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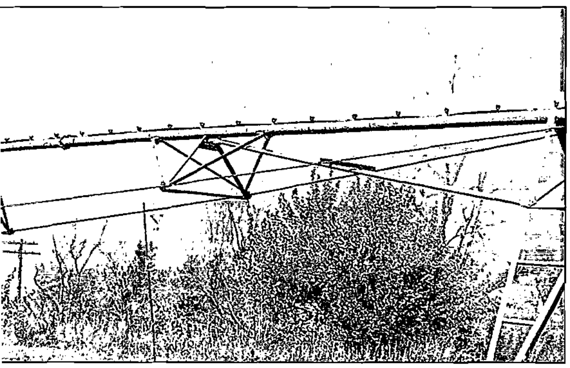
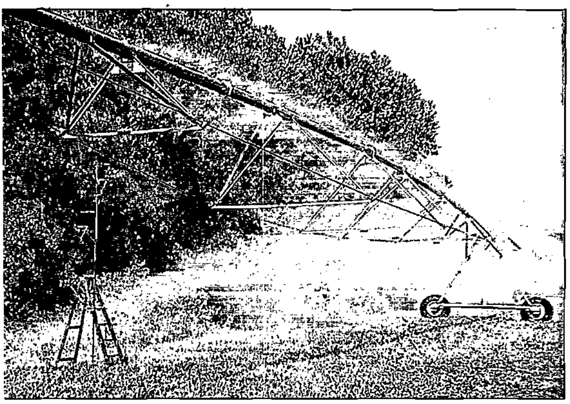
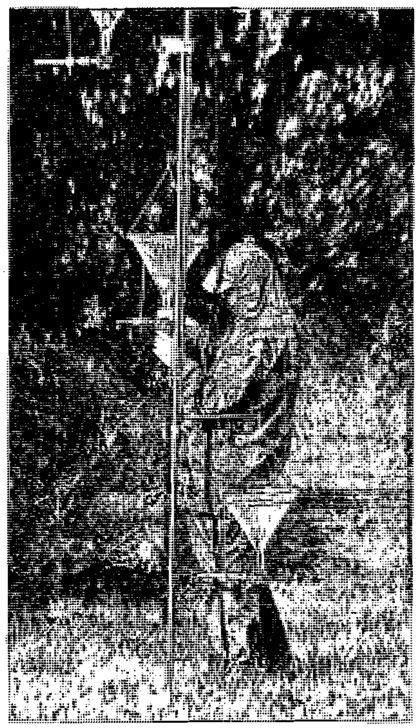
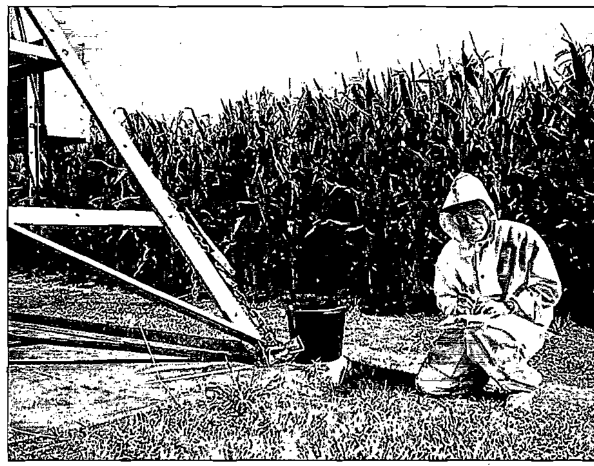
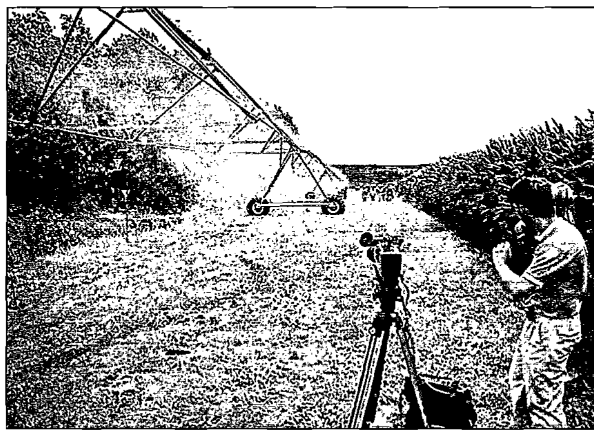
EPA

Sprinkler Irrigation as a VOC Separation and Disposal Method

Innovative Technology Evaluation Report

SITE

SUPERFUND INNOVATIVE
TECHNOLOGY EVALUATION

EPA/540/R-98/502
September 1998

Sprinkler Irrigation as a VOC Separation and Disposal Method

Innovative Technology Evaluation Report

National Risk Management Research Laboratory
Off ice of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

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Foreword

The U. S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and groundwater; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

Abstract

Sprinkler irrigation is a common farming practice in those states where the semi-arid climate and lack of sufficient rainfall during critical growing periods necessitate the use of supplemental water. The source of most irrigation water is groundwater which can be contaminated with volatile organic compounds (VOCs). Since the groundwater may be the primary or only source of drinking water for a community, there is a need for reasonable cost-effective treatment and disposal methods. Typically, groundwater contaminated with VOCs is remediated with conventional pump and treat technologies. The costs associated with conventional pump and treat options can be significant. Since irrigation is a fairly widespread practice, there is an opportunity to employ it as a dual purpose technology: crop irrigation and separation and disposal of contaminated groundwater in order to augment conventional treatment and effect cost savings. Additional benefits of implementation include containment of the groundwater plume, elimination of discharge or reinjection of the treated groundwater, and reduced irrigation expense for site vegetative covers.

This premise provided an impetus to evaluate the performance of sprinkler irrigation for these purposes through the conduct of a SITE program demonstration. This demonstration was conducted by the National Risk Management Research Laboratory (NRMRL) in July 1996 and the final report was completed in August 1997. Results and activities of the demonstration of sprinkler irrigation technology for the separation and disposal of groundwater contaminated with VOCs are detailed in this report.

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Acronyms, Abbreviations, and Symbols

μg/L	Micrograms per liter
AQCR	Air Quality Control Region
AQMD	Air Quality Management District
ARAR	Applicable or Relevant and Appropriate Regulations
CAA	Clean Air Act
c c v	Continuing Calibration Verification
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CT	Carbon Tetrachloride
CWA	Clean Water Act
DCE	1 , 1-Dichloroethene
EDB	1,2-Dibromoethane
EPA	U. S. Environmental Protection Agency
G c	Gas Chromatograph
ISCST3	Industrial Source Complex Model
k	Thousand
kPa	Kilopascal
MCL	Maximum Contaminant Levels
MCLG	Maximum Contaminant Level Goals
MDL	Method Detection Limit
MS	Matrix Spike
MSD	Matrix Spike Duplicate
NAAQS	National Ambient Air Quality Standards
NDOH	Nebraska Department of Health
NDEQ	Nebraska Department of Environmental Quality
NOAA	National Oceanic & Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRMRL	National Risk Management Research Laboratory

Acronyms, Abbreviations, and Symbols (continued)

ORD	Office of Research and Development
OSHA	Occupational Safety and Health Administration
PE	Performance Evaluation
PCE	Tetrachloroethene
POTW	Publicly Owned Treatment Works
psi	Pound Per Square Inch
QAPP	Quality Assurance Project Plan
RCRA	Resource Conservation and Recovery Act
RPD	Relative Percent Difference
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
SE	Southeast
SITE	Superfund Innovative Technology Evaluation
SW	Southwest
SWDA	Solid Waste Disposal Act
TCA	1,1,1-Trichloroethane
TCE	Trichloroethylene
UNL	University of Nebraska-Lincoln
VOC	Volatile Organic Compound

Conversion Factors

	To Convert From	*To*	*Multiply By*
Length	inch	centimeter	2.54
	foot	meter	0.305
	mile	kilometer	1.61
Area:	square foot	square meter	*0.0929*
	acre	square meter	4,047
Volume:	gallon	liter	3.78
	cubic foot	cubic meter	0.0283
Mass:	pound	kilogram	0.454
Energy:	kilowatt-hour	megajoule	3.60
Power:	kilowatt	horsepower	1.34
Temperature:	(“Fahrenheit - 32)	“Celsius	0.556

Acknowledgments

This report was prepared under the direction of Ms. Teri Richardson, the EPA SITE technical project manager at the NRMRL in Cincinnati, Ohio. Contributors to, and reviewers of, this report were Mr. Paul dePercin, Mr. Douglas Grosse, Ms. Rena Howard, Ms. Ann Kern, Mr. Endalkachew Sahle-Demissie, and Mr. Johnny Springer, Jr. of NRMRL, Mr. Richard Schlenker of the Nebraska Department of Environmental Quality (NDEQ), and Dr. Roy Spalding, University of Nebraska-Lincoln (UNL).

The SITE demonstration was conducted as part of the Western Governor's Association initiative on innovative technology and represents a multi-state collaboration on the review of the sprinkler irrigation remediation and disposal alternative.

The cooperation and participation of the following people are gratefully acknowledged: Mr. Paul dePercin, Mr. Vicente Gallardo, Ms. Annette Gatchett, Mr. Samuel Hayes, Ms. Ann Kern, Dr. Ronald Lewis, Ms. Kim McClellan, Mr. Randy Parker, and Ms. Michelle Simon, and Ms. Laurel Staley of NRMRL; Ms. Florence Fulk of EPA National Exposure Research Laboratory; Ms. Diane Easley, Ms. Hattie Thomas, and Mr. Robert Mournighan of EPA Region 7; Dr. Roy Spalding, UNL; Mr. Richard Schlenker, NDEQ; and Ms. Rosie Cunningham and Dr. Neal Sellers, Senior Environmental Employee Program-National Council on Aging.

Executive Summary

This report summarizes the findings of an evaluation of sprinkler irrigation as a volatile organic compound (VOC) separation and disposal method.

Background

A need for lower cost, effective treatment alternatives for the disposal of treated contaminated groundwater provided the impetus to conduct a SITE demonstration of sprinkler irrigation since it provides both separation and disposal options.

Since the application of irrigation is fairly widespread throughout the United States, there may be an opportunity to employ this as a dual purpose technology; concurrent irrigation and disposal of treated groundwater.

In order to determine whether this option is viable, it is necessary to address several issues: 1) can the contaminants be stripped from the groundwater effectively? 2) is irrigation necessary for crop cultivation? 3) are the increased health risks associated with the air emissions acceptable? 4) are there state or federal laws which prohibit the release of the resultant air emissions? and 5) is this an acceptable alternative to the community?

The results of previous studies conducted by the University of Nebraska-Lincoln (UNL) concluded that: irrigation systems can effectively strip VOCs from the groundwater; stripping efficiencies can be improved to produce drinking quality water; water is used on site for beneficial crop needs; capture zones formed will contain contamination; air emissions will not be a concern; and a significant savings in resources will result.

In order to provide independent verification of the technology performance and complement the results previously reported by UNL, an evaluation was conducted by the EPA SITE Program in cooperation with EPA Region 7 and UNL. The demonstration focused on the technology effectiveness, irrigation requirements, air emissions, and costs. The technology demonstration was conducted on July 17, 1996 at a contaminated groundwater site in Hastings, Nebraska.

Sprinkler Irrigation Technology

Sprinkler irrigation is a farming practice that is vital to the successful production of small grains in central Nebraska and to the agricultural economy of western states where the semi- arid climate and lack of sufficient rainfall during critical growing periods necessitate the use of supplemental water.

The heart of the irrigation system is the water dispersion nozzle or sprinkler package. The system that was evaluated by UNL researchers and the SITE Program was a center pivot sprinkler equipped with off-the-shelf, screw-in spray nozzles.

The center pivot is a radial-move pipeline that rotates around a pivot point. The systems have gained widespread usage throughout the United States for agronomic crop production because they are relatively efficient, low in labor and operating costs, and moderate in initial cost.

Waste Applicability

Generally, the use of sprinkler systems is reserved for crop irrigation. However, the need for alternative, lower cost methods to treat and dispose of treated groundwater has prompted an investigation of sprinkler irrigation as a remediation tool.

Previous experience has shown that a high content of iron and/or calcium may cause clogging of the nozzle openings and reduce the system effectiveness. Therefore, the application of sprinkler irrigation may be limited to groundwater which does not contain a significant amount of iron, calcium, sediment, or other material that could clog the nozzles.

The concentration of VOCs in the groundwater may be a limiting factor. This determination is made through the performance of a site-specific risk assessment. Prior to implementing the technology, a determination of an inconsequential health risk should be made in accordance with the applicable federal and state criteria.

A risk assessment was conducted by NDOH prior to the Demonstration. A determination was made that there were no consequential health risks associated with demonstration activities.

Demonstration Objectives and Approach

The SITE demonstration of sprinkler irrigation as a VOC separation and disposal method was designed with one primary and four secondary objectives. The selected objectives are intended to provide potential users of the technology with sufficient information to assess the appropriateness and applicability of sprinkler irrigation for separation and disposal of contaminated groundwater at other sites.

Primary Objective:

Determine the efficacy of the sprinkler irrigation system to treat groundwater contaminated with VOCs to concentrations that average below the maximum contaminant limits (MCLs); specifically, Trichloroethylene (TCE), Carbon tetrachloride (CT), and Tetrachloroethene (PCE) to 5 µg/L, 1,2-Dibromoethane (EDB) to 0.05 µg/L), and 1,1,1-Trichloroethane (TCA) to 200 µg/L at a 95% confidence level.

Secondary objectives:

Determine costs associated with the application of the technology.

Evaluate air emissions risks using the industrial source complex model (ISCST3).

Calculate the average percent removal of critical VOCs in the sprinkler mist.

Calculate the average percent removal of critical VOCs at the lowest sampling height during the last sampling run.

The demonstration objectives were achieved through the collection and analysis of water emitted from the sprinkler (i.e effluent). These samples were collected July 17, 1996 in accordance with an approved quality assurance project plan (QAPP) dated July 10, 1996.

Demonstration Conclusions

Based on the sprinkler irrigation demonstration results, the following conclusions can be made:

- The results of data from all sampling heights indicate that the mean effluent concentration of TCA, CT, and PCE were less than the MCLs. For EDB and TCE, the mean concentration was significantly greater than the MCLs.

- The cost to install a sprinkler irrigation system is estimated to range from $58,000-$97,000. Operation and maintenance costs were estimated to be $35,000/year.

- Air emissions analysis indicated that there were no related health risks associated with the use of the technology at the demonstration site.

- Overall, the reduction of individual VOCs in groundwater ranged from approximately 95.4 % to 97.6 %.

- At the lowest sampling height (H1), the percent removal ranged from 96.1 to 98.9%.

- The results of data from the lowest sample collection height indicate that the mean concentration of TCA, CT, and PCE were well below the MCLs. For TCE, the mean concentration of TCE was shown to be significantly greater than the MCL. The data collected provided no indication that the mean concentration of EDB was significantly larger than the MCL.

Technology Applicability

Sprinkler irrigation was evaluated to identify its advantages, disadvantages, and limitations as a remediation option for the separation and disposal of VOCs in groundwater. The overall effectiveness of the system depends on several factors which include system design, water quality, contaminant properties, nozzle aperture, nozzle pad design, water pressure, and ambient conditions.

Section 1
Introduction

1 .1 Background

This report documents the findings of an evaluation of sprinkler irrigation as a VOC separation and disposal method. This evaluation was conducted by the EPA SITE Program in cooperation with EPA Region 7 and the University of Nebraska-Lincoln (UNL). The sprinkler irrigation demonstration was conducted on July 17, 1996 at a contaminated groundwater site located in Hastings, Nebraska.

The demonstration was performed to determine the efficacy of the sprinkler irrigation system to treat and dispose of groundwater contaminated with VOCs to concentrations that average below the MCL; specifically, TCA (200 µg/L), TCE (5 µg/L), CT (5 µg/L), EDB (0.05 µg/L), and PCE (5µg/L). The MCL for each contaminant was established by Region 7 as the threshold level appropriate to determine the ability of sprinkler irrigation to meet drinking water standards.

The water sampling was conducted by U.S. EPA Office of Research and Development (ORD), EPA Region 7, and UNL personnel. All sample analyses were performed by U.S. EPA ORD, Cincinnati, Ohio. All demonstration activities were conducted in accordance with an approved quality assurance project plan (QAPP) dated July 10, 1996.

This report provides information about the sprinkler irrigation demonstration that is useful to remedial managers, environmental consultants, and other potential users in implementing the technology at contaminated sites. Section 1.0 presents an overview of the SITE Program, describes the sprinkler irrigation technology, and lists key contacts. Section 2.0 presents information relevant to the technology's application, applicable wastes/contaminants, key features of the technology, site support requirements, and limitations of the technology. Section 3.0 presents information on the costs associated with applying the technology. Section 4.0 presents information relevant to the technology's effectiveness, including site background, demonstration procedures, and the results and conclusions of the demonstration. Section 5.0 lists references used in preparing this report.

1.2 Superfund Innovative Technology Evaluation Program

The SITE Program was created in order to develop, demonstrate, and establish the commercial potential of innovative technologies for treating wastes found at Superfund and other hazardous waste sites across the country. Through SITE Demonstrations, the EPA acquires the cost and performance data necessary to properly consider innovative technologies in the remedial action decision-making process. If successfully tested, these technologies may become alternatives to land disposal or other less desirable forms of remedial action.

1.3 Sprinkler Irrigation Technology

Sprinkler irrigation is a farming practice that is vital to the successful production of small grains in central Nebraska and to the agricultural economy of western states where the semi- arid climate and lack of sufficient rainfall during critical growing periods necessitate the use of supplemental water.

The system that was evaluated by UNL researchers was a center pivot sprinkler equipped with off-the-shelf, screw-in spray nozzles. The center pivot sprinkler consists of a radial-move pipeline that rotates around a pivot point. The arm of the sprinkler system can be short or long, depending on the availability of water and land.

The nozzles were configured to have a small opening from which a stream of water is emitted. The high velocity stream strikes an impact pad and forms a thin film of water. The film breaks into small droplets as it leaves the pad. The droplet size depends on the pressure and the impact pad design.

Sprinkler irrigation systems have gained widespread usage throughout the United States for agronomic crop production because they are relatively efficient, low in labor and operating costs, and moderate in initial investment cost.

1.4 Key Contacts

Additional information about the sprinkler irrigation technology and the SITE Program can be obtained from the following sources:

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Section 2
Technology Applications Analysis

The analysis is based primarily on the results of this SITE demonstration, research conducted by UNL, and data compiled by EPA Region 7.

