CNS ENVIRONMENTAL
A REAL ESTATE SERVICES COMPANY

Remedial Action Work Plan
NYSDEC Spill #: 13-10667

<u>Site:</u>
Nostrand Place
3806 Nostrand Avenue
Brooklyn, New York 11235
CNS Job #: D196

Prepared For:

New York State Department of Environmental Conservation
Region II Division of Environmental Remediation
Hunters Point Plaza
47-40 21st Street
Long Island City, NY 11101-5401
Attn: Mr. Santosh Mahat, Spills Manager

On Behalf of:

Acadia 3780-3858 Nostrand, LLC
411 Theodore Fremd Avenue, Suite 300
Rye, New York 10580
Attention: Brian Bacharach

Prepared By:

CNS Environmental Corporation
208 Newtown Road
Plainview, NY 11803

January 2016

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1.0 INTRODUCTION

At the request of Acadia 3780-3858 Nostrand, LLC, CNS Environmental Corp. (CNS), has prepared this Remedial Action Work Plan ("RAWP") for several tenant spaces located within the property known as Nostrand Place in Brooklyn, NY. The focus of this RAWP consists of the tenant spaces located from 3800 through 3808 Nostrand Avenue; referred to hereafter as the "Subject Site". See Figure 1: Site Location Map. This RAWP has been prepared in accordance with the NYSDEC DER-10 Technical Guidance for Site Investigation and Remediation ("DER-10", May 2010) to address NYSDEC Spill #: 13-10667, which is associated with contamination associated with a former dry cleaning tenant located at 3804 Nostrand Avenue currently occupied by Chase Bank.

This work was initiated due to a site investigation conducted by CNS at the 3806 Nostrand Avenue tenant space, identifying dry cleaning compounds within the groundwater. Due to these findings the NYSDEC was notified and spill # 13-10677 was issued to the subject site.

1.1. Purpose and Objectives

The purpose of this RAWP is to incorporate the information gathered during previous investigations, and develop a proposed remedial action to address the identified on-site dry cleaner related chlorinated solvent groundwater impacts. The RAWP is designed to meet the following objectives:

- Provide a brief summary of the subject site, including the previous investigations performed to date;
- Development of site-specific cleanup objectives based upon the information from the investigations;
- Discussion of the proposed remedy for the subject site;
- Provide an engineering evaluation of proposed remedy as per 6 NYCRR-375-1.10C; and
- Outline the implementation of the proposed remedy at the subject site, including a schedule.

1.2. Site Location and Description

The Subject Site is identified as the tenant spaces located from 3800 through 3808 Nostrand Avenue within the property known as Nostrand Place in Brooklyn, NY. Nostrand Place is currently improved with six structures constructed in stages between 1959 through 1982, and spans the entire west side of the city-block from Avenue Y to Avenue Z, and is currently occupied by commercial tenants, including banks, restaurants, retail stores, medical offices and a parking garage. See Figure I: Site Location Map.

1.3. Site History

The subject site was redeveloped into the current structure in 1959, respectively; where the entire footprint was excavated to its current depth. Based upon site borings by CNS, the subject site's footings and slabs are atop a bedrock shelf from 22'-24' below grade surface (bgs) with groundwater encountered at the depth of 12' bgs.

1.4. Previous Environmental Investigations

The following previous Environmental Investigations and/or Reports have been prepared for the Subject Site:

- *Phase I Environmental Site Assessment* prepared by LCS Inc. dated December 6, 2012;
- *Phase II Investigation Report* prepared by CNS dated May 28, 2013;
- *Groundwater Investigation Report* prepared by CNS dated December 5, 2013;
- *Soil Vapor Intrusion Investigation* prepared by CNS dated September 21, 2015
- *Supplemental Phase II Site Investigation* prepared by CNS dated November 17, 2015;
- *2nd Quarter 2014 Quarterly Groundwater Monitoring Report* prepared by CNS dated April 25, 2014;
- *3rd Quarter 2014 Quarterly Groundwater Monitoring Report* prepared by CNS dated July 30 2014;
- *4th Quarter 2014 Quarterly Groundwater Monitoring Report* prepared by CNS dated October 29, 2014;
- *1st Quarter 2015 Quarterly Groundwater Monitoring Report* prepared by CNS dated January 29, 2015;
- *2nd Quarter 2015 Quarterly Groundwater Monitoring Report* prepared by CNS dated June 10, 2015;
- *3rd Quarter 2015 Quarterly Groundwater Monitoring Report* prepared by CNS dated September 14, 2015; and
- *4th Quarter 2015 Quarterly Groundwater Monitoring Report* prepared by CNS dated November 24, 2015

The following narrative describes the environmental history of the Site:

CNS Environmental Corp reviewed a *Phase I Environmental Site Assessment (ESA)* completed by LCS, Inc. (LCS) in December of 2012 for the subject site; where based on CNS' review of the ESA, LCS identified a former drycleaner as an on-site Recognized Environmental Condition (REC), which was said to have operated from at least 1968 through 1996. LCS based this conclusion on a review of historical Sanborn Fire Insurance Maps, which identified the structure improved at 3796 Nostrand Avenue as occupied by a drycleaner. CNS reviewed the historical Sanborn Maps included in the ESA, which depicts the "dry cleaner" notation on the 1968 through 2007 maps; however as stated within the ESA, City Directories for the property were not reviewed because it was LCS' opinion that historical use was adequately determined based on Sanborn maps. LCS concluded that unless sufficient documentation is provided, a subsurface investigation is warranted to assess the environmental conditions on the subject site due to historic use as a drycleaner.

Due to the absence of additional documentation confirming the existence of a drycleaner at the subject site; CNS ordered City Directories, which covered each potential past or current address that may have been used by the property since its construction. The City Directories revealed that the address of 3796 Nostrand Avenue (currently occupied by Chop Stix Restaurant) was not identified with any dry cleaning tenants based on its 1965 through 1992 listings; however a drycleaner by the name of "Debbie Cleaners" was identified under the address of 3804 Nostrand Avenue (currently occupied by Chase Bank). This address identifies the drycleaner in its 1965 through 1973 listings; however its actual occupancy may have occurred as early as 1959 when the building was constructed, through 1985 at which time the tenant is listed as "Flower Den".

In order to further investigate the discrepancy between the Sanborn Maps reviewed by LCS identifying a drycleaner at 3796 Nostrand Avenue, and the City Directories reviewed by CNS identifying a drycleaner at 3804 Nostrand Avenue; CNS compared the historical Sanborn Maps to a site plan showing the current division of tenant spaces within the northernmost building constructed in 1959. Based upon CNS's review, the division of tenant spaces shown on the Sanborn Maps is different from that of the current tenant spaces, and were thus identified under different addresses. When the Sanborn Map is further compared to a current site plan, the drycleaner notation would appear within the current Chase Bank tenant space located at 3804 Nostrand Avenue; therefore it is CNS's opinion that the current 3804 Nostrand Avenue tenant space was originally addressed as 3796 Nostrand Avenue, however remained uncorrected on the Sanborns Maps through the numerous tenant occupancy changes.

Based upon these findings, CNS agreed with LCS' recommendation that a subsurface investigation was warranted to assess the environmental conditions on the subject site due to historic use as a drycleaner; however CNS recommended this investigation be completed within the vicinity of the current 3804 Nostrand Avenue occupant, Chase Bank, based upon its historical data. A site visit was conducted on Wednesday, February 27, 2013 to determine an appropriate investigation approach. During the site visit it was determined that access to the bank space would not be permitted due to the sensitivity of the operation; therefore it was determined that in lieu of conducting the investigation within 3804 Nostrand Avenue, the investigation would take place immediately downgradient of the bank within the basement of the neighboring tenant space located at 3806 Nostrand Avenue, which was vacant at the time.

In response to the above-mentioned findings and recommendations, on Friday, April 12, 2013 CNS conducted a *Phase II Investigation* at the vacant 3806 Nostrand Avenue tenant space. The investigation involved the collection of soil samples and a groundwater sample from one (1) soil boring advanced within the basement, to investigate soil and groundwater quality at the subject site. Additionally, CNS collected one soil-gas sample, one indoor air sample and one ambient air sample to investigate soil vapor and indoor air quality at the subject site. The laboratory results identified that the groundwater and soil vapor contained dry cleaning compounds. CNS recommended notification to the NYSDEC regarding the contaminants, identification, and mitigation of potential sources of indoor air contaminants, and conducting additional site investigations to characterize the extent of the dry-cleaning compounds.

In August of 2013, CNS completed a *Groundwater Investigation* where three (3) permanent monitoring wells (NW1 through NW3) were installed and a total of eight (8) soil samples and three (3) groundwater samples were collected. Monitoring well NW1 was installed in the front sidewalk grade; NW2 was installed at the rear sidewalk grade; and monitoring well NW3 was installed in the basement of the 3806 Nostrand Avenue tenant space. Soil analytical results identified dry cleaning related compounds above the laboratory's minimum detection limit but below their respective NYSDEC Commercial SCO's. Groundwater analytical results identified dry-cleaning related compounds (PCE, DCE and TCE) within monitoring well samples NW2-GW2A (Sidewalk grade to the west) and NW3-GW3A (Basement) exceeding their respective NYSDEC TOGS 1.1.1 GA values. Based upon the findings, CNS contacted the NYSDEC and was issued Spill #13-10667. Since that time, CNS has been conducting quarterly groundwater sampling events on monitoring wells NW1, NW2, and NW3.

In September of 2015, CNS completed a *Soil Vapor Intrusion Investigation* at the subject site, where one sub-slab soil-gas sample, one indoor air sample and one ambient air sample were collected. Based upon analytical results, the VOC constituents Tetrachloroethene and Trichloroethene, both exceeded their respective minimum NYSDOH Decision Matrix concentrations and USEPA Target Shallow Soil Gas Concentrations. Based on the findings, CNS recommended a Sub-slab Depressurization System be designed and installed to mitigate the affected areas of the subject site.

In October/November of 2015, CNS completed a *Supplemental Phase II Investigation* at the subject site, to delineate the identified dry cleaning related solvent plume in order to develop a Remedial Action Plan. On October 14th and 16th of 2015, CNS oversaw the installation of three (3) permanent monitoring wells (NW4, NW5, and NW6), and three (3) temporary wells (TW1, TW2 and TW3) at the subject site. Temporary wells TW1 and TW2 were installed in the northern portion of the basement of the 3808 Nostarnd Avenue tenant space and TW3 was installed in the basement of 3800 Nostrand Avenue.

Permanent monitoring well NW4 was installed in the common western basement hallway; and NW5 and NW6 was installed in the western back alley at street level. A total of sixteen (16) soil samples and three (3) groundwater samples were collected. Soil sample analytical did not identify any VOC constituents exceeding their respective NYSDEC Unrestricted SCO values. Groundwater samples analytical did identify multiple VOC constituents exceeding their respective NYSDEC Groundwater standards values in all three (3) temporary wells.

Based on the laboratory analytical results, it was CNS's opinion that dry cleaning related solvents have impacted the groundwater at the subject site requiring remediation. CNS recommended that the three (3) temporary wells (TW1, TW2 and TW3) will be made permanent and included in the quarterly sampling events starting in 2016; and a Remedial Action Work Plan be generated outlining current conditions and chemical injection remediation considerations that must to be approved by the NYSDEC prior to implementation.

As stated herein, since Spill # 13-10667 was issued; CNS has been completing *Quarterly Groundwater Monitoring* at the subject site. Previous sampling events occurred on November 21, 2013, April 14, 2014, July 14, 2014, October 23, 2014, January 8, 2015, June 3, 2015, September 8, 2015 and October 30, 2015. Note: The October 2015 sampling event also included the newly installed monitoring wells NW4, NW5 and NW6. Monitoring well sampling events consisted of collecting groundwater measurements for temperature, conductivity, pH, dissolved oxygen and oxygen-reduction potential (ORP) and collecting groundwater samples for VOC analysis via EPA Method 8260. Based upon the most recent sampling event, dry cleaning related compounds remain present within all six (6) monitoring wells. Contaminant increases were identified within monitoring wells NW1, NW2, and NW3; and monitoring wells NW4, NW5 and NW6 exhibited dry cleaning compounds consisting of cis-1,2,-Dichloroethene, Tetrachloroethene, and Trichloroethene.

2.0 REMEDIAL ACTION OBJECTIVES

Based upon the evaluation of the current environmental data, as described herein and taking into consideration current and potential future land use and identification of the actual or potential public health and/or environmental exposures, the Remedial Action Objectives ("RAOs") and applicable Standards, Criteria and Guidance ("SCGs") for the Site are:

- Prevent contact with, or inhalation of volatiles, from free phase hydrocarbons;
- Prevent ingestion and direct contact with contaminated soil, prevent inhalation of, or exposure from, contaminants volatilizing from contaminants in soil;
- Restore groundwater to pre-release conditions, to the extent practicable,
- Prevent migration of contaminants that would result in additional groundwater contamination.

3.0 PROPOSED REMEDY

As stated in Section 1.4: Previous Environmental Investigations, dry-cleaning related chlorinated solvents has impacted the groundwater and potentially the soils at the subject site. The area of contamination where contaminants were identified exceeding the NYSDEC Groundwater Standards was found to cover an area of approximately 85 feet by 67 feet spanning between the 3800 Nostrand Avenue tenant space to the 3808 Nostrand Avenue tenant space. The proposed remedy to achieve remedial objectives of the impacted groundwater is *in situ* chemical injection treatments, as described herein. Note: if further investigations identify soil impacts an amendment to this RAP will be submitted. See Figure III: Groundwater Contamination Plume.

Currently there are six (6) monitoring wells advanced to 20' bgs at street grade and 5' bgs within the basement grade; and CNS is proposing to install an additional four (4) wells within the basements. A layout of the current and proposed monitoring well locations is shown on Figure II: Monitoring Well Locations. The following sections describe the proposed remedial techniques and systems in greater detail.

3.1 Soil Objectives

Current analytical data does not support the need for soil remediation, however further delineation and or well installation may present analytical results that can change site conditions. If site conditions change an addendum to this RAP will be issued.

3.2 Groundwater Objectives

To remediate the groundwater to achieve respectable calculated remediation levels is the application of a manual injection system. The injection process will utilize EOS Remediation, LLC Emulsified Oil Substrates (EOS Pro) to degrade VOCs. EOS Pro is a nutrient-enriched, DoD-validated, emulsified vegetable oil engineered to quickly stimulate microbial activity while providing long-term nourishment to enhance anaerobic bioremediation of chlorinated solvents, nitrates, perchlorate, energetics, acid mine drainage, and other recalcitrant chemicals in contaminated groundwater.

This method has the ability to use existing wells for groundwater monitoring, sampling and analysis during and after the injection process where contaminate levels can be observed with respect to the agreed remediation levels. No impacted groundwater is to be extracted or discharged during the remediation proposed by CNS.

3.2.1 Groundwater Remediation Design Plan

Injection points are proposed to be placed in and around the contaminated area, whereby the EOS Pro will be stimulate biological growth at a controlled rate to remediate the groundwater to acceptable NYSDEC limits. See Appendix A: EOS Pro Product Information.

CNS will advance injection points utilizing a Geoprobe™ which will be subsequently attached to a pressurized injection delivery system. The EOS Pro will be injected and handled in compliance with the manufacturers specifications. See Figure IV: Proposed Injection Point Locations.

3.2.2 Monitoring Well Construction

A layout of the current and proposed monitoring well locations for the subject site is shown in Figure II: Monitoring Well Locations. Currently there are six (6) monitoring wells advanced to 20' bgs at street grade and 5' bgs within the basement grade, and CNS is proposing to install an additional four (4) wells within the basements. A layout of the current and proposed monitoring well locations is shown on Figure II: Monitoring Well Locations. The following sections describe the proposed remedial techniques and systems in greater detail.

Permanent monitoring wells will be constructed of 2-inch diameter PVC and installed to a depth of five feet below the water table. Up to ten-feet of 0.010 slot screen will be installed to intersect the water table to allow for groundwater fluctuations and free product (if present) on the water table to enter the well. The annular space between the borehole and the well screen will be backfilled with #2 Morie sand to a depth of two feet above the top of the screen. A two-foot thick hydrated bentonite seal will be installed above the sand and the remainder of the annular space will be backfilled with native soils. The monitoring wells will be completed at grade with a small diameter flush-mount manhole and concrete seal. See Figure V: Well Construction Drawing.

3.3 Points of Compliance

Groundwater samples will be collected on a quarterly basis to verify progress of the remediation. These groundwater samples will be collected from the on-site monitoring wells and be analyzed in accordance with US EPA Methods SW-846: Test Methods for Evaluating Solid Waste and analyzed via 8260 for VOCs. The collected groundwater samples and a submitted demonstration of completion report will show that the established site specific remediation objects have been achieved and demonstrate that remediation has satisfied the NYSDEC for an issuance of a No Further Action of remediation for closure.

4.0 ENGINEERING EVALUATION OF PROPOSED REMEDY

The purpose of this engineering evaluation is to demonstrate that the proposed remedy can achieve the cleanup objectives for the Site. This section evaluates the proposed remedy against the factors given in 6 NYCRR 375-1.8(f).

4.1. Overall Protection of Human Health and the Environment

The proposed remedy will achieve cleanup objectives at the subject site. The removal of potential chlorinated solvents utilizing *in situ* chemical injection treatments will effectively reduce on-site contaminants to the extent possible or where it is no longer present in treatable quantities.

4.2. Compliance with Applicable Regulatory Standards, Criteria and Guidelines

The proposed remedy will utilize *in situ* injection techniques to achieve mass reduction of onsite impacts.

4.3. Long-Term Effectiveness and Performance

The proposed remedy will be a permanent solution after the cleanup objectives described in Section 2.0 are achieved.

After the cleanup objectives described in Section 2.0 are managed to the extent practicable, no significant threats, exposure pathways or risks to the public or environment will be present at the subject site.

4.4. Reduction of Toxicity, Mobility, and Volume

The proposed remedy will reduce the mass in the groundwater impacted with contamination located beneath the subject site. The *in situ* injection techniques described in Section 3.1 will be utilized until chlorinated solvents in treatable quantities are no longer present.

4.5. Short-Term Impacts and Effectiveness

The risks posed to the community, workers and environment due to the implementation of the proposed remedy are minimal:

- During the implementation of remedial activities, risk to community will include off-gas vapor inhalation, potential noise levels coming from the injection points and direct contact if a line ruptures during the injection process. Any off-gas generated will be diverted from the truck away from the community and vented containments will be erected within occupied spaces to mitigate any potential direct contact exposures. Additionally, all fuel powered equipment will be positioned at the site to mitigate any noise impacts to the community. All work will be monitored according to the site specific health and safety plan (HASP), included in Appendix B.

- It is possible that workers on the subject site will be exposed to hydrocarbon contamination during implementation of the injection process, construction of, and operation and maintenance of the injection system. The potential risks include material handling, electrical shock, off-gas vapor inhalation, direct-contact, general trip hazards, and noise. The workers will be required to review a HASP prepared for the subject site prior to the commencement of any site work.

4.6. Implementation

Implementation of the proposed remedy is not anticipated to encounter any difficulties.

4.7. Community Acceptance

It has been assumed that the community will be accepting of the alternative.

4.8. Land Use

Following implementation of the remedy, the subject site will be restored, thereby retaining compatibility with future commercial land use.

5.0 PROPOSED REMEDY IMPLEMENTATION PLAN

The proposed remedy implementation plan provides a more detailed description of the proposed remedy and how the selected remedial technologies will be implemented to meet the cleanup objectives discussed in Section 2.0.

5.1. *In Situ* Chemical Injection Treatments

To remediate the groundwater to achieve respectable calculated remediation levels is the application of a manual injection system. The injection process will utilize EOS Remediation, LLC Emulsified Oil Substrates (EOS Pro) to degrade VOCs. EOS Pro is a nutrient-enriched, DoD-validated, emulsified vegetable oil engineered to quickly stimulate microbial activity while providing long-term nourishment to enhance anaerobic bioremediation of chlorinated solvents, nitrates, perchlorate, energetics, acid mine drainage, and other recalcitrant chemicals in contaminated groundwater. The EOS Pro application is a "final" solution, whereby the system will eliminate contaminants from the subject site. See Appendix A: EOS Pro Product Information.

Additionally, this method has the ability to use existing wells for groundwater monitoring, sampling and analysis during and after the injection process where contaminant levels can be observed with respect to the agreed remediation levels. No impacted groundwater is to be extracted or discharged during the remediation proposed by CNS.

Injection points are proposed to be placed in and around the contaminated area, whereby the EOS Pro will be stimulate biological growth at a controlled rate to remediate the groundwater to acceptable NYSDEC limits. CNS will advance injection points utilizing a Geoprobe™ which will be subsequently attached to a pressurized injection delivery system. The EOS Pro will be injected and handled in compliance with the manufacturers specifications. See Figure IV: Proposed Injection Point Locations.

The area of contamination where contaminants detected exceeded the NYSDEC Groundwater Standards was found to cover an area of approximately 85 feet by 67 feet, respectively. See Figure IV: Groundwater Contamination Plume.

5.1.2 Post-Remedial Groundwater Monitoring

After the product recovery system shutdown and mass reduction has occurred at the subject site, groundwater monitoring will continue until analytical results demonstrate acceptable levels for the period of one year. Monitoring will consist of four consecutive quarterly sampling rounds at all monitoring wells installed at the subject site. Samples collected from monitoring wells will be analyzed for VOCs via EPA Methods 8260.

Prior to sampling, each well will be purged a minimum of three casing volumes of water using a low-flow pump with dedicated disposable tubing. This is to ensure representative samples from the formation surrounding the wells are obtained and to eliminate standing water in the wells.

After the final well purge within each monitoring well, measurements for temperature, conductivity, pH, dissolved oxygen and oxygen-reduction potential (ORP) will be collected, utilizing a YSI 556 Multi Probe System, or similar, within non-chemically analyzed clean sample jars.

Non-disposable sampling equipment (i.e. interface probe, pump) will be cleaned using a distilled water and Alconox detergent wash followed by a distilled water rinse prior to use at each well.

5.2. Proposed Remedy Implementation Schedule

The schedule for the proposed remedy activities is as follows:

- RAWP Submittal – January 2016
- NYSDEC Review of RAWP – March 2016
- Response to NYSDEC Comments to RAWP – April 2016
- Installation of additional Wells and In-Situ Injections – TBD

5.3. Project Reporting

Monitoring reports will be submitted to the NYSDEC on a quarterly basis. The monitoring reports will include items such as: a description of all site activities that occurred during the reporting period, remedial system operation and maintenance data, and any monitoring results.

6.0 CONCLUSION

CNS has submitted this Remedial Action Work Plan to be approved by the NYSDEC to address the VOC contamination detected at the subject site, therefore allowing CNS to proceed with the proposed remediation systems. The proposed remedial actions listed herein consists of *In-Situ* Chemical Injection Treatments which will eliminate the potential for contaminant source migration, mitigate the current groundwater contamination and will achieve the NYSDEC cleanup goals.

7.0 SIGNATURES

If you have any questions or require additional information regarding this project please call (516) 932-3228.

Prepared by:	Reviewed and Approved by:
Wala Canario	Charles Powers
Geologist	President

8.0 PROJECT LIMITATIONS

This report is written for the use of the New York State Department of Environmental Conservation, Acadia 3780-3858 Nostrand, LLC and its partners. No other party shall have any right to rely on this report or any service provided by CNS Environmental without prior written consent by Acadia 3780-3858 Nostrand, LLC and CNS Environmental.

The investigations and subsequent proposed remedial action plan were performed in accordance with professional standards applicable to the industry today. The results of this assessment and the contents of this report are subject to revision based on future events and/or investigations. CNS Environmental assumes no responsibility for the property owner's actions related to the following:

- Violation of any federal, state or local statute or ordinance relating to reporting, identification or disposal of a hazardous substance or its constituents;
- Undertaking of, or arrangement for the reporting, handling, removal, treatment, storage, transportation, or disposal of hazardous substances or constituents found or identified, and;
- Changed conditions or hazardous substances or constituents introduced at the properties by Client or third persons to this contract during or after the completion of services provided by this report.

Therefore, the findings, conclusions and recommendations presented herein are based solely on the aforementioned scope of work and information gathering. Incomplete or outstanding information identified throughout this report is considered a limitation to the assessment.

All findings, conclusions and recommendations stated in this report are based upon facts, circumstances and industry-accepted procedures for such services, as they existed at the time this report was prepared. All findings, conclusions and recommendations stated in this reports are based on the data and information provided and observations and conditions that existed on the date and timework was performed. Responses received from local, state, or federal agencies or other out-sourced or other secondary sources of information after the issuance of this report may change certain facts, findings, conclusions or circumstances to the report. A change in fact, circumstance or industry-accepted procedure upon which this report was based may adversely affect the findings, conclusions and recommendations expressed in this report and is considered a limitation.

FIGURE I

Site Location Map

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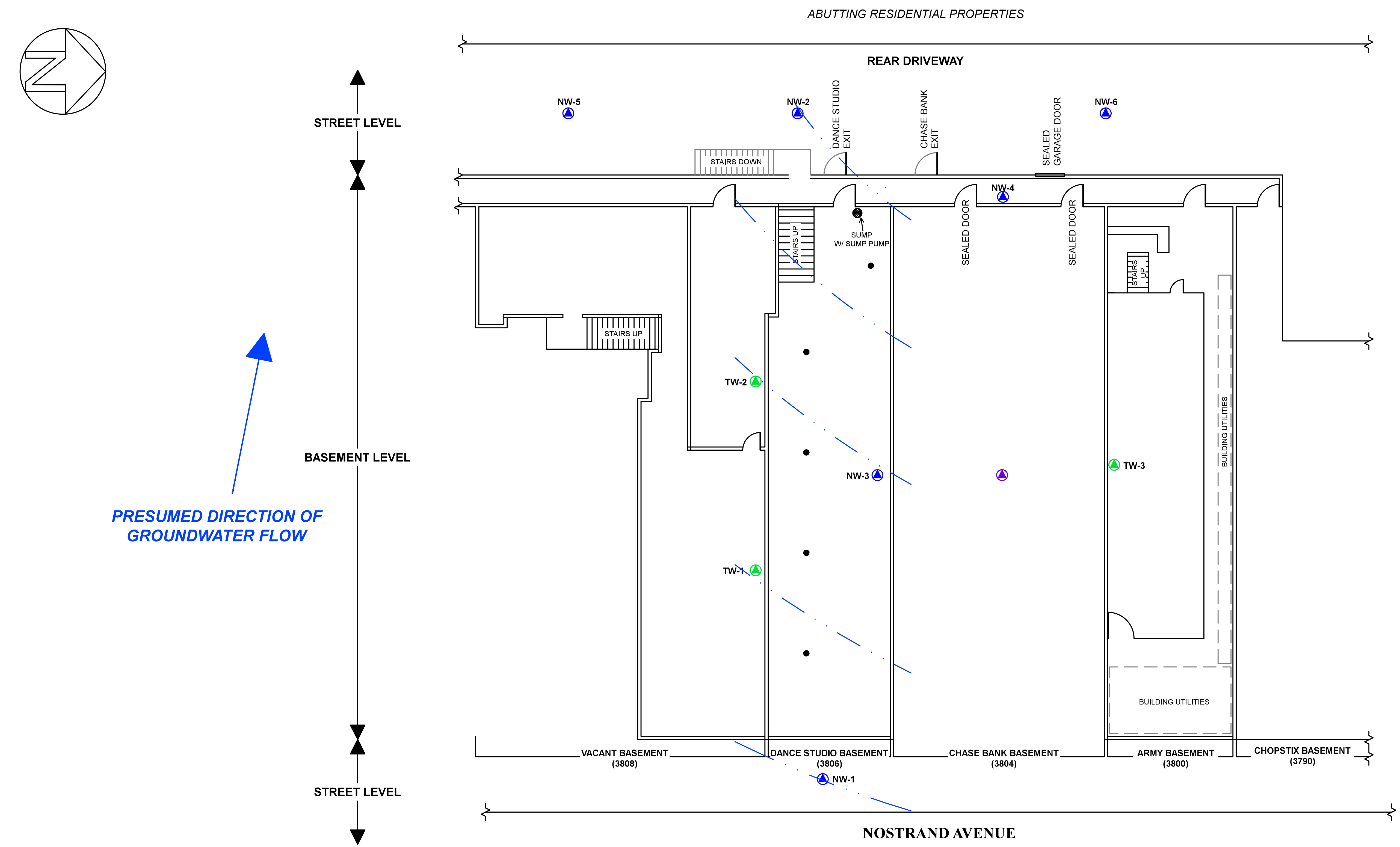
A REAL ESTATE SERVICES COMPANY
208 Newtown Road, Plainview, NY 11803
Tel. (516) 932-3228 / Fax. (516) 932-3288

Figure 1 Site Location Map		Prepared For:	**Acadia 3780-3858 Nostrand, LLC 411 Theodore Fremd Avenue, Suite 300 Rye, NY 10580**	
		Subject Site:	**3780-3860 Nostrand Avenue Brooklyn, New York 11235**	
Scale:	As Noted	Date:	**2015**	CNS Job #: **D196**

FIGURE II

Monitoring Well Locations



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PLAINVIEW, NY 11803

FIGURE II

MONITORING WELL LOCATIONS

SCALE:	1" = 16'

PREPARED FOR:	ACADIA REALTY TRUST, LLC 411 THEODORE FREMD AVE., SUITE 300, RYE, NY 10580				
SUBJECT SITE:	NOSTRAND PLACE BROOKLYN, NEW YORK				
DATE:	JANUARY 2016	CNS JOB #:	D196		
DWN BY:	JL	CKD BY:	WC	APPRVD BY:	CP

