Information Report

GWRTAC I SERIES

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Analysis of Information Contained in the *Completed North American Innovative Remediation Technology Demonstration Projects*

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FOREWORD

About GWRTAC

The Ground-Water Remediation Technologies Analysis Center (GWRTAC) is a national environmental technology transfer center that provides information on the use of innovative technologies to clean up contaminated groundwater.

Established in 1995, GWRTAC is operated by the National Environmental Technology Applications Center (NETAC) in association with the University of Pittsburgh's Environmental Engineering Program through a Cooperative Agreement with the U.S. Environmental Protection Agency's (EPA) Technology Innovation Office (TIO). NETAC is an operating unit of the Center for Hazardous Materials Research and focuses on accelerating the development and commercial use of new environmental technologies.

GWRTAC wishes to acknowledge the support and encouragement received for the completion of this report from the EPA TIO.

About "I" Series Reports

This report is one of the GWRTAC "I" Series of reports, which are prepared on a range of pertinent ground-water topics, including analysis of trends in technology utilization, applicable regulatory issues and perspectives, state policies, and sources of environmental information on the Internet. These reports are generally not peer-reviewed.

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ABSTRACT

This document represents an analysis of information on innovative ground-water remediation demonstration projects as described in the Completed North American Innovative Remediation Technology Demonstration Projects (EPA 542-B-96-002). This report summarizes key information on 259 completed demonstration soil and ground-water remediation projects, including those performed, co-sponsored, or funded through programs developed by U.S. EPA., military services, DOE, Canadian government, and States of California and New Jersey. Information in the report about these projects includes contaminants treated, site type, technology type, media, vendor, project sponsor, reports available, and contacts.

This analysis was prepared for distribution by the Ground-water Remediation Technologies Analysis Center (GWRTAC). GWRTAC is being operated by the National Environmental Technologies Application Center (NETAC), under a Cooperative Agreement with EPA's Technology Innovation Office.

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1.0 INTRODUCTION

This document represents an analysis of information on innovative ground-water remediation demonstration projects as described in Completed North American Innovative Remediation Technology Demonstration Projects (EPA 542-B-96-002). This report summarizes key information on 259 completed demonstration soil and ground-water remediation projects, including those performed, co-sponsored, or funded through programs developed by U.S. EPA., military services, DOE, Canadian government, and States of California and New Jersey. Information about these projects includes contaminants treated, site type, technology type, media, vendor, project sponsor, reports available, and contacts.

A total of 61 of the over 250 projects summarized in the above document involved the treatment of groundwater, and are the subject of this report. Of these 61 ground-water projects, 72% utilized physical/chemical treatment techniques, while 28% utilized biological methods (see Figure 1-1). Of the 44 projects using physical/chemical methods, 55% involved *in situ* technologies and 45% involved ex situ technologies (see Figure 1-2). Of sites demonstrating biological treatment, 71% utilized *in situ* methods, while 29% used ex situ methods (see Figure 1-3). A summary distribution of general ground-water remediation methods used in projects included in the Completed North American Innovative Remediation Technology Demonstration Projects report is shown in Figure 1-4.