The results of studies conducted previously by UNL concluded that 1) sprinkler irrigation technology can effectively strip VOCs from the groundwater, 2) stripping efficiencies can be improved to produce drinking quality water, 3) water is used on-site for beneficial crop needs, 4) capture zones formed will contain contamination, 5) air emissions will not result in increased health risks, and 6) a savings of resources will occur.

2.1 Key Features

Sprinkler irrigation is widely used throughout the United States and the world for crop production for the purpose of irrigating sandy areas and hilly terrains. These systems are self-propelled, highly mechanized, and efficient. In addition, they apply water uniformly, have low labor and operating requirements, do not require land leveling, and start-up costs are not excessive.

The key component of the irrigation system is the water dispersion nozzle or sprinkler package. By placing sprinkler nozzles at relatively close intervals along an elevated pipeline, field water application is, essentially, uniform.

Systems vary in length, from 35 m (115 ft) to more than 914 m (2998 ft) depending on site conditions and the availability of water.

The use of a sprinkler irrigation system for separation and disposal of VOC-contaminated groundwater may be advantageous; especially at locations where crop irrigation is required.

The performance of sprinkler irrigation as a remediation technique primarily depends upon the system configuration, water quality, contaminant, spray nozzle aperture, and ambient conditions. Contaminated water is extracted and pumped through a pipeline onto an impact pad. After striking the impact pad a thin film is formed which breaks into small droplets creating a mist as it leaves the pad. There are no residual wastes generated as a result of this treatment..

Since irrigation is a widespread practice, the ability to have it serve a dual function, irrigation and separation/disposal, can significantly reduce clean-up costs at "select" sites.

2.2 Operability of the Technology

Sprinkler irrigation is simple to operate. It consists of an elevated pipeline with sprinkler nozzles spaced at relatively close intervals. The system can be transportable and moved from site to site.

Water is generally pumped from an aquifer to the pipeline at a rate of 0.7-1 .1 ft^3/min/acre (5-8 gal/min/acre). The operating pressure ranges from 103 to 483 kPa (15-70 psi).

The stripping efficiency of VOCs can be affected by weather conditions such as temperature, humidity, and wind speed.

For the SITE demonstration, three one-hour test runs were conducted in order to obtain a representative evaluation of the system performance.

2.3 Applicable Wastes

Sprinkler irrigation may be applicable to any contaminant that can be effectively stripped from the groundwater (primarily VOCs). For example, the water treated during the SITE demonstration was contaminated with TCE, CT, EDB, TCA, and PCE.

The utilization of sprinkler irrigation as a remediation tool was driven, in part, by the need to find more cost- effective methods for contaminated groundwater treatment. Standard remediation options include pump-and-treat and air sparging. Although these technologies can effectively remove volatile contaminants from the groundwater, the costs are substantially high. In those regions of the country where groundwater contamination is wide spread, the cost to clean up the water supply can be sizable. The use of irrigation to remove these contaminants could potentially reduce or eliminate the need for more expensive treatment options.

The determination of a waste's suitability for treatment is made on an a site specific basis through site characterization and treatability testing.

2.4 Availability and Transportability of the Equipment

Sprinkler irrigation equipment is commercially available from a number of manufacturers. The system is designed to be mobile.

2.5 Site Requirements

The main site requirement for use of sprinkler irrigation is topography with a slope less than 15% and adequate surface drainage.

If an electric drive unit is used, a generator or other source of electricity must be available at the site.

2.6 Limitations of the Technology

When used in tandem with crop irrigation, the effective remediation period is limited to the irrigation season. For western and central U.S. states, the typical irrigation season is from June until September. In other states, such as Florida, irrigation may be performed year round. Rainfall or a low temperature could impact optimal results.

2.6.1 Implemenfation of the Technology

Implementation of the sprinkler irrigation technology will differ from site to site. In order to determine the feasibility of implementing the technology at a specific site, a number of issues should be addressed. These include, but are not limited to, the following: appropriateness of the location, groundwater pumping rate, containment of the groundwater plume, effect on crop production, applicable state regulations, air emissions modeling and monitoring, operational concerns, recharge to an aquifer, and applicable wastes.

These issues were posed to state reviewers during the planning phase of the demonstration activities. A summary of the responses is provided in Appendix A.

2.7 Applicable or Relevant and Appropriate Regulations (ARARs) for Sprinkler Irrigation Technology

ARARs that pertain to the transport, storage, and disposal of wastes generally do not apply because the source of contamination is assumed to be an aquifer and there are no anticipated disposal wastes.

Federal and state ARARs are presented in Table 1. These regulations are reviewed with respect to the demonstration results. State and local regulatory requirements, which may be more stringent, must also be addressed by remedial managers. ARARs may include the following: (1) the Comprehensive Environmental Response, Compensation, and Liability Act; (2) the National Oil and Hazardous Substances Pollution Contingency Plan; (3) the Clean Air Act; (4) the Clean Water Act; (5) the Safe Drinking Water Act; (6) the Solid Waste Disposal Act; and (7) the Occupational Safety and Health Administration regulations. These general ARARs are discussed below.

2.7.1 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)

The CERCLA of 1980 as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986 provides for federal funding to respond to releases or potential releases of any hazardous substance into the environment, as well as to releases of pollutants or contaminants that may present an imminent or significant danger to public health and welfare, or to the environment.

As part of the requirements of CERCLA, the EPA has prepared the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) for hazardous substance response. The NCP is codified in Title 40 Code of Federal Regulations (CFR) Part 300, and delineates the methods and criteria used to determine the appropriate extent of removal and cleanup for hazardous waste contamination.

SARA states a strong statutory preference for innovative technologies that provide long-term protection and directs EPA to do the following:

- use remedial alternatives that permanently and significantly reduce the volume, toxicity, or mobility of hazardous substances, pollutants, or contaminants;

- select remedial actions that protect health and the environment, are cost- effective, and involve permanent solutions and alternative treatment or resource recovery technologies to the maximum extent possible; and

- avoid off site transport and disposal of untreated hazardous substances or contaminated materials when practicable treatment technologies exist [Section 121(b)].

2.7.2 National Oil and Hazardous Substances Pollution Contingency Plan (NCP)

The NCP is required by section 105 of the CERCLA of 1980, 42 U.S.C. 9605, as amended by the SARA of 1986, Pub. L.

The purpose of the NCP is to provide the organizational structure and procedures for preparing for and responding to discharges of oil and releases of hazardous substances, pollutants, and contaminants.

The NCP applies to and is in effect for (1) discharges of oil into or on the navigable waters of the United States, on the adjoining shorelines, the waters of the contiguous zone, into waters of the exclusive economic zone, or that may affect natural resources belonging to, appertaining to, or under the exclusive management authority of the United States and (2) releases into the environment of hazardous substances, and pollutants or contaminants which may present an imminent and substantial danger to public health or welfare of the United States.

2.7.3 Clean Air Act (CAA)

The CAA establishes national primary and secondary ambient air quality standards for sulfur oxides, particulate matter, carbon monoxide, ozone, nitrogen dioxide, and lead. It also limits the emissions of 189 listed hazardous pollutants such as arsenic, asbestos, benzene, and vinyl chloride. States are responsible for enforcing the CAA. To assist in this, Air Quality Control Regions (AQCR) were established. Allowable emissions are determined by the AQCR, or its sub-unit, the Air Quality Management District (AQMD). These emission limits are determined based on whether or not the region is currently within attainment for National Ambient Air Quality Standards (NAAQS).

The CAA requires that treatment, storage, and disposal facilities comply with primary and secondary ambient air quality standards. Emissions from the sprinkler irrigation technology may come from the effluent water mist which may contain small amounts of VOCs. The maximum allowable air emissions are determined by each state on a case-by-case basis.

2.7.4 Clean Water Act (CWA)

The objective of the CWA is to restore and maintain the chemical, physical, and biological integrity of the nation's waters. To achieve this objective, effluent limitations of toxic pollutants from point sources were established. Publicly owned treatment works (POTWs) can accept waste water with toxic pollutants; however, the facility discharging the waste water must meet pre-treatment standards and may need a discharge permit. A facility desiring to discharge water to a navigable waterway must apply for a permit under the National Pollutant Discharge Elimination System (NPDES). When an NPDES permit is issued, it includes waste discharge requirements for volumes and contaminant concentrations.

In its dual function as an irrigation system and separation technology, the sprinkler irrigation system does not generate any waste streams that would be regulated by the

CWA. Therefore, the CWA was not an ARAR for the sprinkler irrigation technology.

2.7.5 Safe Drinking Water Act (SD WA)

The SDWA of 1974, as most recently amended by the Safe Drinking Water Amendments of 1986, requires the EPA to establish regulations to protect human health from contaminants in drinking water. The legislation authorized national drinking water standards and a joint federal-state system for ensuring compliance with these standards.

The National Primary Drinking Water Standards are found in 40 CFR Parts 141 through 149. These drinking water standards are expressed as maximum contaminant levels (MCLs) for some constituents and maximum contaminant level goals (MCLGs) for others. Under CERCLA (Section 121(d)(2)(A)(ii)), remedial actions are required to meet the standards of the MCLGs when relevant.

For the sprinkler irrigation demonstration, EPA Region 7 established the MCLs for each contaminant present in the groundwater, in accordance with the SDWA mandate.

2.7.6 Solid Waste Disposal Act (S WDA)

The Solid Waste Disposal Act, which was passed by Congress in 1965, was the first federal law to require safeguards and encourage environmentally sound methods for disposal of household, municipal, commercial, and industrial refuse. This law was amended in 1970 by the Resource Recovery Act and again in 1976 by the Resource Conservation and Recovery Act (RCRA). The primary goals of RCRA are to protect human health and the environment from potential hazards of waste disposal, conserve energy and natural resources, reduce the amount of waste generated, including hazardous waste, and 4) ensure that wastes are managed in an environmentally sound manner.

The use of sprinkler irrigation for the separation and disposal of VOCs is an environmentally sound remedial option because it relies on an existing process application and there are no additional wastes streams generated. In addition, the use of sprinkler irrigation would result in a significant conservation of energy and natural resources.

2.7.7 Occupational Safety and Health Administration (OSHA) Requirements

CERCLA remedial actions and RCRA corrective actions must be performed in accordance with the OSHA requirements detailed in 20 CFR Parts 1900 through 1926, especially §1910.120 which provides for the health and safety of workers at hazardous waste sites. State OSHA requirements, which may be significantly stricter than federal standards, must also be met.

All personnel operating the sprinkler irrigation system or collecting samples at a hazardous waste site are required to have completed an OSHA training course and must be familiar with all OSHA requirements relevant to hazardous waste sites. Workers on hazardous waste sites must also be enrolled in a medical monitoring program. The elements of any acceptable program must include: (1) a health history, (2) an initial exam before hazardous waste work starts to establish fitness for duty and a medical baseline, (3) periodic (usually annual) examinations to determine whether changes due to exposure may have occurred and to ensure continued fitness for the job, (4) appropriate medical examinations after a suspected or known exposure, and (5) an examination at termination.

For most sites, minimum personal protective equipment for workers will include gloves, hard hats, safety glasses, and steel-toe boots. Depending on contaminant types and concentrations, additional PPE, including respirators or supplied air, may be required.

2.7.6 State Requirements

In many cases, state requirements supersede the corresponding federal program, such as OSHA or RCRA, when the state program is federally approved and the requirements are more strict.

Table 1. Federal and State Applicable or Relevant and Appropriate Regulations (ARARs) for Sprinkler Irrigation Technology

Process Activity	ARAR	Description of Regulation	General Applicability	Specific Applicability to Sprinkler Irrigation
Waste characterization of untreated waste		Standards that apply to identification and characterization of wastes	Chemical and physical analyses must be performed to determine if waste is a hazardous waste.	Chemical and physical properties of waste determine its suitability for treatment by sprinkler irrigation
Waste processing	CAA: 40 CFR Part 50 (or state equivalent)	Regulation governs toxic pollutants, visible emissions, and particulates.	NA	During sprinkler irrigation treatment the concentration of VOCs in the effluent mist must not exceed limits set for the air district of operation. Standards for monitoring and record keeping may apply.
	CERCLA: 40 CFR Part 300	Regulation states a strong preference for innovative technologies that provide for long-term protection.	NA	Sprinkler irrigation is a low-cost, innovative remediation and disposal method that can be used to significantly reduce the toxicity, volume, or mobility of VOCs in groundwater.
Determination of cleanup standards	SARA: Section 121 (d)(2)(A)(ii); SDWA: 40 CFR Part 141	Standards that apply to groundwater sources that may be used as drinking water.	Remedial actions of groundwater are required to meet maximum contaminant level goals (MCLGs) or maximum contaminant levels (MCLs) established under SDWA.	The effluent must be analyzed to determine compliance with MCLs.

Section 3
Economic Analysis

The costs associated with this technology are identified in the 12 cost categories defined by EPA that reflect typical cleanup activities encountered on Superfund sites. These include 1) site and facility preparation, 2) permitting and regulatory requirements, 3) equipment, 4) startup and fixed, 5) labor, 6) consumables and supplies, 7) utilities, 8) effluent separation and disposal, 9) residuals and waste shipping and handling, 10) analytical services, 11) facility modifications and maintenance, and 12) site demobilization.

3.1 Conclusions and Results of the Economic Analysis

The primary purpose of this economic analysis is to provide a cost estimate for application of sprinkler irrigation as a remedial tool in tandem with crop irrigation. The cost categories relevant to the application of this technology include equipment, labor, utilities, analytical services, and maintenance and modifications. Other cost categories that typically apply for site remediations may not be significant for sprinkler irrigation and, therefore, are not addressed in this report. These include site preparation, permitting and regulatory requirements, startup and fixed, consumables and supplies, effluent separation and disposal, residuals and waste shipping and handling, and site demobilization.

Labor and utility costs are based on estimates for crop production in Florida, and are provided for reference only. Cost estimates for these categories will require adjustments to reflect regional wages, utility rates, and crop. The estimates for labor and utility assume an annual pumpage of 10-25 inches of water and 40-500 acres (1.1 - 34 million gallons) coverage for a center pivot irrigation unit.

3.1.1 Equipment Costs

The major piece of equipment is a commercial irrigation unit, sized according to the acreage to be irrigated. Support equipment refers to pieces of purchased or leased equipment that will only be used for one project, or optional items that can be used with the irrigation unit (i.e.- pressure transducer, rain shutoff, flowmeters, surge protectors, gear motors).

The capital cost of the irrigation unit varies according to size. The approximate cost for three different units (including installation and freight costs) is given in Table 2. The estimated costs assume transport of the irrigation equipment from the manufacturer's facility to the Hastings contaminated groundwater site (approximately 150 miles). Freight costs will vary, depending on the site location. For the purpose of these cost estimates, it is also assumed that the irrigation equipment can be tied into water and electrical supplies at the site.

3.1.2 Labor and Utility Costs

Based on the annual pumpage estimates, the labor costs range from 2 - 1250 man-hr (0.05 - 0.1 man-hr/ac-inch). Anticipated utility costs that will be incurred are associated with pumping. Estimated pumping costs range from approximately \$400 - \$22,000 (\$1.00 - \$1.75/ac-inch). The costs will vary depending on the year, crop, location, and fuel source. Typical fuel sources include electricity, gasoline, propane, and diesel fuel.

In addition, the cost to pump the groundwater from the plume to the surface must also be included.

The total treatment cost for a 980 ft unit is estimated to be \$0.07-0.09/gallon (assumes a labor rate of \$10 -20/hour).

Table 2. Installed Costs for Sprinkler Irrigation Equipment

Unit Size (ft)	Acres	Installed Cost	Analytical Tests*	Sub Total	cost**
660	31	$56,000	$1,000	$57,000	$58,000
980	69	$73,000	$2,000	$75,000	$77,000
1300	122	$92,000	$3,000	$95,000	$97,000

Notes:
* To determine the content of **VOCs** in the water.
** Cost indexed for inflation (1997 dollars).

3.1.3 *Maintenance and Modifications costs*

Labor costs and the cost of replacement parts are the major maintenance and modifications costs.

Basic maintenance for irrigation systems include flushing water lines and checking valves and sprinklers, examining valves to ensure they work properly, flushing irrigation lines to remove any sediment which may have accumulated and could clog sprinklers, and checking nozzles for wear. The systems should also be evaluated for proper water pressure, application rate, and application depth.

3.1.4 *Analytical Services*

Sampling and analysis of the system effluent may be performed on a routine basis to ensure proper performance and compliance with regulatory limitations, if stipulated.

Section 4
Sprinkler Irrigation Technology Effectiveness

4.1 Background

The sprinkler irrigation SITE demonstration was conducted at a location down gradient from two subsites, Far-Mar-Co and North Landfill, which are part of the Hastings groundwater contamination site. This location is on the eastern edge of Hastings, Nebraska. The 20-ha (50 acre) experimental site is a furrow-irrigated corn field underlain by commingled plumes of contaminated groundwater. The groundwater is approximately 36.5 m (120 ft) below the land surface and is primarily contaminated with TCE, TCA, 1,1 -Dichloroethene (DCE), cis-1,2-DCE, PCE, CT, and EDB. The Far-Mar-Co subsite is the up gradient source for the CT, EDB, and TCA. The North Landfill subsite is the primary source for TCE, DCE, and PCE.

4.2 Demonstration Objectives and Approach

Demonstration objectives were selected to provide potential users of sprinkler irrigation technology with the necessary technical information to assess the applicability of the system to other contaminated sites.

One primary and four secondary objectives were selected as evaluation criteria. These objectives are summarized below:

Primary objective:

- Determine the efficacy of the sprinkler irrigation system to treat groundwater contaminated with VOCs to concentrations that average below the MCLs; specifically, TCE, CT, and PCE to 5 µg/L, EDB to 0.05 µg/L, and TCA to 200 µg/L at a 95% confidence level.

TCE, CT, PCE, EDB, and TCA were determined to be the contaminants that pose the most significant concern.

The primary objective was achieved by collecting representative samples of the mist emitted from the pivot arm during three test runs. The effluent VOC concentrations for critical VOCs were evaluated.

Secondary objectives:

- Determine costs associated with the application of the technology.
- Evaluate air emissions risks using the ISCST3.
- Calculate the average percent removal of critical VOCs in the sprinkler mist (all heights).
- Calculate the average percent removal of critical VOCs at the lowest sampling height. (Note: The last sampling run was chosen to evaluate this secondary objective to reduce the number of additional sample analyses required of the laboratory. Four samples at the lowest sampling height were collected to evaluate the primary objective. There fore, an additional eight samples were collected and analyzed to meet this secondary objective.)

