	-10.2

	Source	Contaminant / Mixture	Unadj. Sat	WD3	As
1	(1)	Acetic acid	-46	1	-47
2	(1)	Chloroform	-0.7	1	-1.7
3	(1)	Carbon tetrachloride	-100	1	-101
4*	(1)	1,1,1-Trichloroethane	-10.2	1	-11.2
5	(2)	Acetic acid	-46	1	-47
6	(2)	Chloroform	-0.7	1	-1.7
7	(2)	Carbon tetrachloride	-100	1	-101
8*	(2)	1,1,1-Trichloroethane	-10.2	1	-11.2

8 Attenuation due to transport **(A)**

Compute Attenuation due to transport A = Au (step 6) + As (step 7)

	Source	Contaminant / Mixture	Au	As	**A**	**S=(Q+A+T)**
1	(1)	Acetic acid	-1.2	-47	**-48.2**	**-47.1**
2	(1)	Chloroform	-0.3	-1.7	**-2**	**1.4**
3	(1)	Carbon tetrachloride	-100	-101	**-201**	**-196.3**
4*	(1)	1,1,1-Trichloroethane	-0.3	-11.2	**-11.5**	**-9.2**
5	(2)	Acetic acid	-1.2	-47	**-48.2**	**-48.0**
6	(2)	Chloroform	-0.3	-1.7	**-2**	**0.5**
7	(2)	Carbon tetrachloride	-100	-101	**-201**	**-197.2**
8*	(2)	1,1,1-Trichloroethane	-0.3	-11.2	**-11.5**	**-10.1**

SOURCE DATASHEET - Landfills (operating before 1976)

Parameters

SD1	Landfill design	Enter Number (1,2,3,4,or 5) to indicate the design of the landfill (1=unline vegetative cover, 2 = clay lined vegetative cover, 3= synthetic liner + synthetic cover + leachate collection, 4=unlined + clay & synthetic cover, 5= clay & synthetic liner +clay & synthetic cover + leachate collection system	1
SD2	Landfill status	Enter 1,2, or 3 for the status of landfill (1=active, 2=post closure care, 3=abandoned or postcare)	3
SD3	Default assumptions	Was default assumption used for either landfill design or landfill status	yes (Y/N)
SD4	Landfill age	Indicate the age of landfill	0
SD5	Landfill area	Estimate the landfill area in acres (For landfills over 100 acres, round to the nearest 100yr)	3 (yrs)
SD6	Distance score	Determine the Distance score as a function of the shortest distance from the storage area to the well (or ababdoned well if one exists between the well and the source) (use Table: 2640-5280)	4
SD7	Source discharge	Does the source discharge directly to a conduit system that could tranport contaminants directly to a well?	no

SD8 Contaminant data

No.	Contaminants (Mixture)	**Toxicity Score**	Concentration Score	Mobility Score	Persistence score	Cancer/ Noncancer
1	Arsenic	**3.7**	-1.0	H	H	C
2	Chromium & cyanide	**0.8**	-3.6	H	H	C
3	Other metals	**1.4**	1.4	M	H	NC

SOURCE WORKSHEET : Container Storage & Materials Transport: Peanut plant

Step			
1	Likelihood of Release **(L1)**	Determine the likelihood of release score (use Table) L1 score as a function of the Throughput category (SD1), duration of storage (SD2) and storage area design (SD3) Throughput category =2, Duration of storate=M, storage design = unpadded	**-0.2**
2	Volume Score	Determine the Volume score (Use Table) Volume score as a function of the Area of the Throughput category (SD1) and Duration of storage (SD2) Throughput category = 3, Duration of storage=M	0.2
3	Quantity (Q)	Compute the Quantity score for each contaminant Q = Concentration score (SD5) + Area score (Step2)	

	Contaminant (Mixture)	Concentration Score	Area Score	**Quantity (Q)**
1	Arsenic	-1	0.2	**-0.8**
2	Chromium & cyanide	-3.6	0.2	**-3.4**
3	Other metals	1.4	0.2	**1.6**

TRANSPORT WORKSHEET - Landfills (operating before 1976)

Step			
1	Time Frame	Compute Time Frame (years) TF = Age of source (SD) + Planning Period (WD1)	10
2	Hydraulic Conductivity Velocity	Determine the Hydraulic Conductivity and Velocity Adjusted score (use Table) Hydraulic conductivity score as function of contaminant mobility (SD) and unsaturated zone hydraulic conductivity score (WD5) Velocity score as a function of contaminant mobility (SD) and contaminant mobility (SD) and groundwater velocity score (WD7)	