FIGURE 1-1. GROUND-WATER TREATMENT TECHNIQUES

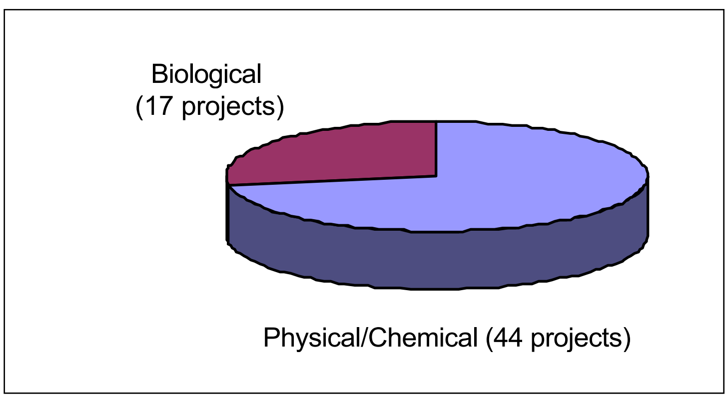


FIGURE 1-2. PHYSICAL/CHEMICAL GROUND-WATER TREATMENT TECHNIQUES

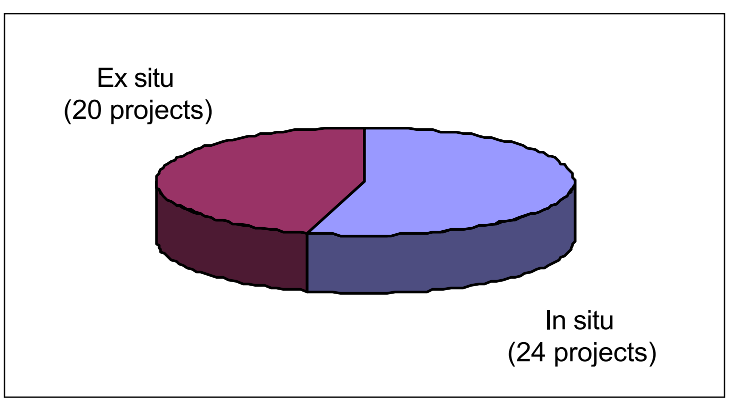


FIGURE 1-3. BIOLOGICAL GROUND-WATER TREATMENT TECHNIQUES

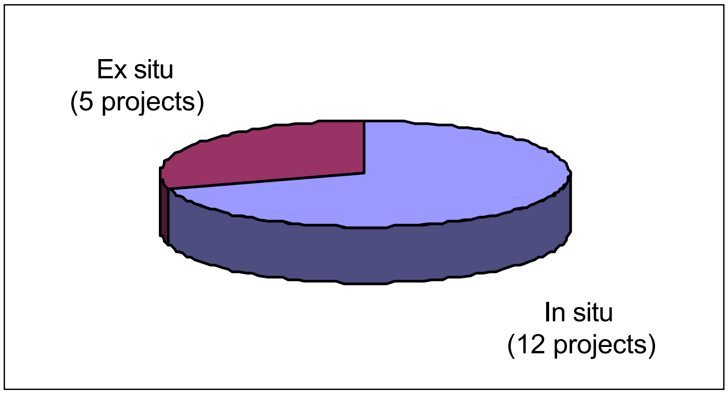
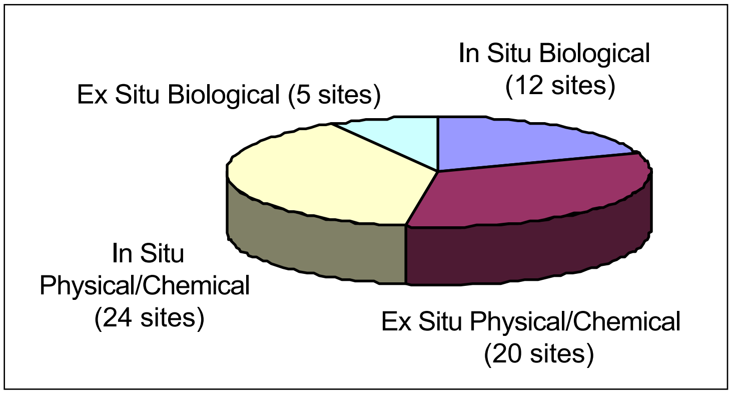


FIGURE 1-4. GENERAL GROUND-WATER TREATMENT METHODS



2.0 *IN SITU* PHYSICAL/CHEMICAL TREATMENT TECHNIQUES

The 24 projects demonstrating *in situ* physical/chemical ground-water remediation methods used 13 different treatment techniques (See Figure 2-1). *In situ* physical/chemical remediation methods used for more than one project included:

- Oxidation, 5 projects; (This category includes projects listed as oxidation, advanced oxidation process, chemical oxidation and evaporation-catalytic oxidation)