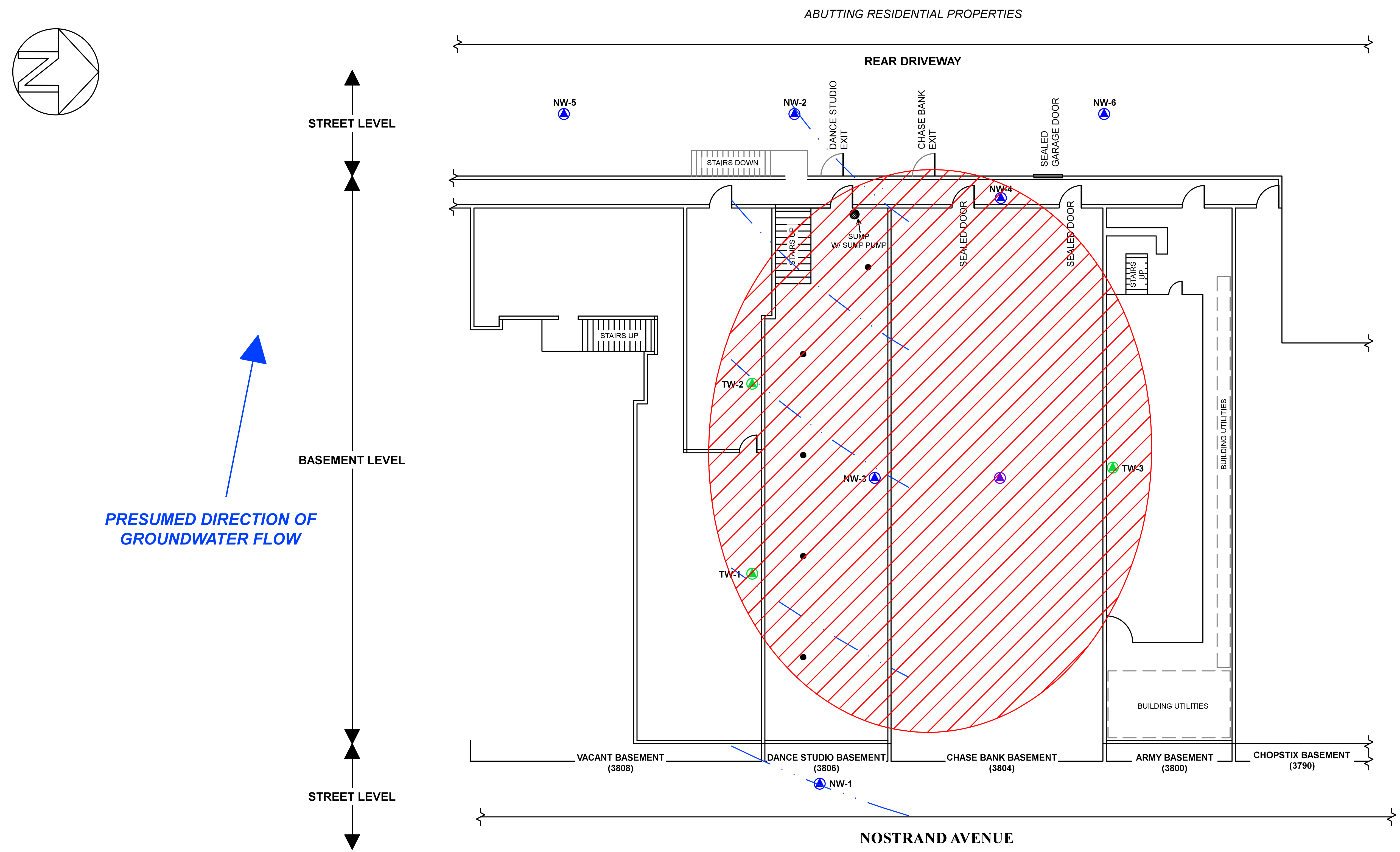
LEGEND:

- = PERMANENT GROUNDWATER MONITORING WELL
- = TEMPORARY GROUNDWATER MONITORING WELL PROPOSED TO BE CONVERTED TO PERMANENT MONITORING WELL
- = PROPOSED PERMANENT MONITORING WELL

NOTES:

FIGURE III

Groundwater Contamination Plume



CNS ENVIRONMENTAL A REAL ESTATE SERVICES COMPANY 208 NEWTOWN ROAD PLAINVIEW, NY 11803	PREPARED FOR:	ACADIA REALTY TRUST, LLC 411 THEODORE FREMD AVE., SUITE 300, RYE, NY 10580			
	SUBJECT SITE:	NOSTRAND PLACE BROOKLYN, NEW YORK			
FIGURE III GROUNDWATER CONTAMINATION PLUME	DATE:	JANUARY 2016	CNS JOB #:	D196	
SCALE: 1" = 16'	DWN BY:	JL	CKD BY: WC	APPRVD BY:	CP

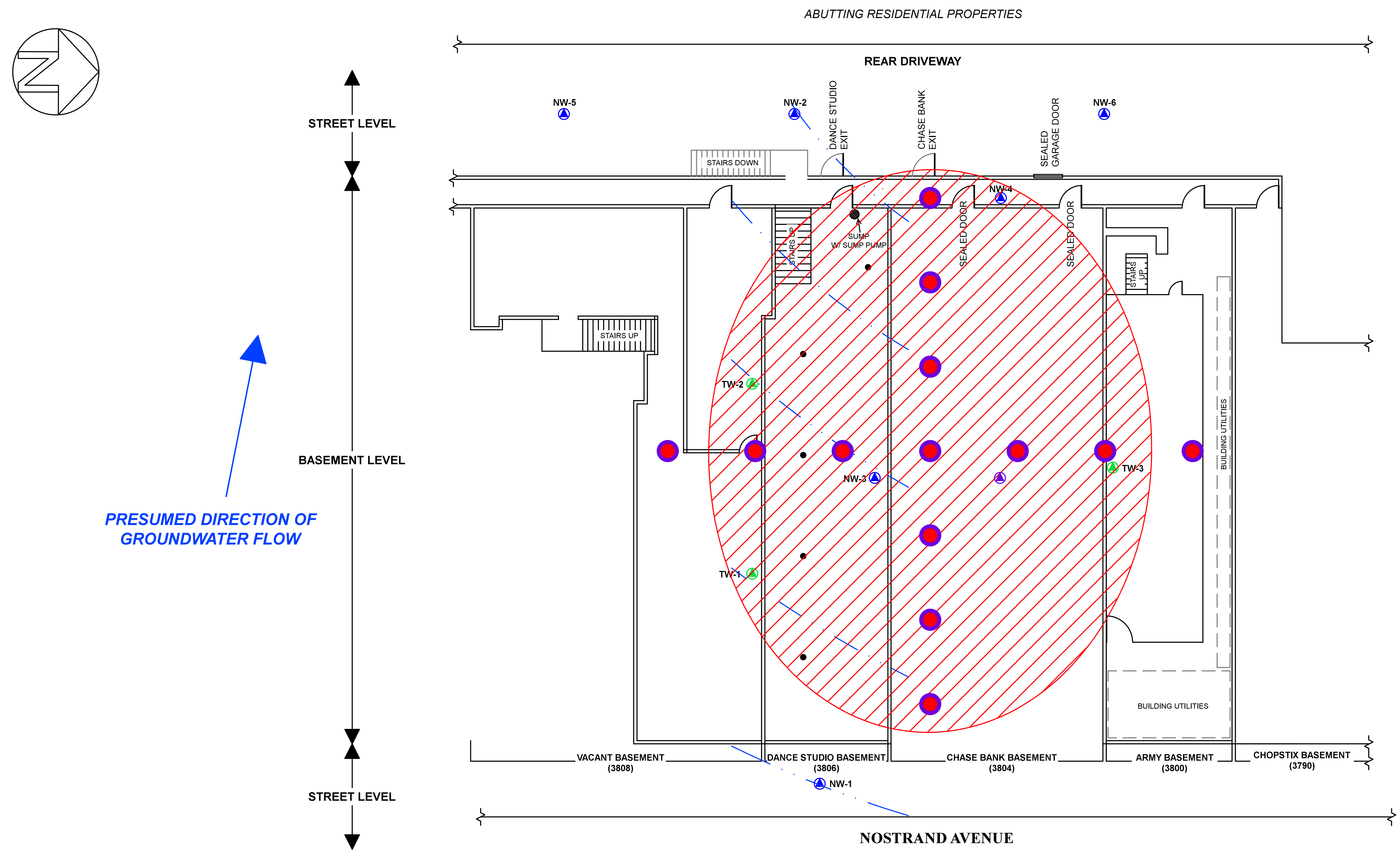
LEGEND:

- = PERMANENT GROUNDWATER MONITORING WELL
- = TEMPORARY GROUNDWATER MONITORING WELL PROPOSED TO BE CONVERTED TO PERMANENT MONITORING WELL
- = PROPOSED PERMANENT MONITORING WELL
- = GROUNDWATER CONTAMINATION PLUME

NOTES:

FIGURE IV

Proposed Injection Point Locations



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PLAINVIEW, NY 11803

FIGURE IV

PROPOSED INJECTION POINT LOCATIONS

PREPARED FOR:	ACADIA REALTY TRUST, LLC 411 THEODORE FREMD AVE., SUITE 300, RYE, NY 10580
SUBJECT SITE:	NOSTRAND PLACE BROOKLYN, NEW YORK

SCALE:	1" = 16'				
DATE:	JANUARY 2016	CNS JOB #:	D196		
DWN BY:	JL	CKD BY:	WC	APPRVD BY:	CP

LEGEND:

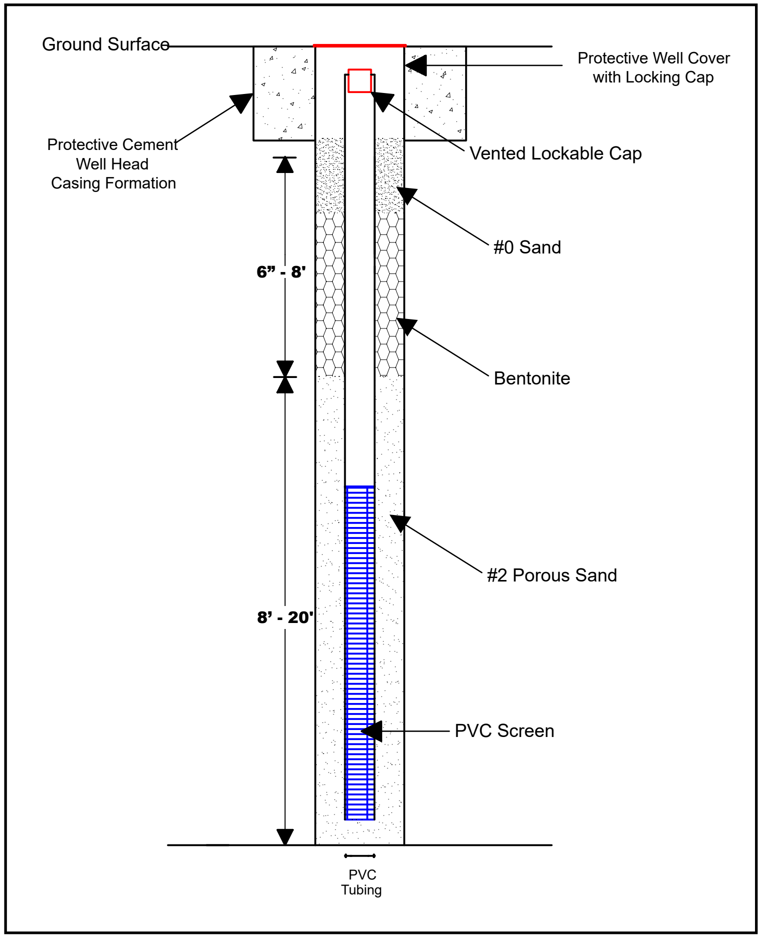
- = PERMANENT GROUNDWATER MONITORING WELL
- = TEMPORARY GROUNDWATER MONITORING WELL PROPOSED TO BE CONVERTED TO PERMANENT MONITORING WELL
- = PROPOSED PERMANENT MONITORING WELL
- = GROUNDWATER CONTAMINATION PLUME
- = PROPOSED INJECTION POINT

NOTES:

FIGURE V

Monitoring Well Construction Drawing

STREET LEVEL GRADE MONITORING WELL



BASEMENT LEVEL GRADE MONITORING WELL

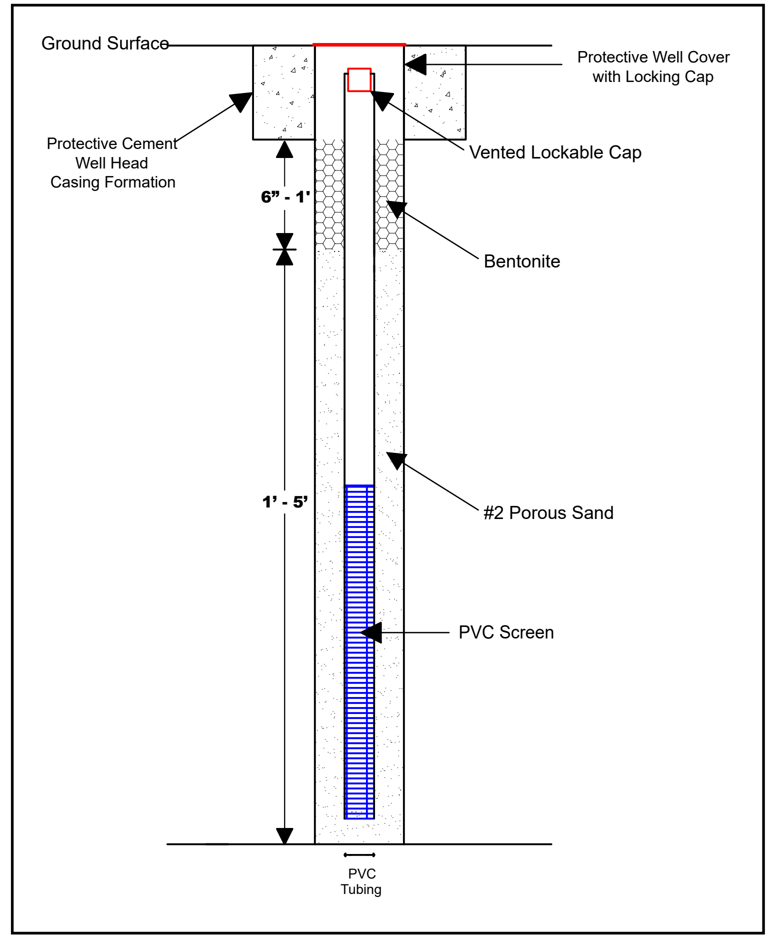


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FIGURE V

MONITORING WELL CONSTRUCTION

PREPARED FOR:	ACADIA REALTY TRUST, LLC 411 THEODORE FREMD AVE., SUITE 300, RYE, NY 10580		
SUBJECT SITE:	NOSTRAND PLACE BROOKLYN, NEW YORK		
DATE:	JANUARY 2016	**CNS JOB #:**	D196

SCALE:	NTS	**DWN BY:**	JL	**CKD BY:**	WC	**APPRVD BY:**	CP

LEGEND:

= #0 SAND

= BENTONITE

= #2 POROUS SAND OVER PVC SCHEDULE 40 TUBING

NOTES:

APPENDIX A

EOS Remediation EOS Pro Product Specifications

EOS Remediation LLC Site: Nostarnd #2
919-873-2204 www.eosremediation.com

Design Summary: Input parameters for the volume estimate are outlined below. When a parameter was unknown with no laboratory or field information provided by the client, a default value was used. A safety factor of 2 is used in our calculations. If your assumptions are different from those included in this table, or you obtain more information following a pilot test, please let us provide another estimate as the product(s) or volume proposed for this site could change.

Treatment Type		Value	Units	Default	Site Value
	Barrier or Source Treatment	Source Area			
	EOS Product	EOS Pro			
	Length of treatment area parallel to groundwater flow, 'x'	49.1	ft		√
	Width of treatment area perpendicular to groundwater flow, "y"	49.1	ft		√
	Treatment thickness, "z"	8	ft		√
	Nominal soil type	Sand			√
	Estimated Porosity (total)	0.38			√
	Effective Porosity	0.23			√
	Soil bulk density	103	pcf	Calculated	
Biogeochemical					
	pH of groundwater	7.39	SU		√
	Acid demand of aquifer material	0.0	OH^- meq/Kg		√
	Acidity of groundwater	0.0	OH^- meq/L		√
	Acidity values based on laboratory data	No			
Geohydrology					
	Hydraulic Conductivity	25	ft/d		√
	Hydraulic Gradient	0.001	ft/ft		√
	Seepage Velocity	0.109	ft/d	Calculated	
	Contact time	60	days	√	
	Design Life per application	5	yrs.	√	
Analytical					
	Dissolved Oxygen (DO)	2.35	mg/L		√
	Nitrate Nitrogen (NO_3^- - N)	1	mg/L		√
	Sulfate (SO_4^{2-})	10	mg/L		√
	Tetrachloroethene (PCE), C_2Cl_4	2.25	mg/L		√
	Trichloroethene (TCE), C_2HCl_3	0.08	mg/L		√
	cis-1,2-dichloroethene (c-DCE), $C_2H_2Cl_2$	0.14	mg/L		√
	Vinyl Chloride (VC), C_2H_3Cl	0	mg/L		√
	Carbon tetrachloride, CCl_4	0	mg/L		√
	Chloroform, $CHCl_3$	0	mg/L		√
	sym-tetrachloroethane, $C_2H_2Cl_4$	0	mg/L		√
	1,1,1-Trichloroethane (TCA), CH_3CCl_3	0	mg/L		√
	1,1-Dichloroethane (DCA), $C_2H_4Cl_2$	0	mg/L		√
	Chloroethane, C_2H_5Cl	0	mg/L		√
	Perchlorate, ClO_4^-	0	mg/L		√
	Hexavalent Chromium, Cr[VI]	0	mg/L		√
	Pentachlorophenol	0	mg/L		√
	User added	0	mg/L		
	User added	0	mg/L		
Design					
	Design Factor	2	times	√	
	Stoichiometric Hydrogen Demand	13.9	lbs	Calculated	
	Effective treatment thickness for substrate, "z_e"	25%		√	
	Absorptive Capacity of soil	0.0012		√	
	Substrate from hydrogen demand	406	lbs	Calculated	
	Substrate required from Adsorption	992	lbs	Calculated	
	DOC Released	351	lbs	Calculated	
	Estimated Amount of $Fe2^+$ Formed	10	mg/L	√	
	Estimated Amount of Manganese (Mn^{2+}) Formed	5	mg/L	√	
	Estimated Amount of CH_4 Formed	5	mg/L	√	
	Target Amount of DOC to Release	60	mg/L	√	
	Effective treatment thickness for buffer, "z_e"	25%		√	
	Base Required for Sediment	0	OH^- eq	Calculated	
	Base Required for Aquifer	0	OH^- eq	Calculated	
	Mass to be treated	494,549	lbs	Calculated	
	Estimated total groundwater volume treated over design life	188,886	gal	Calculated	
Calculated Substrate Requirement					
	Substrate Requirement Based on Hydrogen Demand and Carbon Loss	**406**	**lbs**		
	Substrate Requirement Based on Oil Entrapment by Aquifer Material	**992**	**lbs**		
	EOS Pro Requirement			**3**	**Drums**
	CoBupH-Mg (buffer) Recommended	**0**	**lbs**	**0.0**	**Pails**
	Quantity of Dechlorinating Consortium BAC-9	**13**	**L**		

EOS PRO

PRODUCT INFORMATION SHEET

Emulsified Oils Family

Description

USDA CERTIFIED BIOBASED PRODUCT
PRODUCT 95%

EOS PRO is a nutrient-enriched, DoD-validated, emulsified vegetable oil (EVO). EOS PRO is engineered to quickly stimulate microbial activity while providing long-term nourishment to enhance anaerobic bioremediation of chlorinated solvents, nitrates, perchlorate, energetics, acid mine drainage, and other recalcitrant chemicals in contaminated groundwater. EOS PRO can also be used to reduce redox sensitive metals and radionuclides. The negative surface charges on the droplets combined with small droplet size promote effective transport in the subsurface.

EOS PRO benefits include:

- Biostimulating vitamins and nutrients
- Rapidly-biodegradable substrates to “jump start” bacterial growth
- Slow release biodegradable substrates to promote long-term biological activity
- Engineered for effective transport in the subsurface
    - Small oil droplet size
    - Negative surface charge
- Neutral pH
- Extensive third-party validation

EOS PRO incorporates the patented EOS® technologies that clients have trusted for more than a decade. Domestic supply *made in the USA* with US farmed soybeans.

Chemical & Physical Properties

Oil Emulsion Concentrate: EOS PRO	Typical
Refined and Bleached US Soybean Oil (% by wt.)	59.8
Rapidly Biodegradable Soluble Substrate (% by wt.)	4
Other Organics (emulsifiers, food additives, etc.) (% by wt.)	10
Specific Gravity	0.96 - 0.98
pH (Standard Units)	6 - 7
Median Oil Droplet Size (microns)	1.0
Organic Carbon (% by wt.)	74
Mass of Hydrogen Produced (lbs. H_2 per lbs. EOS PRO)	0.25

Packaging

Shipped in 55-gallon drums, 275-gallon IBC totes or bulk tankers (40,000 lbs.)

Handling & Storage

EOS PRO is shipped as a ready-to-use concentrated emulsion that can be diluted with water in the field to prepare a high quality suspension for easy injection. EOS PRO has a low viscosity and can be distributed with commonly available pumps or by continuous metering with a diluter (e.g., Dosatron™). Dilution ratios for EOS PRO typically range from 4:1 to 20:1 (water: EOS PRO) depending on site conditions. EOS PRO injections should be followed with additional chase water to maximize distribution of EOS PRO into the formation.

For best performance, use EOS PRO within 60 days of delivery and store at a temperature between 40°F (4°C) to 100°F (38°C).

+1 919 873 2204
www.eosremediation.com

USER'S GUIDE

Development of a Design Tool for Planning Aqueous Amendment Injection Systems

ESTCP Project ER-0626

June 2008

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SECTION 1
GENERAL OVERVIEW OF EMULSIFIED OIL PROCESS

1.1 Introduction

This design tool is intended to assist with the design of injection systems for distributing emulsified edible oils to stimulate *in situ* anaerobic bioremediation (AB) of groundwater contaminants. The design tool is intended to assist users in selecting an appropriate injection well spacing and amount of emulsified oil and water to inject. Prior to beginning use of the design tool, users should have already conducted a preliminary screening to determine if AB using emulsified oils is appropriate for the conditions at their site.

Users are expected to have a good understanding of AB using emulsified oils prior to beginning use of the design tool. For information on enhanced AB using emulsified oils, users should first consult the following documents.

- "A Treatability Test for Evaluating the Potential Applicability of the Reductive Anaerobic Biological *In Situ* Treatment Technology to Remediate Chloroethenes" (search for title at http://docs.serdp-estcp.org/index.cfm)
- "Principles and Practices of Enhanced Anaerobic Bioremediation of Chlorinated Solvents" – (http://www.afcee.brooks.af.mil/products/techtrans/Bioremediation/BIOREMresources.asp)
- "Protocol for Enhanced *In Situ* Bioremediation Using Emulsified Edible Oil" – (search for title at http://docs.serdp-estcp.org/index.cfm)
- "Protocol for *In Situ* Bioremediation of Chlorinated Solvents Using Edible Oil" (http://www.afcee.brooks.af.mil/products/techtrans/Bioremediation/BIOREMresources.asp)

Emulsified oils have been applied at several hundred commercial and military sites nationwide. Although emulsified oils have been demonstrated in the laboratory and the field, this technology continues to evolve. This manual is based on the current state of practice at the time of writing.

There are a wide variety of compounds that can be anaerobically biodegraded using emulsified oils including chlorinated ethenes, chlorinated ethanes, halomethanes, perchlorate, nitrate, certain metals, and explosives (e.g., RDX, HMX). For a few of these compounds (e.g., PCE, TCE, perchlorate, and nitrate), the biodegradation pathways and microorganisms that carry out this process are relatively well understood and enhanced anaerobic biodegradation has been demonstrated in the field at multiple sites. However, there are many other compounds (e.g., chlorinated ethanes and methanes, freons) where the factors controlling contaminant biodegradation are much less well understood. In addition, substrate addition has the potential to inhibit biodegradation of petroleum hydrocarbons and related contaminants. If mixtures of chlorinated solvents, petroleum hydrocarbon, and/or solvent stabilizers (e.g., 1,4-dioxane) are present, other alternatives may need to be considered.

1.2 The Emulsified Oil Process

In the emulsified oil process, an oil-in-water emulsion is prepared using vegetable oil and distributed throughout the target treatment zone to provide a long-lasting electron donor to support anaerobic biodegradation processes. These oils are fermented to molecular hydrogen (H_2) and acetate by common subsurface microorganisms. The H_2 and acetate are then used as a carbon and energy source for anaerobic biodegradation of the target pollutants.

Oil-in-water emulsions are completely miscible with water so the emulsions easily disperse with groundwater after injection. Ideally, the emulsion should be stable (i.e., non-coalescing); have small, uniform droplets to allow transport in most aquifers; and have a negative surface charge to reduce droplet capture by the solid surfaces. The emulsified oil is injected into the aquifer with water to distribute and immobilize the oil droplets. As oil droplets migrate through the aquifer pore spaces, they collide with the aquifer material (i.e., soil) surfaces and stick. The surfaces of the aquifer material gradually become coated with a thin layer of oil droplets that provides a carbon source for long-term reductive dechlorination. Oil droplet retention on the aquifer material surfaces is proportional to the clay content with larger amounts of clay resulting in higher oil retention (Coulibaly and Borden, 2004). Soluble substrates and nutrients (e.g., lactate, yeast extract, vitamins) can be added to the mixture prior to injection to stimulate rapid growth of desired bacteria. Field and laboratory studies (Borden et al., 2004; Coulibaly and Borden, 2004, Beckwith et al., 2005) have shown that emulsified oils can be transported substantial distances (up to 50 feet) in a variety of aquifer materials with low to moderate oil retention and with little permeability loss.

1.3 Procedures for Injecting Emulsions

Projects involving injection of oil emulsions typically, but not always, involve the following steps: 1) installation of injection wells and associated equipment; 2) emulsion preparation; and 3) emulsion and water injection. Emulsions can be injected through the end of a direct push rod, through temporary 1-inch direct-push wells, or through permanent 2 or 4-inch conventionally-drilled wells. The selection of the most appropriate method for installing injection points depends on site-specific conditions including drilling costs, flow rate per well, and volume of fluid that must be injected.

Using properly prepared emulsions, it is possible to move injected emulsions 10, 20 or 50 ft away from the injection point. However, achieving effective distribution of the emulsified oil often requires injecting large volumes of water. Depending on the injection well layout and formation permeability, emulsion injection can require an hour to several days per well. As a consequence, several wells may be injected at one time using a simple injection system manifold.

The primary design variables that must be considered when planning an emulsion injection project are:

(1) the spatial arrangement of the injection points;
(2) the type and physical construction of the injection points or wells;
(3) the amount of emulsified oil and water to inject;

(4) the timing of emulsified oil and water injection; and
(5) additional labor and equipment required for mixing and injection.

Each of these variables has an important influence on both the cost and effectiveness of the injection project.

1.3.1 *Arrangement of Injection Points*

There are two general approaches used to distribute emulsions through the subsurface: a) recirculation systems; and b) injection only systems. Recirculation systems can be effective in distributing emulsions significant distances through the subsurface in certain situations, allowing the use of fewer injection points. These systems are particularly useful where drilling costs are high or site access limitations restrict injection point installation. Recirculation systems can also be designed to minimize the physical displacement of contaminants by injection water. However, capital and operating costs of recirculation systems are can be higher due to the more complex equipment and piping requirements and higher operation and maintenance (O&M) costs. In many cases, the design of recirculation systems is more complicated and may require the use of a site-specific groundwater model.

Injection only systems are most useful when drilling and site access conditions allow installation of rows or grids of injection points. Under these conditions, capital and O&M costs are often lower for injection only systems. The design of injection only systems can also be simplified by generating a 'standard' design for a small group of injection points which is then replicated throughout the site.

The design tool described in this document has been developed to assist users in the design of injection only systems for distributing emulsions. There are two basic configurations considered: a) barriers (e.g., rows of injection points) designed to only treat contaminated groundwater as it migrates through the emulsion treated zone; and b) area treatments (e.g., grids or multiple rows of injection points) designed to treat both mobile dissolved contaminants and relatively immobile sorbed/residual contaminants.

Once a general layout has been selected (e.g., barrier or area treatment), the user must then select an injection point spacing. Selecting the best well spacing can be complicated. Increasing the separation between injection wells will reduce the number of wells, reducing drilling costs. However, a larger well spacing can also increase the time required for injection, increasing labor costs. It may also be more difficult to uniformly distribute the emulsion throughout the treatment zone using fewer, widely spaced injection points. In many cases, an intermediate well spacing results in the lowest total cost with reasonably good emulsion distribution throughout the target treatment zone. The design tool provides graphs illustrating the effect of well spacing on emulsion distribution efficiency and comparative costs allowing the designer to select a well spacing that best meets project objectives.

1.3.2 *Injection Point Construction*

Emulsions can be injected through the end of a direct push rod, through temporary 1-inch direct-push wells, or through permanent 2 or 4-inch conventionally-drilled wells. The selection of the most appropriate method for installing injection points depends on site-specific conditions including drilling costs, flow rate per well, and volume of fluid that must be injected.

When the contamination extends over a significant vertical extent, it may be desirable to install several shorter screened wells to target specific intervals. This allows a known quantity of emulsion to be injected in each interval. However, this also increases injection system cost and complexity. Additional information on injecting emulsion through wells and direct push points can be found in Solution-IES (2006) and AFCEE (2007).

1.3.3 *Amount of Water and Emulsified Oil to Inject*

Emulsions are transported in the subsurface by flowing groundwater. Consequently, sufficient water must be injected to transport the oil droplets throughout the target treatment zone. The amount of emulsified oil required is determined by the target treatment volume and the amount of oil retained per mass of aquifer material. Emulsion distribution in the aquifer can be enhanced by injecting more emulsified oil and/or more water. However, injecting additional emulsified oil increases material costs. Injecting additional water increases labor costs. Performance curves are presented in Section 2 illustrating the effect of varying the amount of emulsified oil and/or water injected on contact efficiency. Guidance on use of the design tool to calculate emulsified oil and water injection volumes is presented in Section 3.

1.3.4 *Timing of Fluid Injection*

Achieving effective distribution of the emulsion often requires injecting large volumes of water. To reduce costs, it may be desirable to manifold a group of wells together allowing simultaneous injection of multiple points. However, simultaneous injection of nearby wells can cause well inference effects, resulting in stagnation zones and poor emulsion distribution. Sections 2.2.3 and 2.3.3 provide information on the effect of simultaneous versus sequential injection on emulsified oil contact efficiency.

1.3.5 *Additional Labor and Equipment Required*

The major capital costs for emulsion injection are associated with injection point installation, substrate purchase and labor during the injection. However, there are a number of other factors that can influence the final project cost including mobilization, setup of injection equipment (e.g., pumps, meters), injection water supply, and site cleanup. These costs are not closely related to the specific injection design. However, they can have a significant impact on the final project cost. In the design tool, costs for engineering and permitting, mobilization, equipment setup, water supply and cleanup/demobilization are entered as fixed costs. Costs for equipment rental are entered on a daily basis.

SECTION 2
EFFECT OF INJECTION SYSTEM DESIGN ON CONTACT EFFICIENCY

2.1 Introduction

In situ bioremediation processes will be most effective when the emulsified oil is uniformly distributed throughout the treatment zone. Figure 2.1 shows a hypothetical injection grid for treatment of a source area. The injection system consists of five rows of injection wells. Alternating rows are offset with the objective of improving emulsified oil distribution. The shaded circles are intended to represent the target contact zone around each injection well. From this very simple illustration, it is obvious that some areas will remain uncontacted, even if emulsion could be perfectly distributed throughout the target zone. Coverage could be increased by increasing the size of the circles. However, this would result in overlap between some adjoining circles.