	Contaminant (Mixture)	Unsat. HC	Hydraulic Conductivity	CM	GW velocity	Velocity score
1	Arsenic	3	3	H	3	3
2	Chromium & cyanide	3	3	H	3	3
3	Other metals	3	2	M	2	2

3	Unsat.and sat. zone TOT category	Determine the Unsaturated zone Time of Travel category (use Table) Unsat TOT = function of depth to aquifer score (WD2) and the adjustment hydraulic conductivity score (step2)	

	Contaminant (Mixture)	WD2	Unsaturated TOT	HCS	Saturated TOT	DS	VS
1	Arsenic	1	A	3	C	4	3
2	Chromium & cyanide	1	A	3	C	4	3
3	Other metals	1	C	2	F	4	2

4 Unsat. And sat. zone Likelihoods

Determine the Unsaturated zone (Lu) and saturated zone (Ls) likelihoods of reaching the well (use Table)
Lu as a function of the Unsaturated zone TOT category (step 3) and Time Frame (step 1)
Ls as a function of the Saturated zone TOT category (step 3) and Time Frame (step 1)

	Contaminant (Mixture)	TF	Unsaturated TOT	Lu	Saturated TOT	Ls
1	Arsenic	10	A	0	C	-3
2	Chromium & cyanide	10	A	0	C	-3
3	Other metals	10	C	-3	F	-100

5 Likelihood of Reaching the Well **(L2)**

Compute the Likelihood of reaching the well.
L2 = Lu (step 4) + Ls (step 5)

	Contaminant / Mixture	**L2**	Lu	Ls	**L= (L1+L2)**
1	Arsenic	**-3**	0	-3	**-3.2**
2	Chromium & cyanide	**-3**	0	-3	**-3.2**
3	Other metals	**-103**	-3	-100	**-103.2**

6 Unsaturated zone Attenuation (Au)

Determine the unsaturated zone Attenuation
Au as a function of the Depth to the Aquifer score (WD2), Hydraulic conductivity score (step 2), contaminant Persistence (SD)

	Contaminant (Mixture)	WD2	Hydraulic Conductivity	CP	Au
1	Arsenic	1	3	H	0
2	Chromium & cyanide	1	3	H	0
3	Other metals	1	2	H	0

7 Saturated zone Attenuation (As)

Determine the saturated zone Attenuation (from Table)
As = Unadjusted saturated zone attenuation score - aquifer thickness (WD3)
Unadjusted saturated zone attenuation score as a function of the saturated zone material (WD6), distance score (SD), velocity score (step 2), contaminant, persistence (SD)

	Contaminant (Mixture)	WD6	Distance score	VS	CP	Unadj. sat. score
1	Arsenic	sand	4	3	H	-0.9
2	Chromium & cyanide	sand	4	3	H	-0.9
3	Other metals	sand	4	2	H	-0.7

8 Attenuation due to transport **(A)**

Compute Attenuation due to transport
A = Au (step 6) + As (step 7)

	Contaminant / Mixture	WD3	As	**A**	**S=(Q+A+T)**
1	Arsenic	1	-1	**-1**	**1.9**
2	Chromium & cyanide	1	-1	**-1**	**-3.6**
3	Other metals	1	-1	**-1**	**2**

Appendix 5. RBCA Risk and Hazard Quotient Calculations

Chemicals	Class	RfD (mg/kg-d)	Source	UF	MF	SF (mg/kg-d)$^{-1}$	Concentration (mg/L)
Bromoform	B2	2.00E-02	IRIS	1	1	6.20E-02	0.0006
Chloroform	B2	2.00E-02	IRIS	1	1	6.10E-03	0.0017
DCBM	B2	2.00E-02	IRIS	1	1	7.90E-03	0.0024
PERC	B2	1.00E-02	IRIS	1	1	na	0.1623

$$\text{Intake/Dose (mg/kg-d)} = \frac{CW * IR * EF * ED}{BW * AT}$$

CW = Chemical concentration in water (mg/L)
IR = Ingestion rate (2L/d)
EF = Exposure frequency (365 days/year)
ED = Exposure duration
(30 years for noncarcinogens, 70 years for carcinogen)
BW = Body weight (70 kg)
AT = Averaging Time
(30 yr*365 d/yr for noncarcinogens, 70 y*365 d/yr for carcinogen)