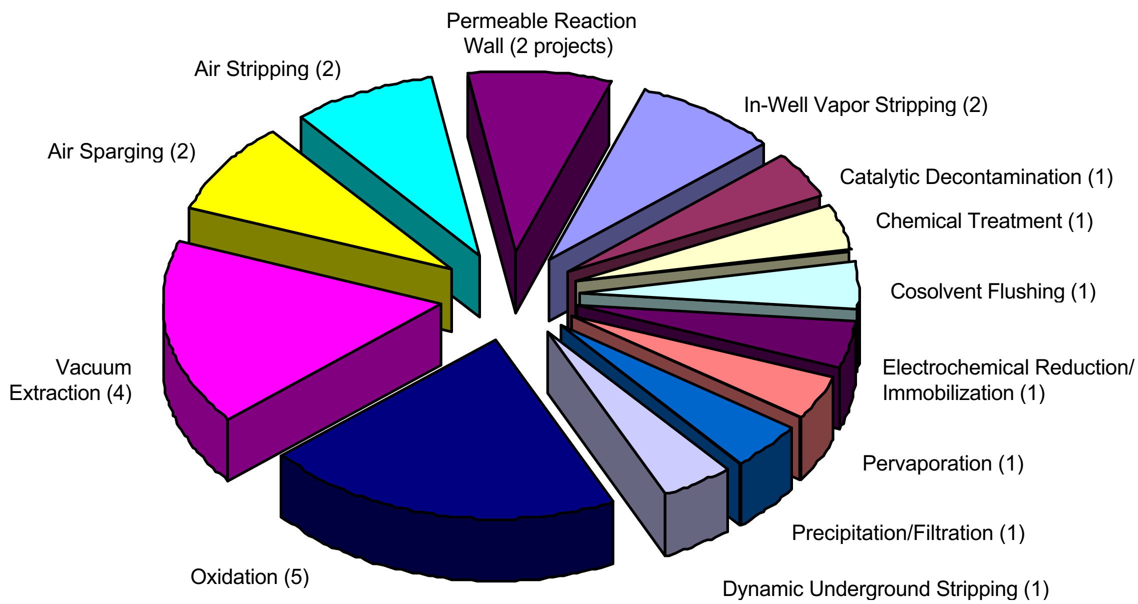
- Vacuum extraction, 4 projects (This category includes projects listed as air stripping/ vacuum extraction, steam injection and vapor extraction, vapor extraction and vapor extraction/steam vapor stripping);

- Air sparging, 2 projects;

- Permeable reaction walls, 2 projects;

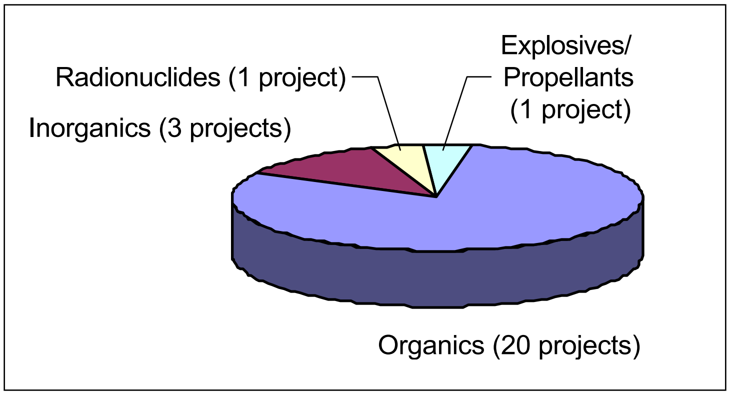
- In-well vapor stripping, 2 projects (This category includes projects listed as density-driven sparging, soil vapor extraction and Unterdruck-Verdamffer-Brunner [UVB]).

FIGURE 2-1. *IN SITU* PHYSICAL/CHEMICAL TREATMENT



Organic contaminants were treated in 83% of demonstration projects using *in situ* physical/ chemical techniques (20 of 25 projects), inorganics were treated in 13% (3 of 25), and explosives/propellants and radionuclides were treated in 4% of projects (each 1 of 25) (See Figure 2-2).

FIGURE 2-2. *IN SITU* PHYSICAL/CHEMICAL TYPES OF CONTAMINANTS TREATED



NOTE: Some projects involved treatment of more than one type of contaminant.

Of the *in situ* physical/chemical projects involving organic contaminants (many of which treated more than one type of organic contaminant), halogenated organics were treated in 6 projects, nonhalogenated organics in 6 projects, and 8 projects treated both halogenated and nonhalogenated organic contaminants (See Figure 2-3). Halogenated and nonhalogenated volatile organic compounds (VOCs) were treated in 70% of projects (14 of 20), nonhalogenated semivolatile organic compounds (SVOCs) were treated in 35% of projects (7 of 20), halogenated VOCs in 15% (3 projects), and explosives/propellants at 5% (1 project) (See Figure 2-4).