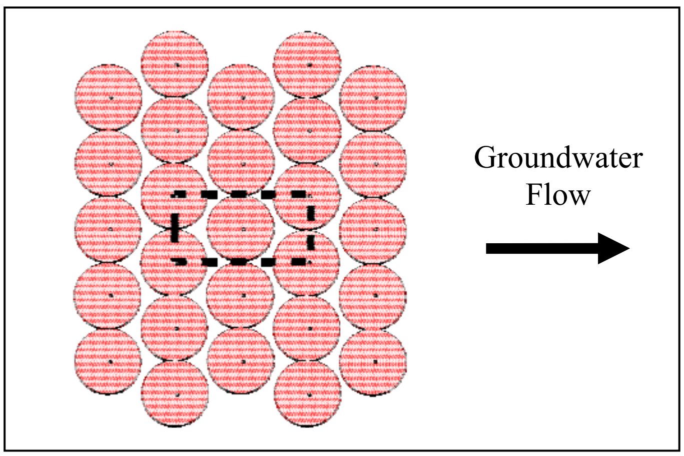

Figure 2.1. Hypothetical Injection Grid Showing Model Domain Subarea.

In real aquifers, emulsion is not uniformly distributed in a perfect circle around each injection well. Simultaneous injection of multiple wells will result in stagnation zones, diverting water and emulsion away from some areas. Aquifer heterogeneity will cause groundwater (and emulsion) to preferentially migrate through higher permeability zones, leaving lower permeability zones uncontacted.

In this project, a series of numerical model simulations were conducted to evaluate the effect of important design parameters on contact efficiency. Model simulations were performed using the numerical modeling packages MODFLOW (McDonald and Harbaugh, 1988) and RT3D (Clement, 1997). Oil droplet capture by the surfaces of the aquifer material was represented by a rate limited Langmuir isotherm. Details of the model setup and validation are presented in Borden et al. (2008). To reduce the computational burden, we have chosen to simulate a subsection of the treatment area shown by the dashed rectangle near the center of Figure 2.1. For a uniform grid, this subsection can be repeated over and over again to simulate the overall treatment area.

2.2 Model Sensitivity Analyses – Area Treatment

2.2.1 *Model Setup and Base Case Conditions*

Figure 2.2 shows an enlarged view of the model domain subsection outlined on Figure 2.1. Aquifer volume contact efficiency (E_V) will be determined for the red shaded rectangular zone between the 1st and 3rd rows of wells at 120 days after the start of emulsion injection. The 120 day period was selected to allow for downgradient transport of oil droplets by the ambient groundwater flow. For the base case, well spacing perpendicular to groundwater flow (S_W) and row spacing along the direction of groundwater flow (S_R) are both 3.0 m. The model domain is 3.25 m by 18.25 m with an effective saturated thickness (Z) of 3 m. A bulk density (ρ_B) of 2 g/cm^3 and effective porosity (n_e) of 0.2 were used in all simulations. In addition to flow induced by the injection wells, constant head boundaries located at the upgradient and downgradient limits of the model result in a background hydraulic gradient through the treatment zone. No flow boundaries are located perpendicular to groundwater flow to simulate a recurring pattern of injection wells. The hydraulic conductivity field was represented as a spatially correlated random field with low, medium and high levels of heterogeneity. Five realizations of the permeability distribution were simulated for each level of heterogeneity. The realizations were generated using the turning bands method (Tompson et al., 1989) with a horizontal correlation length of 2 m and a vertical correlation length of 0.2 m.

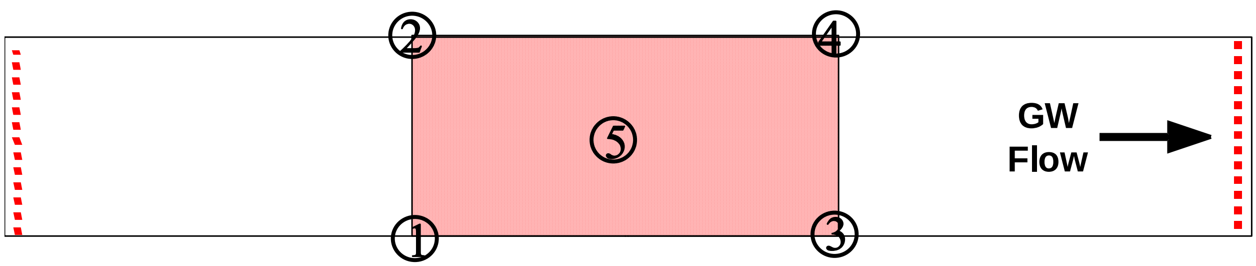

Figure 2.2. Model Domain for Base Case Condition – Area Treatment.

To allow easy comparison between different simulations, the mass of oil injected and volume of fluid injected are presented as dimensionless scaling factors. The volume scaling factor (SF_V) is the ratio of fluid (emulsified oil plus water) injected per well to the pore volume within a Base Treatment Zone around each well or

$$SF_V = \text{Volume fluid injected per well} / (n_e\ BTV)$$

where n_e is the effective porosity. For area treatment, the BTV = $S_W\ S_R\ Z$. Additional details on the model simulations and base case conditions are presented in Borden et al. (2008). The mass scaling factor (SF_M) is the ratio of oil injected per well to the oil required to fill all the attachment sites within the BTV or

$$SF_M = \text{Mass oil injected per well} / (OR_M\ \rho_B\ BTV)$$

where OR_M is the maximum oil retention per unit weight aquifer material.

2.2.2 *Typical Simulation Results – Area Treatment*

Figures 2.3 and 2.4 show the hydraulic conductivity and residual oil distributions in both plan (Fig. 2.3) and longitudinal cross-section (Fig. 2.4) for two representative simulations at 120 days after the start of emulsion injection. Higher permeability is indicated by the darker red and lower permeability is indicated by the lighter pink color. In the residual oil figures, oil treated zones are indicated by the darker red and untreated zones are white. In these simulations, the wells are injected in three steps (wells 1 and 3, wells 2 and 4, then well 5) and the aquifer was assumed to be moderately heterogeneous (permeability realization #2).

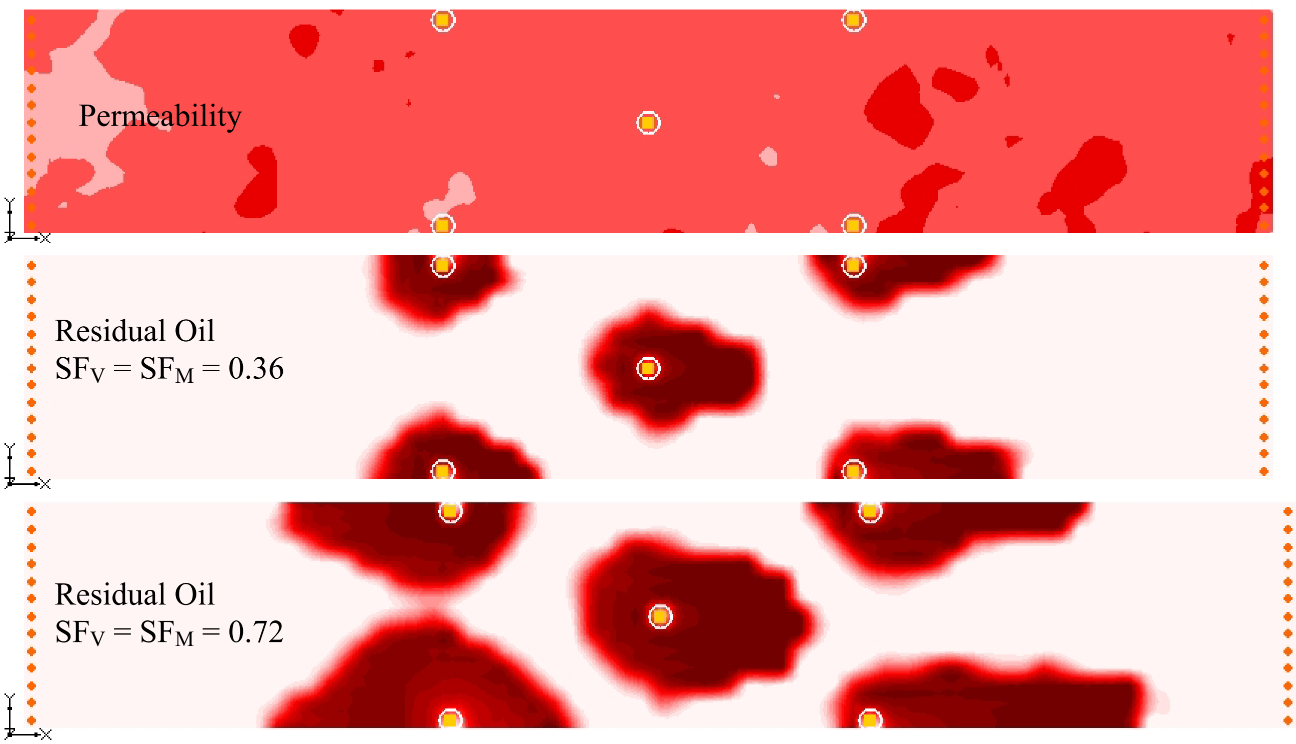

Figure 2.3. Simulated Horizontal Distribution of Hydraulic Conductivity and Residual Oil in Top Layer of Aquifer (see Figure 2.4) **for Moderately Heterogeneous Aquifer** (realization #2)**.**

In plan view (Figure 2.3), the residual oil distribution appears to be primarily controlled by the location of the injection points. As expected, residual oil concentrations are highest immediately adjoining the injection wells. However, the permeability distribution does have some secondary impacts on the residual oil distribution. Injecting additional oil and water ($SF_V = SF_M = 0.72$) enhances oil distribution.

In profile view (Figure 2.4), the residual oil distribution appears to be primarily controlled by the permeability distribution. Oil migrates farthest in the high permeability layers and is much more limited in lower permeability layers. However, the location the injection wells is also very important. Simultaneous injection of wells 2 and 4 (and wells 1 and 3) results in stagnation zones in the middle of the injection grid between each pair of wells, driving water and oil away from adjoining injection wells. However, once injection ends, the ambient hydraulic gradient carries a portion of the oil downgradient of the injection point resulting in more extensive oil distribution downgradient of the injection wells. Again, increasing the amount of oil and water injected enhances distribution.

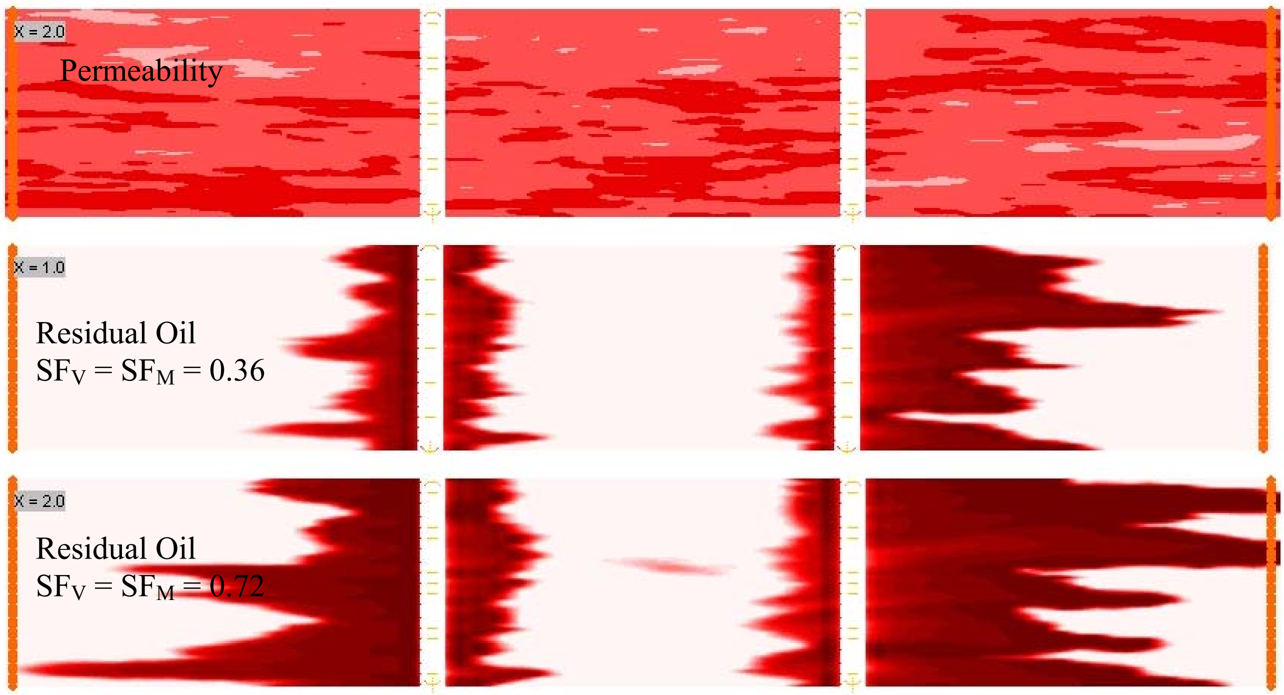

Figure 2.4. Simulated Vertical Distribution of Hydraulic Conductivity and Residual Oil in Last Row of Aquifer (bottom row of Figure 2.3) **for Moderately Heterogeneous Aquifer** (realization #1)**.**

The relatively low contact efficiency for $SF_V = SF_M = 0.36$, is due to: a) the relatively small amount of oil and water injected, and b) the heterogeneous hydraulic conductivity distribution. In subsequent sections, sensitivity analyses will be conducted to examine the effect of each of these parameters on contact efficiency. This information can then be used to generate improved designs with higher contact efficiencies.

2.2.3 *Criteria for Determining Contact Efficiency*

In this work, effective treatment is assumed to occur when the oil retention (OR) following injection is greater than a previously defined critical concentration (OR_C). Results of the model simulations are summarized as a series of performance curves relating the effect of specific design variables on contact efficiency. For area treatments, Aquifer Volume Contact Efficiency (E_V) is used as the primary performance measure where E_V = fraction of treatment zone volume where $OR > OR_C$.

Currently, there is no well established procedure to determine what oil concentration is required for effective treatment. Even very small amounts of oil will initially support anaerobic biodegradation. However, if OR is too low, the oil will be rapidly depleted and long-term performance will be limited.

Figure 2.5 shows the effect of water injection volume on E_V assuming the OR_C is equal to 1%, 5%, 10% and 25% of the maximum oil retention by the aquifer material (OR_M) for sequential injection with $SF_M = 0.36$. These curves were generated by varying the amount of water injected while keeping all other parameters constant (see Borden, 2008, for detailed description). At $SF_V = 0.18$, the volume contact efficiency is 42, 34, 31 and 26% for OR_C/OR_M = 1, 5, 10 and 25%, respectively. All the curves shown in Figure 2-5 follow the same general trend, where increasing the injection volume initially results in a significant improvement in contact efficiency. However, further increases in fluid injection result in progressively less benefit. Increasing the injection volume beyond $SF_V = 0.2$ results in a modest improvement in E_V whether OR_C is 1, 5, 10 or 25% of OR_M. This suggests that it may not be necessary to precisely define OR_C since the designer would draw the same general conclusions whether OR_C is 1% or 25% of OR_M.

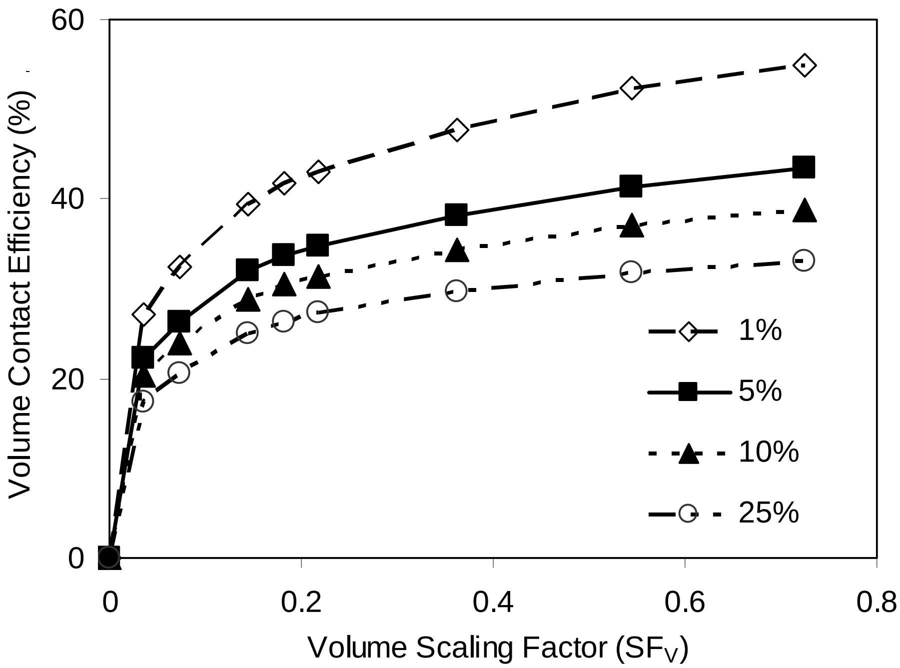

Figure 2.5. Effect of Water Injection Volume on Aquifer Volume Contact Efficiency (E_V) for OR_C/OR_M = 1, 5, 10 and 25% at 120 Days (sequential injection with Mass Scaling Factor = 0.36)**.**

All remaining sensitivity analyses presented in this report have assumed OR_C = 5% of OR_M. For model conditions used in this study (Borden, 2008), OR_M =7.0 mg of oil per g aquifer material. Past operating experience at emulsified oil sites indicates that 5% of this OR_M is sufficient to support anaerobic biodegradation for several years. Readers should recognize that the reported values for contact efficiency would be slightly higher if a less restrictive value of OR_C were used. However, the overall trends for contact efficiency are expected to be similar.

2.2.4 *Effect of Injection Sequence – Area Treatment*

A series of simulations were conducted to evaluate how important is the sequencing of the injection process (i.e., concurrent versus sequential injection) for area treatment. For these simulations, three conditions were evaluated:

Simultaneous Injection -	concurrent injection of all wells;
Three Step Injection -	concurrent inject of wells 1 and 3 followed by concurrent injection of wells 2 and 4; and then well 5; and
Sequential Injection -	inject wells well 1, followed by 2, 3, 4, and 5

For each of these conditions, the SF_V was equal to the mass scaling factor (SF_M). As shown in Figure 2.6, contact efficiency increases approximately linearly with volume and mass scaling factor for a moderately heterogeneous aquifer (permeability realization #2). Results for the three different injection sequences were similar indicating that simultaneous injection results in only a small reduction in contact efficiency.

Sequential injection results in the best contact efficiency, but also requires the most time to implement. Given the small difference in contact efficiency between the different injection approaches, the three step injection approach will be used in all subsequent simulations. The three step injection sequence provides results intermediate between simultaneous and sequential injection and should be reasonably representative of a 'typical' injection process.

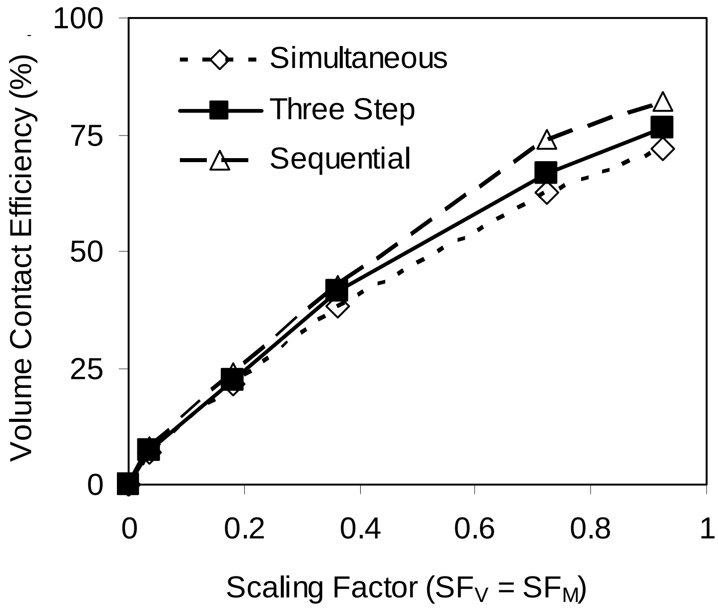

Figure 2.6. Effect of Injection Sequence and Scaling Factor on Volume Contact Efficiency (E_V for OR $\geq$ 0.05 OR_m) at 120 Days for a Moderately Heterogeneous Aquifer (permeability realization #2)**.**

2.2.5 *Effect of Aquifer Heterogeneity – Area Treatment*

Figures 2.7a and 2.7b show the simulated contact efficiency for different hydraulic conductivity realizations for $SF_V = 0.073$ and $SF_V = 0.18$. Simulation results are presented for each of the five low, moderate and high heterogeneity realizations. While there are significant variations between the different realizations, overall, the results are reasonably consistent. In all cases, injecting additional fluid (increasing SF_V from 0.073 to 0.18) improves contact efficiency. As expected, contact efficiencies are highest for the low heterogeneity simulations, and then decrease as the level of heterogeneity increases.

Based on the results presented in Figures 2.7a and 2.7b, medium heterogeneity realization #2 (MID-2) was selected as reasonably representative of contact efficiencies that might be achieved or a range of aquifer conditions. Average contact efficiencies may be slightly lower for high heterogeneity aquifers and somewhat higher for low heterogeneity aquifers.

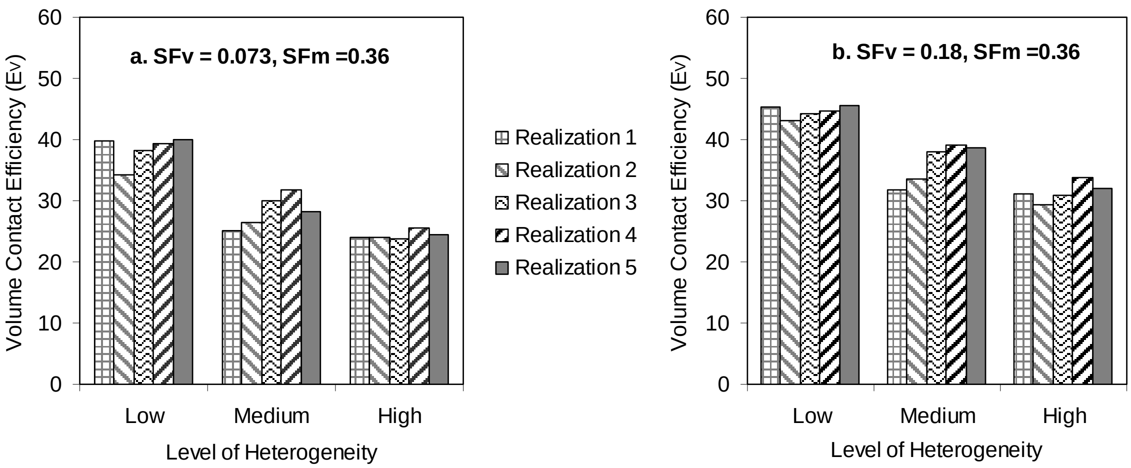

Figure 2.7. Effect of Heterogeneity Realization on Volume Contact Efficiency (E_V) for Low, Moderate and High Heterogeneity Aquifers.

2.2.6 *Effect of Oil Mass and Fluid Volume – Area Treatment*

Sensitivity analyses were also conducted to examine the effect of injection fluid volume and emulsified oil injection mass on contact efficiency. Figure 2.8 shows the effect of the SF_V (ratio of fluid injected to the target treatment zone pore volume) on volume contact efficiency (E_V) for SF_M=0.36. When mass of injected oil is held constant (SF_M=0.36), E_V increases rapidly as SF_V increases from 0 to 0.1. However, additional increases in SF_V provide progressively less benefit, with only a gradual increase in E_V as SF_V is increased from 0.2 to 0.7. Qualitatively similar results were obtained with different values of SF_M. However, the maximum achievable E_V increased with increasing values of SF_M. This indicates that as the amount of oil injected increases, there are benefits to injecting additional fluid to transport the oil.

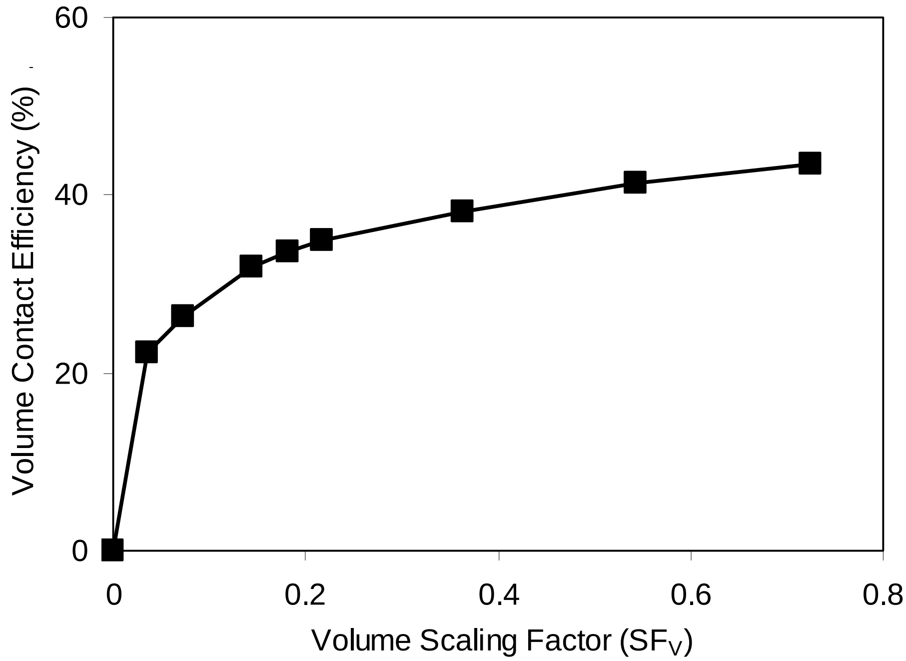

Figure 2.8. Effect of Volume Scaling Factor (SF_V) on Volume Contact Efficiency (E_V for C $\geq$ 0.05 OR_M) **for a Moderately Heterogeneous Aquifer at 120 days** (Mass Scaling Factor = 0.36)**.**

Figure 2.9 shows the effect of the SF_M (ratio of oil injected to the oil required to saturate the BTV) on E_V for $SF_V = 0.18$. When the volume of injected fluid is held constant ($SF_V = 0.18$), E_V increases rapidly as SF_V increases from 0 to 0.4. However, additional increases in SF_M provide progressively less benefit. Qualitatively similar results were obtained with different values of SF_V. However, the maximum achievable E_V increased with increasing values of SF_V. This indicates that as the amount of fluid injected increases, there are benefits to injecting additional oil.

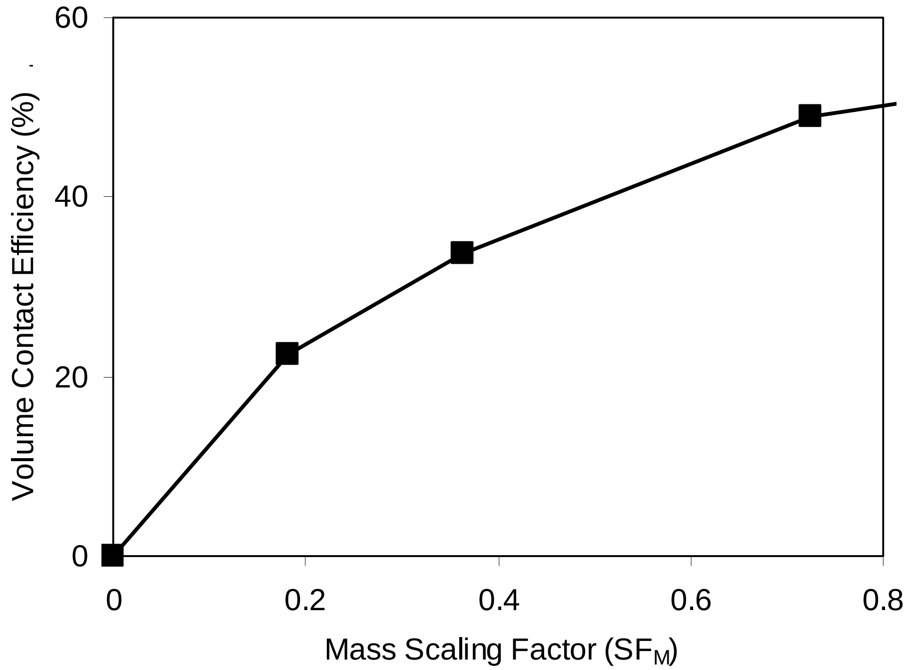

Figure 2.9. Effect of Mass Scaling Factor (SF_M) on Volume Contact Efficiency (E_V for $C \geq 0.05\ OR_M$) **for Sequential Injection of a Moderately Heterogeneous Aquifer at 120 Days.**

2.2.7 *Injection Row Spacing – Area Treatment*

In the simulation results presented so far, the spacing between rows of injection wells was approximately equal to the spacing of wells within a row. Figure 2.10 shows the effect of eliminating the center injection well (#5) on contact efficiency for different values of SF_V. Eliminating well 5 is equivalent to making the row spacing approximately twice the well spacing within a row, reducing the total number of wells by a factor of 2. The mass and volume injected per well were adjusted so the total mass of oil and volume of fluid injected within the target treatment zone remained constant.

When the total amount of injected fluid is small ($SF_V < 0.2$), increasing the row spacing has only a modest impact on contact efficiency. However, for larger values of SF_V, E_V is reduced by 5 to 10% by doubling the row spacing (e.g., eliminating the center injection well).