RISK Dose * SF
HQ = Dose / RfD

SF = Slope factor (mg/kg-d) -1
HQ = Hazard quotient
RfD = Reference Dose (mg/kg-d)

Bromoform

$$\text{Dose} = \frac{0.0006\ \text{mg/L} * 2\ \text{L/d} * 365\ \text{d/yr} * 30\ \text{yr}}{70\ \text{kg} * 70 * 365\ \text{d}} = 7.34\text{E-05}$$

Risk = 7.34E-5 (mg/kg-d) * 6.2E-2 (mg/kg-d)-1 = 4.55E-06

Chloroform

$$\text{Dose} = \frac{0.0017\ \text{mg/L} * 2\ \text{L/d} * 365\ \text{d/yr} * 30\ \text{yr}}{70\ \text{kg} * 70 * 365\ \text{d}} = 2.08\text{E-05}$$

Risk = 2.08E-8 (mg/kg-d) * 6.1E-2 (mg/kg-d)-1 = 1.27E-06

Dichlorobromomethane

$$\text{Dose} = \frac{0.0024\ \text{mg/L} * 2\ \text{L/d} * 365\ \text{d/yr} * 30\ \text{yr}}{70\ \text{kg} * 70 * 365\ \text{d}} = 2.90\text{E-05}$$

Risk = 2.90E-5 (mg/kg-d) * 7.9E-2 (mg/kg-d)-1 = 2.29E-06

Tetrachloroethylene

$$\text{Dose} = \frac{0.1623\ \text{mg/L} * 2\ \text{L/d} * 365\ \text{d/yr} * 30\ \text{yr}}{70\ \text{kg} * 30 * 365\ \text{d}} = 4.60\text{E-03}$$

HQ = 4.60E-3 (mg/kg-d) / 1.0E-2 (mg/kg-d) = 0.464

Calculation of SSTL

Carcinogen

$$Cw = \frac{R * BW (kg) * AT (yr * 365 d/yr)}{IR (L/d) * EF (d/yr) * ED (yr) * SF (mg/kg\text{-}d)\text{-}1}$$

$$Bromoform = \frac{1*10E\text{-}5 * 70 (kg) * 70 (yr) * 365 (d/yr)}{2 (L/d) * 365 (d/yr) * 70 (yr) * 6.2E\text{-}2 (mg/kg\text{-}d)\text{-}1} = 0.0131 \text{ mg/L}$$

$$Chloroform = \frac{1*10E\text{-}5 * 70 (kg) * 70 (yr) * 365 (d/yr)}{2 (L/d) * 365 (d/yr) * 70 (yr) * 6.1E\text{-}2 (mg/kg\text{-}d)\text{-}1} = 0.0133 \text{ mg/L}$$

$$Dichlorobromomethane = \frac{1*10E\text{-}5 * 70 (kg) * 70 (yr) * 365 (d/yr)}{2 (L/d) * 365 (d/yr) * 70 (yr) * 7.9E\text{-}2 (mg/kg\text{-}d)\text{-}1} = 0.0103 \text{ mg/L}$$

Noncarcinogen

$$Cw = \frac{HQ * RfD (mg/kg\text{-}d) * BW (kg) * AT (yr * 365 d/yr)}{IR (L/d) * EF (d/yr) * ED (yr)}$$

$$Tetrachloroethylene = \frac{1*1.0E\text{-}2 * 70 (kg) * 30 (yr) * 365 (d/yr)}{2 (L/d) * 365 (d/yr) * 30 (yr)} = 0.35 \text{ mg/L}$$

Appendix 6. Fate and Transport Parameters and Calculations

Name : Tetrachloroethylene
Molecular Weight : 165.85 g/mole (EPA, 1994; EPA OGWDW, 1998)
Melting Point : -22 C (EPA, 1994; EPA OGWDW, 1998)
Boiling Point : 121 C (EPA, 1994; EPA OGWDW, 1998)

Melting Point : 12.44 (Hounslow and Goff ECOPLUS calculation)
Boiling Point : 215.95 (Hounslow and Goff ECOPLUS calculation)
Vapor Pressure : 18.823 mm Hg (Hounslow and Goff ECOPLUS calculation)