The secondary project objectives and the associated noncritical measurement parameters required to achieve them are listed in Table 3.

To meet the demonstration objectives, data were collected and analyzed using the methods and procedures summarized in the following section.

Table 3. Noncritical Measurements

Secondary Objective	Measurement Parameter
Determine costs associated with the application of the technology.	Commercial treatment costs including capital equipment, labor, utility, maintenance, and analytical costs.
Evaluate air emissions risks using the **ISCST3.**	Effluent VOC concentrations, ambient temperature, and wind speed and direction.
Calculate the average percent removal of critical **VOCs** in the sprinkler mist.	Influent and effluent VOC concentration for critical **VOCs.**
Calculate the average percent removal of critical **VOCs** at the lowest sampling height during the last sampling run.	Influent and effluent VOC concentrations from lowest sampling height samples during last sampling run.

4.2.1 Demonstration Design

This section describes the demonstration design, sampling and analysis program, and sample collection frequency and locations. The purpose of the demonstration was to collect and analyze samples of known and acceptable quality to achieve the primary objective stated in Section 4.2.

The demonstration was comprised of three separate sampling events. Each event was conducted approximately for one hour after the system had reached a constant water pressure of 241 Kpa (35 ± 1 psi). Each event consisted of start up, attainment of a constant pressure, one hour of constant pressure operation (when sampling occurred), and shut down.

Test conditions (i.e.- wind speed and direction, air temperature) were those that existed at the time of testing since they could not be directly controlled. Each test consisted of three one hour runs. Therefore, the total evaluation period was three operating hours. The runs took place at approximately 9:30 a.m., 2:00 p.m., and 6:00 p.m. The average hourly test conditions for air temperature, humidity, pH, flowrate, pressure, and water temperature represent an average of four measurements (one measurement every 15 minutes). Measurements for barometric pressure, wind direction, and wind speed were taken twice per hourly run.

The test conditions are summarized in Table 4.

The technology demonstration incorporated two operating parameters, pressure and flowrate, that were established by the UNL during past operations.

4.2.1 .1 Sampling and Analysis Program

The objective of the sampling program was to collect sufficient data to evaluate the sprinkler irrigation system for the specific objectives outlined in Section 4.2.

The strategy employed to meet the sampling objectives was to:

- Collect VOC samples and take measurements at the influent and effluent streams during each one hour sampling run.
- Measure the total volume of water that flowed into the system during each sampling event (required for the air dispersion model).

All parameters associated with the critical objective were designated as critical measurements and required sufficient quality control (QC) to ensure that reliable and reproducible data were obtained.

Prior to collecting the initial sample for each sampling event, the irrigation well and transmission lines between the well and the pivot were purged completely and the well

Table 4. Operating and Test Conditions

Process Measurement	Measurement Frequency	Condition 1 [1]	Condition 2 [1]	Condition 3 [1]
Air Temperature," F	Every 15 minutes	80	91	94
Barometric Pressure, mm Hg	One hour intervals	29.83	29.81	29.79
Humidity, %	Every 15 minutes	76	63	61
pH	Every 15 minutes	7.10	---*	7.09, 8.55**, 6.57
Water Flowrate, gpm	Every 15 minutes	1150	1150	1150
Water Pressure, psi	Every 15 minutes	34	35	34
Water Temperature, °F	Every 15 minutes	58.9	59.4	59.6
Wind Direction	One hour intervals	170 (SE) 170 (SE)	190 (SW) 170 (SE)	190 (SW) Variable
Wind Speed, mph	One hour intervals	10	9.5	5.5

Notes:

[1] Raw data for process measurements are provided in Appendix B.

* pH meter was not functioning properly.

** Meter was recalibrated at pH 7 after an unusually high groundwater reading was observed.

was pumped for about 30 minutes. Sample collection and flow measurements began after the water flow through the system was constant as determined by uniform flow meter and pressure readings (1150 gpm and 35 ± 1 psi). For each sampling event, the unit was operated at a constant pressure for approximately one hour, during which time samples were collected at designated sampling points.

4.3 Sampling and Measurement Locations

Sampling locations were selected based on the configuration of the irrigation system and demonstration objectives; analytical parameters were selected based on the contaminants to be treated and project objectives. The sampling points for this demonstration are shown in Figure 1.

The influent sampling location was designated S_0. Effluent points were labeled S_1-S_{12}.

- Influent Location: Sample point S_0 represents the pivot (influent stream sampling point).

- Effluent Locations: Sample points S_1-S_{12} represent the effluent from the sprinkler system (i.e. the sprinkler mist).

Influent VOC water samples were collected at 15-minute intervals from a faucet at the pivot after constant water pressure (35 ± 1 psi) was obtained. Process measurements (air temperature, water temperature, water pressure, flow rate, pH, and relative humidity) were measured and recorded before each influent sample was taken. Wind speed, wind direction, and barometric pressure were obtained prior to the start of each, and at the end of each sampling run from the National Oceanic Atmospheric Administration (NOAA) office in Hastings.

The effluent stream was sampled after constant water pressure was obtained. One sample at each of the four heights was taken from each sample location. The sample scheme was repeated for each of three runs. Samples were analyzed for critical VOCs.

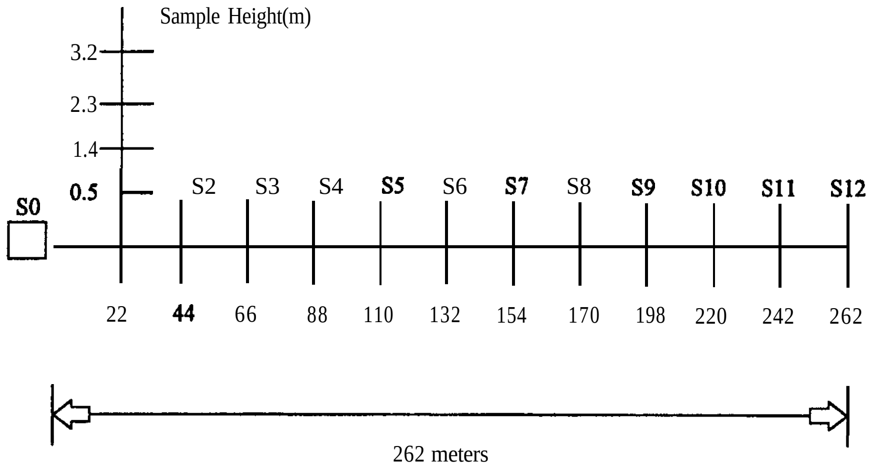

Figure 1. Sampling point location diagram.

4.3.1 Sampling and Analytical Methods

This section describes the procedures for collecting representative samples at each sampling location and analyzing collected samples. Water samples were collected at thirteen locations. These locations include twelve effluent water sampling locations and one influent water sampling location, as previously described. Sampling began after the system was considered to be operating at constant pressure.

There were twelve collectors installed along the length of the pivot arm, approximately 3.7 m (12.1 ft) to its north. This positioning was arranged in order to maximize collection of the relatively fine droplets of the sprinkler mist. The collectors were fabricated from stainless steel. Each collector consists of four rings. Each ring supported an 11-inch glass funnel that collected the sprinkler mist. Each funnel support was attached to a hardened steel rod welded at three-foot intervals to the main vertical support (see Figure 2).

The sampling device allows water droplets to be collected at four different heights, 0.5, 1.4, 2.3, and 3.2 meters (1.6, 4.6, 7.5, and 10.5 ft) above ground, at each of the 12 effluent sampling locations.

4.3.1 .1 Water Samples

A total of 144 primary samples were collected during this demonstration. In addition, duplicates, blanks, and spare samples were also collected for quality control (QC) purposes.

Effluent water samples were collected in new, precleaned and prelabeled 60-mL Teflon-lined screw cap glass vials at each of the 12 locations using a stratified water droplet collector. The sample vial was held beneath the funnel until filled. Care was taken to completely fill each vial so that all of the air would be displaced when the vial was filled with water. If air was present after filling, then additional sample was added and the vial was recapped. This procedure was sometimes repeated several times. If the sampler could not exclude the air after three attempts, the water was poured out and a new sample was collected in the same vial. If three attempts did not produce an acceptable sample, a new vial was filled.

Influent samples were collected by holding the sample vial under the stream of water at the pivot tap. The same procedures used for displacing air of the effluent samples were used for influent samples. Table 5 lists the analytical procedure used for samples collected during the demonstration.

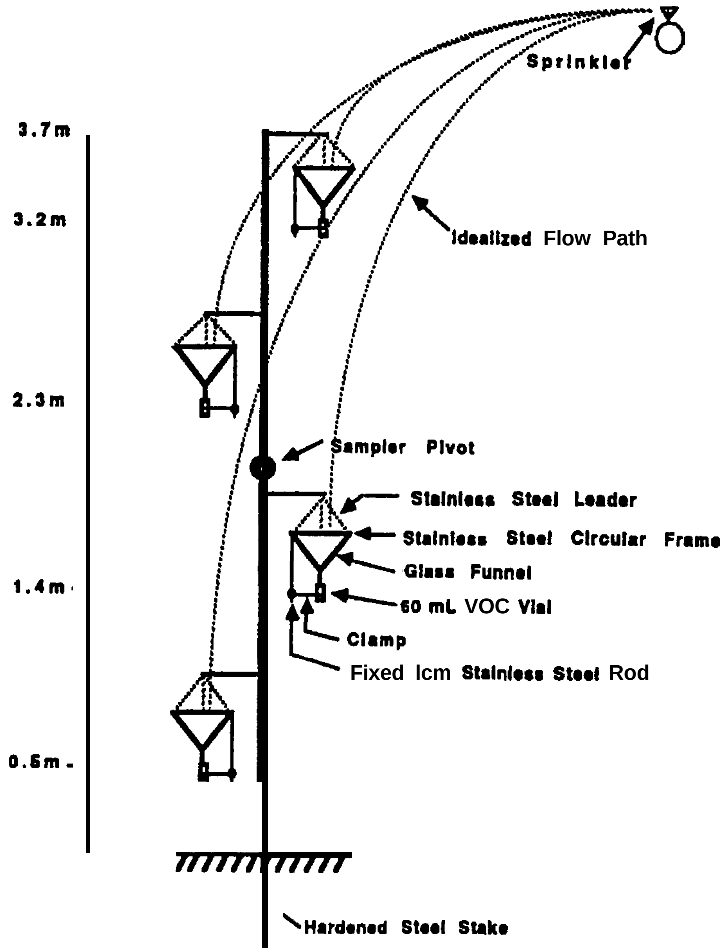

Figure 2. Stratified water droplet collector.

Table 5. Summary Table of Standard Analytical Methods and Procedures

Parameter	Sample Type	Method Number	Method Title	Method Type	Source
VOCs	Influent and Effluent	551.1	Determination of Chlorination Disinfection Byproducts, Chlorinated Solvents, and Halogenated Pesticides/ Herbicides in Drinking Water by Liquid-Liquid Extraction and Gas Chromatography with Electron Capture Detection	GC/ECD	EPA Methods for the Determination of Organic Compounds in Drinking Water

4.3.2 Quality Assurance and Quality Control Program

Quality control checks and procedures were an integral part of the sprinkler irrigation demonstration to ensure that the QA objectives were met. These checks focused on the collection of representative samples and the generation of comparable data. The QC checks and procedures conducted during the demonstration were: (1) checks controlling field activities, such as sample collection and shipping, (2) checks controlling laboratory activities, such as extraction and analysis, and (3) comparison with results obtained by EPA Region 7, including performance evaluation samples and split field samples (§ 4.4). The results of field and laboratory quality control checks are summarized in the following sections. Tables 6-22 provide the results of sampling and QA/QC activities.

4.3.2.1 Field Quality Control Checks

As a check on the quality of field activities, including sample collection, shipment, and handling, three types of field QC checks, field blanks, trip blanks, and temperature blanks were employed. In general, these QC checks assess contamination and temperature of the samples, and ensure that the degree to which the analytical data represent actual site conditions is known and documented. The field QC results are reported in Section 4.3.3 and Tables 19, 20 and 22.

4.3.2.2 Laboratory Quality Control Checks

Laboratory QC checks were designed to determine the precision and accuracy of the analyses, to demonstrate the absence of interferences and contamination from glassware and reagents, and to ensure the comparability of data. Laboratory-based QC checks consisted of method blanks, matrix spikes (MS), duplicates, surrogate spikes, and a comparison with Region 7 performance evaluation samples. The laboratory also performed initial calibrations and continuing calibration checks according to the specified analytical method (see Table 5). The results of the laboratory internal QC checks for critical parameters are summarized in Section 4.4.3 and Tables 13-18, and 21.

4.3.2.3 Field and Laboratory Audits

EPA technical systems audits of field and laboratory activities were conducted July 17 and July 22, 1996. During these audits, observations and suggestions were noted in the areas of (1) project organization and management, (2) field operations and field measurements, (3) sample log-in and custody, and (4) laboratory procedures.

4.4 Demonstration Results

This section presents the operating conditions, results and discussion, data quality, and conclusions of the sprinkler irrigation SITE demonstration. The results of this demonstration, combined with previous results obtained by UNL, provide significant performance data and serves as the foundation for conclusions about the system's effectiveness and applicability to similar remediation projects.

4.4.1 Operating Conditions

During the SITE demonstration, the sprinkler irrigation system was operated at a pressure of approximately 241 Kpa (35 psi), the limit at which the current system had previously been tested. The water flow rate at this pressure was 13 1 ft^3/min (1150 gpm). These values were selected in order to be consistent with the operating conditions during previous UNL tests. To document the system's operating conditions, the pressure gauge and flowmeter readings were recorded at 15 minute intervals. For demonstration purposes, the system operated for a total of three hours. The demonstration consisted of three tests, each for a period of one hour.

Additional parameters that could affect the system performance, but could not be manually controlled, were monitored. These include the wind speed and direction, air temperature, water temperature, and humidity. The barometric pressure and pH were also recorded, although the impact of these parameters on system performance are not considered significant. Appendix B contains all process measurement data.

Weather conditions during the demonstration were obtained from a NOAA weather station located at the Hastings airport, which is approximately 3 km (1.4 miles) northwest of the demonstration site.

4.4.1.1 Sprinkler System Configuration

The sprinkler system evaluated during this demonstration was a Valley 8000 center pivot irrigation system equipped

Table 6. Percent Removal for **VOCs**

Compound	Mean Influent Concentration (μg/L)	Mean Effluent Concentration (μg/L)	Standard Deviation	Mean Effluent Concentration, Height 1 (μg/L)	Overall Percent Removal (%)	Height 1 Percent Removal (%)
TCE	530	13	0.56	5.8	98	99
CT	4.9	0.18	0.007	0.11	96	98
PCE	7.6	0.23	0.011	0.13	97	98
TCA	7.2	0.22	0.009	0.12	97	98
EDB	1.7	0.076	0.003	0.065	96	96

Table 7. Quality Assurance Objectives for Critical Project Measurements

Critical Measurements	Matrix	Method	Units	MDL	Precision [1] RPD	Accuracy [2] % R	Completeness
TCE; CT; TCA; PCE	Water	551.1 (Extraction with methyl-t-but-$ ether (MTBE))	µg/L	0.1 µg/L	Influent ± 20% Effluent ± 30% or ± 0.1 µg/L[3]	80-120%	100%
EDB	Water	" "	" "	0.02 µg/L	Influent ± 20% Effluent ± 30% or ± 0.01 μg/L[3]	80-I 20%	100%
Mass (551.1)	N/A	Balance Check with 2 Standard Weights (50g & 100g)	g	N/A	N/A	± 0.1g	100%

Notes:

‘Precision was evaluated from field duplicate results.
[2]Accuracy was evaluated from matrix spike (MS) results.
[3]Whichever was greater for effluent samples.

Table 8. Hastings Sprinkler Irrigation Demonstration Results - Influent

Sample ID and Data Package Number	TCA (ppb)	CT (ppb)	TCE (ppb)	EDB (ppb)	PCE (ppb)	Surrogate Recovery%
MINF1(9)	8.1	5.6	559	1.9	7.8	108
MINF2 (9)	7.4	5.0	538	1.8	7.4	104
MINF3 (9)	7.3	4.9	484	1.8	7.6	107
MINF4 (9)	a	a	482	a	a	ND
NINF1 (9)	6.8	4.7	535	1.5	7.4	103
NINF2 (9)	7.1	4.8	563	1.6	7.8	108
NINF3 (9)	7.0	4.8	537	1.6	7.6	105
NINF4 (9)	7.1	4.9	541	1.6	7.9	106
EINF1 (11,14)	7.1	4.8	555	1.6	7.6	106
EINF2 (11,14)	6.9	4.7	507	1.6	7.4	103
EINF3 (11,14)	7.1	4.9	533	1.6	7.6	103
EINF4 (11,14)	7.2	4.9	526	1.6	7.5	102

Notes:

[a] There was a problem with the MINF4 injection for compounds with a low concentration. It is believed that the autosample syringe did not inject any sample, therefore, no data were generated for TCA, CT, EDB, and PCE. (TCE was analyzed separately due to its higher concentration). Surrogate recovery also could not be determined.

ND - Not determined.