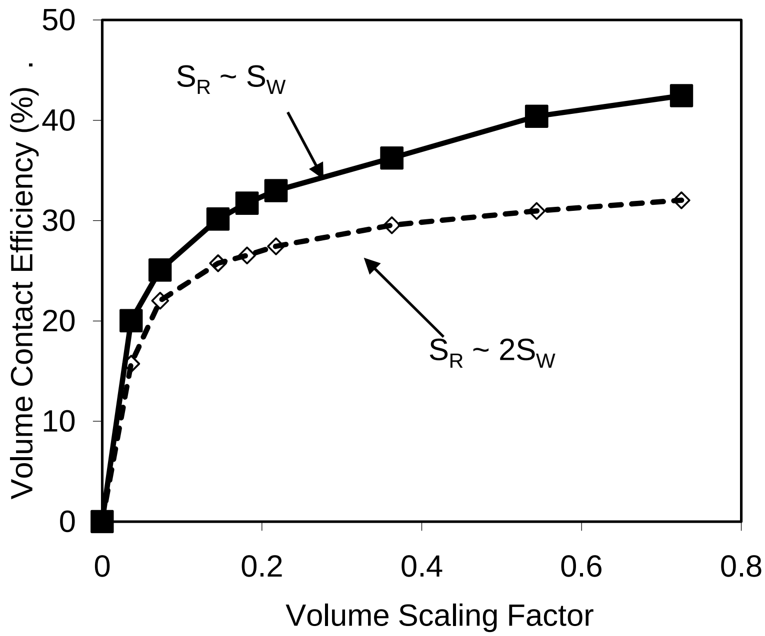

Figure 2.10. Effect of Row Spacing and Fluid Injection Volume on Volume Contact Efficiency (E_V for OR $\geq$ 0.05 OR_M) **for a Moderately Heterogeneous Aquifer.**

2.2.8 *Contact Efficiency – Area Treatment*

The results presented in previous sections indicate there is a complex relationship between SF_M and SF_V on E_V. Multiple linear regression analyses were performed to develop relationships between SF_M, SF_V and E_V for a row-to-well spacings of approximately 1:1 and 2:1. Three dimensional surfaces describing these relationships are shown in Figures 2.11 and 2.12. The highest contact efficiencies are obtained for large values of SF_M and SF_V.

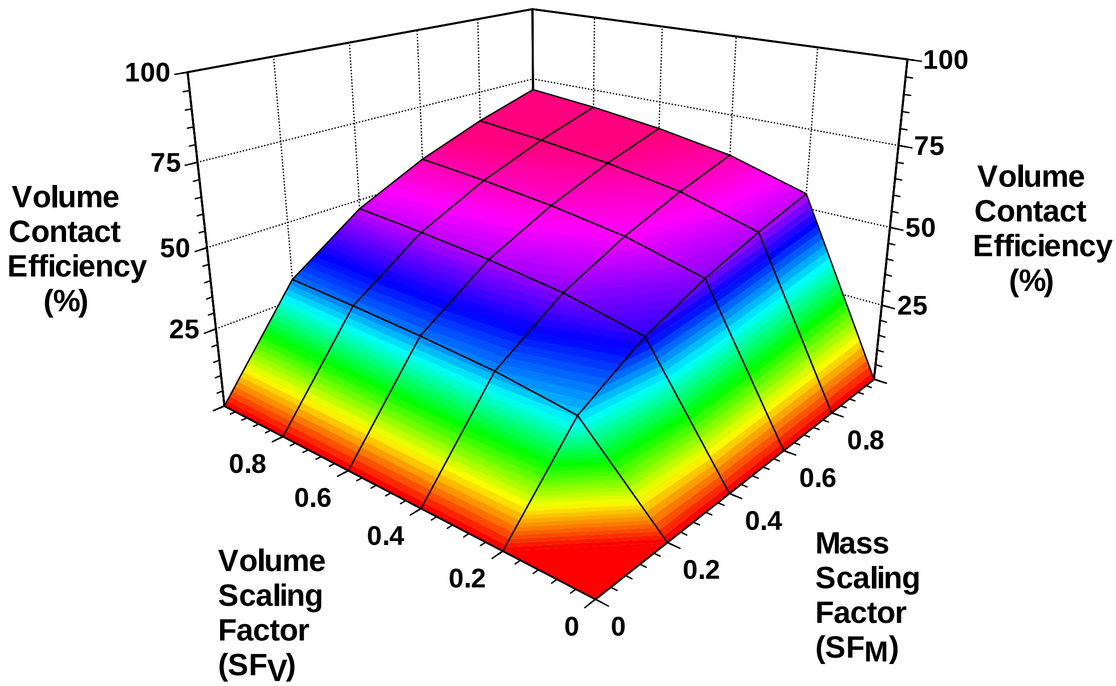

Figure 2.11. Effect of Volume Scaling Factor (SF_V) and Mass Scaling Factor (SF_M) on Volume Contact Efficiency (E_V for OR $\geq$ 0.05 OR_M) **for a Moderately Heterogeneous Aquifer with Well Spacing Approximately Equal to Row Spacing.**

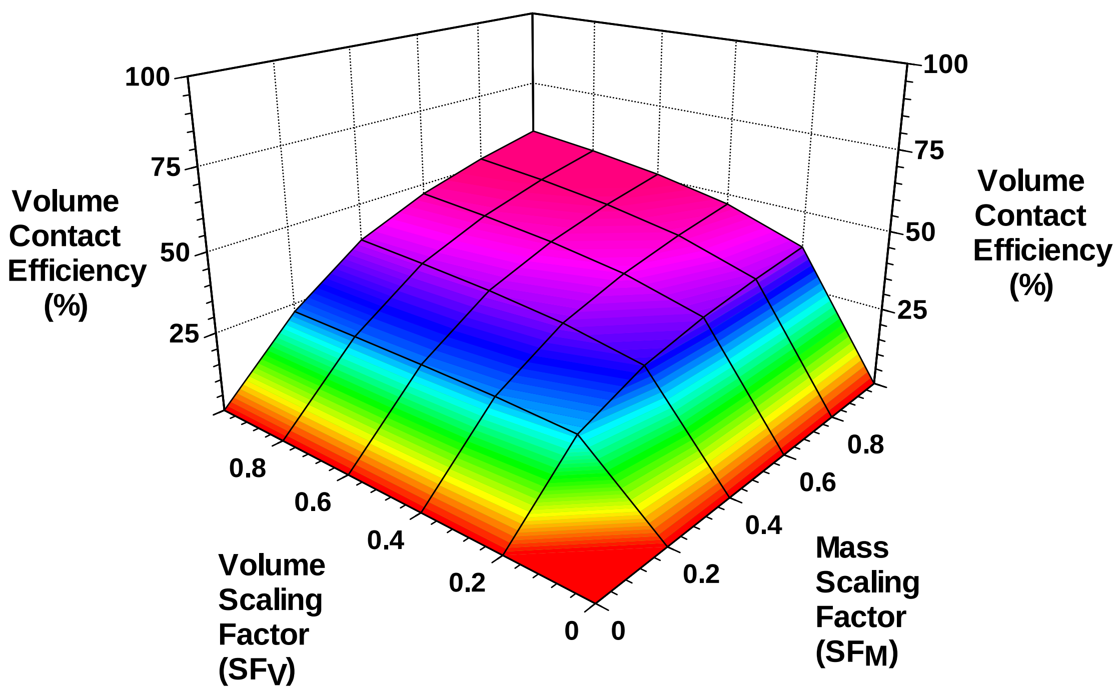

Figure 2.12 Effect of Volume Scaling Factor (SF_V) and Mass Scaling Factor (SF_M) on Volume Contact Efficiency (E_V for OR $\geq$ 0.05 OR_M) **for a Moderately Heterogeneous Aquifer with Row Spacing Equal to Approximately Two Times Well Spacing.**

2.2.9 *Area Treatment Contact Efficiency – Summary of Results*

The sensitivity results presented in this section examine the effect of injection sequence, SF_V, SF_M, and row spacing on E_V. Major results of this work are summarized below:

- When mass of injected oil is held constant (SF_M=0.36), E_V increases rapidly as SF_V increases from 0 to 0.1. However, additional increases in SF_V provide progressively less benefit, with only a gradual increase in E_V as SF_V is increased from 0.2 to 0.7.
- When the volume of injected fluid is held constant (SF_V =0.18), E_V increases rapidly as SF_V increases from 0 to 0.4. However, additional increases in SF_M provide progressively less benefit.
- When the SF_V = SF_M, E_V increases approximately linearly with scaling factor.
- The best contact efficiency is obtained for sequential injection. However, injection sequencing does not have a large impact on contact efficiency.
- Increasing the row spacing (S_R) to approximately double the well spacing (S_W) will significantly reduce contact efficiency.

Overall, the model simulation results indicate that it is relatively easy to achieve a volume contact efficiency of 50 to 60% for a moderately heterogeneous aquifer. However, it becomes progressively more difficult to achieve higher contact efficiencies and it may not be practical to achieve contact efficiencies above 75% in heterogeneous aquifers.

Readers are reminded that contact efficiency is **NOT** the same as treatment efficiency. When emulsified oil is injected into the subsurface, it primarily migrates through and contacts the higher permeability (K) zones. Contaminants present in these higher K zones will come in direct contact with the oil and should biodegrade relatively rapidly. Once contaminants in the higher K zones are degraded, contaminants will begin to slowly diffuse out of the lower K zones and will be treated. However, diffusion out of these lower K zones is a slow process, requiring years or even decades to occur. One of the major advantages of the emulsified oil process is that the edible oils biodegrade slowly, supporting biodegradation for years. As long as significant oil remains in the higher K zones, contaminant concentrations in monitor wells will remain low and the flux of contaminants transported down gradient will remain low. In addition, diffusion of contaminants out of the lower K zones will be enhanced and the rate of source area treatment will be increased. Under these conditions, a volume contact efficiency (E_V) of 30-40% may provide good treatment and increasing E_V to 50% may provide little real benefit. Unfortunately, we do not currently have any way to quantitatively relate volume contact efficiency to cleanup rate.

The time required for contaminants to diffuse out of the low K zones will be a function of the aquifer porosity and permeability, dimensions of the low K body, and sorption of contaminants to the aquifer material. At this time, there is no reliable method to estimate how long before the low K zones are ‘fully’ treated. Currently, the only basis for determining how long before a source area is ‘fully’ treated is prior experience at similar sites.

2.3 Model Sensitivity Analyses – *Barriers*

2.3.1 *Model Setup and Base Case Simulation Results -- Barriers*

Numerical model simulations where conducted to evaluate the effect of different design variables on contact efficiency in permeable reactive barriers (barriers) formed using emulsified oil. However for barriers, Flow Contact Efficiency (E_F) is used as the primary performance measure where E_F = fraction of groundwater flow through the barrier that comes in contact with aquifer material where $OR > OR_C$. As for area treatment, OR_C is assumed equal to 5% of the maximum oil retention capacity of the aquifer material. Readers should note that flow contact efficiency may be greater than volume contact efficiency because the oil preferentially flows through and contacts the high K zones. Since these high K zones also transport most of the water, flow contact efficiency is often greater than volume contact efficiency. However, E_F does not include any contact time criteria so groundwater is considered 'contacted' if it flows through a model cell where $OR > OR_C$, even if the contact time is only a few minutes.

The definition of the Base Treatment Volume is **NOT** the same as that used for area treatment. For barrier treatment, the BTV is equal to the volume of a cylinder with a diameter equal to the well spacing or $BTV = \frac{1}{4} \pi S_W^2 Z$.

Figure 2.13 shows the permeability and residual oil distributions in a cross-section immediately downgradient of injection wells 1 and 2 (Figure 2.1) at 120 days after the start of emulsion injection. The injection wells are located at the left and right edges of each figure. Higher permeability is indicated by the darker red and lower permeability is indicated by the lighter pink color. In the residual oil figures, oil treated zones are indicated by the darker red and untreated zones are white. In this simulation, the wells are injected sequentially and the aquifer was assumed to be moderately heterogeneous (permeability realization #2).

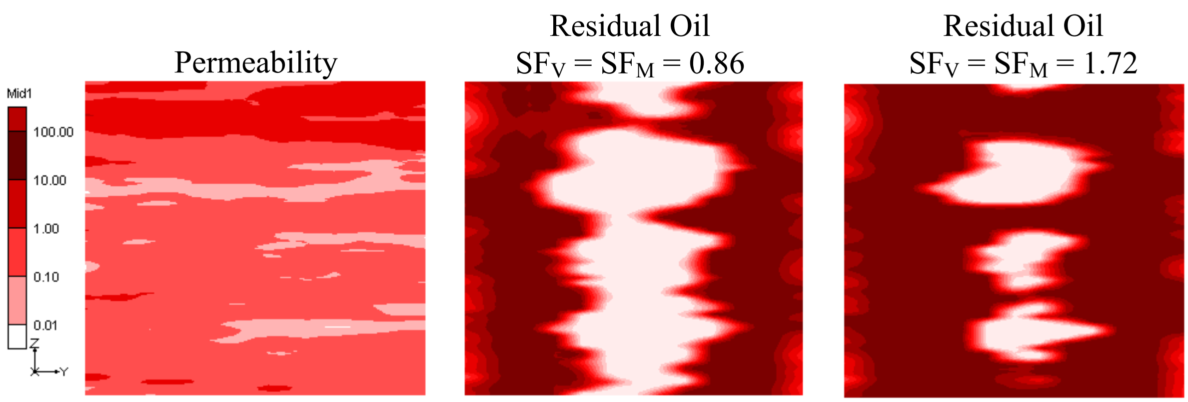

Figure 2.13. Simulated Distribution of Hydraulic Conductivity and Residual Oil in Cross-section Immediately Downgradient of Wells 1 and 2 for Moderately Heterogeneous Aquifer (realization #2)**.**

As expected, residual oil concentrations are highest near the injection wells in Figure 2.13 and decrease with distance. For $SF_V = SF_M = 0.86$, approximately two-thirds of the cross-section between the wells is contacted with oil while approximately one-third remains uncontacted.

However, the flow contact efficiency (E_F) for this simulation is 77%. E_F is somewhat higher than the fraction contacted because the oil emulsion is preferentially transported through the higher K layers. Injecting additional oil and water ($SF_V = SF_M = 1.72$) increases the E_F to over 95%. While there are some relatively large 'white' areas between the two injection wells, these zones have a lower permeability and so only transport a small fraction of the total groundwater flow.

2.3.2 *Effect of Injection Sequence – Barriers*

Results from prior simulations for area treatment were analyzed to evaluate the effect of injection sequence on flow contact efficiency. For this analysis, only two conditions were evaluated:

Simultaneous Injection -	concurrent injection of all wells;
Sequential Injection -	concurrent inject of wells 1 and 3 followed by concurrent injection of wells 2 and 4.

For each of these conditions, the amount of oil injected was held constant at the base condition ($SF_M = 1.0$) and the volume of fluid injected was varied.

Figure 2.14 shows the effect of injection sequencing and SF_V on E_F for a moderately heterogeneous aquifer (permeability realization #2). For small injection volumes, the oil emulsion does not travel far from the injection wells and injection sequencing has little effect. However, as the injection volume increases, well interference effects become more important. For $SF_V = 0.86$, sequential injection results in an 11% increase in flow contact efficiency from 77% to 88%. This is in contrast to area treatment (Figure 2.6), where sequential injection sequence had only a modest impact on volume contact efficiency.

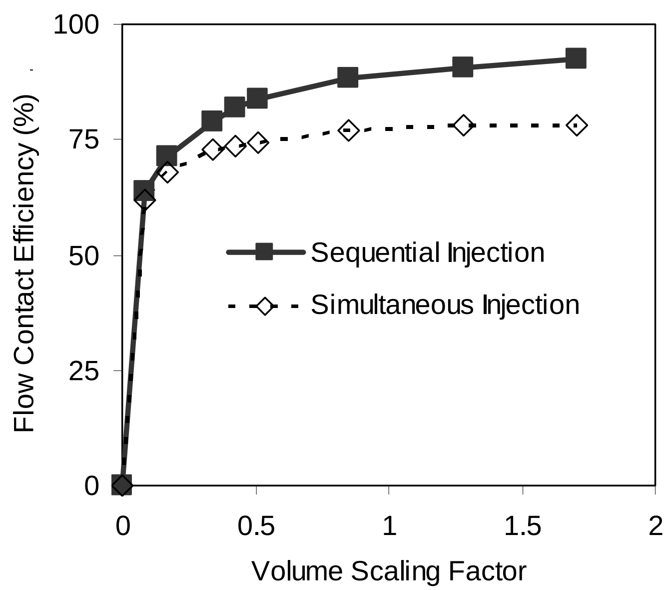

Figure 2.14. Effect of Injection Sequence and Fluid Injection Volume on Flow Contact Efficiency (E_F for OR $\geq$ 0.05 OR_M) at 120 days for a Moderately Heterogeneous Aquifer (realization #2, Mass Scaling Factor = 0.86)**.**

Sequential injection resulted in significantly improved Flow contact efficiency (E_F) compared to simultaneous injection. As a consequence, sequential injection will be used in all further simulations.

2.3.3 *Effect of Oil Mass and Fluid Volume – Barriers*

Sensitivity analyses were also conducted to examine the effect of amount of fluid volume injected and emulsified oil mass injected on flow contact efficiency. Similar to area treatment, a complex relationship was observed where increases in both SF_M and SF_V resulted in improvements in the E_F. Figure 2.15 shows the three dimensional surface describing this relationship. The highest contact efficiencies are obtained for large values of SF_M and SF_V.

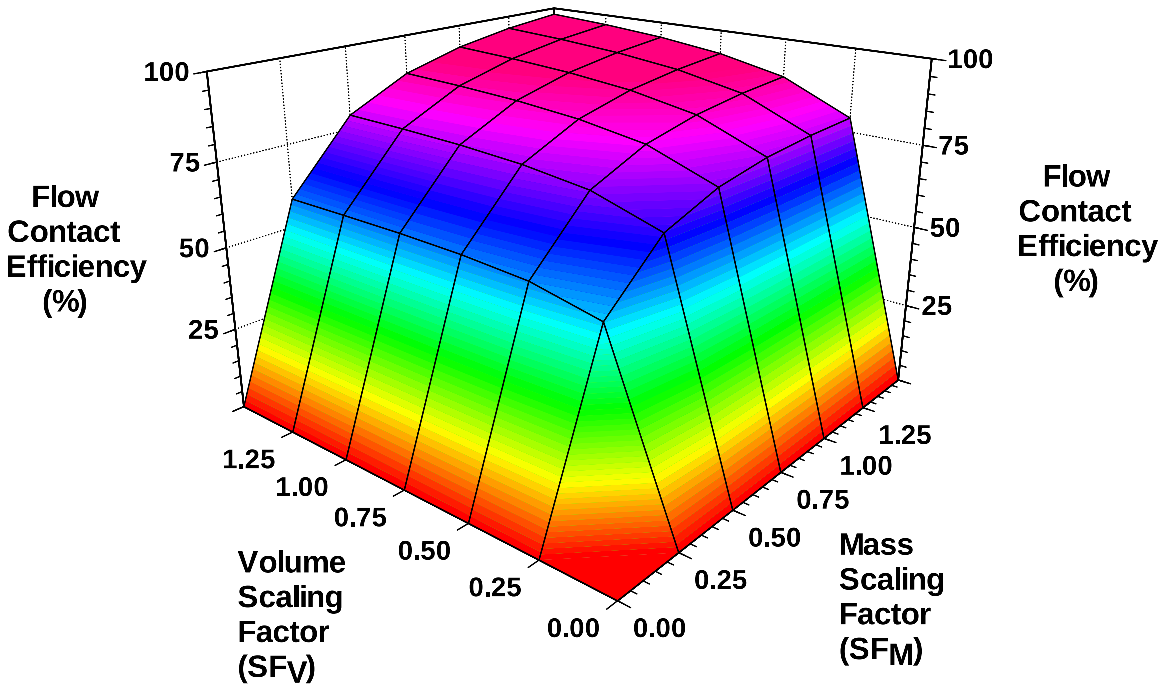

Figure 2.15. Effect of Volume Scaling Factor (SF_V) and Mass Scaling Factor (SF_M) on Flow Contact Efficiency (E_F for OR $\geq$ 0.05 OR_M) for a Moderately Heterogeneous Aquifer (realization #2)**.**

2.3.4 *Barrier Contact Efficiency – Summary of Results*

The sensitivity results presented in this section examine the effect of injection sequence, Volume Scaling Factor (SF_V), and Mass Scaling Factor (SF_M) on E_V. Major results of this work are summarized below:

- For small injection volumes ($SF_V < 0.2$), the oil emulsion does not travel far from the injection wells and injection sequencing has little effect. However, as the injection volume increases, well interference effects become more important. To maximize E_V when $SF_V > 0.4$, adjoining wells should not be injected simultaneously.

- For $SF_V = 1.0$ and $SF_M = 1.0$, it should be possible to achieve a flow contact efficiency of greater than 80%. By injecting additional water and oil, it should be possible to achieve high flow contact efficiencies in barriers. However, the amount of oil and water injected may be significantly higher than current practice.

As discussed in the previous section, flow contact efficiency is not the same as treatment efficiency. However, contact times in barriers are much shorter than in area treatments and molecular diffusion will be much less significant. Therefore, for barriers it is important to achieve a high flow contact efficiency.

SECTION 3
DESIGN PROCESS

3.1 Overview

A general conceptual design for the distribution of the emulsion should be developed after defining the remediation objectives and conceptual site model. This design will consist of determining the general layout of emulsion injection system and will take into account additional planning considerations including remediation objectives.

3.1.1 *Decide on Injection Well Layout*

Several treatment approaches are commonly considered for application of emulsified oils. The most common approaches are source area treatment and use of emulsified oil barriers. A schematic of the two approaches is shown in Figure 3.1. In choosing a treatment approach for a given site, it is important to understand the overall objectives of the project. The objectives may be to reduce contaminant concentrations below the maximum contaminant levels (MCLs), to reduce mass flux as part of an overall risk reduction approach, or to limit plume migration.

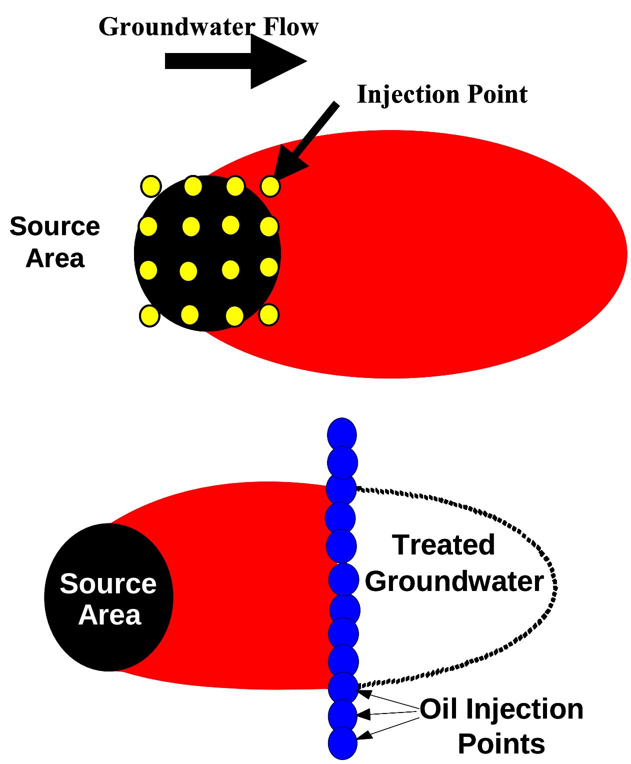

Figure 3.1. Using Emulsions to Treat Contaminated Groundwater in: (a) source areas and (b) barriers.

3.1.2 *Select Trial Well Spacing*

When planning an injection project, designers need to consider the effect of injection point spacing on cost and contact efficiency. The effect of injection point spacing on cost is primarily a trade off between well installation costs and labor costs. Wider spacing of the injection points reduces injection well installation costs, but increases the time/labor required for injection. The well installation costs are affected by the geology and depth to groundwater, while the labor costs are determined by the time required for fluid injection which is largely a function of the aquifer permeability. If the aquifer has a high permeability, fluid injection will be easier and will take less time. Often, multiple wells can be injected simultaneously to reduce the time required to complete the injections. Injection tests are often conducted to help estimate injection flow rates and pressures and the approximate time it will take to complete the injections. Well installation and labor costs associated with injection should be evaluated on a site-specific basis to determine the appropriate injection point spacing.

In real aquifers, subsurface heterogeneities will affect the final oil distribution in the subsurface. Permeability differences will cause some zones to be over-treated and some zones to remain untreated. Groundwater flow and dispersion will provide some spreading of aqueous organic carbon increasing the reactive zone.

In this design tool, SF are used to account for a variety of factors on the final oil distribution. As described in Chapter 2, injection well location, sequencing of the injection process, and subsurface heterogeneity all influence the final oil distribution and need to be considered when selecting an appropriate scaling factor for use when designing an injection system.

3.1.3 *Calculate Amount of Emulsified Oil Required*

The primary factor to consider in determining how much emulsified oil to inject is the entrapment of oil droplets by aquifer material. The amount of emulsified oil required will be a function of: a) maximum amount of oil retained per mass aquifer material; b) treatment zone dimensions; and c) Mass Scaling Factor (SF_M) required to achieve a target contact efficiency. Increasing the SF_M will increase the expected contact efficiency, but will also increase material costs. Appendix 1 describes a standard test procedure for estimating the maximum amount of oil retained per mass aquifer material.

3.1.4 *Calculate Amount of Fluid Required*

Emulsions are transported in the subsurface by flowing groundwater. Consequently, water must be injected to transport the oil droplets throughout the target treatment zone. Common procedures used include: a) injecting a concentrated emulsion followed by chase water to distribute the oil droplets; b) continuous injection of a more dilute emulsion; and c) recirculation of emulsion through the treatment zone. The total amount of fluid (oil and water combined) required will be a function of: a) effective porosity (n_e) of the aquifer material; b) treatment zone dimensions; and c) Volume Scaling Factor (SF_V) required to achieve a target contact efficiency. Increasing the SF_V will increase the expected contact efficiency, but will also increase the time and labor associated with fluid injection.

3.1.5 *Estimate the Effective Treatment Life*

The theoretical life of a single emulsion injection (T) will be determined by the mass of oil injected and the oil consumption rate where

T = mass oil injected (g) / oil consumption rate (g/yr)

The oil consumption rate is calculated as the mass of oil biodegraded per liter of groundwater times the groundwater flow rate through the barrier. The amount of oil biodegraded is primarily controlled by the concentration of pollutants and background electron acceptors (e.g., oxygen, nitrate, sulfate) entering the barrier and the amount of dissolved organic carbon and methane released by the barrier. Appendix 2 provides detailed background on the procedure used to calculate oil consumption. Additional information on calculating oil consumption is presented in Solutions-IES (2006) and AFCEE (2007).

Figure 3.2 illustrates a typical relationship between substrate consumption and pollutant treatment efficiency in an emulsified oil barrier. Field monitoring data indicate that treatment efficiency is fairly constant when excess oil is present. However, as the oil begins to be depleted, treatment efficiency will gradually decline. In the design tool, the decline in barrier treatment efficiency is accounted for using a substrate scaling factor (SF_S) where SF_S is equal to the fraction of oil consumed when treatment declines below acceptable levels. Past experience suggests that treatment efficiency will drop significantly once 30 to 60% of the injected oil has been consumed (Borden, 2007b; Solutions-IES, 2008).

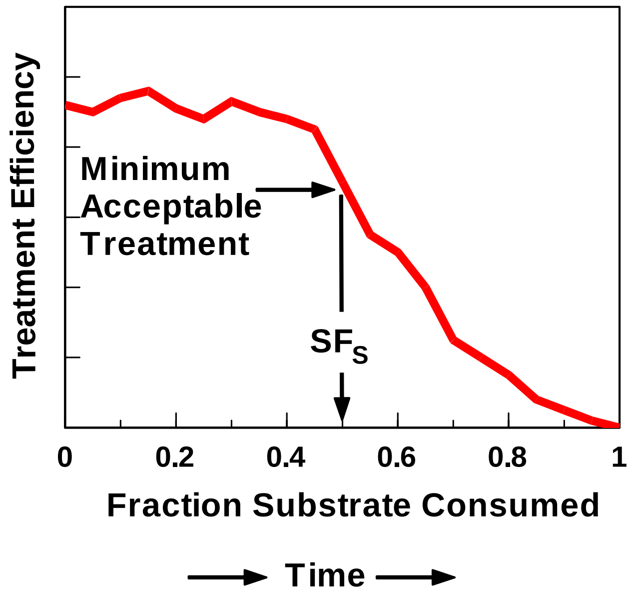

Figure 3.2. Relationship Between Fraction of Substrate Consumed and Treatment Efficiency for an Emulsified Oil Barrier.

Reinjection Interval (RI) is calculated as:

$$RI = T * SF_S$$

Little is known about the decline in area treatment performance over time. When treating source areas, the contaminant biodegradation rate is often limited by slow mass transfer rates. In these cases, maintaining a high biodegradation rate may be less critical and higher values of SF_S maybe acceptable. However, designers should never use a SF_S value greater than the theoretical maximum of 1.

In some cases, the estimation procedure presented above results in an unreasonably large RI. In these cases, designers may wish to specify a maximum allowable RI.

3.1.6 *Repeat Process for Alternate Well Spacings*

The previous steps are repeated for incremental increases in well spacing. Once this is accomplished, a graph can be generated showing the optimal well spacing. Figure 3.3 demonstrates how the well installation, injection labor, and substrate costs vary with different well spacings.

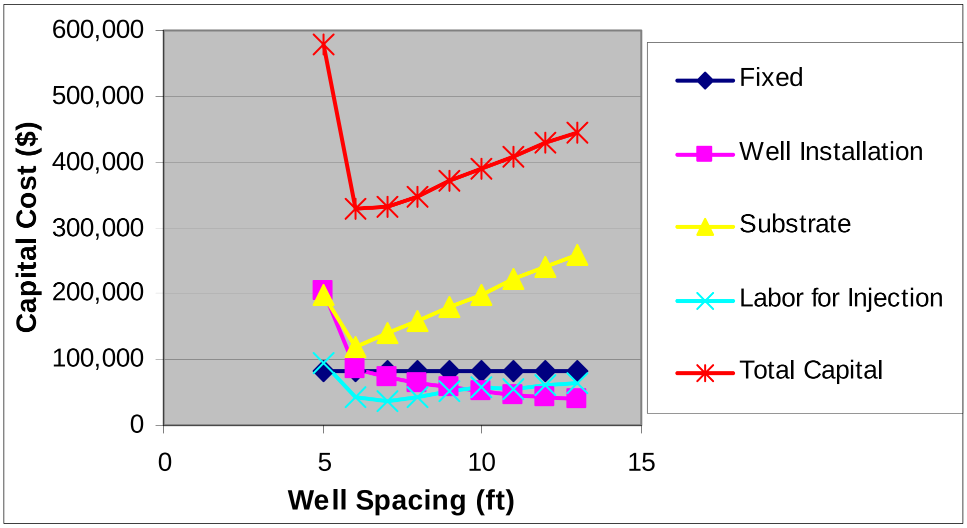

Figure 3.3. Example Cost Analysis for a Barrier with Various Injection Well Spacings.

In this example, a well spacing of 5 ft provides the lowest total installation and injection costs. However, designers may wish to use an alternative well spacing based on site specific constraints and/or personal experience.