Entered solubility : 150 mg/L (EPA, 1994; EPA OGWDW, 1998)
Sol calc. from Kow : 214 mg/L (Hounslow and Goff ECOPLUS calculation)
Entered log Kow : 3.4 (EPA, 1994; EPA OGWDW, 1998)
Entered Koc : 665 (EPA, 1994; EPA OGWDW, 1998)
Entered log Koc : 2.823 (Hounslow and Goff ECOPLUS calculation)
BCF calculated from Kow: 1.684 (Hounslow and Goff ECOPLUS calculation)
Entered BCF : 39 (EPA, 1994; EPA OGWDW, 1998)
49 (EPA, 1994; EPA OGWDW, 1998)
Entered log BCF : 1.641 (Hounslow and Goff ECOPLUS calculation)
Entered Henry's Law constant : 1.80E-02 atm m3/mol (EPA, 1994; EPA OGWDW, 1998)
Entered Henry's Law constant : 0.736 dimensionless (Hounslow and Goff ECOPLUS calculation)

CALCULATION OF RETARDATION COEFFICIENT

% solute in aquifer water = 66.1 (Hounslow and Goff ECOPLUS calculation)
% solute in aquifer solids = 33.9 (Hounslow and Goff ECOPLUS calculation)

Retardation coefficient : 1.6 (Hounslow and Goff ECOPLUS calculation)

Log Koc = 2.81 (Hounslow and Goff ECOPLUS calculation)
Porosity = 0.15 (ODEQ, 1994)
Bulk density = 1.4
% organic carbon = 0.01

AQUIFER PARAMETER
Velocity = 2.67 ft/day
Longitudinal dispersivity = 520 ft
Transverse dispersivity = 52 ft
Aquifer thickness = 24 ft (ODEQ, 1994)
Porosity = 0.15 (ODEQ, 1994)
Retardation coefficient = 1.6 (Hounslow and Goff ECOPLUS calculation)
Half life = 2000 years

SOURCE DATA
Mass injection rate = 0.2 lb/day
Time source starts = 0
Time source ends = 7300 days

CALCULATION OF SOLUTE CONCENTRATION AT POINT (x,y) AFTER TIME T DAYS
Distance from source down gradient = 5200 ft
Distance from source across gradient = 170 ft
Starting time = 0
Ending Time = 9300 days (default)
Time peak = 8184 days (Hounslow and Goff ECOPLUS calculation)
Maximum concentration = 0.1692 mg/L

ADVECTION (ASTM Standard E 1739 User Training, 1996)

$$V_{GW} = \frac{Ki}{\theta E} \longrightarrow 2.67 \text{ ft/d} = \frac{133.69 \text{ ft/d} * 0.003}{0.15}$$

V_{GW} = average ground water linear velocity (ft/d)

K = hydraulic conductivity (ft/d) = 1000 gpd/ft^2 * 1 ft^3/7.48 gallon = 133.69 ft/d

i = hydraulic gradient (unitless) = 0.003

θ_E = effective porosity = 0.15

ADVECTIVE TRANSPORT (ASTM Standard E 1739 User Training, 1996)

$$V_C = \frac{V_{GW}}{R} \qquad R = 1 + \frac{kd\rho s}{\theta_E}$$

V_C = chemical of concern velocity (ft/d)

V_{GW} = average ground water linear velocity (ft/d) = 2.67

R = Retardation factor = 1.6

kd = distribution coefficient [(mg/kg-soil)/(mg/L-H_2O)]

ρs = soil bulk density [kg-soil/L-soil] = 1.4

θ_E = effective porosity = 0.15

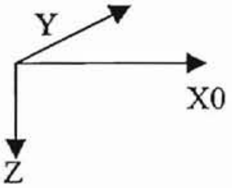
HYDRODYNAMIC DISPERSION (ASTM Standard E 1739 User Training, 1996)

D_x = α_x V = longitudinal (x-direction) dispersion coefficient (ft^2/d)
= α_x = L (distance away from source)/10
= (5200 ft / 10) * 2.67 ft/d = 1388 ft^2/d

D_y = α_y V = lateral (y-direction) dispersion coefficient (ft^2/d)
= α_y = α_x / 3
= (520 ft / 3) * 2.67 ft/d = 462.8 ft^2/d

D_z = α_z V = transverse (z-direction) dispersion coefficient (ft^2/d)
= α_z = α_x / 10
= (520 ft / 10) * 2.67 ft/d = 138.84 ft^2/d

Ground water flow



LOADING (Hounslow, 1995)

Loading (lb/d) = 122400 (gal/d) * 0.1623 (mg/L) * 1 cft/7.48 gal * 1 g/ 1000mg *
1 lb/453.6 g * 28.317 L/1cft
= 0.20 lb/d.