Table 9. Hastings Sprinkler Irrigation Demonstration Results - Height 1

Sample ID and Data Package Number	TCA (ppb)	CT (ppb)	TCE (ppb)	EDB (ppb)	PCE (ppb)	Surrogate Recovery %
M-SI-HI (15)	0.14	0.12	8.5	0.054	0.14	116
M-S6-H1 (1)	0.12	0.078	5.2	0.026 L	0.11	126
N-S2-H1 (3)	0.097	0.084	4.9	0.042	0.11	92
N-S5-H1 (15)	0.14	0.12	6.8	0.055	0.14	126
N-S6-H1 (3)	0.092	0.088	5.3	0.047	0.11	104
N-S9-H1 (15)	0.12	0.10	5.5	0.046	0.12	122
N-S11-H1 (4)	0.055 D	0.043	**>15** H	0.029 L	0.068	112
E-S1-H1 (5)	0.083 D	0.075	4.3	0.043	0.094	111
E-S2-H1 (5)	0.13 D	0.10	6.5	0.053	0.13	97
E-S3-H1 (5)	0.091 **D**	0.078	4.4	0.643	0.095	105
E-S4-H1 (5)	0.032 D	0.032	4.1	0.046	0.10	88
E-S5-H1 (5)	0.10 **D**	0.096	5.9	0.051	0.12	104
E-S6-H1 (6)	0.099	0.095	5.8	0.048	0.12 **D**	102
E-S7-H1 (6)	0.091	0.082	5.0	0.051	0.10 **D**	110
E-S8-H1 (7)	0.13	0.10	5.3	0.064	0.12	109
E-S9-H1 (6)	0.15	0.14	9.1	0.069	0.16 **D**	I I I
E-SIO-HI (8)	0.11	0.10	6.2	0.056	0.12 **D**	106
E-S11-H1 (6)	0.088	0.075	4.3	0.041	0.10 **D**	116
E-S12-H1 (7)	0.29	0.29	8.5	**0.22**[a]	0.28	102

Notes:

[a] Duplicate sample showed 0.068 ppb

D The CCV closest to sample concentration (diluted sample concentration if applicable) was outside **70%-130%** range. (Effluent samples: 0.5 ppb for TCA, CT, EDB, PCE; 5.0 ppb for TCE)
(Influent samples: 5.0 ppb for TCA, CT, EDB, PCE, and TCE)

H Value was estimated because it was outside of the calibration range and could not be reanalyzed.

L Value was estimated because it was less than the low standard, but greater than the MDL.

Table 10. Hastings Sprinkler Irrigation Demonstration Results - Height 2

Sample ID and Data Package Number	**TCA (ppb)**	**CT (ppb)**	**TCE (ppb)**	**EDB (ppb)**	**PCE (ppb)**	**Surrogate** Recovery %
M-SI-H2 (1)	0.20	0.15	9.8	0.046	0.19	125
M-S6-H2 (15)	0.13	0.11	6.3	0.051	0.13	125
N-S5-H2 (3)	0.14	0.13	8.4	0.060	0.15	105
N-S6-H2 (3)	0.13	0.12	7.2	0.051	0.14	105
N-S7-H2 (3)	0.095	0.081	4.9	0.042	0.11	106
N-S12-H2 (15)	0.19	0.17	**10**	0.074	0.20	122
E-S2-H2 (5)	0.18 **D**	0.15	10	0.067	0.18	113
E-S5-H2 (5)	0.24 **D**	0.18	13	0.087	0.22	117
E-S8-H2 (6)	0.17	0.14	9.4	0.089	0.17 **D**	111
E-S9-H2 (6,7)	0.27	0.23	18	0.092	0.29 **D**	111
E-S10-H2 (15)	0.13	0.12	6.9	0.053	0.14	122
E-S11**-H2** (6)	0.18	0.15	9.7	0.072	0.18 D	122
E-S12-H2 (15,16)	0.27	0.24	17	0.11	0.29	117

Notes:

D The CCV closest to sample concentration (diluted sample concentration if applicable) was outside **70%-130%** range. (Effluent samples: 0.5 ppb for TCA, CT, EDB, PCE; 5.0 ppb for TCE)
(Influent samples: 5.0 ppb for TCA, CT, EDB, PCE, and TCE)

H Value was estimated because it was outside of the calibration range and could not be reanalyzed.

L Value was estimated because it was less than the low standard, but greater than the MDL.

Table 11. Hastings Sprinkler Irrigation Demonstration Results - Height 3

Sample ID and Data Package Number	TCA (ppb)	CT (ppb)	TCE (ppb)	EDB (ppb)	PCE (ppb)	Surrogate Recovery %
M-S4-H3 (1)	0.26	0.19	**>15** H	0.065	0.26	127
M-S6-H3 (1)	0.28	0.20	**>15** H	0.058	0.29	124
M-S7-H3 (1)	0.27	0.19	**>15** H	0.063	0.26	112
N-S2-H3 (3)	0.25	0.22	16	0.081	0.26	110
N-S6-H3 (15)	0.20	0.17	10	0.062	0.19	125
N-S10-H3 (4)	0.23 D	0.19	14	0.080	0.23	104
E-S4-H3 (15)	0.21	0.17	11	0.069	0.21	119
E-S5-H3 (5)	0.27 **D**	0.23	21	0.094	0.28	109
E-S8-H3 (6,7)	0.31	0.26	21	0.11	0.33 **D**	114

Notes:

D The CCV closest to sample concentration (diluted sample concentration if applicable) was outside **70%-130%** range. (Effluent samples: 0.5 ppb for TCA, CT, EDB, PCE; 5.0 ppb for TCE)
(Influent samples: 5.0 ppb for TCA, CT, EDB, PCE, and TCE)

H Value was estimated because it was outside of the calibration range and could not be reanalyzed because it was less than the low standard, but greater than the MOL.

Table 12. Hastings Sprinkler Irigation Demonstration Results - Height 4

Sample ID and Data Package Number	TCA (ppb)	CT (ppb)	TCE (ppb)	EDB (ppb)	PCE (ppb)	Surrogate Recovery %
M-S1-H4 (1)	0.28	0.21	>15 H	0.057	0.27	127
M-S2-H4 (15)	0.31	0.26	>15 H	0.089	0.31	126
M-S4-H4 (15,16)	0.33	0.28	19	0.11	0.32	118
M-S5-H4 (1)	0.67	0.47	>15 H	0.16	0.75	121
N-Sl-H4 (3)	0.23	0.19	14	0.074	0.23	102
N-S11-H4 (4)	0.33 D	0.28	25	0.11	0.34	105
N-S12-H4 (4,5)	0.43 D	0.34	29	0.14	0.44	107
E-S3-H4 (5)	0.35 D	0.29	21	0.12	0.35	110
E-S5-H4 (6)	0.34	0.29	23	0.11	0.37 D	106
E-S11-H4 (6,7)	0.44	0.38	30	0.14	0.48 D	108

Notes:

D The CCV closest to sample concentration (diluted sample concentration if applicable) was outside **70%-130%** range.
(Effluent samples: 0.5 ppb for TCA, CT, EDB, PCE; 5.0 ppb for TCE)
(Influent samples: 5.0 ppb for TCA, CT, EDB, PCE, and TCE)

H Value was estimated because it was outside of the calibration range and could not be reanalyzed..

L Value was estimated because it was less than the low standard, but greater than the MOL.

Table 13. QC Results for Groundwater Analyses - Duplicates (TCA)

Sample Name	Sample Concentration μg/L	Duplicate Concentration μg/L	RPD
MS1 H2	0.21	0.18	15
MS1 H4	0.28	0.27	3.6
MS5H3	0.31	0.37	18
MS6H1	0.12	0.12	0.0
NS6H1	0.092	0.091	1.1
NS7H2	0.095	0.12 D	23
NSl OH3	0.23 D	0.19 D	19
NS10H4	0.50 D	0.41 D	20
ES3H4	0.35 D	0.33 D	5.9
ES5H3	0.27 D	0.29	7.1
ES8H2	0.17	0.13	27
ES12H1	0.29	0.12	83 *
MINF4[a]	---	---	---
NINF4	7.1	7.0	1.4
EINF4	7.2	7.7	6.7

[a] There was a problem with the MINF4 injection for compounds with a low ppb concentration. It is believed that the autosample syringe did not inject any sample, therefore, no data were generated for TCA, CT, EDB, and PCE. (TCE was analyzed separately due to its higher concentration). Surrogate recovery also could not be determined.

* Outside of control limit.

D The CCV closest to sample concentration (diluted sample concentration if applicable) was outside 70%-1 30% range.
(Effluent samples: 0.5 ppb for TCA, CT, EDB, PCE; 5.0 ppb for TCE)
(Influent samples: 5.0 ppb for TCA, CT, EDB, PCE, and TCE)

Table 14. QC Results for Groundwater Analyses - Duplicates (CT)

Sample Name	Sample Concentration $\mu g/L$	Duplicate Concentration $\mu g/L$	RPD
MS1 H2	0.15	0.14	6.9
MS1 H4	0.21	0.21	0.0
MS5H3	0.22	0.27	20
MS6H1	0.078	0.081	3.8
NS6H1	0.088	0.085	3.5
NS7H2	0.081	0.10	21
NS1OH3	0.19	0.17	11
NS1OH4	0.38	0.35	8.2
ES3H4	0.29	0.27	7.1
ES5H3	0.23	0.25	8.3
ES8H2	0.14	0.11	24
ES12H1	0.29	0.11	90 *
MINF4[a]	---	---	---
NINF4	4.9	4.8	2.1
EINF4	4.9	5.3	

Notes:

[a] There was a problem with the MINF4 injection for compounds with a low ppb concentration. It is believed that the autosample syringe did not inject any sample, therefore, no data were generated for TCA, CT, EDB, and PCE. (TCE was analyzed separately due to its higher concentration). Surrogate recovery also could not be determined.

* Outside of control limit.

Table 15. QC Results for Groundwater Analyses - Duplicates (TCE)

Sample Name	Sample Concentration $\mu g/L$	Duplicate Concentration $\mu g/L$	RPD
MS1 H2	9.8	9.1	7.4
MS1 H4	17H	17H	0.0
MS5H3	20 H	25 H	22
MS6H1	5.2 H	5.5	5.6
NS6H1	5.3	5.1	3.8
NS7H2	4.9	6.2	23
NS1OH3	14	12	15
NS1OH4	26	32	21
ES3H4	21	21	0.0
ES5H3	21	20	4.9
ES8H2	9.4	7.2	27
ES12H1	8.5	5.8	38 *
MINF4	482	530	9.5
NINF4	541	540	0.2
EINF4	526	583	10

Notes:

* Outside of control limit.
H Value was estimated because it was outside of the calibration range and could not be reanalyzed.

Table 16. QC Results for Groundwater Analyses - Duplicates (EDB)

Sample Name	Sample Concentration μg/L	Duplicate Concentration μg/L	RPD
MS1 H2	0.046	0.040	14
MS1H4	0.057	0.059	3.4
MS5H3	0.075	0.086	14
MS6H1	0.026 L	0.028 L	7.4
NS6H1	0.047	0.043	8.9
NS7H2	0.042	0.047	11
NS1OH3	0.080	0.071	12
NS1OH4	0.18	0.14	25
ES3H4	0.12	0.11	8.7
ES5H3	0.094	0.092	2.2
ES8H2	0.069	0.055	23
ES12H1	0.22	0.068	106 *
MINF4[a]			---
NINF4	1.6	1.6	0.0
EINF4	1.6	1.7	6.1

Notes:

[a] There was a problem with the MINF4 injection for compounds with a low ppb concentration. It is believed that the autosample syringe did not inject any sample, therefore, no data were generated for TCA, CT, EDB, and PCE. (TCE was analyzed separately due to its higher concentration). Surrogate recovery also could not be determined.

* Outside of control limit.

L Value was estimated because it was less than the low standard, but greater than the MDL.

Table 17. QC Results for Groundwater Analyses - Duplicates (PCE)

Sample Name	Sample Concentration μg/L	Duplicate Concentration μg/L	RPD
MS1 H2	0.19	0.18	5.4
MS1 H4	0.27	0.27	0.0
MS5H3	0.33	0.39	17
MS6H1	0.11	0.11	0.0
NS6H1	0.11	0.11	0.0
NS7H2	0.11	0.13	17
NS10H3	0.23	0.20	14
NS10H4	0.64	0.43	39*
ES3H4	0.35	0.33	5.9
ES5H3	0.28	0.30 D	6.9
ES8H2	0.17 D	0.14 D	19
ES12H1	0.28	0.13	73 *
MINF4[a]	---	---	---
NINF4	7.9	7.6	3.9
EINF4	7.5	8.2	8.9

Notes:

[a] There was a problem with the MINF4 injection for compounds with a low ppb concentration. It is believed that the autosample syringe did not inject any sample, therefore, no data were generated for TCA, CT, EDB, and PCE. (TCE was analyzed separately due to its higher concentration). Surrogate recovery also could not be determined.

* Outside of control limit.

D The CCV closest to sample concentration (diluted sample concentration if applicable) was outside 70%-1 30% range.
(Effluent samples: 0.5 ppb for TCA, CT, EDB, PCE; 5.0 ppb for TCE)
(Influent samples: 5.0 ppb for TCA, CT, EDB, PCE, and TCE)

Table 18. QC Results for Groundwater Analyses

Sample Number (Spike Concentration, ppb) MS or MSD [Data Sets]	Matrix Spike Recovery (%)				
	TCA	CT	TCE	EDB	PCE
M-S5-H4 (5.0) MSD **[1/15,16]**	121	125	*[a]	115	113
M-S1 l-H3 (0.5) MSD **[2/8]**	100	94	*	106	86
M-SIP-HI (5.0) MS **[2/15]**	112	115	104	105	108
M-S12-H2 (5.0) MS **[2/8]**	95	96	118	103	93
N-S2-H3 (0.5) MS **[3/4]**	130	88	*	98	106
N-S2-H3 (1 .O) MSD **[3/8]**	125	108	•	122	114
N-S5-H2 (5.0) MS **[3/4]**	99	97	112	99	97
N-S1 l-HI (0.5) MS **[4/8]**	117	103	•	104	96
N-S1 2-H4 (0.5) MS **[4,5/8]**	104	90	•	104	106
E-S7-H1 (5.0) MS **[6/8]**	100	102	98	101	98
E-S8-H3 (0.5) MS **[6,7/8]**	114	96	*	106	106
E-S9-H2 (0.5) MS **[6,7/8]**	114	96	*	106	108
E-S1 l-H4 (0.5) MS **[6,7/8]**	96	80	*	102	88
MINF4 (5.0) MS **[9/11,14]**[b]		--	*		
NINF4 (5.0) MS **[9/1** 1,141	98	94	*	100	82
EINF4 (5.0) MS **[11,14/11,14]**	78	100	•	93	95
QA Recovery Objective	80-120	80-120	80-I 20	80-120	**80-1**20

Notes:

* Inappropriate spike level: spike amount too low compared to sample concentration.

[a] While a 5.0 ppb spike was used, the native concentration of TCE in this effluent sample was seven times greater (i.e., 35 ppb). Recovery was 60%.

[B] There was a problem with the MINF4 injection for compounds with a low ppb concentration. It is believed that the autosample syringe did not inject any sample, therefore, no data were generated for TCA, CT, EDB, and PCE. **(TCE** was analyzed separately due to its higher concentration). Surrogate recovery also could not be determined.

Table 19. QC Results of Field Blank Analyses

Blank Type (Data Set)	TCA µg/L	CT µg/L	TCE µg/L	EDB µg/L	PCE µg/L
Field (1)	.029 u	.0084 U	.016 U	ND	.013 u
Field (3)	.027 U	.0083 u	.017 u	ND	.038
Field (4)	.051	.012 u	.022 u	ND	.038
Acceptance Criteria	<40	<1	<1	<0.018	<1
MDL	0.036	0.030	0.025	0.018	0.036

Notes:

ND Not detected.
U Value was less than the MDL.

Table 20. QC Results of Trip Blank Analyses

Blank Type (Data Set)	TCA µg/L	CT µg/L	TCE I d -	EDB & L	PCE µg/L
Trip (1)	.028 U	.0077 u	ND	ND	.0048 U
Trip (3)	.026 U	.010 u	ND	ND	.030 u
Trip (4)	.026 U	,011 u	ND	ND	.029 u
Trip (7)	.030 u	.020 u	.021 u	ND	.047 *
Trip (9)	.026 U	.013 u	.0082 U	ND	.046 •
Trip (9)	.042 •	.022 u	ND	ND	.049 •
Acceptance Criteria	c MDL	< MDL	<MDL	<MDL	<MDL
MDL	0.036	0.030	0.025	0.018	0.036

Notes:

ND Not detected.
U Value was less than the MDL.
• Outside of control limit.

Table 21. QC Results of Laboratory Blank Analyses

Blank Type (Data Set)	TCA $\mu g/L$	CT $\mu g/L$	TCE $\mu g/L$	EDB $\mu g/L$	PCE $\mu g/L$
Laboratory (2)	0.029 u	0.0092 u	ND	ND	0.0091 u
Laboratory (3)	0.025 U	0.010 u	ND	ND	0.030 u
Laboratory (4)	0.026 U	0.010 u	ND	ND	0.035 u
Laboratory (5)	0.029 u	0.010 u	ND	ND	0.034 u
Laboratory (6)	0.025 U	0.098	ND	ND	0.030 u
Laboratory (7)	0.026 U	0.013 u	0.0063 U	ND	0.034 u
Laboratory (8)	0.032 U	0.0092 u	0.0062 U	ND	0.0021 u
Laboratory (9)	0.027 U	0.016 U	ND	ND	0.042
Laboratory (9)	0.043	0.027 U	ND	ND	0.013 u
Laboratory (11)	0.025 U	0.013 u	ND	ND	0.041
Acceptance Criteria	<40	<1	<1	<0.018	<1
MDL	0.036	0.030	0.025	0.018	0.036

Notes:

ND Not detected.
U Value was less than the MDL.

Table 22. Temperature Blanks

Cooler Number	Temperature Blank 1, °C	Temperature Blank 2, °C
1	13.5	13.5
2	10.0	10.0
3	10.5	10.5
4	11.5	12.0
5	4.0	4.0
6	2.0	---[a]
7	14.0	12.5
8	8.5	---[a]
9	**2.0***	---[a]

Notes:

* Water temperature inside of the cooler.

[a] Sample was not collected.

with off-the-shelf impact pads. The nozzle aperture along the pivot arm ranged from 2.0 mm (0.08 in) to 6.4 mm (0.25 in). The total length of the pivot arm was 232 m (859ft).

4.4.2 Results and Discussion

This section presents the results of the sprinkler irrigation SITE demonstration in Hastings, Nebraska and a comparison of results obtained from split sample which were collected by Region 7 personnel. The results are presented by, and have been interpreted in relation to, project objectives. The data used to evaluate the primary objective are presented in Tables 8-12. Data quality and conclusions based on these results are presented in Section 4.4.3. A discussion of the sampling activities and results obtained by Region 7 is provided in Appendix C.

The data obtained from the experiment were analyzed to statistically determine if the average concentration of VOCs exceeds the stated MCLs. All statistical inference and estimation were based on the fact that samples were collected using stratified random sampling (Appendix D).

4.4.2.1 Primary Objective

The primary objective was considered critical for the evaluation of the sprinkler irrigation system as a remediation and disposal alternative for VOC contaminated groundwater.