3.1.7 Life Cycle Cost Analysis

After looking at the capital cost analysis it is necessary to determine if multiple reinjections over the life of the design changes the optimum well spacing from the capital cost analysis. Figure 3.4 shows how well spacing affects the design life net present value (NPV).

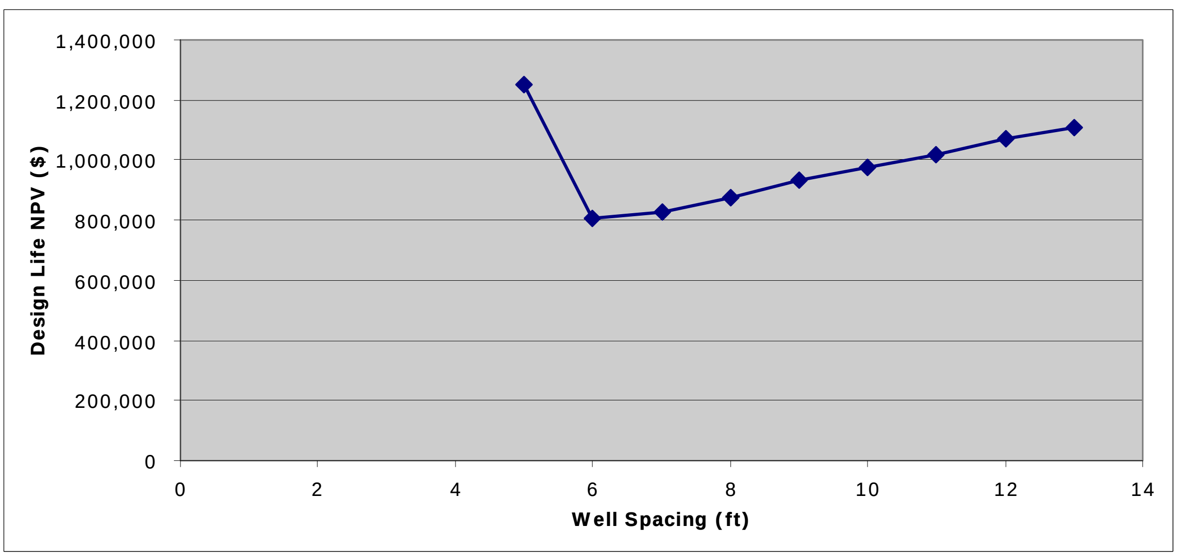

Figure 3.4. Example Life Cycle Analysis for a Barrier with Various Injection Well Spacings.

This example shows that a well spacing of 6 ft has the lowest design life net present value, but a well spacing of 7 is very similar. However, when comparing Figures 3.2 and 3.3 it is evident that the optimum well spacing for this design is 6 ft as it provides the lowest capital and life cycle cost.

3.2 Design Tool Flow Chart

A flow chart of the design process is shown in Figure 3.5.

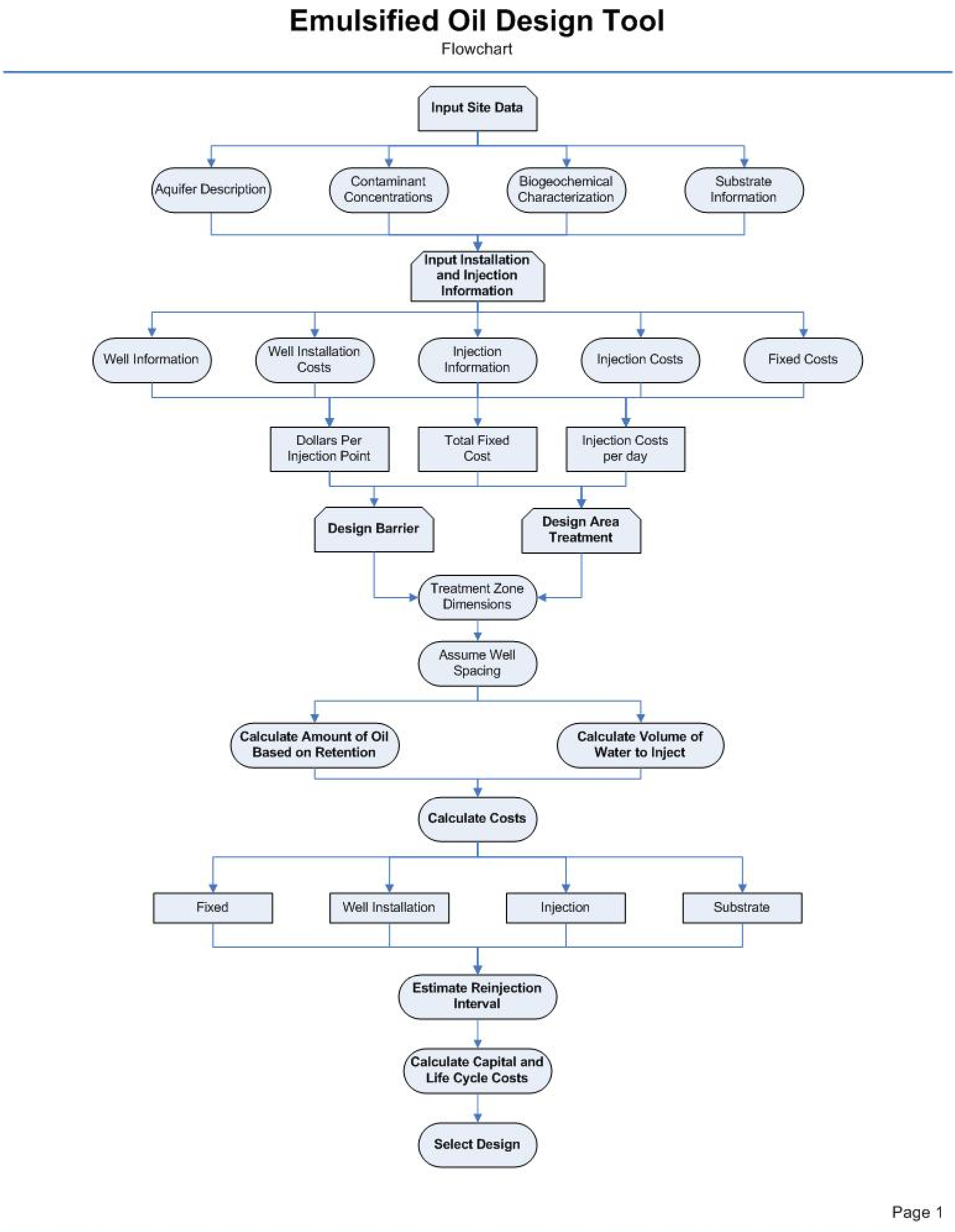

Figure 3.5. Flow Chart of the Design Process for Distributing Emulsified Oil.

SECTION 4
DETAILED DESCRIPTION OF THE DESIGN TOOL

4.1 Overview

This tool is intended to assist engineers with the design of systems for distributing emulsified oil for *in situ* enhanced AB of groundwater contaminants in barrier and area treatments. The design tool consists of several worksheets broken into four sections entitled: Site Data, Installation and Injection, Barrier Treatment, and Area Treatment. Within each section, there are several worksheets for data entry and design calculations. Using the Design Tool Table of Contents, users may easily move between worksheets.

For the design tool to work properly all worksheets within the *Site Data* section and at least one of the three methods in the *Installation and Injection* section must be filled out. Input cells are white and outlined in red, and non-input cells are shaded light gray. There are a few pages that have light yellow cells. These cells are not used in any calculations, but are provided for the user to include additional information for future reference. Yellow cells may be left blank.

4.2 Site Data – Aquifer Description

4.2.1 *General Description*

Information about hydraulic and soil characteristics is entered on this page. The characteristics are used in determining the theoretical injection rate as well as calculating injection volumes of water and substrate.

4.2.2 *Definitions*

1. Site Information

a, b, c. Name, description, and location: These are used to identify and describe the project. The titles show up again in the *Summary of Design* page.

2. Hydraulic Characteristics

a, b, c. Depth to water table and depth to top and bottom of injection zone: The depth to water table is used in calculating the theoretical estimate of injection rate per well. The depth to top and bottom of injection zone are used to determine the interval of the injection well screens (i.e., the screened thickness). The screened thickness is used to determine the thickness of the treatment zone and the volume of water to be treated.

d, e, f, g. Hydraulic gradient, hydraulic conductivity, and porosity (total and effective): These data are used to calculate the seepage velocity (h) and groundwater flux through the treatment zone. Typical values of effective porosity are presented in Table 4.1.

3. Soil Characteristics

a. Description of soil lithology (optional): Space is provided to enter additional information for future reference.

b. Bulk density: Used to determine the amount of emulsified oil required based on maximum oil retention.

c. Maximum oil retention by aquifer material: Used to determine the amount of emulsified oil required. This value has a critical impact on cost and treatment performance. Some example values are provided in Table 4.2.

4.2.3 *Additional Information*

Effective Porosity:

Table 4.1. Typical Values for Dry Bulk Density, Total Porosity and Effective Porosity of Aquifer Materials.

Aquifer Matrix	Dry Bulk Density (g/cm^3)	Total Porosity	Effective Porosity
Clay	1.00-2.40	0.34-0.60	0.01-0.2
Peat	--	--	0.3-0.5
Glacial Sediments	1.15-2.10	--	0.05-0.2
Sandy Clay	--	--	0.03-0.2
Silt	--	0.34-0.61	0.01-0.3
Loess	0.75-1.60	--	0.15-0.35
Fine Sand	1.37-1.81	0.26-0.53	0.1-0.3
Medium Sand	1.37-1.81	--	0.15-0.3
Coarse Sand	1.37-1.81	0.31-0.46	0.2-0.35
Gravely Sand	1.37-1.81	--	0.2-0.35
Fine Gravel	1.36-2.19	0.25-0.38	0.2-0.35
Medium Gravel	1.36-2.19	--	0.15-0.25
Coarse Gravel	1.36-2.19	0.24-0.36	0.1-0.25
Sandstone	1.60-2.68	0.05-0.30	0.1-0.4
Siltstone	--	0.21-0.41	0.01-0.35
Shale	1.54-3.17	0.0-0.10	--
Limestone	1.74-2.79	0.0-50.0	0.01-0.24
Granite	2.24-2.46	--	--
Basalt	2.00-2.70	0.03-0.35	--
Volcanic Tuff	--	--	0.02-0.35

From: AFCEE, 1995.

Maximum Oil Retention by Aquifer Material:

For effective treatment, oil emulsions must be distributed throughout the treatment zone. However, as emulsions migrate through the aquifer pore spaces, a significant amount is retained. The small oil droplets coat the surfaces of the aquifer material, typically retaining a maximum of between 0.0001 and 0.01 g of oil per g of aquifer material. Appendix 1 describes a standard test procedure for estimating the maximum amount of oil retained per mass aquifer material. Some observed values of Maximum Oil Retention are presented in Appendix 1 – Table A1.1.

4.3 Site Data – Contaminant Concentrations

Enhanced AB is applicable to a wide variety of contaminants. Some of these contaminants (e.g., chlorinated solvents, perchlorate, hexavalent chromium) are listed on the spreadsheet. There are also empty spaces for user-entered contaminants (lines **m, n and o**). If the user adds contaminants, the molecular weight and electron equivalents per mole **must** be entered for these contaminants to be included in the calculations. The contaminant data are used to calculate the total electron equivalent demand which is used to estimate the annual substrate consumption rate.

4.4 Site Data – Biogeochemical Characterization

The biogeochemical data are used to determine the electron equivalent demand from background electron acceptors. The total electron equivalent demand is the sum of the electron equivalent demand from contaminants and background electron acceptors and is shown on the bottom of the spreadsheet. This value is an important component of the substrate demand. The soil manganese content (**e**), soil iron content (**g**), pH (**i**), and alkalinity (**j**) are **NOT** used in **ANY** calculations and may be left blank.

4.5 Site Data – Substrates and Reagents

4.5.1 *General Description*

Information on the substrate to be used in the design is entered on this page. The properties of the substrate are used to calculate the electrons released per mole and ultimately the electron equivalents per Kg of raw product. This value is used to determine how much substrate is needed per year.

4.5.2 *Definitions*

1. Substrate Used in Design:

a, b. Brand and product ID, and chemical formula (optional): These are used to document what substrate is used in the design.

h. Percent vegetable oil: This property is used to calculate the electron equivalents per Kg raw product (**i**) and the annual substrate demand. Typical values range from 50% to 70%.

j. Cost per pound of product including shipping: Bulk costs typically range from $1.30 to $3.00, but a distributor should be contacted to determine actual costs including delivery.

k. Cost per pound of oil: This is the cost per pound of oil based on the cost per pound of product and the percent vegetable oil in the product. This is the cost that is used in calculating the total substrate cost.

4.6 Installation and Injection – Injection Through Direct Push Rods

4.6.1 *General Description*

Information on the labor and materials required for injection of emulsified oil by direct push technology (DPT) is entered on this page. In this approach, the injection points are installed and emulsion is injected in a single operation where the DPT equipment drives the rod to the desired depth immediately followed by emulsion/water injection. Once injection is complete, the rod is moved to a different depth and the operation is repeated. Once injection is complete, the rod is removed, the borehole grouted, and the DPT equipment is shifted to a new location.

4.6.2 *Definitions*

1. Injection Information

a, b. Top and bottom of injection screen: These values are carried over from the Aquifer Description page and used to compute the number of injection intervals (**d**).
c. Length of injection screen: The injection screen length specifies the vertical injection point spacing.
e, f. Injection pressure and injection rate: The injection flow rate is used when calculating the injection time for a point. The injection pressure is not used in the calculations. The space for injection pressure is provided for future reference by the user and may be left blank.
g, h. Gallons injected per foot of injection interval and total gallons per injection point: The number of gallons injected per foot of injection value is a user-controlled value and is dependent upon site conditions and personal experience with an average value of 10 gal/ft. This value is used to determine the injection well spacing as explained in the barrier and area treatment capital cost analysis sections. The total gallons per injection point is the product of the gallons injected per foot of injection interval and the saturated thickness.

2. Fixed Costs: The total fixed cost (**h**) is made up of costs that are independent of the duration of the well installation and fluid injection.

3. Prime Contractor Information and Daily Costs: Information about the prime contractor including the number of personnel on site, average labor rate, and per diem are entered. These values make up the total daily cost for prime contractor (**j**) and factor into the total cost per boring (**4-h**) and the injection cost per gallon (**5-d**). An additional cost can be entered in (**i**).

4. Subcontractor Information and Daily Costs: Information about the daily cost for direct push equipment is entered along with additional material and IDW costs per boring (**g**) to compute the total cost per boring (**h**).

5. Costs for Injection Using DPT Equipment: The injection costs per day (**a**) is the sum of the daily costs for the DPT equipment and operator and the daily cost for the prime contractor.

4.7 Installation and Injection – DPT Well Installation

4.7.1 *General Description*

Information on the labor and materials required for injection point installation and emulsion injection is entered on this page. This approach assumes that temporary or permanent wells are installed first using direct push equipment. Well installation is assumed to be by a subcontract driller with supervision by the prime contractor. Once the wells are installed, multiple wells are manifolded together for emulsion injection.

4.7.2 *Definitions*

1. Well Information

a, b. Top and bottom of injection screen: These values are carried over from the Aquifer Description page and are used later in the design to determine the effective treatment zone thickness.

c, d. Well screen diameter and effective diameter of sand pack: The well screen diameter is not used in the design, but the effective diameter of sand pack is used to determine the theoretical estimate of injection rate per well (**3-e**). The effective diameter of sand pack is typically 0.75 to 2 inches depending on the installation method.

2. Well Installation Costs for Direct Push Installation: Daily costs for equipment, material costs, and personnel costs are entered to compute the total cost per well (**k**). Per diem, vehicle rental, and lodging costs from (**5-d, e, f**) are also included in the total cost per well. In addition, the subcontractor mobilization (**f**) is only included in the total fixed cost (**4-g**).

3. Injection Information

a, b. Injection pressure and well loss coefficient: These values along with hydraulic conductivity, depth to top and bottom of injection zone, and effective diameter of sand pack are used to calculate the theoretical estimate of injection rate per well (**c**). The well loss coefficient is a factor ranging from 5 to 20 to account for: (1) pressure buildup associated with simultaneous injection of multiple wells; (2) entrance losses through the well screen; and (3) clogging around the well screen and/or sand pack. The equation used in the design is based on specific capacity of injection and pumping wells (from Todd, 1980).

$$\text{Rate}_{\text{theo}} = \frac{\dfrac{2 * \pi * k * Z}{1 + \text{Ln}\left(\dfrac{Z}{D_{\text{eff}}}\right)} * \dfrac{7.48\dfrac{\text{gal}}{\text{ft}^3}}{1440\dfrac{\text{min}}{\text{day}}} * \left(\dfrac{P * 144\dfrac{\text{in}^2}{\text{ft}^2}}{62.4\dfrac{\text{lbs}}{\text{ft}^3_{\text{H2O}}}} + d_{\text{wt}}\right)}{\text{Well}_{\text{loss}}}$$

k = hydraulic conductivity (ft/day)
Z = effective treatment zone thickness (ft)
D_{eff} = effective diameter of sand pack (ft)
P = injection pressure (psi)
d_{wt} = depth to water table (ft)
$Well_{loss}$ = well loss coefficient
$Rate_{theo}$ = theoretical estimate of injection rate per well (gpm/well)

d. Injection rate to be used in design: This is the value used in the design and should not exceed the theoretical estimate of injection rate per well. Users may wish to use a lower injection rate in the design based on personal experience.

4. Fixed Costs: The total fixed cost (**h**) is made up of costs that are independent of the duration of the well installation and fluid injection.

5. Injection Costs: Information about personnel, labor rates, and injection daily costs are entered to determine the injection costs per day (**l**). Additional daily costs can be entered in **i, j and k**.

4.8 Installation and Injection – Well Installation by Conventional Drilling

4.8.1 *General Description*

Information on the labor and materials required for conventional well installation and emulsion injection is entered on this page. This approach assumes that temporary or permanent wells are installed first using conventional drilling equipment. Well installation is assumed to be by a subcontract driller with supervision by the prime contractor. Once the wells are installed, multiple wells are manifolded together for emulsion injection.

4.8.2 *Definitions*

1. Well Information

a, b. Top and bottom of injection screen: These values are carried over from the Aquifer Description page and are used later in the design to determine the effective treatment zone thickness.

c, d. Well screen diameter and effective diameter of sand pack: The well screen diameter is not used in the design, but the effective diameter of sand pack is used to determine the theoretical estimate of injection rate per well (**3-e**). The effective diameter of sand pack is typically 1 to 3 inches depending on the installation method.

2. Well Installation Costs for Conventional Drilling: The cost for well installation ($/ft), material costs, and personnel costs are entered to compute the total cost per well (**k**). Per diem, vehicle rental, and lodging costs from (**5-d, e and f**) are also included in the total cost per well. In addition, the subcontractor mobilization (**f**) is only included in the total fixed cost (**4-g**).

3. Injection Information

a, b. Injection pressure and well loss coefficient: These values along with hydraulic conductivity, depth to top and bottom of injection zone, and effective diameter of sand pack are used to calculate the theoretical estimate of injection rate per well (**c**). The well loss coefficient is a factor ranging from 5 to 20 to account for: (1) pressure buildup associated with simultaneous injection of multiple wells; (2) entrance losses through the well screen; and (3) clogging around well screen and/or sand pack. The equation used in the design is based on specific capacity of injection and pumping wells (from Todd, 1980).

$$\text{Rate}_{\text{theo}} = \frac{\dfrac{2 * \pi * k * Z}{1 + \text{Ln}\left(\dfrac{Z}{D_{\text{eff}}}\right)} * \dfrac{7.48\,\dfrac{\text{gal}}{\text{ft}^3}}{1440\,\dfrac{\text{min}}{\text{day}}} * \left(\dfrac{P * 144\,\dfrac{\text{in}^2}{\text{ft}^2}}{62.4\,\dfrac{\text{lbs}}{\text{ft}^3_{\text{H2O}}}} + d_{\text{wt}}\right)}{\text{Well}_{\text{loss}}}$$

k = hydraulic conductivity (ft/day)
Z = effective treatment zone thickness (ft)
D_{eff} = effective diameter of sand pack (ft)
P = injection pressure (psi)
d_{wt} = depth to water table (ft)
$Well_{loss}$ = well loss coefficient
$Rate_{theo}$ = theoretical estimate of injection rate per well (gpm/well)

d. Injection rate to be used in design: This is the value used in the design and should not exceed the theoretical estimate of injection rate per well. Users may wish to use a lower injection rate in the design based on personal experience.

4. Fixed Costs: The total fixed cost (**g**) is made up of costs that are independent of the duration of the well installation and fluid injection.

5. Injection Costs: Information about personnel, labor rates, and injection daily costs are entered to determine the injection costs per day (**l**). Additional daily costs can be entered in **i, j and k**.

4.9 Installation and Injection – Installation and Injection Summary

This worksheet has a button to select the method to be used in the design. The five parameters for each method that factor into the design are:

a. Total fixed cost
b. Dollars per injection point
c. Injection rate per well to be used in design
d. Injection costs per day

4.10 Barrier Treatment – Design Information

4.10.1 *General Description*

Barrier configurations are often used for plume containment. Barriers are typically installed across the plume perpendicular to groundwater flow. Design information is entered on this page which is used to determine material quantities and estimate costs for different well spacings through capital and life cycle cost analyses.

4.10.2 *Definitions*

1. Treatment Zone Dimensions: A schematic of the barrier design is provided in Figure 4.1 and in the design tool.

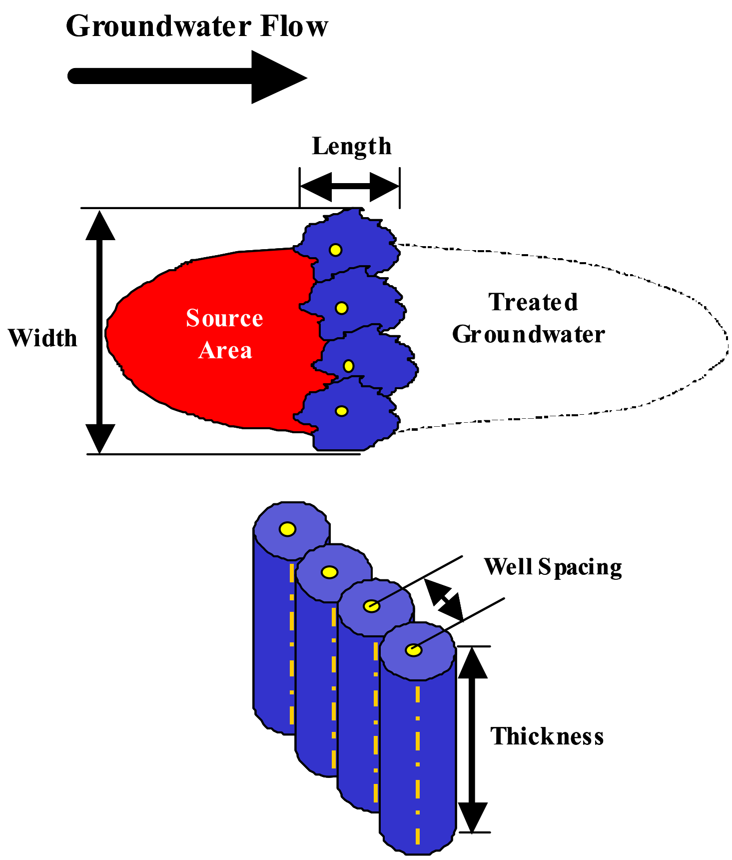

Figure 4.1. Emulsified Oil Barrier Design Schematic.

a. Width (Y): The user should enter the width of the barrier perpendicular to groundwater flow. Typically, the barrier should be 10% to 30% wider than the plume to account for changes/uncertainty in groundwater flow direction and hydraulic conductivity.
c. Percentage of injection zone that transmits most flow: This user entered value is used to account for the fact that the treatment zone may contain substantial layers of impermeable layers. The effective treatment zone thickness (**d**) should exclude the impermeable layers. If impermeable layers are unaccounted for then the design may be over designed resulting in much higher costs.
e. Seepage velocity: This value is copied over from the Aquifer Description page and is used along with the minimum allowable contact time to determine the number of rows necessary.

2. Treatment Zone Contact Time

a. Minimum allowable contact time: The user enters an estimated contact time within the barrier reactive zone to achieve degradation of the target contaminants. The contact time is then used to calculate the number of rows needed (**see Capital Cost Analysis – Well Layout**).

$$r = \frac{C_t * v}{S_w}$$

r = number of rows
C_t = contact time (days)
v = non-reactive transport velocity (ft/day)
S_w = well spacing ft

If C_t * v is less than the well spacing then the number of rows needed is determined by taking (C_t * v)/S_W and rounding up to the next whole number where S_W is the desired well spacing in feet. If C_t * v is greater than S_W then only one row is needed to achieve the desired contact time.

The required contact time will be dependent on the target contaminants. Laboratory column experiments and limited field studies suggest a 2 to 4-month contact time when treating moderate to high concentrations of chlorinated solvents. The contact time for perchlorate may be substantially less. Longer contact times should be considered if there is high sulfate loading, very high contaminant concentrations, and a high removal efficiency is desired.

3. Targeted Carbon Released

a. Average amount of DOC released: Dissolved organic carbon (DOC) will be released from the barrier as the emulsified oil slowly degrades. This DOC released is in excess of that required for contaminant biodegradation and consumption of competing electron donors. Field monitoring data indicate that DOC released from barriers declines from hundreds of mg/L shortly after emulsion injection to tens of mg/L near the end of the operating life. Long-term average DOC concentrations are typically in the range of 40 to 100 mg/L. This value is an important component of the substrate consumption rate.

4. Design Life

a. Total project life: In this section, the user enters the project design life with a maximum of 30 years. For barriers, the design life is typically based on the expected life of the contaminant source.

b. Substrate scaling factor (SF_S): Typically, contaminant treatment efficiency for emulsified oil barriers begins to decrease when 30 to 60% of the oil has been consumed by bacteria. While treatment efficiency does not go to zero, it may decline to unacceptable levels and reinjection may be needed to maintain performance. To account for this, the design tool includes a substrate scaling factor (SF_S). For example, if the theoretical life of a single injection (T) is 20 years and treatment performance declines to unacceptable levels once 40% of the oil is consumed (e.g., $SF_S = 0.4$), the model will calculate a required reinjection interval (RI) as:

$$RI = T * SF_S = 20 \text{ yr} * 0.4 = 8 \text{ yr}$$

c. Maximum time between reinjections: This allows the user to specify a maximum reinjection interval to override the calculated reinjection interval. For example, if the model calculates a reinjection interval (RI) of 8 years, the user may decide to specify a maximum RI of 5 years based on personal experience. The design tool will then use an RI of 5 years in the life cycle cost analysis.

5. Contact Efficiency

a, b. Mass and Volume Scaling Factors: For the most effective treatment, emulsified oil should be uniformly distributed throughout the treatment zone. However in real aquifers, a variety of factors (e.g., injection well location, injection sequencing, subsurface heterogeneity) lead to a non-uniform oil distribution. A SF_M and a SF_V are used to account for these effects in the design tool.

Effects of SF_M and SF_V on flow contact efficiency are shown in Figure 4.2. Upper and lower limits of the expected contact efficiency are printed on the spreadsheet as a function of the SF_M and SF_V to be used in the design. Higher values of SF_M and SF_V will result in improved contact efficiency while increasing cost.

Users should note that flow contact efficiency does not include any contact time criteria so groundwater is considered 'contacted' if it flows through a zone with greater than 5% of the maximum oil retention, even if the contact time is only a few minutes. Consequently, pollutant removal efficiency will likely be less than the contact efficiency.

The following equations are used to determine the amount of oil and water to inject in each well.

$$\text{Mass of oil injected per well} = SF_M \, OR_M \, \rho_B \, BTV$$

$$\text{Volume of fluid per well} = SF_V \, n_e \, BTV$$

OR_M = maximum oil retention by aquifer material (lb/lb)
ρ_B = bulk density (lb/ft^3)
n_e = effective porosity
BTV = base treatment volume (ft^3)

For barrier treatment, the BTV is defined as the volume of a cylinder with a diameter equal to the well spacing (S_W) and an effective treatment zone thickness, Z, where $BTV = \frac{1}{4} \pi S_W^2 Z$.

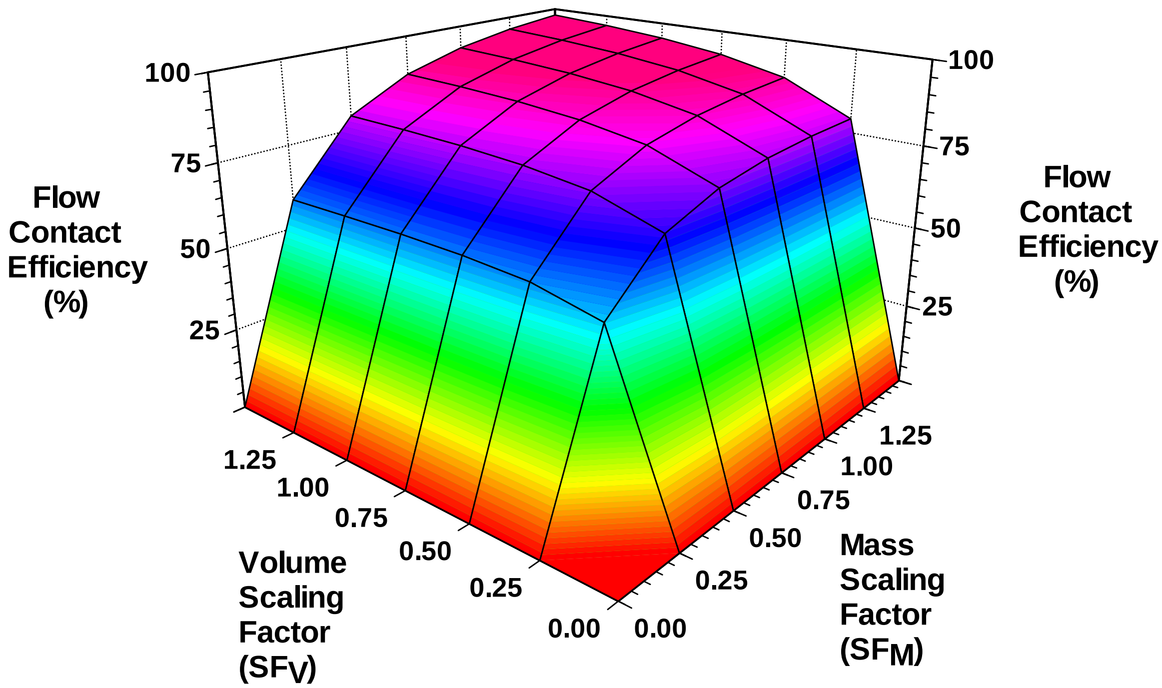

Figure 4.2. Contact Efficiency for Barrier Treatment.