Appendix 7. Longitude and Latitude Positions of Points

	Sources	Latitude			Longitude				
1	Well #1	34	58	15	96	14	59	34.9708	-96.2497
2	Well #2 (shut down)	34	58	9	96	14	39	34.9690	-96.2442
3	Abandoned well (old)	34	58	9	96	14	40	34.9690	-96.2443
4	Agrichemical burial (old)	34	58	9	96	14	42	34.9690	-96.2450
5	Peanut plant	34	58	12	96	14	49	34.9700	-96.2469
6	Peanut crops	34	58	14	96	14	51	34.9706	-96.2475
7	Dry Cleaner (1940)	34	58	13	96	14	58	34.9703	-96.2494
8	Old laundry mat	34	57	58	96	14	35	34.9661	-96.2429
9	Oil well 1	34	57	58	96	14	35	34.9661	-96.2429
10	Salvage2	34	57	58	96	14	35	34.9661	-96.2429
11	Gas station (old)	34	57	58	96	14	32	34.9661	-96.2421
12	Well #3	34	57	57	96	14	22	34.9658	-96.2394
13	Horse stable	34	57	57	96	14	22	34.9658	-96.2394
14	Well #4	34	57	55	96	14	14	34.9651	-96.2372
15	Country barn	34	57	57	96	14	14	34.9658	-96.2372
16	City sewage lagoons	34	39	56	96	14	55	34.6654	-96.2486
17	Old city dump	34	57	26	96	14	9	34.9572	-96.2358
18	Oil wells 2	34	57	3	96	14	11	34.9508	-96.2363
19	Agricultural field	34	58	25	96	14	56	34.9736	-96.2489
20	Salvage1	34	58	8	96	14	52	34.9689	-96.2476
21	Salvage3	34	57	54	96	15	3	34.9650	-96.2508
22	Old bins	34	57	54	96	15	7	34.9649	-96.2518
23	Cemetery	34	57	47	96	15	11	34.9631	-96.2531
24	Gas station	34	58	3	96	14	42	34.9675	-96.2450

Appendix 8. Water Quality Sample Analysis of Well #1 and #2

AMPLE NUMBER:	005803
GENCY NUMBER:	
ATE COLLECTED:	03/17/97
IME COLLECTED:	13:45
ATE RECEIVED:	03/18/97
ATE COMPLETED:	03/20/97
WS ID:	2003201
TATION:	
OLLECTED BY:	TDS
ATE REPORTED:	03/21/97

OKLAHOMA DEPARTMENT OF ENVIRONMENTAL QUALITY

REPORT OF ANALYSIS BY GC LABORATORY

LOCAL DEQ
WATER QUALITY DIVISION
FILE COPY

CC: CALVIN
PO BOX 368
CALVIN, OK 74531
(405) 645-2434

CONCENTRATION IN SAMPLE — PAGE 1

PARAMETER NAME	CODE	<	VALUE	UNITS	METHOD
DICHLOROBROMOMETHANE	32101	<	0.500	UG/L	502.2
CARBON TETRACHOLRIDE	32102	<	0.500	UG/L	502.2
BROMOFORM	32104	<	0.500	UG/L	502.2
DIBROMOCHLOROMETHANE	32105	<	0.500	UG/L	502.2
CHLOROFORM	32106	<	0.500	UG/L	502.2
TOLUENE	34010	<	0.500	UG/L	502.2
BENZENE	34030	<	0.500	UG/L	502.2
CHLOROBENZENE	34301	<	0.500	UG/L	502.2
CHLOROETHANE	34311	<	0.500	UG/L	502.2
ETHYLBENZENE	34371	<	0.500	UG/L	502.2
HEXACHLROBUTADIENE W	34391	<	0.500	UG/L	502.2
METHYL BROMIDE	34413	<	0.500	UG/L	502.2
METHYL CHLORIDE	34418	<	0.500	UG/L	502.2
METHYLENE CHLORIDE	34423	<	0.500	UG/L	502.2
TETRACHLOROETHENE ⊕	34475		0.1623 mg/L 162.300	UG/L	0.005 mg/L 502.2
TRICLOROFLUROMTHNE W	34488	<	0.500	UG/L	502.2
1,1-DICHLOROETHANE	34496	<	0.500	UG/L	502.2
1,1-DICHLOROETHENE	34501	<	0.500	UG/L	502.2

SOURCE: WELL HOUSE #2
PROGRAM: Public Water Supply
COUNTY: HUGHES CITY: CALVIN

LEGAL DESCRIPTION
/4 /4 /4 SEC T R M

LAB REFERENCES:

SAMPLER'S COMMENTS: RESAMPLE OF SELS # 5666 [TCEE 153 UG/L.]