Primary Objective

Determine the efficacy of the sprinkler irrigation system to treat groundwater contaminated with VOCs to concentrations that average below the MCLs; specifically, TCE (<5µg/L), CT (<5 µg/L), PCE (<5 µg/L), TCA (<200 µg/L), and EDB (<0.05 µg/L) at a 95% confidence level.

This objective was achieved by collecting samples of the sprayed effluent water which was emitted from the nozzles along the arm of the system and analyzing the samples for VOCs.

Based on the results of data from all sampling heights, the mean effluent concentration of TCA (0.224 µg/L), CT (0.183 µg/L), and PCE (0.231 µg/L) were shown to be well below the respective MCLs of 200 µg/L (p=1.0000), 5 µg/L (p=1.0000), and 5 µg/L (p= 1.0000). A 95% confidence interval on the mean level of TCA was (0.206,0.242), (0.169,0.196) for CT, and (0.210,0.252) for PCE. For TCE, the mean concentration (12.623) was shown to be significantly greater than the MCL of 5 µg/L (p=.0001). A 95% confidence interval on the mean level was (11.52, 13.72). The mean concentration of EDB (0.076) was shown to be significantly larger than the MCL of 0.05 µg/L (p=0.0001). A 95% confidence interval on the mean level was (0.069,0.082). Table 6 presents the mean influent concentration for all contaminants of concern.

The results of data from the lowest sample collection height indicate that the mean effluent concentration of TCA (0.116 µg/L), CT (0.108 µg/L), and PCE (0.128 µg/L) were well below the respective MCLs. A 95% confidence interval on the mean level of TCA was (0.087,0.145), (0.079,0.136) for CT, and (0.104,0.152) for PCE. For TCE, the mean concentration (5.783) µg/L was shown to be significantly greater than the MCL. A 95% confidence interval on the mean level was (5.022,6.545). The data collected provided no indication that the mean level of EDB (0.065) was significantly larger than the MCL. A 95% confidence interval on the mean level was (0.042,0.089) which overlaps the 0.05 µg/L MCL for EDB.

A summary of the data analysis is provided in Appendix E.

4.4.2.2 Secondary Objectives

Secondary objectives provide additional information that is useful, but not critical, for the evaluation of the sprinkler irrigation technology. Four secondary objectives were selected for the SITE demonstration of the sprinkler irrigation system. The noncritical measurement parameters required to achieve the secondary project objectives are presented in Table 3.

4.4.2.2.1 Secondary Objective S-l

Determine costs associated with the application of the technology.

The estimated cost to install a sprinkler irrigation system and perform compliance sampling at the Hastings site ranges from \$58K to \$97K (see Table 2). Operation and maintenance costs are estimated to be \$35K per year. Labor and utility (pumping) costs will vary depending on the site location and crop and are estimated to be 0.05-0.1 man-hr/acre-inch and 1.00-1.75 \$/acre-inch, respectively.

4.4.2.2.2 Secondary Objective S-2

Evaluate air emissions risks using the ISCST3.

Removal of the VOCs from groundwater and subsequent release into the atmosphere in the gaseous phase could pose a potential inhalation risk to individuals working or residing in the area of the irrigation system. The NDOH evaluated the magnitude of this inhalation risk and determined the carcinogenic risk and hazard index (Appendix F).

The risk assessment evaluated inhalation risks for the most likely individuals to be exposed to the irrigation system, specifically, site workers and observers present during the demonstration and nearby residents exposed to emitted volatiles during a long-term remediation at the site. The locations of these receptors in relation to the irrigation system were identified using a global positioning system.

The average concentrations of contaminants detected in the groundwater were input into the Industrial Source Complex Model (ISCST3) to predict volatile concentrations of these chemicals from the irrigation system. The concentrations of contaminants in the air as well as the standard default assumptions were utilized to quantify the noncarcinogenic and carcinogenic risks potentially associated with the SITE Demonstration.

The proposed remediation technology is predicted to operate 24 hours/day during a maximum summer irrigation season in Nebraska of 90 days. The potential inhalation risk for two of the nearest residents to the irrigation system was evaluated by the NDOH. The noncarcinogenic and carcinogenic risks for a child resident at both of these locations was quantified to ensure protection of this sensitive subgroup.

The carcinogenic risks were calculated to be: TCE - 2.41×10^{-10}; CT - 1.45×10^{-10}; and EDB - 7.8×10^{-11}. The calculated hazard indexes were: TCA - 9.48×10^{-8}; CT - 3.40×10^{-5}; and EDB - 1.32×10^{-4}. The Carcinogenic Risk Reference Value was 1 x 10-6. The Hazard Index Reference Value was 1.00.

Predicted carcinogenic risk factors and hazard risks were also calculated for remediation applications.

For remediation applications, the technology is predicted to operate 24 hours/day during a maximum summer irrigation in Nebraska of 90 days. The potential inhalation risk for two of the nearest residents to the irrigation system was evaluated by the NDOH. The noncarcinogenic and carcinogenic risks for a child resident at both of these locations was quantified to ensure protection of this sensitive subgroup.

The carcinogenic risks were calculated to be: TCE - 1.83 x 10^{-10}; CT - 0.92 x 10^{-9}; and EDB - 0.74 x 10^{-10}. The calculated hazard indexes were: TCA - 1.75 x 10^{-7}; CT - 2.13 x 10^{-3}; and EDB - 1.18 x 10^{-4}. The Carcinogenic Risk Reference Value was 1 x 10-6. The Hazard Index Reference Value was 1.00.

4.4.2.2.3 Secondary Objective S-3

Calculate the average percent removal of critical VOCs in the sprinkler mist.

Based on the sprinkler irrigation demonstration results, the overall reduction of individual VOCs were: TCE - 98%, CT - 96%, PCE - 97%, TCA - 97%, and EDB - 96%. The overall percent removal for each VOC is shown in Table 6.

4.4.2.2.4 Secondary Objective S-4

Calculate the average percent removal of critical VOCs at the lowest sampling height during the last sampling run.

All samples collected during the last sampling run from the lowest sampling height (H_1) were analyzed in order to determine an average percent removal of critical VOCs. The results of data from the lowest sample collection height indicate that the average percent removals were: TCE - 99%, CT - 98%, PCE - 98%, TCA - 98%, and EDB - 96%. The overall percent removal for each VOC is shown in Table 6.

4.4.3 Data Quality

This section discusses the QA data with respect to project QA objectives. Specifically, instances of nonconformance and the impact, if any, on the overall project objectives are discussed. Tables 13-22 summarize key QA/QC data with respect to the QA objectives, field QA/QC, and internal QC.

A data quality assessment was conducted to incorporate the analytical data validation results and the field data quality QC results, evaluate the impact of all QC measures on the overall data quality, and remove all values which did not meet QC criteria from the investigation data set. The results of this assessment were used to produce the known, defensible information used to define the evaluation findings and derive conclusions.

The overall QA objective for the SITE Program demonstration was to produce well-documented data of known quality as indicated by the data's precision and accuracy, completeness, representativeness, comparability, and the reporting limits for the analytical methods. Specific quality assurance objectives were established as benchmarks by which each of these criteria would be evaluated. The following sections outline the QA objectives that were established.

4.4.3.1 Critical Parameters

This subsection discusses conformance with QA objectives for laboratory analyses for all critical parameters analyzed by EPA NRMRL. QA objectives for laboratory analysis of critical VOCs (TCA, CT, TCE, EDB, PCE) were evaluated based on MSs, blanks, duplicates, surrogate compound analysis, and calibration criteria. QA objectives for the critical mass measurements made in the laboratory were evaluated based on measurement of a standard weight.

4.4.3.1.1 Completeness

The QA Objective for data completeness specified by the QAPP stipulated that 100 percent of all effluent sample measurements necessary to draw statistically valid conclusions would be obtained and would be valid. A May 22, 1996 memorandum estimating sample size states "the recommended number of total samples 40. The 40 samples would be evenly distributed across each strata, ten samples from each sampling height. The samples would be randomly selected from the 36 samples collected at each height."

Due to significant analytical variations, (i.e., continuing calibration checks and surrogates fell outside acceptance criteria) sample results generated from 07/22/96 to 07/23/96 were not used to draw conclusions. The GC was recalibrated and back-up samples were analyzed to obtain data for 10 samples from each strata, with one exception.

Adequate quality data were generated for only nine height 3 samples. Thus, the percent completeness was actually 97.5% instead of 100%. All sample results used to evaluate objectives are reported. These results are discussed in more detail in Appendix E. All effluent samples were analyzed within the holding times specified in the QAPP.

The statistical analysis performed weighted each strata based on the number of samples present. Therefore, although only 97.5% completeness was achieved, a sufficient number of valid VOC measurements were obtained to evaluate the project objectives.

4.4.3.1.2 Comparability and Analytical Reporting Limits

All critical VOC data are considered to be comparable. As specified by the QAPP, the EPA NRMRL laboratory used Method 55 1.1 (USEPA, Revision 1.0) to analyze all VOC sample fractions. The low-level method detection limits (MDL) specified in Table 7 were mostly met in the MDL study performed prior to the project. The MDLs for TCA, CT, TCE, EDB, and PCE were 0.036 µg/L, 0.030 µg/L, 0.025 µg/L, 0.018 µg/L, and 0.036 µg/L, respectively.

4.4.3.1.3 Accuracy and Precision

QA Objectives for accuracy and precision were evaluated based on MS percent recoveries and relative percent differences (RPDs) respectively. Surrogate compound percent recovery values also supported QA Objectives for accuracy.

<u>ACCURACY - Matrix Spikes</u>

As specified in the QAPP, field personnel collected three sequential samples to provide a primary sample, an MS sample, and a back-up matrix spike duplicate (MSD) sample (i.e., the MSD sample was only used if the MS sample was unusable). Sixteen primary/MS/MSD effluent sample triplicates were collected. In addition, three primary MS/MSD influent sample triplicates were collected. Table 18 details MS recovery results for 13 spiked samples (i.e., data generated from 07/22/96-07/23/96 are not reported). Seven of the thirteen effluent MS or MSD samples were spiked at 0.5 ppb, five were spiked at 5.0 ppb, and one was spiked at 1.0 ppb. The samples were spiked at different concentrations to obtain recovery results for all five critical contaminants. Typically, the 0.5 ppb and 1.0 ppb spikes were appropriate for TCA, CT, EDB, and PCE in the effluent samples. The 5.0 ppb spike was appropriate for TCE in the effluent samples and for TCA, CT, EDB, and PCE in the influent samples. The influent TCE concentration was too high to enable an adequate spike to be performed.

All critical spike data exhibited recoveries within 70-130% (when spiked at the appropriate level).

The following was observed:

- All TCA, CT, EDB, and PCE data exhibited recoveries within the QAPP specified limits (80-120%) except four TCA recoveries, one CT recovery, and one EDB recovery. As previously stated, these results were within 70-130%.

- All appropriately spiked samples for TCE exhibited recoveries within the QAPP specified limits (80-120%).

Because the MCL for TCA was 200 ppb, and sample results for TCA were all < 1 ppb, the wider recovery results (70-130%) are acceptable for meeting project objectives relative to TCA.

Similarly, because sample results for CT were all < 1 ppb, and the CT MCL was 5 ppb, the wider recovery results (70-130%) are acceptable for meeting project objectives relative to CT.

The spike result that was outside QAPP specified limits for EDB was sample N-S2-H3-MSD. The percent recovery was 122%. Eleven of the other 12 effluent spike recoveries were between 98 and 106%. (The remaining one was 115%). There does not appear to be any matrix affect with EDB since acceptance criteria was only slightly exceeded for one spiked sample.

<u>ACCURACY - Surrogates</u>

The acceptance criteria for all samples was 80-120%. The surrogate recovery for each sample is provided in Tables 8-12. After several samples were analyzed, the analyst observed that the 80-120% criteria was not met in all cases. Project and QA Management reviewed the data and determined that wider acceptance criteria would still allow project objectives to be met. Therefore, 70-130% was used. It should be noted that most of the surrogates exceeded this range in samples analyzed on 07/22/96 and 07/23/96, and therefore, additional samples were analyzed.

For results used to evaluate project objectives, surrogate recoveries ranged from 86-127%. Fourteen of the 51 effluent samples had surrogate recoveries between 120-127%. Because the effluent sample results were significantly lower than the MCLs for TCA, CT, and PCE, these higher recoveries have no effect on project conclusions. In other words, even if sample results were biased high, TCA, CT, and PCE still met the MCLs.

For TCE and EDB, effluent sample results (total across heights) were significantly higher than the MCLs for these compounds. For TCE, even if samples were biased high by 30%, project conclusions would remain unchanged. The higher surrogate recoveries have no effect on project conclusions for TCE. The mean for EDB, however, was 0.076 ppb (EDB MCL was 0.05). If sample results were biased high (even by < 30%), project conclusions for EDB may change because the mean is so close to the MCL.

All surrogate recoveries met QAPP specified limits (80-120%) for Height 1 data; therefore, secondary objective 4 was met.

In sum, it appears that surrogate recoveries obtained for project samples were acceptable for meeting the primary project objective with the possible exception of EDB. The recoveries obtained were acceptable for meeting secondary objective 4.

<u>ACCURACY - Mass</u>

The determination of mass was made using a standard analytical balance. The balance calibration was checked with standard 50 and 100 g weights prior to each use.

<u>PRECISION - Sample Duplicates</u>

As specified in the QAPP, twelve effluent sample duplicates were collected and analyzed. The results of these duplicates (see Tables 13-17) indicate that all compounds met the QAPP specified criteria in all samples with the exception of PCE in the sample pair N-S10-H4/N-S10-H4-D, and all compounds in sample pair E-S12-H1/E-S12-H1-D.

It should be noted that for sample N-S10-H4, surrogate recovery was also high (152%). This sample was not reanalyzed. Because PCE concentrations were well below the MCL, the higher RPD obtained for the duplicate pair will not affect project conclusions.

It is uncertain why sample pair E-S12-H1/E-S12-H1D did not meet the criteria. No explanation could be derived.

4.4.3.1.4 Represen tativeness and Sample Contamination

Field personnel ensured representative sampling by allowing the water to purge through the sprinkler for a consistent amount of time prior to sampling, and by collecting samples in the same manner at all similar points.

The EPA NRMRL laboratory analyzed field, trip, and method (laboratory) blank samples to determine if any VOCs were potentially introduced during sample collection, shipping, preparation, and analysis.

Two field blanks for each sampling event were collected to provide a check on sample contamination originating from field conditions. Two beakers were filled with distilled water and were placed upwind of the sprinkler system at opposite ends of the sprinkler arm at the start of each sampling run. At the end of the run, the water was poured into screw cap vials and shipped as samples. One field blank from each run was analyzed.

Two temperature blanks for each sampling event were prepared and placed in different locations within the cooler. These were prepared by filling two extra vials at the last sampling point (S_{12}) for each sampling event. The temperature was measured and recorded when the samples were received at the laboratory.

Trip blanks are designed to provide a check on sample contamination originating from sample transport, shipping and site conditions. Trip blanks for the water sampling were prepared by filling screw cap glass vials with reagent water, transferring them to the demonstration site, and then returning them unopened with the samples to the laboratory. Two trip blanks were used per cooler.

All field and method blank sample results met QAPP specified criteria as can be seen in Tables 19 and 21. Three trip blanks (Table 20) did not meet QAPP specified criteria for PCE. One of those three did not meet QAPP specified criteria for TCA. All blank values were still < 0.05 µg/L. Because sample results were lower than the MCLs for PCE and TCA, there is no effect on project conclusions due to these > MDL blank values. The reported concentrations of critical parameter VOCs appear to be representative of actual concentrations in the effluent samples based on available QC data.

The EPA NRMRL laboratory measured the temperature of the temperature blanks after opening each cooler at the laboratory. The temperature blank results are indicated in Table 22.

The results indicate that all samples were not cooled to 4°C as specified in the QAPP. Because VOC contaminants could be lost at higher temperatures, sample results could be biased low. Coolers 3 and 4, however, contained Region 7 PE samples shipped from the field. The results of the PE samples were acceptable, therefore it is believed that sample concentrations were not affected by slightly > 4°C temperatures.

4.4.3.1.5 Conformance with Calibration Requirements

GC calibration was performed taking into account the anticipated high levels of TCE compared to all other contaminants of interest. Two calibration curves were prepared, a high curve (0.5 ppb to 15 ppb) and a low curve (0.03 ppb to 1 ppb). A linear fit was used for the low curve, while a quadratic fit was used for the high curve. Samples were extracted as specified in the QAPP. One portion of the extract was saved and the other portion was analyzed. Contaminant concentrations <1 ppb were quantitated using the low curve. Contaminant concentrations between 1 ppb and 15 ppb were quantitated using the high curve. In most cases, if any contaminant concentration exceeded the range of the high curve (i.e., 15 ppb), the saved extract was diluted and the diluted extract was injected to obtain the actual concentration. It should be noted that seven TCE concentrations exceeded the range of the high curve but were not diluted and reanalyzed. These results are flagged. Because these sample results exceed 15 ppb, well above the MCL of 5 ppb, there is no effect on project conclusions.

Continuing calibration verifications (CCVs) at the 0.5 ppb level frequently exceeded the QAPP specified criteria (80-120%) for TCA in the effluent samples. Less frequently, 0.5 ppb CCVs exceeded the QAPP specified criteria for CT and PCE. The acceptable CCV range was raised to 70-130% because the affect on data quality was thought to be minimal. Because sample results for TCA, CT and PCE are well below the respective MCLs, there is no effect on project conclusions.

A 5.0 ppb standard was used to check the adequacy of the calibration curve for TCE. No 5.0 ppb standard was performed for data sets 1 or 15, but the 0.5 ppb standard was performed and the TCE CCV was within the 70-130% range. All 5.0 ppb CCVs met QAPP specified criteria for TCE (for other data sets). Project conclusions are not impacted.

All EDB CCV results met the QAPP specified criteria.

4.4.3.1.6 Data Validation

A validation review of the analytical data for the groundwater samples was conducted to ensure that all laboratory data generated and processed are scientifically valid, defensible, and comparable.
A data quality assessment was conducted to incorporate the analytical data validation results and the field data quality QC results, evaluate the impact of all QC measures on the overall data quality, and remove all unusable values from the investigation data set. The results of this assessment were used to produce the known, defensible information used to define the evaluation findings and derive conclusions.

Section 5
References

1. U.S Environmental Protection Agency. 1996. Demonstration Plan for Sprinkler Irrigation as a VOC Treatment and Disposal Method.