4.11 Barrier Treatment – Capital Cost Analysis

4.11.1 *General Description*

This section evaluates the capital costs associated with various well spacing configurations based on the design information. A graph of well spacing versus capital cost is displayed at the bottom of the page.

4.11.2 *Definitions*

Calculation of Well Spacing for Injection through Direct Push Rods

For direct push injection, the design tool calculates the well spacing required to deliver the necessary injection volumes based upon the gallons injected per foot of injection interval as specified on the *Injection through Direct Push Rods* page. The well spacing is determined as follows:

$$S_W = \sqrt{\frac{IV_{pt}}{SF_V * \frac{1}{4} * \pi * Z * n_e * 7.48 \frac{gal}{ft^3}}}$$

S_W = calculated well spacing (ft)
IV_{pt} = gallons injected per injection point (gal)
SF_V = volume scaling factor
Z = effective vertical thickness of injection zone (ft)

n_e = effective porosity

The well spacing is a function of the amount of fluid that can be injected per foot by direct push as well as the desired contact efficiency. Higher contact efficiencies require larger volumes to be injected which require more closely spaced injection points. This in turn increases cost. Once the well spacing is calculated, all subsequent calculations follow those outlined below.

1. **Well Layout:** The tool determines the number of wells needed for each well spacing by dividing the barrier width by the well spacing.
   a. **Minimum well spacing:** This is the minimum well spacing to be evaluated.
   b. **Incremental increase in well spacing:** A total of nine different well spacings are evaluated. Changing the minimum and incremental values allows one to optimize the design by looking for the minimum capital cost.
   e. **Number of rows:** See the section on contact time in section **4.10** for additional information.

2. **Fixed Costs**
   a. **Planning, engineering, and permitting:** This is an estimate for the planning, engineering, and permitting costs that goes into the initial design. It is summed with the fixed cost from the selected installation and injection method to make up the total fixed cost (**c**). If post-remediation costs are significant they should be included here.

3. **Well Installation:** This cost is calculated by multiplying the number of wells for a given well spacing by the dollars per injection point for the selected installation and injection method.

4. **Injection Information**
   a. **Hours of injection per day:** The number of hours per day that injection will occur. This includes both attended and unattended injection and is used to calculate the time required to inject a well. This value will default to the value entered on the Injection through Direct Push Rods if this method is selected.
   b. **Maximum number of wells to inject at one time:** Injecting multiple wells together reduces the total time it takes to complete injection resulting in a lower total cost. However, the number of wells to inject at once is usually limited to 10 wells to limit the chance that injecting too much emulsion and water at once will displace contaminants downgradient. When using Injection through Direct Push Rods only one well can be injected at a time.
   c. **Percentage of total wells to inject at one time:** This value controls how many wells are injected at one time and is usually set to 50% to allow for enhanced contact throughout the aquifer. For example, if a barrier has 16 wells, and up to 50% of the wells may be injected at one time, then only 8 wells would be injected one day followed by the second 8 wells the next day. When using Injection through Direct Push Rods, this value will automatically go to 100% since only one well will be injected at a time.
   d. **Required total water supply rate:** The amount of water needed for injection is the product of injection rate to be used in the design and the actual number of wells

injected simultaneously. If the required amount of water at a site is not available then either a lower injection rate or injecting fewer wells at a time will need to be used.

5. Injection Costs: For each well spacing, the total volume of injection fluid (water plus emulsified oil) is calculated based on the well spacing (S_W), vertical thickness of injection zone (Z), effective porosity (n_e) and the Volume Scaling Factor (SF_V) where:

$$\text{Volume of fluid per well} = SF_V\, n_e\, \tfrac{1}{4}\, \pi\, S_W^2\, Z$$

The total injection volume, expected injection rates, number of wells injected simultaneously, and daily injection costs are then used to determine the amount of injection time required for each well and the total injection costs. When using either well installation by direct push or conventional drilling, the time to complete a set of wells is rounded up to the next nearest day. This allows time for the emulsion to spread throughout the aquifer and minimizes the risk of displacing the contaminant. If injection through direct push rods is selected, then multiple wells can be injected in a day since only one well is injected at a time.

6. Substrate: For each well spacing, the amount of oil required is determined based on the well spacing (S_W), effective vertical thickness of injection zone (Z), maximum oil retention by the aquifer material (OR_M), aquifer material bulk density (ρ_B) and the mass scaling factor (SF_M) where:

$$\text{Mass of oil per well} = SF_M * OR_M * -_B * BTV$$

The effective life of a single emulsion injection and the reinjection interval are calculated by using the following equations:

$$T = \frac{Oil_{total}}{D * Q}$$

$$Q = Y * Z * K * i * 28.3 \frac{L}{ft^3} * 365 \frac{day}{yr}$$

$$RI = T * SF_S$$

T = effective life of single injection (yrs)
Oil_{total} = total mass of oil injected (lbs)
D = oil demand (lbs/L)
Q = water flux (L/yr)
Y = treatment zone width (ft)
Z = effective treatment zone thickness (ft)
K = hydraulic conductivity (ft/day)
i = hydraulic gradient (ft/ft)
RI = reinjection interval (yrs)

SF_S = substrate scaling factor

7. Total Installation and Injection Costs: The fixed well installation, injection, and substrate costs are summed to provide the user with the total capital costs for each well spacing. The cost data are also displayed graphically. Based on the cost data, the user can see the effect of well spacing on capital cost. It is important to keep in mind that these costs are only for the initial installation and injection event.

4.12 Barrier Treatment – Life Cycle Analysis

4.12.1 *General Description*

This section calculates estimated re-injection costs which can be used to estimate life-cycle costs. Information related to future injections is entered and then costs are calculated for future injections as well as the net present value of the design. A graph displays well spacing vs. NPV to aid in selecting a design. Selecting a design lets one see a breakdown of the costs for that design.

4.12.2 *Definitions*

1. First Event Costs: These values are the capital costs for the initial installation and injection event carried over from the capital cost analysis.

2. Life Cycle Analysis

a. Annual interest rate: This is the annual interest rate used to compute NPV. Typically, a rate between 3.5% and 5% is used.

b. Engineering, planning, and permitting costs: The estimated cost to engineer, plan, and permit future installation and injection events. This value will typically be less than the value for the initial design entered in the Capital Cost Analysis page.

c. Fixed costs: This value is carried over from the selected installation and injection method.

d. Annual monitoring and reporting costs: The cost each year for monitoring and reporting. Depending on the number of wells and how often samples are taken, this can range from $5,000 per year upwards to $20,000 per year.

e. Well rehabilitation and/or installation cost: The percentage of the first event cost for well installation that will be used for future events. This covers any costs necessary to prepare the wells for injection. If injection through direct push rods is selected then this value will always be 100% as the points are temporary.

3. Life-Cycle Cost Analysis

a. Injection costs per future event: Based on the information supplied in section 2 above, this is the capital cost for each future installation and injection event. Once again, the reinjection interval is determined by taking the lesser of the calculated reinjection interval ($RI = T * SF_S$) and the user entered maximum time between reinjections.

b. Net present value for design life: This section shows the reinjection frequency (**b**), the NPV for monitoring and reporting (**c**), and the NPV for the total injection costs (**d**). The project life NPV (**e**) is the sum of the NPV for monitoring and reporting and the NPV for the total injection costs.

4.13 Barrier Treatment – Net Present Value For Selected Design

This section breaks down the net present values for the design selected on the Life Cycle Analysis page. The NPV cost is shown for each item pertaining to a year. The event total is the sum of fixed costs, well installation, labor for injection, and substrate. Total is the sum of monitoring and the injection event. The cumulative cost is the total NPV up to and including that year. The total cost (**b**) shows the sum of each component: monitoring, fixed costs, well installation, labor for injection, substrate, event, and total. The graph on the bottom left shows the annual costs for the different components to see what is contributing most to the cost of the design. The graph to the right shows the cumulative NPV versus the year.

4.14 Barrier Treatment – Selected Design

This is a summary of the selected design and shows information on the design layout, costs for initial and future installation and injection events, and the total life cycle costs. Design parameters, which directly affect the design, are also shown as well as section to include additional notes about the design. The summary should be printed or saved before modifying the design.

4.15 Area Treatment – Design Information

4.15.1 *General Description*

Area treatments are often used to treat source areas or entire plumes. The area treatment design assumes several rows of injection wells are installed across the plume or source area perpendicular to groundwater flow. Design information is entered on this page and used to determine material quantities and estimate costs for different well spacings through capital and life cycle cost analyses.

4.15.2 *Definitions*

1. Treatment Zone Dimensions: A schematic of the barrier design is provided in Figure 4.3 and in the design tool.

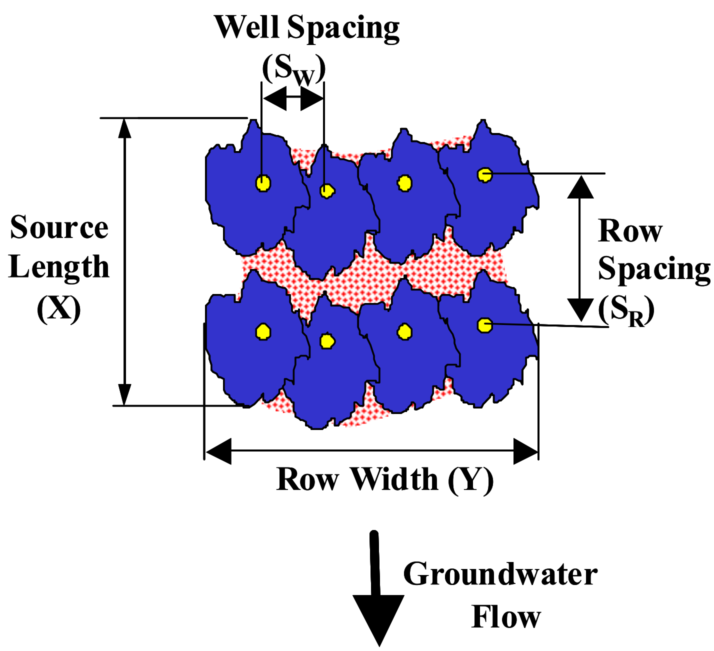

Figure 4.3. Emulsified Oil Area Treatment Design Schematic.

a. Width (Y): The user should enter the width of the treatment zone perpendicular to groundwater flow.
b. Length (X): The user enters the length of the treatment zone parallel to groundwater flow.
c. Row spacing: This is a ratio of well spacing to row spacing to determine how far apart the barriers will be spaced. For example, a ratio of 2 to 1 and a well spacing of 5 ft the rows will be spaced 10 feet apart for the length of the treatment zone. Depending on which ratio is selected the graph of contact efficiency will change.
d. Percentage of injection zone that transmits most flow: This user entered value is used to account for the fact that the treatment zone may contain substantial layers of impermeable layers. The effective treatment zone thickness (**f**) should exclude the impermeable layers. If impermeable layers are unaccounted for then the design may be over designed resulting in much higher costs.

2. Design Life

a. Reinjection interval: The reinjection interval is a fixed value specified by the user. The value entered will carry over to the life-cycle cost analysis. Personal experience or other studies should be consulted when determining this value.
b. Total project life: In this section, the user enters the project design life with a maximum of 30 years. Accurate estimation of the actual time to remediate a source area is extremely difficult and is beyond the scope of this design tool. Laboratory studies and field pilot tests have demonstrated that oil addition can stimulate rapid biodegradation of contaminants in the higher permeability zones with contaminants degraded to low levels in 6 to 12 months. However, mass transfer limitations may greatly reduce the rate that DNAPLs and contaminants in low permeability zones are

degraded. If residual oils are present, aqueous phase contaminants will be degraded as they diffuse out into the more mobile portions of the aquifer. However, once the oil is depleted, aqueous phase contaminants may be released to the downgradient aquifer. For most source areas, a five-year project life should be provided as a minimum with the expectation that additional oil may need to be injected at some time in the future.

3. Contact Efficiency

a, b. Mass and Volume Scaling Factors: In an ideal, homogeneous aquifer, emulsified oil should be uniformly distributed between throughout the treatment zone. However, in real aquifers, a variety of factors such as injection well location, injection sequencing, subsurface heterogeneity lead to a non-uniform oil distribution. A Mass Scaling Factor (SF_M) and Volume Scaling Factor (SF_V) are used to account for these effects in the design tool.

Effects of SF_M and SF_V on the volume contact efficiency are shown in Figure 4.4 and 4.5 depending on which row spacing ratio is used. Upper and lower limits of the expected contact efficiency are printed on the spreadsheet as a function of the SF_M and SF_V to be used in the design. Higher values of SF_M and SF_V will result in improved contact efficiency, while increasing cost. The following equations are used to determine the amount of oil and water to inject in each well.

$$\text{Mass of oil injected per well} = \frac{SF_M * OR_M * n_e * BTV}{w}$$

$$\text{Volume of fluid per well} = \frac{SF_V * n_e * BTV}{w}$$

OR_M = maximum oil retention by aquifer material (lb/lb)
ρ_B = bulk density (lb/ft^3)
n_e = effective porosity
BTV = base treatment volume (ft^3)
w = total number of wells

The BTV is defined as the volume of the target treatment zone where BTV = X*Y*Z.

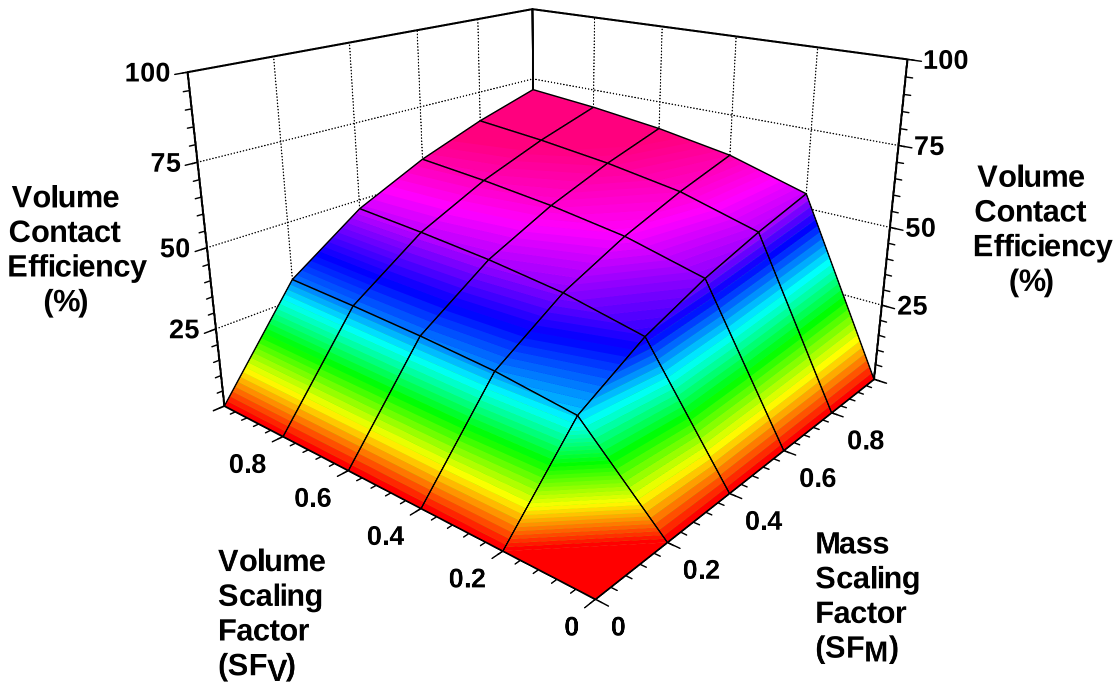

Figure 4.4. Contact Efficiency for Area Treatment when Row Spacing = Well Spacing.

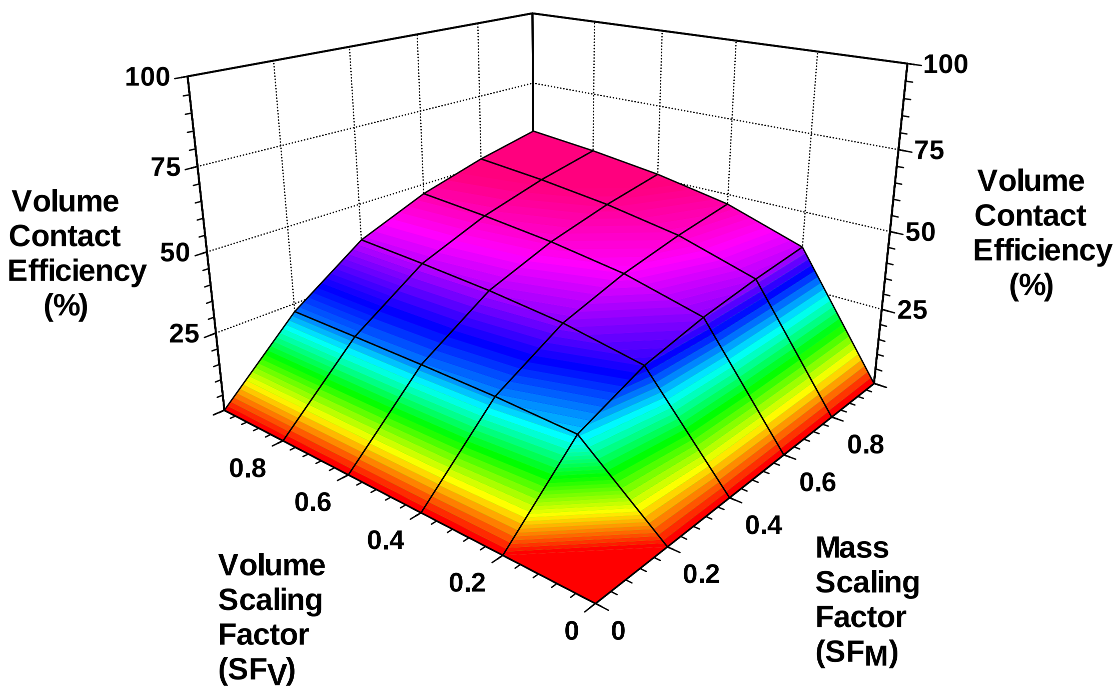

Figure 4.5. Contact Efficiency for Area Treatment when Row Spacing = 2 * Well Spacing.

4.16 Area Treatment– Capital Cost Analysis

4.16.1 *General Description*

This section evaluates the capital costs associated with various well spacing configurations based on the design information. A graph of well spacing versus capital cost is displayed at the bottom of the page.

4.16.2 *Definitions*

Calculation of Well Spacing for Injection through Direct Push Rods
For direct push injection, the design tool calculates the well spacing required to deliver the necessary injection volumes based upon the gallons injected per foot of injection interval as specified on the *Injection through Direct Push Rods* page. First the total injection volume is calculated then the well spacing is determined. The equations are as follows:

$$IV_{total} = SF_V * X * Y * Z * n_e$$

$$S_W = \sqrt{\frac{X * Y}{\frac{IV_{total}}{IV_{pt}} * 7.48 \frac{gal}{ft^3}}}$$

IV_{total} = total injection volume (ft^3)
SF_V = volume scaling factor
X = treatment zone width (ft)
Y = treatment zone length (ft)
Z = effective vertical thickness of injection zone (ft)
n_e = effective porosity
S_W = calculated well spacing (ft)
IV_{pt} = gallons injected per injection point (gal)

The well spacing is a function of the volume of fluid that that can be injected per direct push point and the desired contact efficiency. Higher contact efficiencies require larger injection volumes and more injection points. This in turn increases cost. Once the well spacing is calculated, all subsequent calculations follow those outlined below.

1. **Well Layout:** The tool determines the number of wells for each row of wells by dividing the width by the well spacing. The number of rows is the treatment zone length divided by the row spacing.
   a. **Minimum well spacing:** This is the minimum well spacing to be evaluated.
   b. **Incremental increase in well spacing:** A total of nine different well spacings are evaluated. Changing the minimum and incremental values allows one to optimize the design by looking for the minimum capital cost.

2. Fixed Costs

a. Planning, engineering, and permitting: This is an estimate for the planning, engineering, and permitting costs that goes into the initial design. It is summed with the fixed cost from the selected installation and injection method to make up the total fixed cost (**c**). If post-remediation costs are significant then they should be included here.

3. Well Installation: This cost is calculated by multiplying the number of wells for a given well spacing by the dollars per injection point for the selected installation and injection method.

4. Injection Information

a. Hours of injection per day: The number of hours per day that injection will occur. This includes both attended and unattended injection and is used to calculate the time required to inject a well. This value will default to the value entered on the *Injection through Direct Push Rods* page if that method is selected.

b. Maximum number of wells to inject at one time: Injecting multiple wells together reduces the total time it takes to complete injection resulting in a lower total cost. However, the number of wells to inject at once is usually limited to 10 wells to limit the chance that injecting too much emulsion and water at once will displace contaminants downgradient. When using Injection through Direct Push Rods only, one well can be injected at a time.

c. Percentage of total wells to inject at one time: This value controls how many wells can be injected at one time and is usually set at 50% to allow for enhanced contact throughout the treatment zone. For example, if an area treatment has 16 wells and up to 50% of the wells may be injected at one time, then only 8 wells will be injected one day followed by the second set of 8 wells the next day. When using injection through direct push rods, this value will automatically go to 100% since only one well will be injected at a time.

d. Required total water supply rate: The amount of water needed for injection is the product of injection rate to be used in the design and the actual number of wells injected simultaneously. If the required amount of water at a site is not available, then either a lower injection rate needs to be used or fewer wells can be injected at a time.

5. Injection: For each well spacing, the total volume of injection fluid (water plus emulsified oil) is calculated based on the well spacing (S_W), vertical thickness of injection zone (Z), effective porosity (n_e) and the Volume Scaling Factor (SF_V) where:

$$\text{Volume of fluid per well} = \frac{SF_M * n_e * BTV}{w}$$

The total injection volume, expected injection rates, number of wells injected simultaneously, and daily injection costs are then used to determine the amount of injection time required for each well and the total injection costs. When using either well installation by direct push or conventional drilling the time to complete a set of wells is rounded up to the next nearest day. This allows time for the emulsion to spread throughout the aquifer and minimizes the risk of displacing the contaminant. If injection through direct push rods is selected then multiple wells can be injected in a day since only one well is injected at a time.

6. Substrate: For each well spacing, the amount of oil required is determined based on the based on the well spacing (S_W), vertical thickness of injection zone (Z), maximum oil retention by the aquifer material (OR_M), aquifer material bulk density (ρ_B) and the mass scaling factor (SF_M) where:

$$\text{Mass of oil per well} = \frac{SF_M * OR_M * {-}_B * BTV}{w}$$

7. Total Installation and Injection Costs: The fixed, well installation, injection, and substrate costs are summed to provide the user with the total capital costs for each well spacing. The cost data are also displayed graphically. Based on the cost data, the user can see the effect of well spacing on capital cost. It is important to keep in mind that these costs are only for the initial installation and injection event.

4.17 Area Treatment – Life Cycle Analysis

4.17.1 *General Description*

This section calculates estimated re-injection costs which can be used to estimate life-cycle costs. Information related to future injections is entered and then costs are calculated for future injections as well as the net present value of the design. A graph displays well spacing vs. NPV to aid in selecting a design. Selecting a design lets one see a breakdown of the costs for that design.

4.17.2 *Definitions*

1. First Event Costs: These values are the capital costs for the initial installation and injection event carried over from the capital cost analysis.

2. Life Cycle Analysis

- **a. Annual interest rate:** This is the annual interest rate used to compute net present values. Typically, a rate between 3.5% to 4.5% is used.
- **b. Planning, engineering, and permitting costs:** The estimated cost to engineer, plan, and permit future installation and injection events. This value will typically be less than the value for the initial design entered in the Capital Cost Analysis page.
- **c. Fixed costs:** This value is carried over from the selected installation and injection method.
- **d. Annual monitoring and reporting costs:** The cost each year for monitoring and reporting. Depending on the number of wells and how often samples are taken this can range from $5,000 per year upwards to $20,000 per year.

e. Well rehabilitation and/or installation cost: The percentage of the first event cost for well installation that will be used for future events. This covers any costs necessary to get the wells ready for injection. If injection through direct push rods is selected, then this will always be 100%.

2. Life-Cycle Cost Analysis

a. Injection Costs per Future Event: Based on the information supplied in section B this is the capital cost for each future installation and injection event.

b. Net Present Value for Design Life: This section shows the reinjection frequency (**b**), the NPV for monitoring and reporting (**c**), and the NPV for the total injection costs (**d**). The project life NPV (**e**) is the sum of the NPV for monitoring and reporting and the NPV for the total injection costs.

4.18 Area Treatment – Net Present Value for Selected Design

This section breaks down the net present values for the design selected on the Life Cycle Analysis page. The NPV cost is shown for each item pertaining to a year. The event total is the sum of fixed costs, well installation, labor for injection, and substrate. Total is the sum of monitoring and the injection event. The cumulative cost is the total NPV up to and including that year. The total cost (**b**) shows the sum of each component: monitoring, fixed costs, well installation, labor for injection, substrate, event, and total. The graph on the bottom left shows the annual costs for the different components to see what is contributing most to the cost of the design. The graph to the right shows the cumulative NPV versus the year.

4.19 Area Treatment – Selected Design

This is a summary of the selected design and shows information on the design layout, costs for initial and future installation and injection events, and the total life cycle costs. Design parameters, which directly affect the design, are also shown as well as section to include additional notes about the design. The summary should be printed and saved before modifying the design.

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APPENDIX 1
MEASUREMENT OF MAXIMUM OIL RETENTION ON DISTURBED SAMPLES OF AQUIFER MATERIAL

Objective:

The objective of this procedure is to determine the maximum potential retention of emulsified oil by aquifer material.

Procedure:

1. Homogenize sample of aquifer material. Determine the organic content of untreated samples by Total Organic Carbon (TOC) analysis. Collect three subsamples and measure TOC on each sample following standard analytical methods (EPA 9060A or equivalent).
2. Pack a 2.5 cm diameter laboratory column with 15 cm of aquifer material and saturate with water. Larger columns may be used but will require collection and eventual disposal of more aquifer material. In many cases, the easiest approach to saturating the aquifer material is to partially filling the column with water, adding 1-2 cm of aquifer material, and repeatedly tamping the material with a small rod to compact the soil and remove any entrained air bubbles. Once the material is adequately compacted, add more aquifer material and repeat the process until the column is filled with soil. During packing, visually observe the soil to ensure there are no visible layers or entrapped air bubbles.
3. Prepare dilute emulsion containing 12% by weight oil.
4. Pump 3 pore volumes (PV) of 12% emulsion through the column packed with aquifer material followed by 3 PV of water. Flowrate should be adjusted so that approximately one pore volume of water is flushed through the column per hour. Lower flowrates may be used if pressure buildup is excessive. One PV equals the column volume times sample porosity.
5. Remove the treated aquifer material from the column, homogenize, collect three subsamples, and analyze each subsample for TOC.

Oil Retention Calculation

Carbon content of oil (g/g) = CCO (Note: CCO of soybean oil = 0.77 g carbon per g oil)
Average initial organic content (g/g) = TOC_I
Average final organic content (g/g) = TOC_F
Maximum oil retention by aquifer material (g/g) = $OR_M = (TOC_F - TOC_I) * CCO$

Table A1.1. Observed Emulsified Oil Retention by Aquifer Material.

Site-Specific Aquifer Material	Mean Grain Size (mm)	finer than 200 sieve (75 µm)	Hydraulic Conductivity (m/d)	Emulsion	Test Condition	Maximum Retention (g/g)	Reference
Fine clayey-sand	0.38	6.9%	2	Homemade	Lab Column	0.0054	Coulibaly and Borden, 2004
Fine clayey sand amended with kaolinite	0.36	9.2%	1.3	Homemade	Lab Column	0.0061	Coulibaly and Borden, 2004
Fine clayey sand amended with kaolinite	0.37	11.5%	0.7	Homemade	Lab Column	0.0095	Coulibaly and Borden, 2004
Clayey sand alluvium	1.0 - 0.4	15% - 23%	10.7	EOS® 598B42	Lab Column	0.0037	ESTCP, 2006b; Borden, 2007a
Low K, weathered rock (sandy clay with remnant fractures)	NA	NA	0.4	EOS® 598B42	Field (estimated)	0.0030	Borden et al., 2007
Coarse grained sand and gravel	NA	NA	64	EOS® 598B42	Field (estimate)	0.0004	Kovacich et al., 2007
Medium grain sand	0.35	0.8%	6.5	Emulsified Vegetable Oil	Lab Column	0.0024	Konzuk et al., 2006
White, fine-grained sand	NA	NA	NA	HRC-A (3DMe™)	Lab Column	0.0500	Regenesis, 2008

APPENDIX 2
OIL CONSUMPTION RATE FOR BARRIERS

This appendix describes the approach used to calculate the oil consumption rate for barriers. This approach has been tested at a limited number of emulsified oil barrier sites and shown to be reasonably accurate. However, as the science and engineering behind the emulsified oil technology evolves, new and improved procedures will likely become available.

A2.1 Annual Groundwater Flow through Barrier

For a barrier design, the volume of water to be treated per year is calculated by multiplying the width of the barrier perpendicular to flow (Y), effective vertical height of the treated zone (Z), effective porosity of the treatment area (n_e), and groundwater flow velocity. Barriers are typically placed across a plume perpendicular to the direction of groundwater flow with a width (Y) that is somewhat greater than the plume to minimize the potential for contaminated groundwater to flow around the barrier without passing through the treatment zone.

When determining the effective vertical height (Z), designers should consult boring logs from the site to estimate the vertical thickness of the aquifer that transmits most of the groundwater. For example, at a typical site, the chlorinated solvent plume may extend from 20 to 40 ft below grade. However, this contaminated interval consists of sand and clay layers. Essentially all of the groundwater flow will be through the sand layers, so these layers should be targeted for treatment. While it might be desirable to treat the entire vertical extent of contamination, experience has shown that most of the emulsion is distributed in the higher permeability layers.

A2.2 Hydrogen Demand

Edible oils ferment in the subsurface generating hydrogen and acetate. The hydrogen and acetate are then used to support reductive dechlorination. However, hydrogen and acetate may also be consumed during biodegradation of naturally occurring electron acceptors including oxygen, nitrate, sulfate, ferric iron, and manganese. As a consequence, designers must consider both the amount of contaminant to be degraded and the background electron acceptor load.