FIGURE 2-3. *IN SITU* PHYSICAL/CHEMICAL TREATMENT ORGANIC CONTAMINANTS

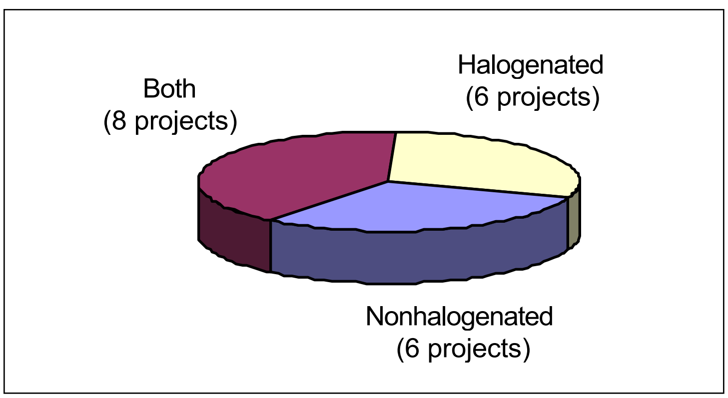
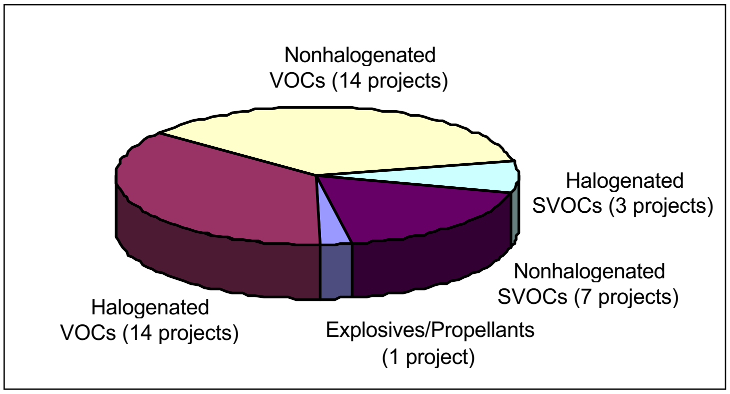


FIGURE 2-4. *IN SITU* PHYSICAL/CHEMICAL ORGANIC CONTAMINANT CATEGORIES



NOTE: Some projects involved treatment of more than one type of contaminant.

The distribution of specific contaminants treated via *in situ* physical/chemical methods is illustrated in Figure 2-5. The most common contaminants treated included TCE (7 projects), BTEX (6 projects), and PCE (5 projects). Table 2-1 shows the specific types of *in situ* physical/chemical treatment techniques used for specific contaminants.

FIGURE 2-5. *IN SITU* PHYSICAL/CHEMICAL TREATMENT METHODS SPECIFIC CONTAMINANTS (where indicated)