2. Spalding, Roy F. And Burbach Mark E. 1994. "Sprinkler Irrigation: A VOC Remediation Alternative." *Journal of the Franklin Institute,* 1994. Vol. 331A, pp. 231-241.

3. Office of Federal Register. 1993. *Code of Federal Regulations Title 40,* Protection of Environment. U.S. Government Printing Office, Washington, D.C. July 1993.

4. Florida Agricultural Information Retrieval System (http://www.agnic.org/agdb/fairs.html).

5. STATKING Consulting, Inc. 1997. Nebraska Demonstration Project for Sprinkler Irrigation: Hastings Irrigation Water Contamination Study.

Appendix A

The following list of questions relating the sprinkler irrigation SITE demonstration was presented to state reviewers from California, Florida, New Mexico, and Nebraska.

Table A-l. Sprinkler Irrigation Technology Implementation Factors - State Responses

Factor (Question)	California	Florida	New Mexico	Nebraska
Is irrigation appropriate for this state?		Depends on the amount of rainfall. During some times of the year, the ground is saturated and water runoff may be a concern.	Irrigation is a good method. There usually is not a problem associated with runoff.	Irrigation is very common in Nebraska. The demonstration site is currently used for crop production and has been previously irrigated.
Is the irrigation groundwater pumping rate a concern?				The pumping rate for irrigators in Nebraska often range from 500-1000 gpm due to the productive aquifers. Groundwater use is regulated by the state and each irrigation well must be registered. An existing irrigation well was used for the SITE demonstration.
Will irrigation contain the groundwater plume?		Modeling will be required to account for mounding effects.		A modeling analysis previously performed at the Hastings location predicted the irrigation pumping at the rates proposed would contain the plume. The modeling evaluated whether seasonal pumping of the irrigation well at the higher irrigation rates would act in the same manner as lower rate year-round remediation pumping.
Would the use of solvent contaminated groundwater have an adverse affect ***on crop production?***				If the demonstration goals are achieved, the water that reaches the crop and the ground will meet drinking water standards. The health department (and others) have indicated that the plants do not accumulate VOCs.

Table A-l. Sprinkler Irrigation Technology Implementation Factors - State Responses (continued)

Factor (Question)	California	Florida	New Mexico	Nebraska
What are the state *regulations and concerns for air emissions?*		Permit requirements are 15 **lbs/day** and 800 **lbs/year.** Permits are site-specific. A permit is required for non-petroleum sites.	No permit is required as long as the emissions are below 10 **lbs/hour** or 10 tons/year.	The mass emission threshold is 2.5 tons/year for permitting (1 ton/year for the demonstration scenario).
How does the site specific air modeling employed for the SITE demonstration compare with other situations?		Currently uses the deterministic method.	Will accept the use of an EPA air dispersion model (air and risk).	Actual data were used, where possible, including contaminant concentrations from previous testing, actual physical dimensions of the irrigation system, and actual distances to exposure points. The calculation methods were **standard** EPA procedures for risk assessment. A standard EPA air dispersion model was also used. It is anticipated that these models could be used to evaluate other scenarios.
Would air monitoring be required?	Could get a permit to construct. Monitoring would probably be required.	"Up front" modeling would probably be required.	Precautionary "up front" modeling.	Not typically.
What *are the operational concerns?*		Manifold piping; evenly distributed flow through the nozzles; high water tables may require that the system be shut off for a while.		The control of leaks and **non-**spray discharges.

Table A-l. Sprinkler Irrigation Technology Implementation Factors - State Responses (continued)

Factor (Question)	California	Florida	New Mexico	Nebraska
Would there be concern regarding recharge to the aquifer?		Typically, drinking water standards are in force. However, If a determination that the discharge is surface water, then NPDES regulations **apply.**	Not a concern.	No. The predicted performance indicates that the discharged water would meet drinking water standards.
Would RCRA of Land Disposal Regulations be a concern?				No. The **LDRs** are greater than the **MCLs.**
Should there be concern about the non-destruction of VOCs?		Site specific. The target reduction is 90%.	Site specific. More stringent standards for sites located in the city (i.e. Albuquerque) than for remote sites.	Literature indicates that the **VOCs** naturally degrade in air and sunlight, although the degradation rate depends on the compound.
Are there any operational considerations that ***may limit the application of the technology?***		Year round irrigation in the northern part of the state.	Large temperature fluctuations. Altitude. Irrigation will occur during the summer.	Rainfall and temperature.
Would the system be able to strip **VOCs** other than those being evaluated through the SITE demonstration?				Henry's Law may be used to predict how easily a compound may be stripped from water.

Appendix B

Table B-l. Process Measurements - Sprinkler Irrigation SITE Demonstration

Process Measurement	Value		
	Run 1 (Morning)	Run 2 (Noon)	Run 3 (Evening)
Barometric Pressure, mm Hg	**29.83**	29.81	29.79
Barometric Pressure, mm Hg	----	29.80	---
Wind Direction	170	190	190
Wind Direction	170	170	Variable
Wind Speed, mph	09	09	07
Wind Speed, mph	011	IO	04
Water Temperature," F	59.5	59	60.5
Water Temperature," F	58.5	60	60
Water Temperature, ° F	58.5	60	59
Water Temperature," F	59.0	58.5	59
Water Pressure, psi	34	35	34
Water Pressure, psi	34	35	34
Water Pressure, psi	34	35	34
Water Pressure, psi	34	35	34
Air Temperature, ° F	79	90	96
Air Temperature, ° F	80	91	93
Air Temperature, ° F	81	91	93
Air Temperature, ° F	81	91	92
pH	7.08	---	7.09
pH	7.09	---	8.55
pH	7.11	---	6.57
pH	7.11	- -	
Humidity, %	77	63	55
Humidity, %	77	63	62
Humidity, %	77	63	65
Humidity, %	74	62	63
Flowrate, gpm	1150	1150	1150
Flowrate, gpm	1150	1150	1150
Flowrate, gpm	1150	1150	1150
Flowrate, gpm	1150	1150	1150

Appendix C
Project Objectives for Region 7 Sampling

The purpose of the sampling event conducted by Region 7 was to collect groundwater split samples during the SITE Demonstration from irrigation well I-49 and to analyze the samples for chlorinated solvents and EDB. The Region 7 results were compared to the analytical results obtained by NRMRL to determine any bias in the analytical methods and preservation techniques used by NRMRL.

Elevated levels of VOCs were present in the influent samples and very low levels of VOCs were present in the samples collected after the water was discharged through the spray irrigation system. The information from the SITE Demonstration was evaluated by EPA's Regional office for inclusion in this Innovative Technology Evaluation Report.

Introduction

Three influent and nine effluent groundwater samples were collected and analyzed. The effluent samples were collected from locations 10, 11 and 12, which were beneath the nozzles with the largest openings. EPA Region 7 selected these locations as the locations where the irrigation system would most likely fail to adequately strip the VOCs from the water.

Site Description

The North Landfill/Far-Mar-Co subsite is located in Hastings Nebraska. Since 1983, EPA has been investigating the groundwater contamination in and adjacent to the city of Hastings. Contaminants associated with the North Landfill subsite include TCE, TCA, PCE, DCE and vinyl chloride (VC). Contaminants associated with the Far-Mar-Co subsite include CCl_4 and EDB. I-49 is an irrigation well located down gradient from both of these subsites. Three tests have been performed on this well. The first test was a pump test and the second and third tests were sprinkler irrigation studies. The first test, which investigated the effects of the sprinkler head design in relation to the volatilization of VOCs, was performed by the University of Nebraska. The second test was conducted by Region 7 and the third test was the SITE Demonstration which was conducted in July 1996.

Site History

The Hastings Groundwater Contamination site includes seven subsites. The information collected for this limited study was from one irrigation well, I-49. The SITE Demonstration, forms the basis for the evaluation of the sprinkler irrigation performance for remediation of groundwater contaminated sites. The demonstration consisted of three separate sampling events, one each in the morning, noon, and evening. EPA-Region 7 collected one influent and three effluent groundwater samples during each sampling event. All samples collected by the Region 7 personnel were analyzed using Regional protocol.

Target Compounds

Influent groundwater samples were analyzed for VOCs at standard CLP detection limits. Effluent groundwater samples were analyzed for VOCs at 1 ppb detection limits. Detection limits for EDB was 0.05 ppb for all samples.

The compounds of interest were vinyl chloride, methylene chloride, 1,1-dichloroethene, 1,2--dichloroethene (both cis and trans), 1,2-dichloroethane, carbon tetrachloride, ethylene dibromide, trichloroethene, 1,1 ,2-trichloroethane, tetrachloroethene, and 1 ,1 , 1-trichloroethane.

The detection limit for the influent samples ranged from 5-10 μg/L. The detection limit for effluent samples was 1 µg/L. The detection limit for ethylene dibromide (influent and effluent) was 0.05 µg/L.

All equipment used for the collection of the water samples were prepared in accordance with Regional SOP #OPQAM. Sample containers, preservation, and holding times met Regional SOP # 2130.4B. Sample shipment was by government owned vehicle in accordance with the procedures identified in SOP #2130.6A. Sample custody and documentation of field activities followed SOP #2130.2A and #2130.3B.

Sample Network and Rationale

Procedures identified in EPA's Region 7 draft document no. 1200.4A Generic QA Project Plan for Oversight and Split Sample Collection at CERCLA PRP Activities, Section 5 were followed for the collection of groundwater samples. Field QA elements followed SOP #2130.3B. Laboratory QC elements followed SOP #1610.1C. The frequency of QC checks followed SOP #2130.3B. Control limits and corrective actions followed SOP #2110.2C.

In fluent Samples

Three influent groundwater grab samples were collected from I-49. One grab sample was taken at the beginning of each sampling event (3 total). These samples were analyzed using the Region's method (WV, W13 and WV69) and detection limits. The detection limit for EDB analyzes was 0.05 µg/L.

No influent field duplicate samples were collected.

Effluent Samples

Nine effluent split groundwater samples were collected from the irrigation system. These samples were collected at approximately the same time as those collected by NRMRL personnel. The samples were collected at the far end of the irrigation system where the water spray was the strongest. Duplicate water samples were collected in 40-mL VOA vials, labeled, and placed in a cooler.

Field sheets and sample tags, which were supplied by the Region, provided the following sample information:

1. Sample number (see corresponding field sheet)
2. Sample type (i.e. influent or effluent, collected)
3. Date and time of collection

Bottles, holding times, and preservation requirements for these analysis are shown below:

Groundwater samples were collected directly into sample containers and placed on ice. No acid preservatives were used with any of these samples. Field sheets were modified to reflect this fact. No BTEX compounds were present in the samples.

Each sample was accompanied by a field sheet. The shipment of the samples from the field to the EPA Region 7 laboratory was accompanied by a chain-of-custody sheet.

Analytical Methodology

These samples were analyzed using Regional protocol identified in SOP #OPQAM for routine VOCs, low level VOCs, and EDB.

Target Compounds

Influent groundwater samples were analyzed for VOCs at a detection limit of 5 µg/L and were analyzed using the "WV" method. These samples contained TCE at a concentrations that ranged from 200-1000 µg/L and EDB at a concentration of approximately 1 µg/L. Several other VOCs were present at a concentration that ranged from 5-20 µg/L. Effluent groundwater samples were analyzed for VOCs at a 1µg/L detection limit using the W13 protocol. These low levels of detection were needed to validate the percent removal efficiencies of the spray irrigation system. The detection limit for EDB was 0.02 µg/L using the WV69 protocol.

Data Review, Validation, and Reporting

Level 4 data were required for this sampling event. The Regional methods cited were used. The Regional laboratory followed Regional SOP #1610.1C during the review process and to evaluate the acceptability of the data based on these criteria. Data deliverables followed SOP #2119.2C. Data generated from this sampling event were used in the evaluation of split samples generated by NRMRL. The results were compared to the NRMRL analytical results to determine if NRMRL's methods were within 20 % of the results generated using the Region 7 analytical protocols. If the data indicated that the NRMRL results were not similar to the Region 7 results, a more through evaluation of the analytical procedures was conducted.

A performance evaluation (PE) sample was prepared using the following water supply audits: WS035, CONC1; WS035 CONC2, and WS034 CONC4. The true value (µg/L)of each compound (with control limits) is as follows:

TCA-8.78	CL 5-12;
CT-10.8	CL 8.2-12.9;
TCE-6.13	CL 3.6-8.5;
EDB-0.051	CL 0.04-0.06
PCE-4.93	CL 3-6.8

The MCL for each compound was: TCA - 200 µg/L, CT, TCE, and PCE - 5 µg/L, and EDB 0.05 µg/L.

Discussion of Results

All groundwater samples collected by the Region were analyzed. Table 1 presents the analytical results for the five compounds of concern (TCA, CT, TCE, EDB, and PCE). Samples were collected during the morning (M), noon (N), and evening (E) at locations 10, 11 and 12. Influent samples were coded with an "INF" symbol. Detection limits are shown in the table followed by a "U." EPA-NRMRL analytical results are denoted by the prefix "NRMRL."

Comparison of EPA-NRMRL and EPA-Region 7 Results

Acceptable results were defined as those results for positive compounds above the MCL (within 20%) which was established by Region 7 as the action level.

Morning-Influent

EPA-NRMRL collected and analyzed several samples from the morning effluent. For this comparison, an average of the results were compared to one sample collected by EPA-Region 7. The data indicates that the TCA results were within 10%. For CT, EPA Region 7 indicates a detection limit of 4U and EPA-NRMRL indicates a presence at 5.2. These results are acceptable. The TCE results were within 4%. EDB results were within a range of 22-28% and the PCE the results were within 10%. Overall these results are acceptable.

Effluent

There were no locations where groundwater samples were collected and analyzed by both EPA-NRMRL and EPA-Region 7 laboratories. EPA Region 7 compared these results with the second site sampling event and found that the results compare favorable to previous test results.

Noon-Influent

The data indicates that the TCA results were within 17%. For CT, EPA Region 7 results indicate a non-detect at 4U; EPA-NRMRL results indicate a presence at 4.8, within 20%. The results for TCE were within 4%. The results for EDB were within a range of 26-36%. The PCE results were within 10%. Overall, these results are acceptable.

Effluent

There were two locations from which samples were collected and analyzed by both laboratories. The TCA results compare as follows: for location 11, height 1 (closest to the ground), EPA Region 7 indicates a non-detect with a detection limit of 0.6U and EPA-NRMRL's result indicates a positive at 0.055C. These results are acceptable. For CT, EPA-Region 7 indicates non-detect at 0.2U and EPA-NRMRL indicates a presence at 0.043. These results agree. For TCE. EPA-Region 7 indicates a presence at 2 and EPA-NRMRL indicates a presence at >15J. These results do not agree and should be verified. For EDB, the EPA Region 7 result is non-detect at 0.009U. The EPA-NRMRL result indicates a presence at 0.029L. These results are acceptable. For PCE, the EPA-Region 7 result indicates a non-detect at 0.03U. The EPA-NRMRL result indicates a presence at 0.068. These results are acceptable.

The TCA results compare as follows: for location 10, height 1 (closest to the ground), EPA Region 7 indicates a non-detect with a detection limit of 0.6U and EPA-NRMRL' s result indicates a positive at 0.11S. These results are acceptable. For CT, EPA-Region 7 indicates a non-detect at 0.2U and EPA-NRMRL indicates a presence at 0.083S. These results agree. For TCE, EPA-Region 7 indicates a presence at 5 and EPA-NRMRL indicates a presence at 4.3S. These results are acceptable. For EDB, EPA Region 7 results indicate a presence at 0.017 and EPA-NRMRL results indicate a presence at 0.048S. These results are acceptable. For PCE, EPA-Region 7 results

Table C-l. SITE Demonstration Comparison of Region 7 Data and EPA-NRMRL

	LOCATION	TCA (μg/L)	CT (μg/L)	TCE (μg/L)	EDB (μg/L)	PCE (μg/L)
	M-10-H1	0.6U	0.2U	4	0.01U	0.3U
	M-l 1-H1	0.6U	0.2U	2	0.011	0.3U
	M-12-H1	0.6U	0.2U	6	0.023	0.3U
	N-12-H1	0.6U	0.2U	7	0.019	0.3U
	N-l I-HI	0.6U	0.2U	2	0.009U	0.3U
NRMRL	N-l 1-H1	0.055 D	0.043	>15 H	0.029 L	0.068
	N-10-H1	0.6U	0.2U	5	0.017	0.3U
NRMRL	N-10-H1	0.11 S,D	0.083 S	4.3 s	0.048 S	0.11 s
	PE	9	11	7	0.053	5
NRMRL	PE(AVE)	6.2	9.2	6.0	0.057	4.6
	E-l 1-H1	0.6U	0.2U	5	0.015	0.3U
NRMRL	E-l I-HI	0.088	0.075	4.3	0.041	0.10 D
	E-l O-HI	0.6U	0.2U	5	0.012	0.3U
NRMRL	E-IO-HI	0.11	0.10	6.2	0.056	0.12 D
	E-12-HI	0.6U	0.2U	10	0.04	0.3U
NRMRL	E-12-HI	0.29	0.29	8.5	0.22[a]	0.28
	M-INF	7	4u	500	1.4	7
NRMRL	M-INF-AV	7.6	5.2	516	1.8	7.6
	N-INF	6	4u	520	1.1	7
NRMRL	N-INF-AV	7.0	4.8	544	1.5	7.7
	E-INF	6	4u	500	1.1	7
NRMRL	E-INF-AV	7.1	4.8	530	1.6	7.5

Notes:

[a] See Table 9.

indicate a non-detect at 0.03U and EPA-NRMRL's results indicate a presence at 0.11 S. These results are acceptable.

Evening - Influent

The data indicate that the TCA results were within 18%. For CT, EPA Region 7 results indicate a non-detect at 4U and EPA-NRMRL results indicate a presence at 4.8, within 20%; the TCE results were within 4%, the EDB results were within a range of 31-45%, and the PCE results were within 10%. The results for EDB should be verified, otherwise the results for the are acceptable.

Effluent

There were three locations from which samples were collected and analyzed by both laboratories. The TCA results compare as follows: for location 11, height 1 (closest to the ground) EPA Region 7 indicates a non-detect with a detection limit of 0.6U and EPA-NRMRL's result indicates a positive at 0.088C. These results are acceptable. For CT, EPA-Region 7 indicates non-detect at 0.2U and EPA-NRMRL indicates a presence at 0.075C. These results agree. For TCE, EPA-Region 7 indicates a presence at 5 and EPA-NRMRL indicates a presence at 4.3. These results agree. For EDB, EPA Region 7 result was 0.015 and EPA-NRMRL results indicates a presence at 0.041. These results are acceptable since they were below the MCL of 0.05. For PCE, EPA-Region 7 results indicate a non-detect at 0.03U and EPA-NRMRL's results indicate a presence at 0.103C. These results are acceptable.