The amount of substrate required to reduce the mass of dissolved contaminants and/or electron acceptors can be determined by calculating the stoichiometric hydrogen demand of the dissolved contaminants and electron acceptors. First, the contaminant and electron acceptor mass to be degraded is calculated by multiplying the average concentrations by the total groundwater treatment volume. The stoichiometric hydrogen demand required to reduce the contaminant mass can then be calculated by determining the amount of molecular hydrogen (H_2) required for complete reduction of each contaminant or background electron acceptor. The stoichiometric demand is the mass ratio of the contaminant to hydrogen (weight contaminant/weight H_2) and is based upon balanced chemical reduction equations. For example, TCE (C_2HCl_3) can be completely reduced to ethene according to the following equation:

$$C_2HCl_3 + 3H_2 \rightarrow C_2H_4 + 3H^+ + 3Cl^-$$

Since it takes 3 moles of hydrogen (molecular weight = 2.016) to reduce 1 mole of TCE (molecular weight = 131.389) to ethene, the stoichiometric hydrogen demand is 131.389 divided by 6.048 (3 x 2.016) or 21.72 (wt/wt H_2). Therefore, 21.72 grams of TCE is degraded per gram of hydrogen. Similar calculations can be done for each contaminant and electron acceptor to determine the stoichiometric hydrogen demand. For each contaminant or electron acceptor, the mass is divided by the stoichiometric hydrogen demand to determine the mass of hydrogen required to reduce the contaminant mass. **Table A2.1** provides the chemical reduction equations and stoichiometric hydrogen demand for typical chlorinated solvents and electron acceptors.

Table A2.1. Stoichiometric Hydrogen Demand for Different Contaminants and Electron Acceptors.

Chlorinated Solvents and Electron Acceptors	Chemical Reduction Equation	Stoichiometric Hydrogen Demand (wt/wt H_2)
PCE	$C_2Cl_4 + 4H_2 \rightarrow C_2H_4 + 4H^+ + 4Cl^-$	20.57
TCE	$C_2HCl_3 + 3H_2 \rightarrow C_2H_4 + 3H^+ + 3Cl^-$	21.73
cis-DCE	$C_2H_2Cl_2 + 2H_2 \rightarrow C_2H_4 + 2H^+ + 2Cl^-$	24.05
Vinyl Chloride	$C_2H_3Cl + H_2 \rightarrow C_2H_4 + H^+ + Cl^-$	31.00
Carbon Tetrachloride	$CCl_4 + 4H_2 \rightarrow CH_4 + 4H^+ + 4Cl^-$	19.08
Chloroform	$CHCl_3 + 3H_2 \rightarrow CH_4 + 3H^+ + 3Cl^-$	19.74
1,1,1-TCA	$C_2H_3Cl_3 + 3H_2 \rightarrow C_2H_6 + 3H^+ + 3Cl^-$	22.06
1,1-DCA	$C_2H_4Cl_2 + 2H_2 \rightarrow C_2H_6 + 2H^+ + 2Cl^-$	24.55
Chloroethane	$C_2H_5Cl + H_2 \rightarrow C_2H_6 + H^+ + Cl^-$	32.18
Oxygen	$O_2 + 2H_2 \rightarrow 2H_2O$	7.94
Nitrate	$2NO_3^- + 2H^+ + 5H_2 \rightarrow N_2 + 6H_2O$	12.30
Sulfate	$2SO_4^{-2} + 3H^+ + 8H_2 \rightarrow H_2S + HS^- + 8H_2O$	11.91
Ferric Iron	$2Fe^{+3} + H_2 \rightarrow 2Fe^{+2} + 2H^+$	55.41
Manganese	$MnO_2 + 2H^+ + H_2 \rightarrow Mn^{+2} + 2H_2O$	27.25

The hydrogen released from different edible oils is approximately 0.18 moles of H_2 per gram of oil (0.36 to 0.365 g H_2/g oil) depending on the oil composition. The substrate demand is determined by dividing the calculated hydrogen demand for degradation of contaminants and electron acceptors by the amount of hydrogen produced from oil.

In addition to the contaminants and electron acceptors entering the treatment zone, hydrogen can be consumed during reduction of iron oxides and manganese oxides present in the aquifer material, production of methane, and release of dissolved organic carbon (DOC). The ideal approach for estimating the iron and manganese demand is to directly measure the amount of bioavailable iron and manganese oxides in the aquifer material and determine the fraction of these oxides that will be reduced per year. Unfortunately, these data are not commonly available. An alternative approach is to calculate the iron and manganese demand based on the amount of dissolved iron and manganese released to the downgradient aquifer. This approach may somewhat under estimate the iron and manganese demand, but should be a reasonable approximation in most cases. In previous field studies, dissolved iron concentrations released from emulsified oil barriers typical varied between 10 and 100 mg/L with somewhat lower levels of dissolved manganese.

Hydrogen and acetate that is not consumed by reductive dechlorination or electron acceptor reduction will be fermented to methane or released to the downgradient aquifer. As a consequence, additional substrate must be injected to account for any methane production and dissolved organic carbon (DOC) released. In previous emulsified oil projects, methane concentrations downgradient from the treatment zone have varied between 5 and 20 mg/L. Immediately after oil injection, DOC concentrations released from oil barriers may exceed 500 mg/L. However, DOC concentrations decline with time reaching quasi-steady-state levels of 20 to 50 mg/L. Consequently, 60 to 100 mg/L DOC appears to be a reasonable range for the long-term average concentration released.

The barrier treatment design spreadsheets estimate the amount of substrate used for methane production and the amount of carbon lost from the barrier over time. These values are estimated by entering estimated methane concentrations and DOC concentrations. The total amount of oil required to support contaminant biodegradation is then calculated. This value is only the amount of oil required. Other materials including easily biodegradable soluble substrates, bacterial nutrients and vitamins, and surfactants may be added to aid in emulsion preparation and to stimulate rapid growth of desired microbial populations. However, these materials are rapidly depleted and are not expected to support long-term anaerobic biodegradation.

APPENDIX 3
EMULSIFIED OIL DESIGN TOOL -- BARRIER TUTORIAL

A3.1 Objective

Upon completion of this tutorial, the user will have a good understanding of how to design a single emulsified oil barrier to control plume migration. The tutorial will cover what information needs to be entered along with how to select a design by looking at a case study.

A3.2 Case Study

The site used throughout the tutorial is a facility located in eastern Maryland and manufactures fireworks, munitions, and pesticides. The water table aquifer is comprised of silty sand and gravel and extends to a depth of 15 ft below ground surface (BGS) where a clay confining layer is encountered. The water table is located between 3 and 10 ft BGS. The site is contaminated with trichloroethene (TCE), 1,1,1-trichloroethane (TCA), and perchlorate (ClO_4). Concentrations of TCA are shown in **Figure A3.1**. The contaminants were released from a small impoundment that was closed in the late 1980's. For the next 15 years the groundwater was treated through a pump and treat system that removed significant amounts of TCE and TCA, but ClO_4 levels were unaffected.

The tutorial will go through the design of a 400 ft long barrier as located in **Figure A3.1**. The barrier is located along a road where there are minimal obstructions and will prevent the plume from entering the stream.

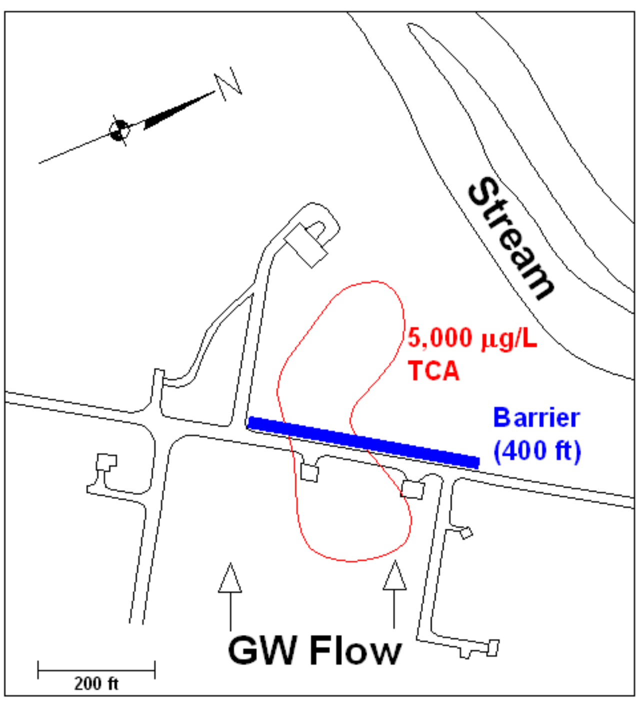


Figure A3.1. Map of the Maryland Site Showing Plume of Elevated TCA (µg/L) in Red and Location of the Proposed Barrier in Blue.

A3.3 Getting Started

Open up the Emulsified Oil Design Tool. The opening page gives a brief introduction as well as buttons that take you to the different pages. There are four sections in the design tool as shown in **Figure A3.2**.

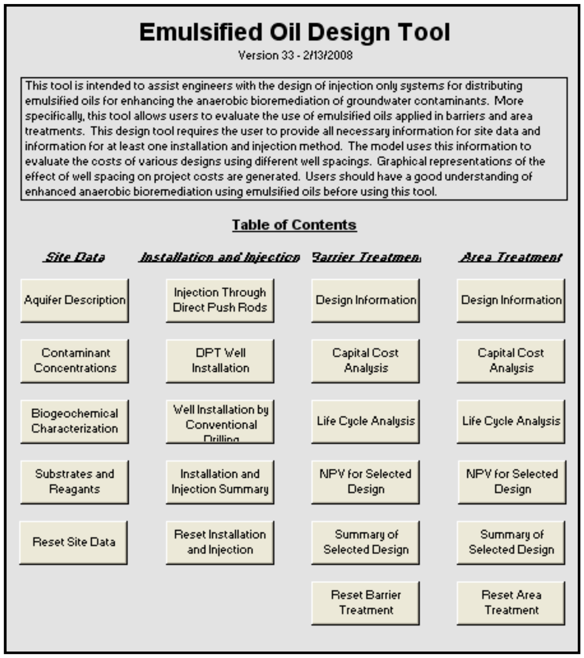


Figure A3.2 Introduction Page of the Design Tool.

In order for the design tool to work all required information must be entered within the **Site Data** section and at least one of the **Installation and Injection** methods must be completed. This tutorial goes through designing a barrier, but designing an area treatment follows a similar procedure.

1. Click on *Aquifer Description* within the **Site Data** section to get started.

A3.4 Site Data

Cells that need to be filled in are white and outlined in red. All user input cells within this section must be filled in for the design tool to work properly.

A3.4.1 *Aquifer Description*

A3.4.1.1 <u>Site Information</u>

1. Enter **Pilot Test Site** for the *Name*.
2. Enter **Case Study** as the *Description*.
3. For *Location* enter **Maryland**.

A3.4.1.2 Hydraulic Characteristics

1. Enter **6** ft for the *Depth to water table*.
2. Enter **6** ft for the *Depth to top of injection zone*.
3. Enter **15** ft for the *Depth to bottom of injection zone*.
4. Enter **0.002** ft/ft for the *Hydraulic Gradient*.
5. Enter **20** ft/day for the *Hydraulic Conductivity*.
6. Enter **0.25** for the *Estimated Total Porosity*.
7. Enter **0.18** for the *Estimated Effective Porosity*.
8. The *Seepage Velocity* should be **0.22** ft/day.

A3.4.1.3 Soil Characteristics

1. For the *Description of Soil Lithology* enter **silty sand and gravel**.
2. Enter **115** lb/ft^3 for the *Bulk Density*.
3. Enter **0.002** lbs oil/lbs soil for the *Maximum Oil Retention*.
4. Click on the button *Go Forward to Next Page (Contaminant Concentrations)* to continue.

A3.4.2 *Contaminant Concentrations*

Using average concentrations for the site contaminants:

1. Enter **90** µg/L for *Trichloroethene (TCE)*.
2. Enter **5,000** µg/L for *1,1,1-Trichloroethane (TCA)*.
3. Enter **8,600** µg/L for *Perchlorate* (ClO_4).
4. Leave all other *contaminant concentrations* **blank**.
5. The *e- equiv demand from contaminant concentrations* should be **9.21E-04** e- equiv/L.
6. Click on the button *Go Forward to Next Page (Biogeochemical Characterization)* to continue.

A3.4.3 *Biogeochemical Characterization*

Using average values for background electron acceptors:

1. Enter **2.7** mg/L for *Background Dissolved Oxygen*.
2. Enter **9.5** mg/L for *Background Nitrate*.
3. Enter **28** mg/L for *Background Sulfate*.
4. Enter **5** mg/L for *Estimated Methane Produced*.
5. Leave *Soil Manganese Content* **blank**.
6. Enter **2.0** mg/L for *Estimated* Mn^{2+} *Produced*.
7. Leave *Soil Iron Content* **blank**.
8. Enter **10** mg/L for *Estimated* Fe^{2+} *Produced*.
9. Enter **5.9** for the *pH*.
10. Leave *Alkalinity* **blank**.
11. The *e- equiv demand from biogeochemical characterization* should be **8.81E-03** e- equiv/L.
12. The *Total e- equiv demand* should be **9.73E-03** e- equiv/L.
13. Click on the button *Go Forward to Next Page (Substrates and Reagents)* to continue.

A3.4.4 *Substrates and Reagents*

1. For the *Brand and Product ID* enter **ABC Brand 600**.
2. Enter $\mathbf{C_{56}H_{100}O_6}$ for the *Chemical Formula*.
3. Enter **60**% for the *% vegetable oil*.
4. The *Electron equivalents per kg raw product* should be **217.75** e^-/kg.
5. For the *Cost per pound of product including shipping* enter **2.00** $/lb.
6. The *Cost per pound of oil* should be **3.33** $/lb.
7. **Save** design.
8. Click on the button *Go Forward to Next Page (Injection through Direct Push Rods)* to - continue.

A3.5 Installation and Injection

As stated previously only one of the three methods needs to be filled out, but we will look at each method in this tutorial.

A3.5.1 *Injection through Direct Push Rods*

A3.5.1.1 Injection Information

1. For the *Length of injection screen* enter **1.5** ft.
2. Enter **20** psi for the *Injection pressure*.
3. Enter **4** gpm for the *Injection rate to be used in Design*.
4. Enter **10** gal/ft for the *Gallons injected per foot of injection interval*.

A3.5.1.2 Fixed Costs

1. Enter $**0** for the *Prime contractor mobilization*.
2. Enter $**500** for the *Subcontractor mobilization*.
3. Enter $**100** for *Water Supply*.
4. Enter $**500** for *Piping and other equipment*.
5. For the *Time required for equipment setup and removal* enter **5** person-hr.
6. Enter **75** $/hr for the *Average labor rate for equipment setup and removal*.
7. The *Total fixed cost* should be $**1,475**.

A3.5.1.3 Prime Contractor Information and Daily Costs

1. Enter **1** persons for the *Prime contractor personnel on-site each day of injection*.
2. Enter **75** $/hr for the *Average labor rate of prime contractor personnel*.
3. For the *Hours billed per person per day* enter **10** hr/person/day.
4. Enter **60** $/person/day for *Per Diem*.
5. Enter **30** $/day for *Vehicle rental*.
6. Enter **70** $/person/day for *Lodging*.
7. Enter **100** $/day for *Additional costs*.
8. Enter **75** $/day for *Injection equipment costs*.
9. The *Total daily cost for prime contractor* should be **1,085** $/day.

A3.5.1.4 Subcontractor Information and Daily Costs

1. Enter **Geoprobe 6600** for the *Drilling Equipment to be used*.
2. Enter **1,800** $/day for the *Daily cost for DPT equipment and operator*.
3. For the *Productive working time per day* enter **9** hr.
4. For the *Rig time to complete one boring* enter **1.0** hr/boring.
5. Enter **50** $/boring for *Additional material and IDW costs per boring*.
6. The *Total cost per boring (without fluid injection)* should be **371** $/boring.

A3.5.1.5 Costs for Injection using DPT Equipment

1. The *Injection costs per day* should be **2,885** $/day.
2. Click on the button *Go Forward to Next Page (Well Installation by Direct Push)* to continue.

A3.5.2 *DPT Well Installation followed by Manifolded Emulsion Injection*

A3.5.2.1 Well Information

1. For the *Well Screen Diameter* enter **1** in.
2. For the *Effective Diameter of Sand Pack* enter **1.5** in.

A3.5.2.2 Well Installation Costs for Direct Push Installation

1. For the *Drilling Equipment to be used* enter **Geoprobe 6600**.
2. Enter **3,190** $/day for the *Daily cost for DPT equipment and operator*.
3. Enter **6** wells/day for *Wells installed per day*.
4. Enter **300** $/well for *Additional material and IDW costs per well*.
5. Enter $**0** for *Subcontractor mobilization*.
6. Enter **2** for the *Number of supervising personnel on-site each day*.
7. Enter **85** $/hr for the *Average labor rate of personnel*.
8. For the *Supervision Hours billed per person per day* enter **9** hr/person/day.
9. Enter **200** $/day for *Additional costs*.
10. The *Total cost per well* should be **1,120** $/well. This value will increase to **1,157** $/well as additional *Injection Costs* are entered in **Section 5.2.5**.

A3.5.2.3 Injection Information

1. Enter **5** psi for the *Injection pressure*.
2. For the *Well loss coefficient* enter **5**.
3. The *Theoretical estimate of injection rate per well* should be **3.9** gpm/well.
4. Enter **1.5** gpm/well for the *Injection rate to be used in Design*.

A3.5.2.4 Fixed Costs

1. Enter $**2,500** for *Mobilization*.
2. Enter $**0** for *Water Supply*.
3. Enter $**1,000** for *Piping and other equipment*.
4. For the *Time required for equipment setup and removal* enter **45** hr.
5. Enter **100** $/hr for the *Average labor rate for equipment setup and removal*.
6. The *Total fixed cost* should be $**8,000**.

A3.5.2.5 Injection Costs

1. Enter **2** persons for the *Number of personnel on-site each day of injection*.
2. Enter **85** $/hr for the *Average labor rate of personnel*.
3. For the *Hours billed per person per day* enter **9** hr/person/day.
4. Enter **40** $/person/day for *Per Diem*.
5. Enter **0** $/day for *Vehicle rental*.
6. Enter **70** $/person/day for *Lodging*.
7. Enter **750** $/day for *Injection equipment costs*.
8. Enter **100** $/day for *Additional costs*.
9. The *Injection costs per day* should be **2,600** $/day.
10. Click on the button *Go Forward to Next Page (Well Installation by Conventional Drilling)* to continue.

A3.5.3 *Well Installation by Conventional Drilling followed by Emulsion Injection*

A3.5.3.1 Well Information

1. For the *Well Screen Diameter* enter **2.0** in.
2. For the *Effective Diameter of Sand Pack* enter **2.5** in.

A3.5.3.2 Well Installation Costs for Conventional Drilling

1. For the *Drilling Equipment to be used* enter **Hollow Stem Auger**.
2. Enter **30** $/ft for the *Cost for well installation*.
3. Enter **3** wells/day for *Wells installed per day*.
4. Enter **250** $/well for *Additional material and IDW costs per well*.
5. Enter $**0** for *Subcontractor mobilization*.
6. Enter **2** for the *Number of supervising personnel on-site each day*.
7. Enter **85** $/hr for the *Average labor rate of personnel*.
8. For the *Supervision Hours billed per person per day* enter **9** hr/person/day.
9. Enter **200** $/day for *Additional costs*.
10. The *Total cost per well* should be **1,277** $/well. This value will increase to **1,350** $/well as additional *Injection Costs* are entered in **Section 5.3.5**.

A3.5.3.3 Injection Information

1. Enter **10** psi for the *Injection pressure*.
2. For the *Well loss coefficient* enter **5**.
3. The *Theoretical estimate of injection rate per well* should be **7.2** gpm/well.
4. Enter **3.0** gpm/well for the *Injection rate to be used in Design*.

A3.5.3.4 Fixed Costs

1. Enter $**2,500** for *Mobilization*.
2. Enter $**0** for *Water Supply*.
3. Enter $**1,500** for *Piping and other equipment*.
4. For the *Time required for equipment setup and removal* enter **45** hr.
5. Enter **100** $/hr for the *Average labor rate for equipment setup and removal*.
6. The *Total fixed cost* should be $**8,500**.

A3.5.3.5 Injection Costs

1. Enter **2** persons for the *Number of personnel on-site each day of injection*.
2. Enter **85** $/hr for the *Average labor rate of personnel*.
3. For the *Hours billed per person per day* enter **9** hr/person/day.
4. Enter **40** $/person/day for *Per Diem*.
5. Enter **0** $/day for *Vehicle rental*.
6. Enter **70** $/person/day for *Lodging*.
7. Enter **1,000** $/day for *Injection equipment costs*.
8. Enter **100** $/day for *Additional costs*.
9. The *Injection costs per day* should be **2,850** $/day.
10. Click on the button *Go Forward to Next Page (Summary of Installation and Injection Costs)* to continue.

A3.5.4 *Summary of Installation and Injection Costs*

1. Look at **Figure A3.3** which shows a summary of the three methods.

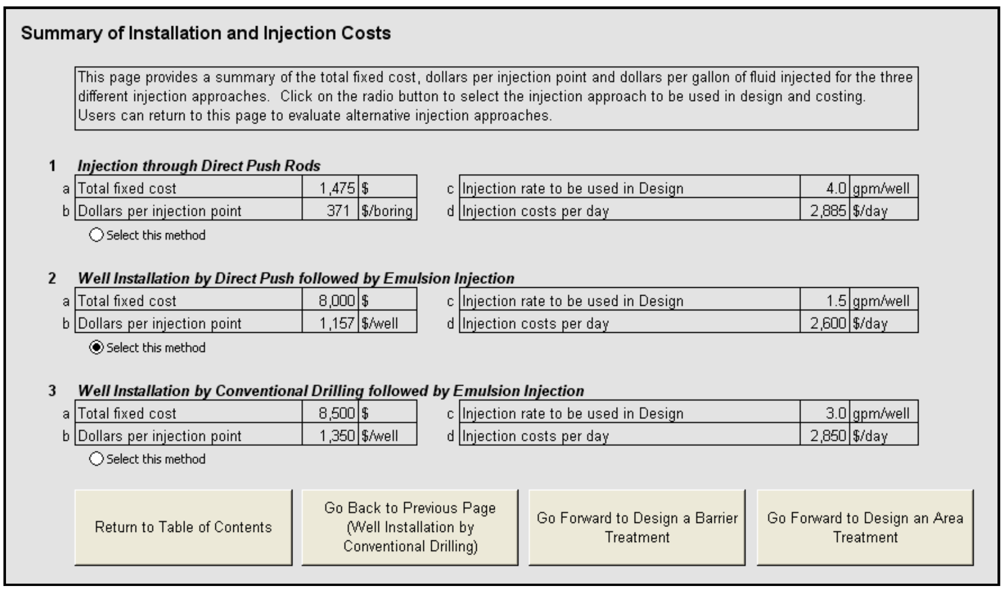


Figure A3.3. Summary of the Different Methods that Shows Which Items are Used in the Design.

2. Click on the radio button *Select this method* for **Well Installation by Direct Push followed by Emulsion Injection** as shown in **Figure A3.3**.
3. **Save** design.
4. Click on the button *Go Forward to Design a Barrier Treatment* to continue.

A3.6 Barrier Treatment

The objective of this tutorial is to design a 400 ft long barrier to stop the plume from migrating further downgradient. An area treatment to treat the source follows similar steps as outlined below.

A3.6.1 *Design Information*

A3.6.1.1 Treatment Zone Dimensions
1. Enter **400** ft for the *Width (perpendicular to groundwater flow).*
2. Enter **80**% for the *Percentage of injection zone that transmits most flow*.

A3.6.1.2 Treatment Zone Contact Time
1. Enter **60** days for the *Minimum Allowable Contact time*.

A3.6.1.3 Targeted Carbon Released
1. Enter **75** mg/L for the *Average Amount of DOC Released*.
2. The *DOC Released per year* should be **197** lb.

A3.6.1.4 Design Life
1. Enter **25** years for the *Total Project Life (Max of 30 years)*.
2. Enter **0.5** for the *Substrate Scaling Factor*.
3. Enter **7** years for the *Maximum Time between Reinjections*.

A3.6.1.5 Contact Efficiency
1. Enter **0.8** for the *Volume Scaling Factor*.
2. Enter **0.6** for the *Mass Scaling Factor*.
3. The *Estimated Contact Efficiency for Injection* should be **74**% to **87**%.
4. Click on the button *Go Forward to Next Page (Capital Cost Analysis)* to continue.

A3.6.2 *Capital Cost Analysis*

A3.6.2.1 Well Layout
1. Enter **5** ft for the *Minimum Well Spacing*.
2. Enter **5** ft for the *Incremental Increase in Well Spacing*.

A3.6.2.2 Fixed Costs
1. Enter $**15,000** for *Planning, Engineering, and Permitting*.

A3.6.2.3 Injection Information
1. Enter **9** hrs for the *Hours of injection per day*.
2. Enter **10** wells for the *Maximum number of wells to inject at one time*.
3. Enter **50**% for the *Percentage of total wells to inject at one time*.

A3.6.2.4 Total Installation and Injection Costs
1. *The Total Installation and Injection Costs* for a *Well Spacing* of **5** ft should be $**378,607**.

2. See if graph of Well Spacing vs Capital Cost matches **Figure A3.4**.

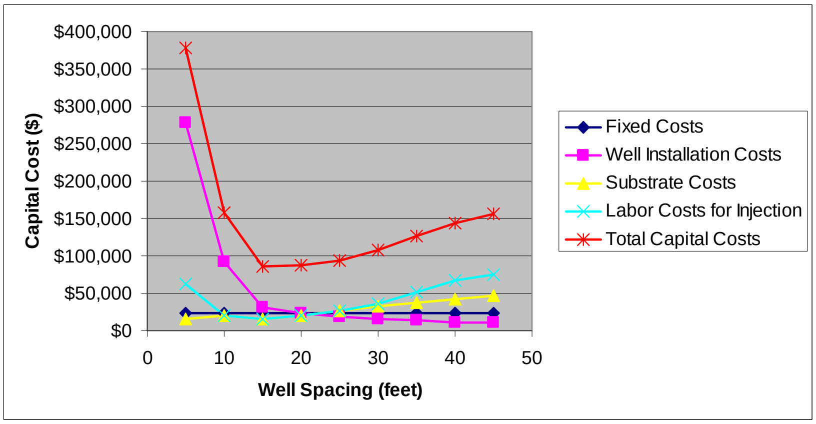


Figure A3.4 Graph of Well Spacing Versus Capital Costs.

3. Click on the button *Go Forward to Next Page (Life Cycle Analysis)* to continue.

A3.6.3 *Life Cycle Analysis*

A3.6.3.1 Life Cycle Analysis

1. Enter **4**% for the *Annual Interest Rate*.
2. Enter $**5,000** per future event for *Planning, Engineering, and Permitting Costs*.
3. Enter $**7,500** per year for *Annual Monitoring and Reporting Costs*.
4. Enter **20**% for *Well Rehabilitation and/or Installation Cost (% of Initial Drilling)*.

A3.6.3.2 Net Present Value for Design Life

1. The *Project Life NPV* for a *Well Spacing* of **5** ft should be $**832,590**.
2. See if graph of Well Spacing vs NPV matches **Figure A3.5**.

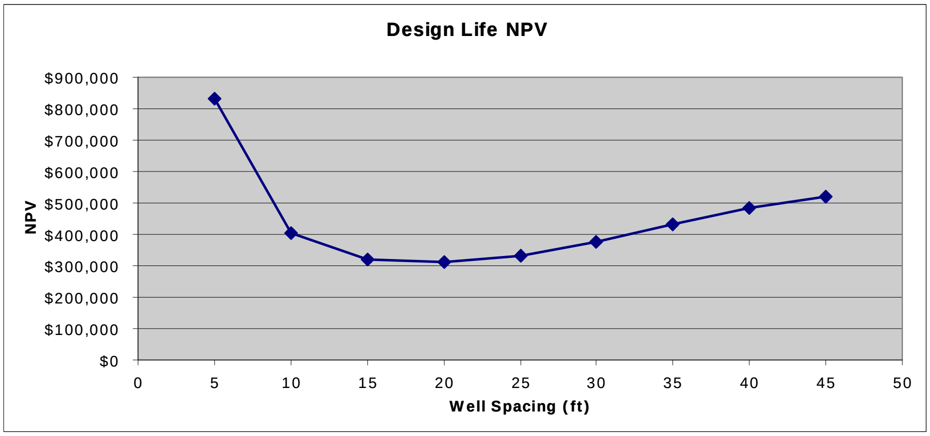
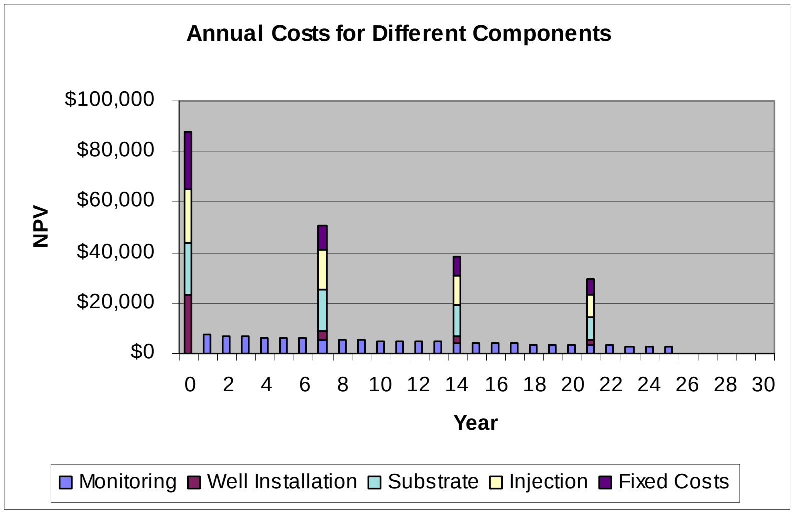


Figure A3.5. Graph of Well Spacing Versus Design Life Net Present Value.

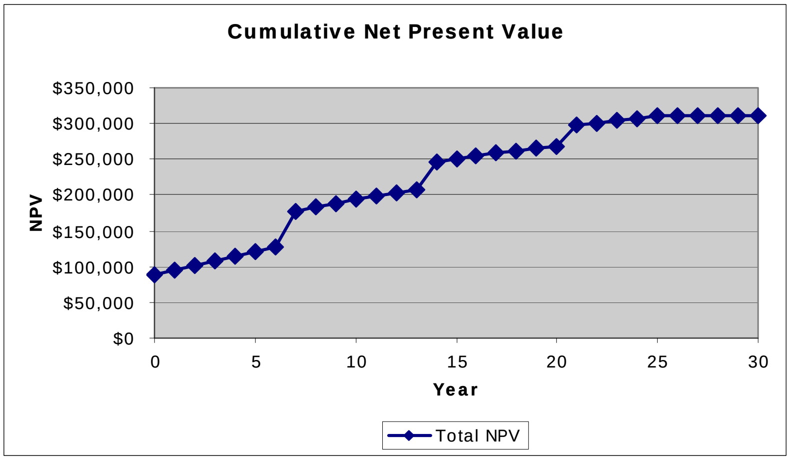
3. From looking at **Figures A3.4** and **A3.5** click on the radio button *Select a Design* corresponding to a **well spacing** of **20** ft.
4. Click on the button *Go Forward to Next Page (Net Present Value)* to continue.