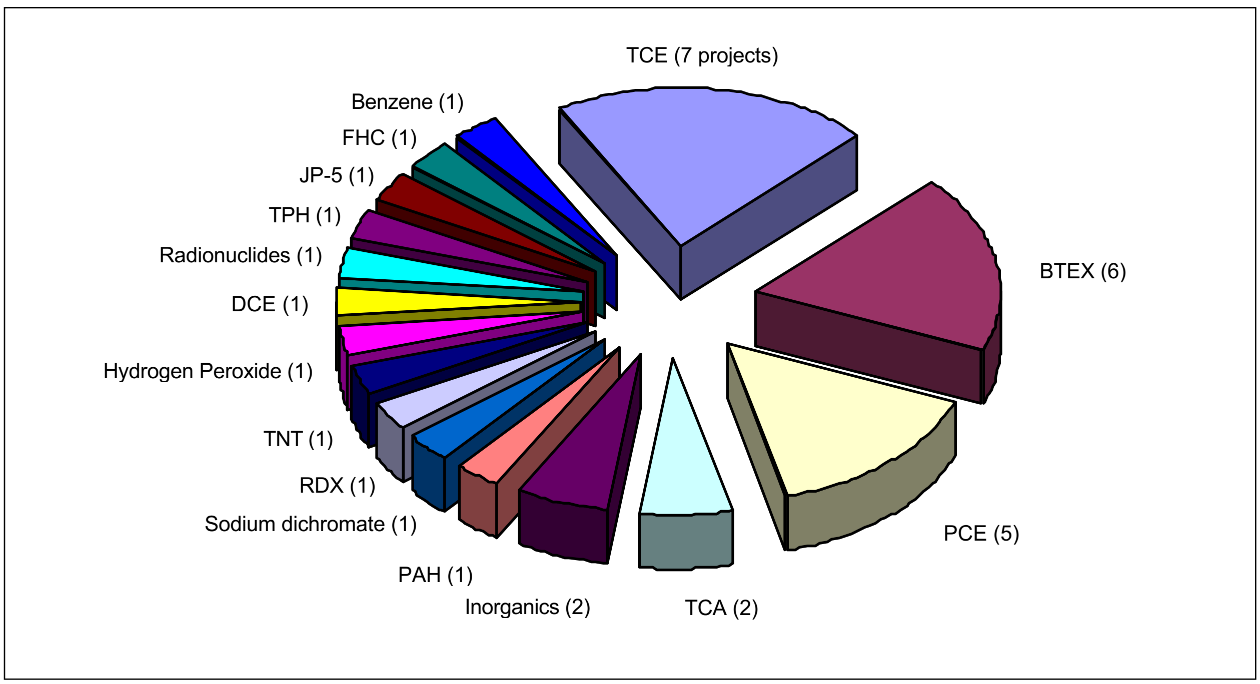


TABLE 2-1
CONTAMINANTS TREATED vs. REMEDIATION METHOD
***IN SITU* PHYSICAL/CHEMICAL TREATMENT TECHNIQUES**

METHOD	CONTAMINANT					
	TCE	**BTEX**	**PCE**	**TCA**	**INORGANICS**	**OTHER**
Oxidation	1	-	-	-	-	1 (TNT,RDX) 1 (Hydrogen peroxide, various fuels) 2 (VOCs) 1 (SVOCs)
Vacuum Extraction	-	-	-	-	-	1 (VOCs, Volatile fuel)
Air Sparging	1	2	1	-	-	-
Treatment Walls	1	1	1	-	-	1 (DCE)
In-Well Vapor Stripping	-	1	-	-	-	1 (TPH) 1 (VOCs)
Catalytic Decontamination	-	-	-	-	-	1 (VOCs)
Chemical Treatment	-	-	-	-	1	-
Cosolvent Flushing	1	1	1	1	-	1 (PAH)
Electrochemical Reduction/ Immobilization	-	-	-	-	1 (Sodium dichloride)	-
Pervaporation	-	-	-	-	-	1 (Hydrocarbons)
Precipitation/Filtration	-	-	-	-	-	1 (Naturally occurring radioactive material)
Dynamic Underground Stripping	-	1	-	-	-	1 (FHC, Benzene)
Air Stripping	2	-	2	1	-	-
Air Stripping/Vapor Extraction	-	-	-	-	-	1 (Chlorinated solvents)
Steam Injection and Vapor Extraction	-	-	-	-	-	1 (JP-5)
Vapor Extraction/Steam Vapor Stripping	1	-	-	-	-	1 (VOCs)

NOTE: Several projects involved the treatment of more than one type of contaminant.

3.0 EX SITU PHYSICAL/CHEMICAL TREATMENT TECHNIQUES

Figure 3-1 shows the types of ex situ physical/chemical treatment techniques used in completed demonstration projects. The most common include:

- Groundwater extraction and air stripping, 30% or 6 of 20 projects;
- Oxidation (including ground-water extraction and oxidation, photochemical oxidation, UV oxidation, and peroxidation), 25% or 5 of 20 projects;
- Membrane filtration, 10% or 2 of 20 projects.

The types of contaminants treated using ex situ physical/chemical techniques is illustrated in Figure 3-2. Organic compounds were treated in 16 of 20 projects (80%), inorganic compounds in 5 of 20 projects (25%), and radionuclides in 1 of 20 projects (5%).