Effluent

For TCA at location 10, height 1 (closest to the ground) EPA Region 7 indicates a non-detect with a detection limit of 0.6U and EPA-NRMRL's result indicates a positive at 0.114C. These results are acceptable. For CT, EPA-Region 7 indicates a non-detect at 0.2U and EPA-NRMRL indicates a presence at 0.102. These results agree. For TCE, EPA-Region 7 indicates a presence at 5 and EPA-NRMRL indicates a presence at 6.2. These results should be verified. For EDB, EPA Region 7 results indicate a presence at 0.012 and EPA-NRMRL results indicates a presence at 0.056. These results are acceptable. For PCE, EPA-Region 7 results indicate a non-detect at 0.03U and EPA-NRMRL's results indicate a presence at 0.12C. These results are acceptable.

For TCA at location 12, height 1 (closest to the ground), EPA Region indicates a non-detect with a detection limit of 0.6U and EPA-NRMRL's result indicates a positive at 0.29. These results are acceptable. For CT, EPA-Region 7 indicates a non-detect at 0.2U and EPA-NRMRL indicates a presence at 0.29. These results agree. For TCE, EPA-Region 7 indicates a presence at 10 and EPA-NRMRL indicates a presence at 8.5. These results are acceptable. For EDB, EPA Region 7 results indicate a presence at 0.04 and EPA-NRMRL results indicates a presence at 0.22. These results need to be verified. For PCE, EPA-Region 7 results indicates a non-detect at 0.03U and EPA-NRMRL's results indicate a presence at 0.28. These results are acceptable. A comparison of Region 7 and EPA-NRMRL data are shown in Table 1.

Performance Evaluation Sample

A PE sample was analyzed by each laboratory. The results indicate that both laboratories were within the control limits for all compounds. Sample information is provided in Table 2.

Table C-2. Sample information - Region 7

Parameter	Container	Preservation (Holding Time)
VOCs-WV	2 x 40 mL VOA Vial	Ice to 4 C (14 Days)
vocs-w13	4 x 40 mL VOA Vial	ice to 4 C (14 Days)
VOCs-WV69	2 x 40 mL VOA Vial	Ice to 4 C (14 Days)

Appendix D
Sample Size Estimation

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
NATIONAL EXPOSURE RESEARCH LABORATORY
CINCINNATI, OH 45268

OFFICE OF
RESEARCH AND DEVELOPMENT

Date: May 22, 1996

Subject: Sample Size Estimation for the Nebraska Sprinkler Irrigation Experiment

To: Randy Parker, Environmental Engineer
Remediation and Contamination Branch
Land Remediation and Pollution Control
National Risk Management Research Laboratory

From: Florence A. Fulk, Statistician
National Water Quality Assurance Programs Branch
Ecological Exposure Research Division

A study to assess the effectiveness of sprinkler irrigation in removal of carbon tetrachloride (CT), trichloroethylene (TCE), and dibromoethane (EDB) is planned for June 1996. As part of the experimental design, the number of samples needed to determine if the average levels of CT, TCE or EDB exceed the maximum contaminant level (HCL) were estimated.

Due to the nature of the sampling device a stratified random sampling plan was adopted to reduce the variability among samples and consequently reduce the total number of samples needed for the study. At a sample point along the irrigation arm, a sampling device collects samples at four heights. Prom previous studies, it was shovn that the levels of the contaminants decreased with decreasing height due to volatilization of the compounds. Four strata for sampling were thus chosen, one for each of the heights along the sampling device. Twelve sampling devices will be placed equi-distant along the irrigation arm and three sampling events will occur within a day for a total of 144 collected samples, 36 at each of the four heights.

To estimate the number of samples to be analyzed from the total of 144 collected samples, an estimate of the variability within each strata for CT, TCE and EDB is necessary. Samples that were collected on 8/23/95 and analyzed for CT, TCE and EDB were used to obtain the estimates. (Copy of data attached.) The variability estimates are limited by the fact that the samples were collected on a single day at a single time point and are probably less than if the samples were taken at different times across a day. For each analyte and height, the coefficient of variation (CV) was calculated from the data. Since the majority of the data for CT was below the detection limit, the same CV values for TCE were used for CT. The CV was then applied to the MCL for each analyte to obtain an estimate for s^2 at each height. The s^2 estimates at each height were utilized in a modified formula for estimating the variability of a stratified sample to acquire the overall variability estimate for each analyte[1]. To calculate the sample size, an alpha level of 0.05 and a beta level of 0.01 were chosen. This corresponds to a significance level of 95% and a power of 99%. The amount of difference, or effect size, from the HCL to detect was 1 µg/L for CT and TCE and 0.01 µg/l for EDB. The variability estimate, normal table values of alpha and beta, and the effect size vere applied to the formula for sample size estimation for each analyte[2]. For each of CT, TCE and EDB, the estimated total number of samples for analysis was calculated to be 32. To account for additional variability from sampling at different time points, the recommended number of total samples is 40. The forty samples would be evenly distributed across each strata, ten samples from each sampling height. The samples would be randomly selected from the 36 samples collected at each height.

Modified formula for variability of a stratified sample:

$$S_T^2 = .25\ \Sigma\ S_h^2$$

Formula for estimating sample size:

$$n = S_T^2\ (Z_\alpha + Z_\beta)^2 / \Delta^2$$

1. Cochran, William G. (1977), *Sampling Techniques*, 3rd ed., John Wiley & Sons, New York, New York.

2. Lipsey, Mark W. (1990), *Design Sensitivity: Statistical Power for Experimental Research*, SAGE Publications Inc. , Newbury Park, California.

cc: M. Kate Smith
Robert Graves

Appendix E
Statistical Analysis Report

NEBRASKA DEMONSTRATION PROJECT
FOR SPRINKLER IRRIGATION

HASTINGS IRRIGATION WATER CONTAMINATION STUDY

Statistical Analysis Report

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REVISED FINAL VERSION - 12/12/97

CONFIDENTIALITY STATEMENT

The following description will constitute the final report of the data analysis on the Hastings Irrigation Water Contamination Study data. Any information contained herein is strictly confidential and is not to be released to anyone without written consent of the US EPA. Upon final acceptance of this report, the US EPA becomes sole owner of the information contained. All written and electronic information concerning this study will be kept on file at STATKING Consulting for a period of one year.

The report will be divided into two parts. The first is a general summary of the statistical analysis of the data. The second part of the report is a technical summary and justification of the statistical methods used to analyze the data.

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1. DATA ANALYSIS SUMMARY

1.1 Background

The main objective of this experiment was to determine the efficacy of the sprinkler irrigation system to treat ground water contaminated with volatile organic compounds (VOCs) to concentrations that average below the acceptable maximum contaminant levels (MCLs). The objective was evaluated through the collection and analysis of samples from the sprinkler mist. The data obtained from the experiment was statistically analyzed to statistically determine if the average concentrations of VOCs exceed the stated MCLs. The study was conducted by the US EPA at the USEPA Research Station in Hastings, NE in the summer of 1996.

Analyzed Population, Sampling Plan and Strata Definitions

The target population for this study was the water released from the particular irrigation arm under study at the Hastings, NE site. All statistical estimation and inference described in this report is relative to this and only this population.

It has been shown in previous studies that levels of VOCs tend to decrease as the irrigation water falls from the pivot onto the field. Since VOC levels in samples collected from a specific height will tend to be similar, the population of irrigation water coming from the pivot was divided into homogeneous groups known as strata corresponding to the height above ground where the water was sampled. By dividing the population into strata before sampling, a better estimate of the mean level of VOCs can be obtained. The statistical term for this type of sampling setup is stratified random sampling.

For this experiment, four heights or strata were identified. The sampling of the irrigation water was conducted at four different heights ranging from just under the pivot to ground level. The data collected from each of these heights was then sampled in order to obtain an estimate of the mean level of a particular VOC for the pivot.

Response Variables

The VOCs recorded and statistically analyzed were 1,1,1-trichloroethane (TCA), carbon tetrachlotide (CT), trichloroethylene (TCE), dibromoethane (EDB) and tetrachloroethene (PCE). The response values were measured in parts per billion. A listing of the data values collected and statistically analyzed is shown in appendix Table Al. Samples N-S1 O-H 1, M-S 11 -H3 and M-S9-H4 failed to meet the quality assurance (QA) criteria and were dropped from the data set before the statistical analyses were conducted. The data for these samples are not shown anywhere in this report. The MCL for each of the **VOCs** analyzed is given in the following table.

Table 1. Maximum Contaminant Levels for VOCs

Contaminant	MCL
TCA	200 µg/L
CT	5 µg/L
TCE	5 µg/L
EDB	.05 µg/L
PCE	5 µg/L

1.2 Results of Statistical Analyses of VOC Contaminants Data

Tables **A2-A11** in the appendix show the results of the data analysis of the VOC data collected during this study. Statistical analyses were performed first on all data and then on data sampled from height one only.

Results of Statistical Analyses of Data From All Heights

Tables **A2-A6** in the appendix summarize the results of the hypothesis tests conducted on the VOC data from all sampling heights. From Table A2, TCA levels were shown to be well below the MCL of 200 **µg/l (p=1.0000)**. A 95% confidence interval on the mean level of TCA was **(.21,.25)**. The same was true of CT and PCE **VOCs** shown in Tables A3 and A6 **(p=1.0000,** 1 .OOOO, respectively). For TCE, shown in Table A4, the mean level was shown to be significantly greater than the MCL of 5 **µg/l (p=.0001).** A 95% confidence interval on the mean level was **(11.98,14.13).** From Table A5, the **mean** level of EDB was shown to be significantly larger than the MCL of **.05 µg/l (p=.0028).** A 95% confidence interval on the mean level was **(.06,.** 10).

Results of Statistical Analyses of Data From Height One

During the evening sampling period, samples were collected at all twelve sampling locations along height one of the sampling mechanism. Tables **A7-A11** in the appendix summarize the results of the hypothesis tests conducted on the VOC data for this data. From Table A7, TCA levels were shown to be well below the MCL of 200 **µg/l** **(p=1** .OOO). A 95% confidence interval on the mean level of TCA was (**.09,.** 15). The same was true of CT and PCE **VOCs** shown in Tables A8 and Al 1 **(p=1.0000,** 1 .OOOO, respectively). For TCE, shown in Table A9, the mean level was shown to be significantly greater than the MCL of 5 μg/l (p=.0219). A 95% confidence interval on the mean level was (5.02,6.55). From Table A10, the data collected provided no indication that the mean level of EDB was significantly larger than the MCL of .05 μg/l (p=.0959) at the .05 level. A 95% confidence interval on the mean level was (.04,.09).

Power Analysis

The results of this study can be used to give indication of the power of the hypothesis tests conducted on the data. Power is the probability of detecting a significant difference between the mean level of a VOC and its MCL if that difference, in fact, exists. For each VOC, power calculations were conducted for ranges of differences between the population mean and the MCL for the particular VOC using the standard deviations and sample sizes observed in the current study.

Tables A12-A16 in the appendix give the power curves for each of the VOCs observed in this study. From these curves, the sensitivity of the hypothesis test can be examined. The most interesting difference on these tables is the smallest difference between the population mean and the MCL that can be detected 80% or greater of the time by the hypothesis test. These values are sometimes called the minimum detectable differences for the hypothesis test. These differences are summarized in the Table 2.

Table 2. Minimum Detectable Differences for Tests on VOCs

VOC	Min. Detectable Difference
TCA	.0036
CT	.0036
TCE	.2000
EDB	.0036
PCE	.0036

From Table 2, it can be concluded that, with the current sample sizes, minute differences between the mean level of a VOC and its MCL can be detected if, in fact, those differences exist.

2.1 Stratified Random Sampling Estimators

It has been shown that levels of **VOCs** tend to decrease as the irrigation water falls from the pivot onto the field. Since VOC levels in samples collected from a specific height will tend to be similar, the population of irrigation water coming from the pivot can be divided into homogeneous groups **known** as strata corresponding to the height above **ground where** the water is to be sampled. By dividing the population into strata before sampling, **a** better estimate of the mean level of **VOCs** can be obtained. The statistical term for this type of sampling setup is stratified random sampling.

For this experiment, four heights or strata were identified. The sampling of the irrigation water was conducted at four different heights ranging from just under the pivot to ground level, The data collected from each of these heights was then sampled in order to obtain an estimate of the mean level of a particular VOC for the pivot.

Levy and Lemeshow (1991) have shown that an estimate of the mean level of a response variable using a stratified random sampling plan is given by

$$\bar{x}_{str} = \sum_{h=1}^{L} N_h \cdot \bar{x}_h \,/\, N$$

where $\bar{x}_h$ is the mean of the response variable in strata h, N_h is the size of strata h, N is the size of the population sampled and L is the number of strata in the population. Note that this estimate is a weighted average of the strata means. The estimated variance of this estimate is

$$\hat{\mathrm{v}}\mathrm{ar}(\bar{x}_{str}) = \sum_{h=1}^{L} N_h^2 \times \frac{s_h^2}{n_h}\left(\frac{N_h - n_h}{N_h - 1}\right) / \, N^2$$

where s_h^2 is the estimated variance of the response data in strata h and n_h is the sample size in strata h. The estimated standard error of the estimate is

$$\hat{s}e(\bar{x}_{str}) = \sqrt{\hat{\mathrm{v}}\mathrm{ar}(\bar{x}_{str})}\,.$$

2.2 **Confidence Intervals**

It is also of interest in this study to give some measure of the reliability of the estimated mean levels of VOC in the irrigation water. This can be done using confidence intervals. A confidence interval is an interval estimate of the population mean VOC content which will contain the true population mean VOC a prespecified proportion of the time.

Cochran (1954) and Levy and Lemeshow (1991) have shown that for normally distributed data and/or large samples, a 100(l-a)% confidence interval on the population mean under stratified random sampling is given by

$$\bar{x}_{str} \pm Z_{1-(\alpha/2)} \cdot se(\bar{x}_{str}).$$

In repeated sampling, this interval will contain the population mean 100(l-a)% of the time.

2.3 Hypothesis **Tests**

The main statistical objective of this study was to determine if VOC content of the irrigation water was significantly below acceptable maximum contaminant levels **(MCLs)**. This situation requires a one-side hypothesis test that the mean level of the VOC is below the MCL.

Snedecor and Cochran (1980) have shown that a large sample test of the one-sided hypotheses

$$H_0 : \mu \le \mu_0 \text{ vs. } H_a : \mu > \mu_0,$$

where μ_0 is the MCL for the particular VOC being tested, can be conducted using the test statistic

$$Z = (\bar{X}_{str} - \mu_0) / \sqrt{\text{var}(\bar{X}_{str})}$$

and rejecting when Z $> Z_{1-\alpha}$ where $Z_{1-\alpha}$ is the (1 $-\alpha)$x 100th percentile of the standard normal distribution.

2.7 **PowerCalculations**

Power calculations were computed using the central and noncentral T distributions. The power of a statistical hypothesis tests is the probability of rejecting H_0 assuming H_0 is false. For a one-sided, one sample hypothesis test on the mean level, this probability is given by

$$\text{Power} = P(\text{Reject } H_0 | H_0 \text{ is false}) = P(T^* > t_{1-\alpha, n-1, \Phi} | H_0 \text{ is false})$$

where T^* is a non central T random variable with n-f degrees of freedom and non centrality parameter

$$\Phi = \frac{\sqrt{n}|\mu - \mu_0|}{\sigma},$$

n is the total number of subjects, μ_0 is the hypothesized population mean value and σ is the standard deviation of the data. Power curve tables were constructed by computing power for a range of A = $\mu - \mu_0$ values using the sample size used in this study and the standard deviations observed from this study. For a further discussion of power calculations, see Guenther (1973).

2.5 Other Technical Notes

All computing was done using v6.11 of the SAS System on an IBM PC350 100MHz personal computer running the OS/2 v3.0 operating system.

REFERENCES

Cochran, W.G. (1977). Sampling Techniques, New York, John Wiley & Sons, 3rd edition.

Guenther, W.C. (1973). Concepts of Statistical Inference, New York, NY: McGraw-Hill Book Company, 2nd edition.

Levy, P.S. and Lemeshow, S. (1991). The Sampling of Populations, New York, NY: John Wiley & Sons.

Snedecor, G.W. and Cochran, W.G. (1980). Statistical Methods, Ames, IA: The Iowa State University Press, seventh edition.