A3.6.4 *Net Present Value for Selected Design*

1. The *Total Cost* should be $**310,126**.
2. Check to see if the net present value graphs match **Figure A3.6** (a) and (b).



(a)



(b)

Figure A3.6. Graph of a Breakdown of the Costs Per Year (a) and Cumulative NPV over the Design Life (b).

3. Click on the button *Go Forward to Next Page (Summary of Selected Design)* to continue.

A3.6.5 *Selected Design*

This page summarizes the selected design that has a *well spacing* of **20** ft.

1. Review the information on the page.
2. **Save** design.
3. Click on the button *Print this Page*.

A3.7 Conclusions

This concludes the Emulsified Oil Design Tool – Barrier tutorial. Some additional comments are listed below:

- Different designs can be compared by selecting a different **well spacing** on the *Life Cycle Analysis* page and then printing the summary on the *Selected Design* page.

- Some of the main variables that directly affect the design are found on the *Design Information* page. They are:
    - Contact Time
    - Substrate Scaling Factor
    - Volume Scaling Factor
    - Mass Scaling Factor

  Another important parameter is the Maximum Oil Retention found on the Aquifer Description page.

- To design an area treatment go to the *Table of Contents* and click on the button *Design Information* under the heading **Area Treatment**.

APPENDIX B

Health and Safety Plan

CNS ENVIRONMENTAL
A REAL ESTATE SERVICES COMPANY

Health & Safety Plan
(HASP)
NYSDEC Spill #: 13-10667

<u>Site:</u>

Nostrand Place
3806 Nostrand Avenue
Brooklyn, New York 11235
CNS Job #: D196

<u>Prepared For</u>:

New York State Department of Environmental Conservation
Region II Division of Environmental Remediation
Hunters Point Plaza
47-40 21st Street
Long Island City, NY 11101-5401
Attn: Mr. Santosh Mahat, Spills Manager

<u>On Behalf of</u>:

Acadia 3780-3858 Nostrand, LLC
411 Theodore Fremd Avenue, Suite 300
Rye, New York 10580
Attention: Brian Bacharach

<u>Prepared By</u>:

CNS Environmental Corporation
208 Newtown Road
Plainview, NY 11803

January 2016

TABLE OF CONTENTS

1.0 Introduction

This document is a compilation of minimum health and safety and emergency response requirements to be followed by CNS Environmental's (CNS) field technical personnel and subcontractors during implementation of remedial efforts that will disturb the site's surficial soils and/or contact groundwater beneath the site. This Health and Safety Plan applies to the work to be completed at the tenant spaces located from 3800 through 3808 Nostrand Avenue in Brooklyn, NY; referred to hereafter as the "subject site".

The Subject Site is identified as the tenant spaces located from 3800 through 3808 Nostrand Avenue within the property known as Nostrand Place in Brooklyn, NY. Nostrand Place is currently improved with six structures constructed in stages between 1959 through 1982, and spans the entire west side of the city-block from Avenue Y to Avenue Z, and is currently occupied by commercial tenants, including banks, restaurants, retail stores, medical offices and a parking garage.

CNS conducted a Phase II Investigation at the vacant 3806 Nostrand Avenue tenant space. The investigation involved the collection of soil samples and a groundwater sample from one (1) soil boring advanced within the basement, to investigate soil and groundwater quality at the subject site. Additionally, CNS collected one soil-gas sample, one indoor air sample and one ambient air sample to investigate soil vapor and indoor air quality at the subject site. The laboratory results identified that the groundwater and soil vapor contained dry cleaning compounds. CNS recommended notification to the NYSDEC regarding the contaminants, identification, and mitigation of potential sources of indoor air contaminants, and conducting additional site investigations to characterize the extent of the dry-cleaning compounds.

In August of 2013, CNS completed a Groundwater Investigation where three (3) permanent monitoring wells (NW1 through NW3) were installed and a total of eight (8) soil samples and three (3) groundwater samples were collected. Monitoring well NW1 was installed in the front sidewalk grade; NW2 was installed at the rear sidewalk grade; and monitoring well NW3 was installed in the basement of the 3806 Nostrand Avenue tenant space. Soil analytical results identified dry cleaning related compounds above the laboratory's minimum detection limit but below their respective NYSDEC Commercial SCO's. Groundwater analytical results identified dry-cleaning related compounds (PCE, DCE and TCE) within monitoring well samples NW2-GW2A (Sidewalk grade to the west) and NW3-GW3A (Basement) exceeding their respective NYSDEC TOGS 1.1.1 GA values. Based upon the findings, CNS contacted the NYSDEC and was issued Spill #13-10667. Since that time, CNS has been conducting quarterly groundwater sampling events on monitoring wells NW1, NW2, and NW3.

In September of 2015, CNS completed a Soil Vapor Intrusion Investigation at the subject site, where one sub-slab soil-gas sample, one indoor air sample and one ambient air sample were collected. Based upon analytical results, the VOC constituents Tetrachloroethene and Trichloroethene, both exceeded their respective minimum NYSDOH Decision Matrix concentrations and USEPA Target Shallow Soil Gas Concentrations. Based on the findings, CNS recommended a Sub-slab Depressurization System be designed and installed to mitigate the affected areas of the subject site.

In October/November of 2015, CNS completed a Supplemental Phase II Investigation at the subject site, to delineate the identified dry cleaning related solvent plume in order to develop a Remedial Action Plan. On October 14th and 16th of 2015, CNS oversaw the installation of three (3) permanent monitoring wells (NW4, NW5, and NW6), and three (3) temporary wells (TW1, TW2 and TW3) at the subject site. Temporary wells TW1 and TW2 were installed in the northern portion of the basement of the 3808 Nostarnd Avenue tenant space and TW3 was installed in the basement of 3800 Nostrand Avenue. Permanent monitoring well NW4 was installed in the common western basement hallway; and NW5 and NW6 was installed in the western back alley at street level. A total of sixteen (16) soil samples and three (3) groundwater samples were collected. Soil sample analytical did not identify any VOC constituents exceeding their respective NYSDEC Unrestricted SCO values. Groundwater samples analytical did identify multiple VOC constituents exceeding their respective NYSDEC Groundwater standards values in all three (3) temporary wells.

Based on the laboratory analytical results, it was CNS's opinion that dry cleaning related solvents have impacted the groundwater at the subject site requiring remediation. CNS recommended that the three (3) temporary wells (TW1, TW2 and TW3) will be made permanent and included in the quarterly sampling events starting in 2016; and a Remedial Action Work Plan be generated outlining current conditions and chemical injection remediation considerations that must to be approved by the NYSDEC prior to implementation.

As stated herein, since Spill # 13-10667 was issued; CNS has been completing Quarterly Groundwater Monitoring at the subject site. Previous sampling events occurred on November 21, 2013, April 14, 2014, July 14, 2014, October 23, 2014, January 8, 2015, June 3, 2015, September 8, 2015 and October 30, 2015. Note: The October 2015 sampling event also included the newly installed monitoring wells NW4, NW5 and NW6. Monitoring well sampling events consisted of collecting groundwater measurements for temperature, conductivity, pH, dissolved oxygen and oxygen-reduction potential (ORP) and collecting groundwater samples for VOC analysis via EPA Method 8260. Based upon the most recent sampling event, dry cleaning related compounds remain present within all six (6) monitoring wells. Contaminant increases were identified within monitoring wells NW1, NW2, and NW3; and monitoring wells NW4, NW5 and NW6 exhibited dry cleaning compounds consisting of cis-1,2,-Dichloroethene, Tetrachloroethene, and Trichloroethene.
CNS has developed the following health and safety procedures for all field personnel to follow during remedial activities. The CNS Site Safety Officer (SSO) will be responsible for informing all field technical personnel of the pertinent level of personal protection required and work rules to be observed. The SSO will also maintain a daily sign in sheet to document all on-site personnel and visitors. No smoking, eating, chewing of tobacco, or use of lip balm will be permitted on the subject site during any activity associated with the implementation of remedial efforts. Under no circumstance will excavation activities commence prior to completion of utility mark-out activities by New York One-Call (Dig Safe).

The health and safety requirements are based on currently available information and a preliminary analysis of associated potential hazards. This plan establishes the minimum protocols necessary for protecting all on-site field technical personnel during implementation of remedial efforts.

All field technical personnel will be equipped with personnel protection/safety equipment which, at a minimum, meets the requirements of this Health and Safety Plan (HASP).

2.0 Potential Chemical Exposure

Based on site-specific information provided in the investigation reports completed by CNS; potential environmental soil exposures maybe encountered. Identified contaminants associated with the project consist of dry cleaning related chlorinated VOC solvents. See Appendix HASP-1: Data Sheets for Contaminants of Concern.

The most likely routes of exposure are breathing of vapors and/or particulate-laden air released during soil disturbing activities. Dermal contact is also a potential exposure pathway. The remaining sections of this

HASP address procedures (including training, air monitoring, work practices, and emergency response) to reduce the potential exposure to these contaminants.

The potential adverse health effects from the broad classes of contaminants potentially present at the site are diverse and potentially severe. Although many of these contaminants are known or suspected to result in chronic illness from long duration exposures, due to the limited nature of the field activities, acute effects are both more likely to be of concern and noticeable.

- Typical symptoms of acute exposure, particularly to VOC's and SVOCs are irritated eyes, nose or upper respiratory tract, headache, nausea, drowsiness, dizziness and difficulty breathing.

- Long-term exposure to heavy metals, such as lead and mercury, can affect the central nervous system, kidneys, and immune system, particularly in young children. In adults, lead may decrease reaction time, cause weakness in fingers, wrists, or ankles, and possibly affect the memory.

This HASP addresses potential environmental hazards from the presence of potentially hazardous materials. It is not intended to address the normal hazards of construction work, which are covered by OSHA regulations and/or local and state construction codes or regulations.

3.0 Medical Emergency

Medical emergencies can be described as situations which present a significant threat to the health of personnel involved in the implementation of the subsurface assessment activities. These can result from chemical exposure, heat stress, cold stress and poisonous insect bites. Medical emergencies must be dealt with immediately and proper care should be administered. This may be in the form of first aid and emergency hospitalization.

In the event of a medical emergency, assess whether or not the victim can be safely transported to medical facilities. If the victim cannot be moved without the risk of aggravating their condition, refer to Section 3.2 "Emergency Notification" and summon an ambulance and appropriate emergency response personnel.

3.1 Transporting Victims

If the victim can be safely transported without risk of additional injury, the nearest hospital is New York Community Hospital.

The hospital is located on the south side of Kings Highway between Bedford Avenue and E 27th Street. The most direct or emergency route from the subject site to the hospital is as follows:

1. Head south on Nostrand Ave toward Avenue Z
2. Turn right at the 1st cross street onto Avenue Z
3. Turn right at the 3rd cross street onto E 27th St
4. Turn left onto Kings Hwy
5. Keep right to stay on Kings Hwy. Destination will be on the right
6. Arrive at New York Community Hospital, 2525 Kings Highway, Brooklyn, NY 11229.

Total mileage 2.1 miles; total travel time is eleven (11) minutes.
See Appendix HASP-2: Mapped Hospital Directions.

3.2 Emergency Notification

The following is a list of telephone numbers for the nearest hospital and emergency response personnel:

New York Community Hospital	1-718-692-5300
Fire Emergency	911
Ambulance/Rescue Squad	911
NYC Police Department 61st Precinct	911
NYSDEC Spill Hotline	1-800-457-7362
NYC Department of Health	1-212-442-9666
NYSDEC Region II Division of Hazardous Waste Remediation	1-718-482-4933
CNS Senior Project Manager (Charles Powers)	1-516-932-3228 (office)
	516-448-5004 (mobile)
CNS Site Safety Officer (Wala Canario)	1-516-932-3228 (office)
	516-459-8069 (mobile)

4.0 Personal Protection On-Site

Based on currently available information, Level D protection should be adequate for most of the work to be performed on-site. For the purpose of this Health and Safety Plan, Level D areas are defined as areas where gross ambient organic vapor levels (monitoring in real time) range from site background to 5 parts per million (ppm) over background. Background readings will be obtained each day within the work area prior to commencement of work and along the perimeter of the work site.

For the purpose of this Health and Safety Plan, during implementation of remedial/testing efforts, Level D personnel protection will be required. Level D protection consists of coveralls or similar work clothes, work gloves, noise protection, safety boots and a hard hat. No shorts will be allowed on site during implementation of remedial efforts. If concentrations of organic vapors, as monitored in real time exceed 5ppm over site background or toxic airborne substances are known to exist, personal protection will be upgraded to Level C.

For the purpose of this Health and Safety Plan, Level C areas are defined as areas where gross ambient organic vapor levels, as monitored in real time exceed 5ppm over background but are less that 500ppm, or where the presence of toxic airborne substances are known or suspected. Level C protection adds a full-face air-purifying respirator to the Level D protection described above and requires Tyvek coveralls, chemical resistant gloves and boots.

During the course of any earth disturbance activities, all efforts will be made to minimize dust. Dust suppression, including wetting down the work area, will be used, but not likely necessary.

4.1 Basic Equipment

Basic safety equipment will be kept on-site to monitor site conditions and respond to emergency situations. This equipment includes, but is not limited to the following:

- First Aid Kits
- Portable eyewash
- Type ABC fire extinguisher
- Photo Ionization Detector (HNU or equivalent)

4.2 Personnel Training

All personnel working on-site who have the potential for coming into contact with site soils during implementation of remedial efforts must have received the minimum Health and Safety training in accordance with OSHA 1910.120(E)(2).

5.0 Field Procedures

Work areas will be defined, respectively, as Level 'C' or 'D' to correspond with the required level of personal protection. Each work area will be cordoned off while work is taking place. Access to these areas will be provided only to those persons directly involved in the field operations and only if the appropriate level of personal protection is worn. All equipment and personnel will be subjected to decontamination procedures before leaving an area of restricted access. Separate work zones and decontamination zones will be predesignated in areas requiring Level C protection.

5.1 Air Monitoring

Throughout the duration of construction activities, air quality will be monitored at the work site and at off-site construction areas with a photo ionization detector (PID). Work will stop if levels of organic vapors exceed 500ppm.

5.2 Record Keeping

The environmental professional on site will maintain a record of all individuals present at the work site, levels of worker protection and general conformance with this HASP. PID readings will be periodically recorded in addition to noting observed peak readings.

6.0 Decontamination

All equipment and personnel will be subjected to decontamination procedures before leaving an area of restricted access. Separate work zones and decontamination zones will be predesignated, if needed, in areas requiring Level C protection.

6.1 Level C Areas

The decontamination zone within a Level C area will be lined with plastic to contain wash waters. Reusable equipment will be cleaned with appropriate solutions. Disposable equipment, coveralls, gloves, etc. will be placed in plastic bags and disposed of as household waste in available on-site receptacles.

Respirators will be worn throughout the decontamination process. Liquid wastes, contained in the process of Level C decontamination, will be placed in drums to be supplied by the contractor for disposal in accordance with applicable regulations.

6.2 Level D Areas

Before leaving Level D work areas, loose soil will be brushed from equipment and clothing. Equipment will be rinsed with potable water. Disposable coveralls, gloves, etc. will be placed in plastic bags and disposed of as household waste in available on-site receptacles.

Appendix HASP-1: Data Sheets for Contaminants of Concern

Volatile Organic Compounds (VOCs) in Commonly Used Products

People spend most of their time indoors – at home, school and work. This makes the quality of the indoor air you breathe important. This fact sheet focuses on certain kinds of chemicals called *volatile organic compounds* or *VOCs* that are found in many products that we commonly use. It is designed to help you think about what VOCs may be present in your indoor air and steps you can take to reduce them.

What are VOCs?

VOCs are chemicals that easily enter the air as gases from some solids or liquids. They are ingredients in many commonly used products and are in the air of just about every indoor setting. The table to the right shows some examples of products that contain VOCs.

How do VOCs get into indoor air?

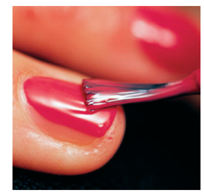
Products containing VOCs can release these chemicals when they are used and when they are stored. Many times you'll notice an odor when using these products. Product labels often list VOC ingredients and recommend that they should be used in well ventilated areas. *Ventilation* means bringing in fresh, outdoor air to mix with indoor air.

When you use a product containing VOCs indoors, the levels of these chemicals in the air increase, then decrease over time after you stop using them. The amount of time the chemical stays in the air depends on how quickly fresh air enters the room and the amount of the chemical used. Levels of VOCs will decrease faster if you open windows or doors, or use exhaust fans.

Building materials and furnishings, such as new carpets or furniture, slowly release VOCs over time. It may be necessary to ventilate areas with new carpeting or furniture for longer time periods because VOC levels can build up again after the windows are closed. If possible, unroll new carpets or store furniture outside your home (in a shed or detached garage) to minimize odors before bringing them in the home. If that's not possible, open windows, close doors and try to stay out of rooms until odors are reduced.

If VOC containing products are used outdoors near your home, you may want to close windows and nearby vents to prevent chemicals from coming inside.

Products used at home or work can release VOCs into the air when used and stored.



Examples of Household Products	Possible VOC Ingredients
Fuel containers or devices using gasoline, kerosene, fuel oil and products with petroleum distillates: paint thinner, oil-based stains and paint, aerosol or liquid insect pest products, mineral spirits, furniture polishes	BTEX (benzene, toluene, ethylbenzene, xylene), hexane, cyclohexane, 1,2,4-trimethylbenzene
Personal care products: nail polish, nail polish remover, colognes, perfumes, rubbing alcohol, hair spray	Acetone, ethyl alcohol, isopropyl alcohol, methacrylates (methyl or ethyl), ethyl acetate
Dry cleaned clothes, spot removers, fabric/ leather cleaners	Tetrachloroethene (perchloroethene (PERC), trichloroethene (TCE))
Citrus (orange) oil or pine oil cleaners, solvents and some odor masking products	d-limonene (citrus odor), a-pinene (pine odor), isoprene
PVC cement and primer, various adhesives, contact cement, model cement	Tetrahydrofuran, cyclohexane, methyl ethyl ketone (MEK), toluene, acetone, hexane, 1,1,1-trichloroethane, methyl-iso-butyl ketone (MIBK)
Paint stripper, adhesive (glue) removers	Methylene chloride, toluene, older products may contain carbon tetrachloride
Degreasers, aerosol penetrating oils, brake cleaner, carburetor cleaner, commercial solvents, electronics cleaners, spray lubricants	Methylene chloride, PERC, TCE, toluene, xylenes, methyl ethyl ketone, 1,1,1-trichloroethane
Moth balls, moth flakes, deodorizers, air fresheners	1,4-dichlorobenzene, naphthalene
Refrigerant from air conditioners, freezers, refrigerators, dehumidifiers	Freons (trichlorofluoromethane, dichlorodifluoromethane)
Aerosol spray products for some paints, cosmetics, automotive products, leather treatments, pesticides	Heptane, butane, pentane
Upholstered furniture, carpets, plywood, pressed wood products	Formaldehyde

VOCs can also get into indoor air from contaminated soils and groundwater under buildings. The chemicals enter buildings through cracks and openings in basements or slabs. When nearby soil or groundwater is contaminated, you might be asked for permission to investigate indoor air at your property. More information can be found at *www.nyhealth.gov/environmental/indoors/vapor_intrusion/.*

Should I be surprised if VOCs are in the air I breathe?

No. Because they are commonly used, some VOCs are almost always found in indoor air. The New York State Department of Health (DOH) and other agencies have studied typical levels of VOCs that may be present in indoor and outdoor air. Sometimes these levels are called "*background levels".*

The term "background levels" can be confusing because they can vary depending on where an air sample was collected and whether VOCs were used or stored. For example, a study of VOCs in urban areas might find higher levels than another study in rural areas. Some studies look at office environments, others examine residences. Please keep in mind study findings may or may not make sense for your setting.

More information about levels of VOCs collected by DOH is available in Appendix C of the guidance for evaluating vapor intrusion at *www.nyhealth.gov/environmental/investigations/soil_gas/svi_guidance.*

How can VOCs affect human health?

Chemicals can enter the body through three major pathways (breathing, touching or swallowing). This is referred to as *exposure*. No matter how dangerous a substance or activity is, it cannot harm you without exposure.

Whether or not a person will have health effects after breathing in VOCs depends on:

1. The *toxicity* of the chemical (the amount of harm that can be caused by contact with the chemical).
2. How much of the chemical is in the air.
3. How long and how often the air is breathed.

Differences in age, health condition, gender and exposure to other chemicals also can affect whether or not a person will have health effects.

Short-term exposure to high levels of some VOCs can cause headaches, dizziness, light-headedness, drowsiness, nausea, and eye and respiratory irritation. These effects usually go away after the exposure stops. In laboratory animals, long-term exposure to high levels of some VOCs has caused cancer and affected the liver, kidney and nervous system. In general, we recommend minimizing exposure to chemicals, if possible.

How can I reduce the levels of VOCs indoors?

- Find out if products used or stored in your home contain VOCs. Information about the chemicals in many household products are listed on the front of this fact sheet and a larger list is on the National Institute of Health's website at *hpd.nlm.nih.gov/products.htm*.
- If you must store products containing VOCs, do so in tightly sealed, original containers in a secure and well-ventilated area. If possible store products in places where people do not spend much time, such as a garage or outdoor shed. Better yet, buy these products in amounts that are used quickly.
- Dispose of unneeded products containing VOCs. Many of these products are considered *household hazardous wastes* and should be disposed of at special facilities or during special household hazardous waste collection programs in your area. Contact your town or visit the New York State Department of Environmental Conservation's website at *www.dec.ny.gov/chemical/8485.html* for more information about disposing of these products.
- Use products containing VOCs in well-ventilated areas or outdoors. Open windows and doors or use an exhaust fan to increase ventilation. Repeated or prolonged ventilation may be necessary for reducing levels from building materials (new carpeting or furniture) that release VOCs slowly over time.
- Carefully read labels and follow directions for use.

Where can I find out more?

- **New York State Department of Health**
  (800) 458-1158
  www.nyhealth.gov/environmental/
- **Indoor Air Quality and Your Home** from the New York State Energy Research and Development Authority *www.nyserda.org/publications/iaq.pdf*
- **The Inside Story: A Guide to Indoor Air Quality**
  www.epa.gov/iaq/pubs/insidest.html
- **New York State Department of Environmental Conservation** website for information about household hazardous waste disposal
  www.dec.ny.gov/chemical/8485.html
- **National Institute of Health's** website for information about chemicals found in many household products.
  hpd.nlm.nih.gov/products.htm

December 2007

Volatile Organic Compounds
Health Effects Fact Sheet
November 2000

Colorado Department
of Public Health
and Environment

WHAT ARE VOLATILE ORGANIC COMPOUNDS (VOCs)?

- Volatile Organic Compounds (VOCs) area a group of chemicals that contain organic carbon, and readily evaporate – changing from liquids to gases when exposed to air. Volatile Organic Compounds are usually in such solvents as paint wastes, dry cleaning chemicals, furniture stripper, carburetor cleaners and other solvents and waste sludges.
- Volatile Organic Compound Contamination in the environment is mainly the result of the historic disposal practices of industrial wastes containing these solvents. Many of them have been considered *hazardous materials* since the early 1970s, when the first environmental laws were enacted. Landfills, in particular, complied with these laws by adjusting their criteria for acceptance of appropriate landfill material, and excluded most industrial waste containing solvents.
- If used for drinking, cooking, bathing, or irrigation at relatively low concentrations, there is a possibility of exposure to Volatile Organic Compounds by: ingestion (if it is swallowed flowing from a garden hose, for example); respiration; or absorption through the skin. The amount of exposure is related to the concentration in water, and other factors.
- Volatile Organic Compounds generally do not stick (adsorb) to soils at low concentrations, and readily evaporate from water and soil when the water is used for irrigation purposes.

HOW ARE HUMAN HEALTH EFFECTS OF VOLATILE ORGANIC COMPOUNDS DETERMINED?

The potential for human health effect is related to dose and exposure pathway. That is, the amount of the chemical taken into the body over time. Dose is estimated, based on the concentration of the chemical in the water. Human health effects are also related to routes of exposure, or exposure pathways. The three primary routes of exposure for humans are:

- Ingestion (swallowing),
- Respiration (lungs), and
- Dermal absorption (through the skin).

If the exposure pathway is incomplete---no human contact—there will be no exposure.

For most common chemicals, the U.S. Environmental Protection Agency (EPA) establishes standards (or acceptable levels) for drinking water that are called "Maximum Contaminant Levels" (or MCLs). These Levels are based on available health effects data, and other factors (technology, for example), for each chemical, and are designed to protect municipal drinking water supplies, and ensure public safety.

Although Maximum Contaminant Levels are not used to regulate privately owned wells, the available standards are commonly used to evaluate the quality of water in them. Colorado Ground Water Standards set limits for concentrations of various chemicals in water supplies not known to be slated for domestic use. These standards currently are comparable to the Maximum Contaminant Levels. Drinking water standards are set to protect against the possibility of health effects from these chemicals. As long as the chemical concentration in water used for in-home purposes remains below drinking water standards, health effects are unlikely to occur.

WHAT ARE THE HUMAN HEALTH EFFECTS ASSOCIATED WITH VOLATILE ORGANIC COMPOUNDS?

Many Volatile Organic Compounds may produce health effects if humans are exposed to high enough concentrations. Most available toxicity information is based on animal testing. These results are the basis for determining human health effects, and serve as the basis for setting drinking water and air quality standards.

In general, long-term exposure to low concentrations of Volatile Organic Compounds in water or air, at or above regulatory standards—such as Maximum Contaminant Levels, may result in liver or kidney effects. These effects may include elevation of serum enzyme levels, mild cellular changes and changes in lipid metabolism. At somewhat higher concentrations, breathing some of these contaminants may cause irritation of the respiratory tract. The reproductive and developmental effects of these contaminants have been poorly studied.

Chloroform, trichloroethylene (TCE), dichloroethylene (DCE), and perchloroethylene (PCE) have been evaluated for their carcinogenic potential. Although health scientists disagree whether these chemicals might produce cancer in humans, public health officials have taken a cautious approach and have set conservative standards accordingly.

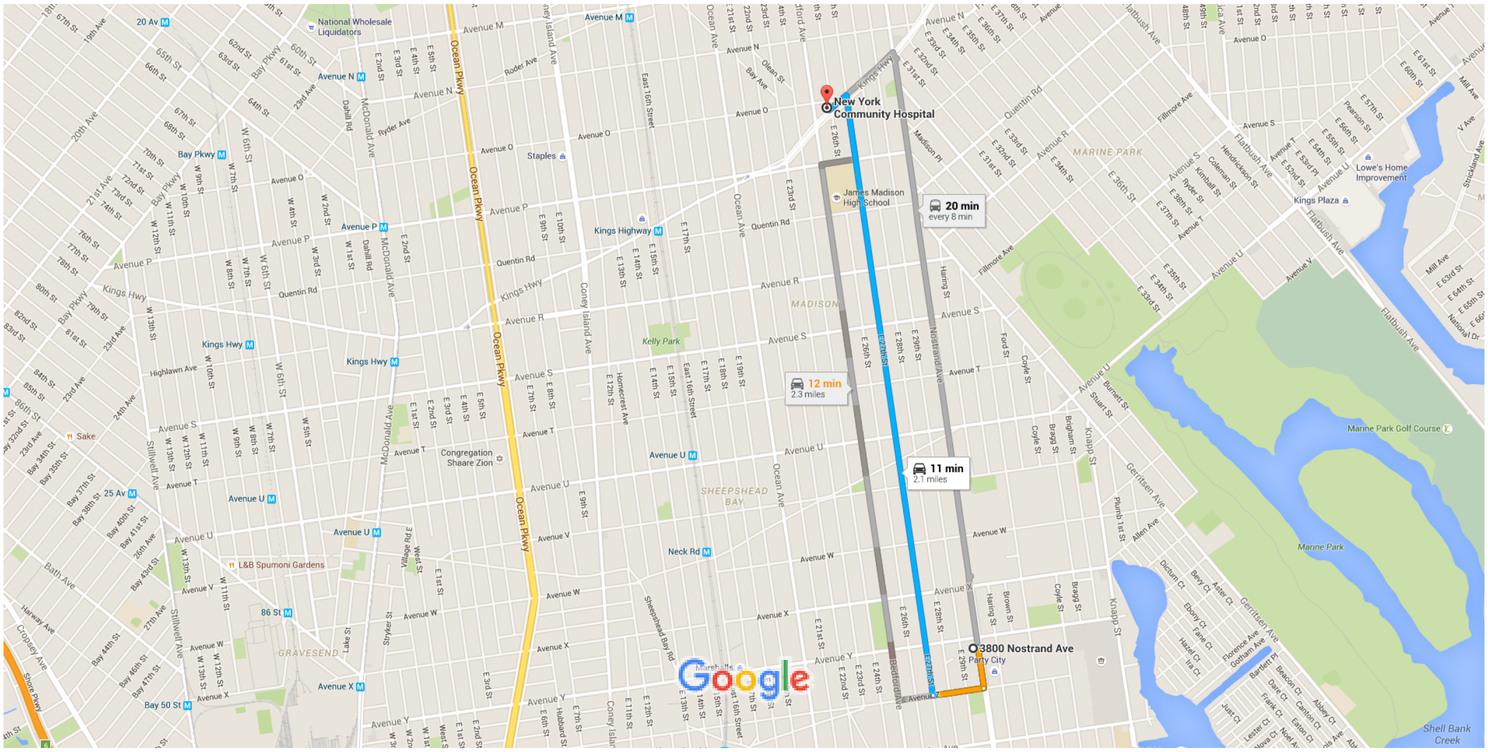
Appendix HASP-2: Mapped Hospital Directions

Google Maps

3800 Nostrand Avenue, Brooklyn, NY to New York Community Hospital

Drive 2.1 miles, 11 min

Subject Site to Hospital



Map data ©2016 Google 1000 ft

3800 Nostrand Ave

Brooklyn, NY 11235

1. Head south on Nostrand Ave toward Avenue Z

   0.1 mi

2. Turn right at the 1st cross street onto Avenue Z

   0.1 mi

3. Turn right at the 3rd cross street onto E 27th St

   1.7 mi

4. Turn left onto Kings Hwy

   410 ft

5. Keep right to stay on Kings Hwy

   Destination will be on the right

   36 ft

New York Community Hospital

2525 Kings Highway, Brooklyn, NY 11229