FIGURE 3-1. EX SITU PHYSICAL/CHEMICAL TREATMENT TECHNIQUES

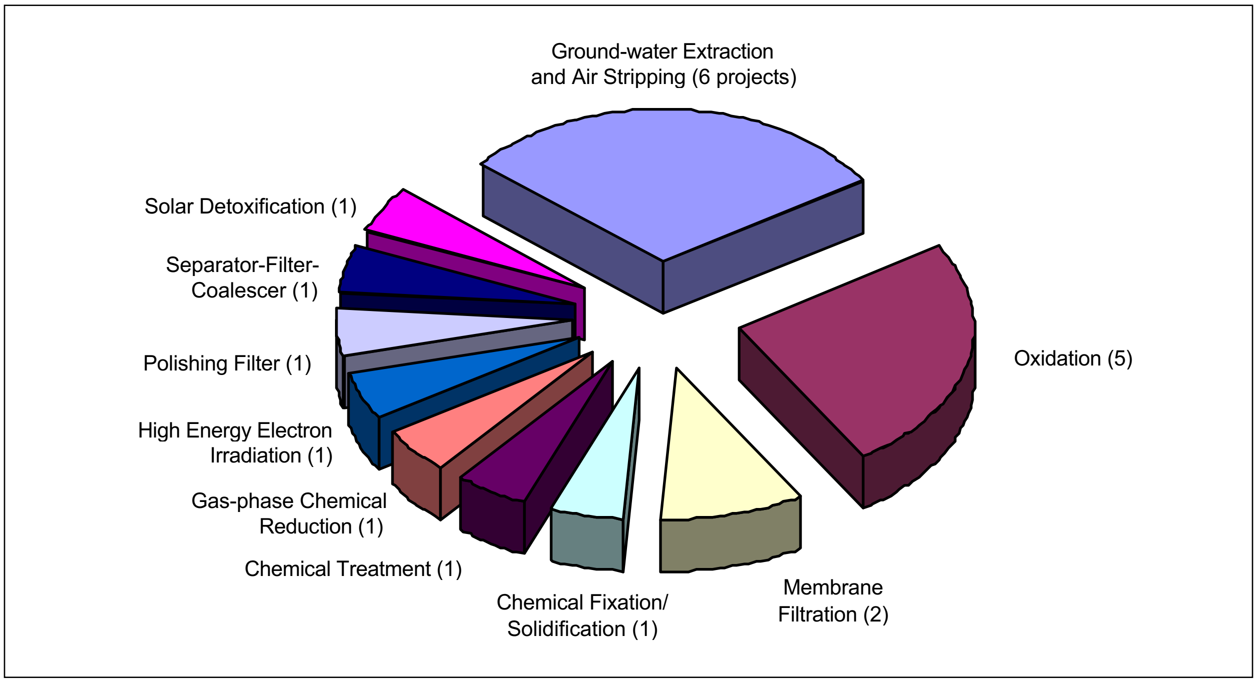
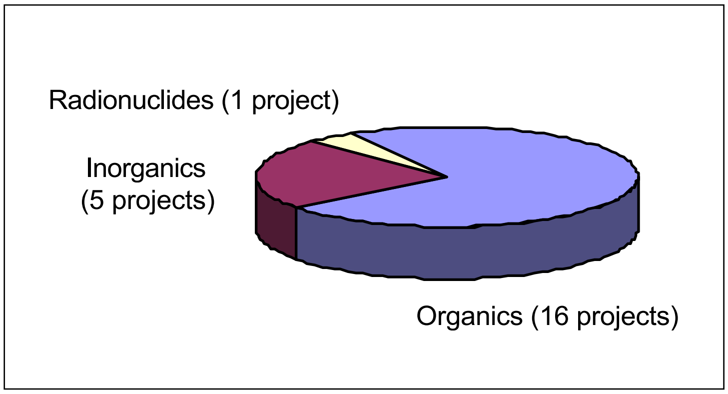


FIGURE 3-2. EX SITU PHYSICAL/CHEMICAL TREATMENT METHODS TYPES OF CONTAMINANTS TREATED



NOTE: Some projects involved treatment of more than one type of contaminant.

The distribution of types of organic contaminants treated in ex situ physical/chemical demonstration projects are shown in Figures 3-3 and 3-4. As seen in Figure 3-3, halogenated organics were treated in 10 of the 16 projects. Nonhalogenated organics and both halogenated and nonhalogenated organics were treated in 3 projects each. The numbers of projects treating halogenated and nonhalogenated VOCs and SVOCs using ex situ physical/chemical methods are shown in Figure 3-4.