Table AI. Nebraska Demonstration Project for Sprinkler Irrigation
US EPA - Hastings Data
Data Listing

OBS	Sample ID	HEIGHT	TCA (ppb)	CT (ppb)	ICE (ppb)	EDB (ppb)	PCE (ppb)	RECOVERY (%)	STRATA
1	M-S1-H1 (15)	1	0.14	0.12	6.5	0.05	0.14	116	1
2	M-S6-H1 (1)	1	0.12	0.08	5.2	0.03	0.11	126	1
3	N-S2-H1 (3)	1	0.10	0.08	4.9	0.04	0.11	92	1
4	N-S5-H1 (15)	1	0.14	0.12	6.8	0.06	0.14	126	1
5	N-S6-H1 (3)	1	0.09	0.09	5.3	0.05	0.11	104	1
6	N-S9-H1 (15)	1	0.12	0.10	5.5	0.05	0.12	122	1
7	N-S11-H1 (4)	1	0.06	0.04	15.0	0.03	0.07	112	1
8	E-SI-tII (5)	1	0.08	0.08	4.3	0.04	0.09	111	1
9	E-S2-H1 (5)	1	0.13	0.10	6.5	0.05	0.13	97	1
10	E-S3-H1 (5)	1	0.09	0.08	4.4	0.04	0.10	105	1
11	E-S4-H1 (5)	1	0.03	0.06	4.1	0.05	0.10	86	1
12	E-S5-H1 (5)	1	0.10	0.10	5.9	0.05	0.12	104	1
13	E-S6-H1 (6)	1	0.10	0.10	5.8	0.05	0.12	102	1
14	E-S7-H1 (6)	1	0.09	0.08	5.0	0.05	0.10	110	1
15	E-S8-H1 (7)	1	0.13	0.10	5.3	0.06	0.12	109	1
16	E-S9-H1 (6)	1	0.15	0.14	9.1	0.07	0.16	111	1
17	E-S10-H1 (6)	1	0.11	0.10	6.2	0.06	0.12	106	1
18	E-S11-H1 (6)	1	0.09	0.08	4.3	0.04	0.10	116	1
19	E-S12-H1 (7)	1	0.29	0.29	8.5	0.22	0.28	102	1
20	M-S1-H2 (11	2	0.20	0.15	9.8	0.05	0.19	125	2
21	M-S6-H2 (15)	2	0.13	0.11	6.3	0.05	0.13	125	2
22	N-S5-H2 (3)	2	0.14	0.13	8.4	0.06	0.15	105	2
23	N-S6-H2 (3)	2	0.13	0.12	7.2	0.05	0.14	105	2
24	N-S7-H2 (3)	2	0.10	0.08	4.9	0.04	0.11	106	2
25	N-S12-H2 (15)	2	0.19	0.17	10.0	0.07	0.20	122	2
26	E-S2-H2 (5)	2	0.18	0.15	10.0	0.07	0.18	113	2
27	E-S5-H2 (5)	2	0.24	0.18	13.0	0.09	0.22	117	2
28	E-S8-H2 (6)	2	0.17	0.14	9.4	0.07	0.17	111	2
29	E-S9-H2 (6 7)	2	0.27	0.23	18.0	0.09	0.29	111	2
30	E-S10-H2 (15)	2	0.13	0.12	6.9	0.05	0.14	122	2
31	E-S11-H2 (6)	2	0.18	0.15	9.7	0.07	0.18	122	2
32	E-S12-H2 (15 16)	2	0.27	0.24	17.0	0.11	0.29	117	2
33	M-S4-H3 (1)	3	0.26	0.19	15.0	0.07	0.26	127	3
34	M-S6-H3 (1)	3	0.20	0.20	15.0	0.06	0.29	124	
3s	M-S7-H3 (1)	3	0.27	0.19	15.0	0.06	0.26	112	3
36	N-S2-H3 (3)	3	0.25	0.22	16.0	0.08	0.26	110	3
37	N-S6-H3 (15)	3	0.20	0.17	10.0	0.06	0.19	125	3
38	N-S10-H3 (4)	3	0.23	0.19	14.0	0.08	0.23	104	3
39	E-S4-H3 (15)	3	0.21	0.17	11.0	0.07	0.21	119	3
40	E-S5-H3 (5)	3	0.27	0.23	21.0	0.09	0.28	109	3
41	E-S8-H3 (6 7)	3	0.31	0.26	21.0	0.11	0.33	114	3
42	M-S1-H4 (1)	4	0.28	0.21	15.0	0.06	0.27	127	4
43	M-S2-H4 (15)	4	0.31	0.26	15.0	0.09	0.31	126	4
44	M-S4-H4 (15 161	4	0.33	0.20	19.0	0.11	0.32	118	4
45	M-S5-H4 (1)	4	0.67	0.47	15.0	0.16	0.75	121	4
46	N-S1-H4 (3)	4	0.23	0.19	14.0	0.07	0.23	102	4
47	N-S11-H4 (4)	4	0.33	0.28	25.0	0.11	0.34	105	4
48	N-S12-H4 (4 5)	4	0.43	0.34	29.0	0.14	0.44	107	4
49	E-S3-H4 (5)	4	0.35	0.29	21.0	0.12	0.35	110	4
50	E-SS-N4 (6)	4	0.34	0.29	23.0	0.11	0.37	106	4
51	E-S11-H4 (6 7)	4	0.44	0.36	30.0	0.14	0.48	108	4

Table A2. Nebraska Demonstration Project for Sprinkler Irrigation
US EPA - nestings Data
Full Data Set
Contaminant: TCA

Strata	Strata TCA Mean	Strata TCA SD	Strata Sample Sire	Overall TCA Mean	Overall TCA SEM	95% CI on the Mean TCA	Z Statistic	One Sided P Value
1	0.11	0.05	19					
2	0.18	0.05	13					
3	0.25	0.04	9					
4	0.37	0.12	10	0.23	0.01	(0.21, 0.25)	-19977	1.0000

Table A3. Nebraska Demonstration Project for Sprinkler Irrigation
US EPA - Hastings Data
Full Date Set
Contaminant: Cl

Strata	Strata CT Mean	Strata CT SD	Strata Sample Size	Overall CT Mean	Dverrll CT SEM	95% Cl on the Mean CT	2 Statistic	One Sided P Value
1		0.05	19					
2	0.10 0.15	0.05	13					
3	0.20	0.03						
4	0.30	0.08	1X	0.19	0.01	(0.17, 0.21)	-481.2	1.0000

Table A4. Nebraska Demonstration Project for Sprinkler Irrigation
US EPA - Hastings Data
Full Data Set
Contaminant: TCE

Strata	strata ICE Mean	Strrtr TCE SD	Strata Sample Size	Overall TCE Mean	Overall TCE SEM	95% CI on the Mean TCE	2 Statistic	one Sided P Value
1								
2	10.056.24	:2.51	19					
			13					
3								
4	20 [illegible]	6.00	10 9	13.06	0.55	(11.98,14.13)	14.67	0.0001

Table AS. Nebraska Demonstration Project for Sprinkler Irrigation
US EPA - Meetings Data
Full Data Set
Contaminant: EDB

Strata	Strata EDB Mean	Strata EDB SD	Strrtr Sample Size	Overall EDB Mean	Overall EDB SEM	95% CI on the Mean EDB	2 Statistic	One Sided P Value
1	0.06	0.04	19					
2			13					
3	0.08	0.02 0.02	9					
4	0.11	0.03	10	0.08	0.01	(0.06, 0.10)	2.77	0.0028

Table A6. **Nebraska Demonstration** *Project for Sprinkler* Irrigation
US EPA - **Hastings** *Data*
Full Date Set
Contaminant: *PCE*

Strata	*Strata PCE Mean*	*Strata PCE SO*	*Strata Sample Size*	**Overall PCE Mean**	*Overall PCE* **SEM**	*95% Cl* **on** *the Mean PCE*	*2 Statistic*	**One** *Sided P* **Value**
1	0.12	0.04	19					
2								
3	0.26 0.18	0.06 0.01	13 9					
4	0.39	0.15	10	0.24	0.01	(0.22, 0.261	-428.5	1.0000

Table A7. Nebraska Demonstration Project for Sprinkler Irrigation
US EPA - Nestings Data
Height One Date Only
Contaninant: TCA

Strata	Strata TCA Mean	Strrta TCA SD	Strata Sample Size	Overall TCA Mean	Overall TCA SEM	95% CI on the Mean TCA	2 Statistic	One Sided P Value
1	0.12	0.06	12	0.12	0.01	(0.09, 0.15)	-13439	1.0000

Table A8. Nebraska Demonstration Project for Sprinkler Irrigation
US EPA - Hastings beta
Weight One Data Only
Contaminant: CT

Strata	Strata CT Mean	Strrtr CT SD	Strrtr Sample Size	Overall CT Mean	Overall CT SEM	95% CI on the Mean CT	2 Statistic	me Sided P Value
1	0.11	0.06	12	0.11	0.01	(0.08, 0.14)	-337.4	1.0000

Table A9. Nebraska Demonstration Project for Sprinkler Irrigation
US EPA - Hastings Data
Height One Data Only
Contminant: TCE

Strata	Strata TCE Mean	Strata TCE SD	Strata Sample Size	Overall TCE Mean	Overall TCE SEM	95% CI on the Mean TCE	2 Statistic	One Sided P Value
1	5.78	1.63	12	5.78	0.39	(5.02, 6.55)	2.02	0.0219

Table A10. Nebraska Demonstration Project for Sprinkler Irrigation
US EPA - Hastings Data
Height One Data Only
Contaminant: EDB

Strata	Stratr EDB Mean	Strrtr EDB SO	Strata Sample Size	Overall EDB Wean	Overall EDB SEW	95% CI on the Mean EDB	2 Statistic	One Sided P Value
1	0.07	0.05	12	0.07	0.01	(0.04, 0.09)	1.31	0.0959

Table All. Nebraska Demonstration Project for Sprinkler Irrigation
US EPA - Hastings Date
Height One Data Only
Contaminant: PEE

Strata	Strata PCE Mean	Strata PCE SD	Strrta Sample Size	Overall PCE Mean	Overall PCE SEM	95% CI on the Mean PCE	2 Statistic	Dne Sided P Value
1	0.13	0.03	12	0.13	0.01	(0.10, 0.15)	-397.0	1.0000

Table A12. Nebraska Demonstration Project for Sprinkler Irrigation
US EPA - Hastings Data
TCA Power Curve for Detecting Significance Above MCLs , n= 51

Variable: TCA,
Sample Size: 51,
AND Std. Dev. 0.01

Difference from Hypthesized Value	PMR
0	0.050
0.0002	0.066
0.0004	0.086
0.0006	0.111
0.0008	0.140
0.001	0.174
0.0012	0.212
0.0014	0.255
0.0016	0.302
0.0018	0.353
0.002	0.407
0.0022	0.462
0.0024	0.518
0.0026	0.5741
0.0028	0.628
0.003	0.680
0.0032	0.729
0.0034	0.773
0.0036	0.814
0.0038	0.849
0.004	0.880
0.0042	0.906
0.0044	0.927
0.0046	0.945
0.0048	0.959
0.005	0.970
0.0052	0.978

(CONTINUED)

Power is the probability of detecting a difference of
size delta if thrt difference ● ctwlly exists.

Reference for Variance Estimate ad Delta Range: Hastings Study Results using Stratified Random Sampling

Table A12. Nebraska Demonstration Project for Sprinkler Irrigation
US EPA - Hastings Data
TCA Power Curve for Detecting Significance Above MCLs , n= 51

Variable: TCA,
Sample Site: 51,
AWD Std. Dev. 0.01

Difference from Hypthesized Value	POWER
0.0054	0.985
0.0056	0.989
0.0058	0.993
0.006	0.995

Power is the probability of detecting a difference of size delta If that difference ● cturlly ● xistr.

Reference for Variance Estimate and Delta Range: Hastings Study Results using Stratified Random Sampling

fable A13. Nebraska Demonstration Project for Sprinkler Irrigation
US EPA - Hastings Data
CT Power Curve for Detecting Significance Above MCLs , n= 51

Variable: CT,
SampleSize: 51,
AND Std. Dev. 0.01

Difference from Hypthesized Value	POWER
0	0.050
0.0002	0.066
0.0004	0.086
0.0006	0.111
0.0008	0.140
0.001	0.174
0.0012	0.212
0.0014	0.255
0.0016	0.302
0.0018	0.353
0.002	0.407
0.0022	0.462
0.0024	0.518
0.0026	0.574
0.0028	0.628
0.003	0.680
0.0032	0.729
0.0034	0.773
0.0036	0.814
0.0038	0.849
0.004	0.880
0.0042	0.906
0.0044	0.927
0.0046	0.945
0.0048	0.959
0.005	0.970

Power is the probability of detecting a difference of size delta if that difference actually exists.

Reference for Variance Estimate ● rd Delta Range: Hastings Study Results using Stratified Random Sampling

Table A14. Nebraska Demonstration Project for Sprinkler Irrigation
US EPA - Hastings Data
TCE Power Curve for Detecting Significance Above MCLs , n= 51

Variable: TCE,
Sample Size: 51,
AND Std. Dev. 0.55

	POWER
Difference from Hypthesized Value	
0	0.050
0.02	0.082
0.04	0.129
0.06	0.190
0.08	0.268
0.1	0.358
0.12	0.457
0.14	0.559
0.16	0.657
0.18	0.746
0.2	0.820
0.22	0.880
0.24	0.923
0.26	0.954
0.28	0.974
0.3	0.986
0.32	0.993
0.34	0.997
0.36	0.998

Power is the probability of detecting a difference of sire delta if that difference actually exists.

Reference for Variance Estimate and Delta Range: Hastings Study Results using Stratified Random Sampling

Table A15. Nebraska Demonstration Project for Sprinkler Irrigation
US EPA - Hastings Data
EDB Power Curve for Detecting Significance Above MCLs , n= 51

Variable: EDB,
Sample Size: 51,
AND Std. Dev. 0.01

Difference from Hypthesized Value	POWER
0	0.050
0.0002	0.066
0.0004	0.086
0.0006	0.111
0.0008	0.140
0.001	0.174
0.0012	0.212
0.0014	0.255
0.0016	0.302
0.0018	0.353
0.002	0.407
0.0022	0.462
0.0024	0.518
0.0026	0.574
0.0028	0.628
0.003	0.680
0.0032	0.729
0.0034	0.773
0.0036	0.814
0.0038	0.849
0.004	0.880
0.0042	0.906
0.0044	0.927
0.0046	0.945
0.0048	0.959
0.005	0.970

Power is the probability of detecting a difference of size delta if that difference actually • xi8ts.

Reference for Variance Estimatead Delta Range: Hasting6 Study Results using Stratified Random Sampling

Table A16. Nebraska Demonstration Project for Sprinkler Irrigation
US EPA - Hastings Data
PCE Power Curve for Detecting Significance Above MCLs , n= 51

Variable: PCE,
SampleSize: 51,
AND Std. Dev. 0.01

Difference from Hypthesized Value	POWER
0	0.050
0.0002	0.066
0.0004	0.086
0.0006	0.111
0.0008	0.140
0.001	0.174
0.0012	0.212
0.0014	0.255
0.0016	0.302
0.0018	0.353
0.002	0.407
0.0022	0.462
0.0024	0.518
0.0026	0.574
0.0028	0.628
0.003	0.680
0.0032	0.729
0.0055	0.773
0.0036	0.814
0.0038	0.849
0.004	0.880
0.0042	0.906
0.0044	0.927
0.0046	0.945
0.0048	0.959
0.005	0.970
0.0052	0.978

(CONTINUED)

Power is the probability of detecting 6 difference of sire delta if that difference ● ctuaulty exists.

Reference for Variance Estimate and Delta Range: Hastings Study Results using Stratified Random Sampling

Table A16. Nebraska Demonstration Project for Sprinkler Irrigation
US EPA - Hastings Data
PCE Power Curve for Detecting Significance Above MCLs , n= 51

Variable: PCE,
Sample Size: 51,
AND Std. Dev. 0.01

Difference from Hypthesized Value	POWER
0.0054	0.985
0.0056	0.969
0.0058	0.993
0.006	0.995

Power is the probability of detecting a difference of size delta If that difference actually exists.

Reference for Variance Estimate and Delta Range: Hastings Study Results using Stratified Random Sampling

Appendix F
Risk Assessment

Sprinkler Irrigation for VOC Remediation
Innovative Technology
Hastings, Nebraska Demonstration'

RISK ASSESSMENT

Sprinkler irrigation has been proposed as an innovative technology for remediation of volatile organic chemicals (VOCs) in groundwater. The system is designed to provide for maximum stripping efficiency of these volatile chemicals from the water and into the vapor or gaseous phase. Use and effectiveness of this proposed technology is to be demonstrated at a Superfund *site* in Hastings. Nebraska. Groundwater at this site has been contaminated with several volatile organic chemicals which include: carbon tetrachloride, 1,2-dibromoethane, 1,1,1-trichloroethane and trichloroethylene.

Removal of these contaminants from groundwater and releasing them as a gaseous phase may pose an inhalation risk to individuals working or residing in the area of the irrigation system. The Nebraska Department of Health (NDOH) has, therefore, evaluated the magnitude of this potential inhalation risk. This risk assessment evaluates inhalation risks for the *most likely* individuals to be exposed to the irrigation system, specifically, site workers and observers present during the demonstration and nearby residents exposed to emitted volatiles during along-term remediation at this site. Locations of these receptors in relation to the irrigation system were identified using a global positioning system (GPS).

Demonstration

The proposed demonstration of this new remediation technology has been assumed for purposes of this risk assessment, to occur for one hour. During this time 'site workers and demonstration observers may be exposed via inhalation to volatile organic chemicals. The risk to these individuals has been quantified by using standard default assumptions for exposure provided in the U.S. Environmental Protection Agency's (EPA) Exposure Factors Handbook, 1990, and by using risk calculations provided in the US. EPA's Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual, 1989.

Average concentrations of contaminants detected in groundwater were placed into an Industrial Source Complex Model (ISCST3) to predict volatile concentrations of these chemicals from the irrigation system (Appendix I). The concentrations of contaminants in the air as well as the standard default assumptions were utilized to qualify the noncarcinogenic and carcinogenic risks potentially associated with this site demonstration

Demonstration Risk Assessment

Predicted **Carcinogenic Risk**		**Actual**
TCE	2.82×10^{-10}	2.41×10^{-10}
TCA	NA	NA
CT	1.82×10^{-11}	1.45×10^{-11}
EDB	1.29×10^{-10}	7.8×10^{-11}

Carcinogenic Risk Reference Value - 1×10^{-6}

Demonstration Risk **Assessment**
(Continued)

Predicted **Hazard Index**		**Actual**
TCE	NA	NA
TCA	8.78×10^{-8}	9.48×10^{-8}
CT	4.2×10^{-5}	3.40×10^{-5}
EDB	2.0×10^{-4}	1.32×10^{-4}

Hazard Index Reference Value 1.00

Remediation

This proposed remediation technology is predicted to operate 24 hours/day during a maximum summer irrigation season in Nebraska of 90 days. The potential inhalation risk for two of the nearest residents to the irrigation system was evaluated by the NDOH. The noncarcinogenic and carcinogenic risks for a child resident at both of these locations was quantified to ensure protection of this sensitive subgroup.

Remediation Risk Assessment

Original Predicted Carcinogenic Risk Closest Resident		**Revised**
TCE	1.90×10^{-10}	1.83×10^{-10}
TCA	NA	NA
CT	1.01×10^{-9}	0.92×10^{-9}
EDB	1.08×10^{-10}	0.74×10^{-10}

Carcinogenic *Risk* Reference Value - 1 x 10^{-6}

Predicted Hazard Risk		**Revised**
TCE	NA	NA
TCA	1.43 x 10”	1.75 x 10”
CT	2.34×10^{-3}	2.13×10^{-3}
EDB	1.72×10^{-4}	1.18×10^{-4}

Hazard Index **Reference Value 1.00**

[1] Text information taken from the Nebraska Department of Health/Environmental Health Risk Assessment dated May 13. 1996. Revisions based on actual demonstration data from SITE Report dated October 1997.