ANALYST'S COMMENTS:

ANALYST

SAMPLE NUMBER: 005802
AGENCY NUMBER:
DATE COLLECTED: 03/17/97
TIME COLLECTED: 13:30
DATE RECEIVED: 03/18/97
DATE COMPLETED: 03/20/97
PWS ID: 2003201
STATION:
COLLECTED BY: TDS
DATE REPORTED: 03/21/97

OKLAHOMA DEPARTMENT OF ENVIRONMENTAL QUALITY

REPORT OF ANALYSIS BY GC LABORATORY

LOCAL DEQ
WATER QUALITY DIVISION
FILE COPY

CC: CALVIN
PO BOX 368
CALVIN, OK 74531
(405) 645-2434

CONCENTRATION IN SAMPLE PAGE 1

PARAMETER NAME	CODE	<	VALUE	UNITS	METHOD
DICHLOROBROMOMETHANE	32101		0.0024 mg/L 2.400	UG/L	0.005 mg/L 502.2
CARBON TETRACHOLRIDE	32102	<	0.500	UG/L	502.2
BROMOFORM	32104		0.0006 mg/L 0.600	UG/L	502.2
DIBROMOCHLOROMETHANE	32105	<	0.500	UG/L	502.2
CHLOROFORM	32106		0.0017 1.700	UG/L	502.2
TOLUENE	34010	<	0.500	UG/L	502.2
BENZENE	34030	<	0.500	UG/L	502.2
CHLOROBENZENE	34301	<	0.500	UG/L	502.2
CHLOROETHANE	34311	<	0.500	UG/L	502.2
ETHYLBENZENE	34371	<	0.500	UG/L	502.2
HEXACHLROBUTADIENE W	34391	<	0.500	UG/L	502.2
METHYL BROMIDE	34413	<	0.500	UG/L	502.2
METHYL CHLORIDE	34418	<	0.500	UG/L	502.2
METHYLENE CHLORIDE	34423	<	0.500	UG/L	502.2
TETRACHLOROETHENE	34475	<	0.500	UG/L	502.2
TRICLOROFLUROMTHNE W	34488	<	0.500	UG/L	502.2
1,1-DICHLOROETHANE	34496	<	0.500	UG/L	502.2
1,1-DICHLOROETHENE	34501	<	0.500	UG/L	502.2

SOURCE: WELL HOUSE #1
PROGRAM: Public Water Supply
COUNTY: HUGHES CITY: CALVIN

LEGAL DESCRIPTION
/4 /4 /4 SEC T R M.

LAB REFERENCES:

SAMPLER'S COMMENTS: RESAMPLE OF SELS # 5665

ANALYST'S COMMENTS:

2

VITA

Maifan R. Silitonga

Candidate for the Degree of

Master of Science

Thesis: EVALUATION OF RISK SCREENING VERSUS OKLAHOMA RISK-BASED CORRECTIVE ACTION FOR THE WELLHEAD PROTECTION AREAS

Major Field: Environmental Science – Biosystems & Agricultural Engineering

Biographical:

Personal Data: Born in Bogor, West Java, Indonesia, On June 10, 1969, the daughter of Toga and Sorta Silitonga.

Education: Graduated from Universitas Nasional, Jakarta, Indonesia in October, 1994; received Bachelor of Science degree in Biology. Completed the requirements for the Master of Science degree with a major in Environmental Science at Oklahoma State University in December, 1998.

Experience: Raised in Indonesia, have lived with the family in St. Paul, MN in 1979-1983 while parents pursue the degrees in Animal Science - MS (mother) and Forest Products – Ph.D. (father). Employed as an administrative assistant by SGS Regional Representative Office (previously SGS Jakarta Liaison Office) from 1993-1996, employed by Oklahoma State University, Department of Biosystems and Agricultural Engineering as a graduate research assistant to Dr. Mike D. Smolen, from January 1998 to present.

Professional memberships: Society of Environmental Scientists at Oklahoma State University, Oklahoma National Academy of Science, American Water Resource Association.