FIGURE 3-3. EX SITU PHYSICAL/CHEMICAL ORGANIC CONTAMINANTS

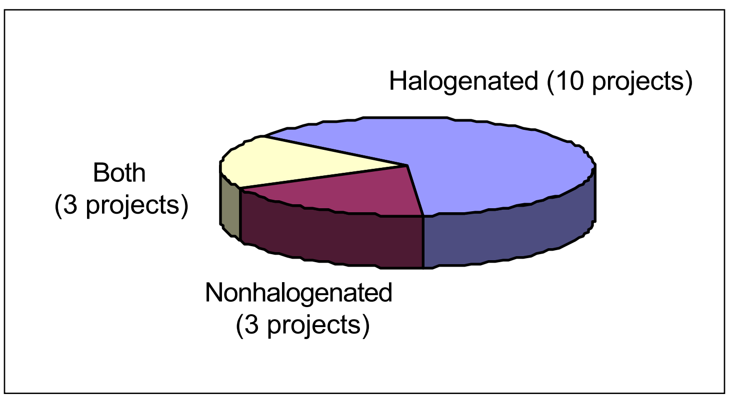
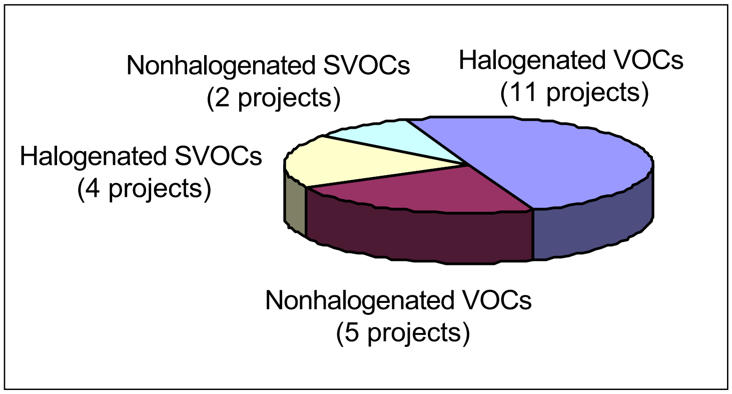


FIGURE 3-4. EX SITU PHYSICAL/CHEMICAL TREATMENT METHODS ORGANIC CONTAMINANT CATEGORIES



NOTE: Some projects involved treatment of more than one type of contaminant.

Figure 3-5 shows the distribution of specific contaminants treated using ex situ physical/chemical techniques. The most common contaminant remediated was TCE, treated in 35% (7 of 20) of the projects. PCE was treated in 30% (6 of 20) of theprojects, and metals and DCE were treated in 20% (4 of 20) of the projects each.

FIGURE 3-5. EX SITU PHYSICAL/CHEMICAL TREATMENT METHODS SPECIFIC CONTAMINANTS (where indicated)

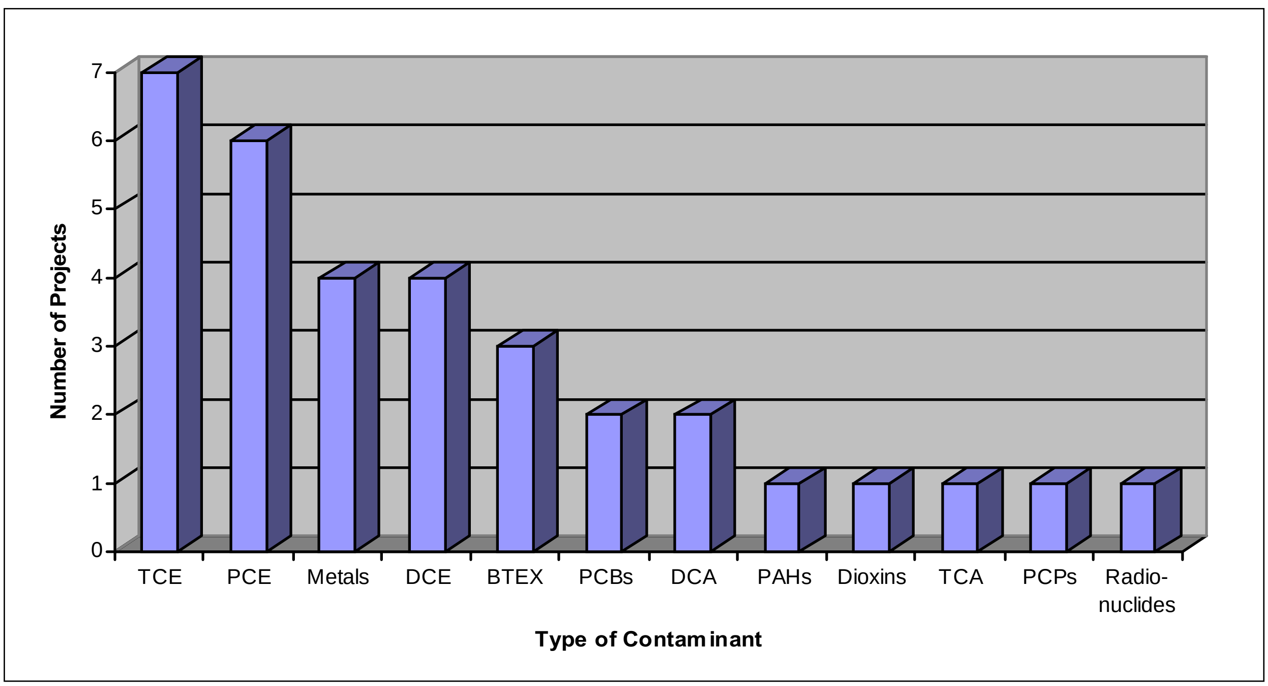


Table 3-1 shows the ex situ physical/chemical methods used to treat specific contaminants.

TABLE 3-1
CONTAMINANTS TREATED vs. EX SITU PHYSICAL/CHEMICAL TREATMENT TECHNIQUES

METHOD	CONTAMINANT								
	TCE	PCE	DCE	METALS	BTEX	PCBs	DCA	VOCs	OTHER
Chemical fixation/solidification	-	-	-	1	-	-	-	-	1 (PCPs)
Chemical treatment	-	-	-	1	-	-	-	-	-
Gas-phase chemical reduction	-	-	-	-	-	1	-	-	1 (PAHs, Dioxins)
Groundwater extraction & air stripping	4	4	3	-	2	-	1	-	1 (TCA)
Groundwater extraction & oxidation	-	1	1	-	-	1	-	-	-
High-energy electron irradiation	-	-	-	-	-	-	-	-	1 (Chlorinated solvents and fuels)
Membrane filtration	-	-	-	-	-	-	-	-	1 (Hazardous waste)
Oxidation	-	-	-	-	-	-	-	-	-
- Photochemical	1	-	-	-	-	-	-	-	1 (VOCs, SVOCs)
- UV oxidation	1	-	-	-	1	-	-	-	1 (Halogenated VOCs)
- Peroxidation	1	1	-	-	-	-	1	-	-
Polishing filter	-	-	-	1	-	-	-	-	1 (Radionuclides)
Separator-filter-coalescer	-	-	-	-	-	-	-	-	1 (Hydrocarbons)
Solar detoxification	-	-	-	-	-	-	-	-	1 (VOCs)

NOTE: Several projects involved the treatment of more than one type of contaminant.

4.0 *IN SITU* BIOLOGICAL TREATMENT TECHNIQUES

In situ biological treatment methods were used in 12 of the completed demonstration projects as shown in Figure 4-1. Bioremediation/biological treatment was the most common technique, used in 50% of these projects. Organic contaminants were treated in 92% (11 of 12) of these projects (See Figure 4-2), and of the 11 projects in which organics were treated, 6 involved nonhalogenated organics, 4 involved halogenated organics, and one project treated both types of organic compounds (See Figure 4-3). Figure 4-4 shows the breakdown of organic contaminants treated by halogenated and nonhalogenated VOCs and SVOCs. Eight projects involved the treatment of SVOCs, seven treating nonhalogenated SVOCs and one treating halogenated SVOCs. Twelve projects involved the treatment of VOCs, eight nonhalogenated and four halogenated. Specific contaminants treated via *in situ* biological treatment methods are shown in Figure 4-5 and a matrix of methods used to treat specific contaminants is presented in Table 4-1.

FIGURE 4-1. *IN SITU* BIOLOGICAL TREATMENT PER TECHNIQUES

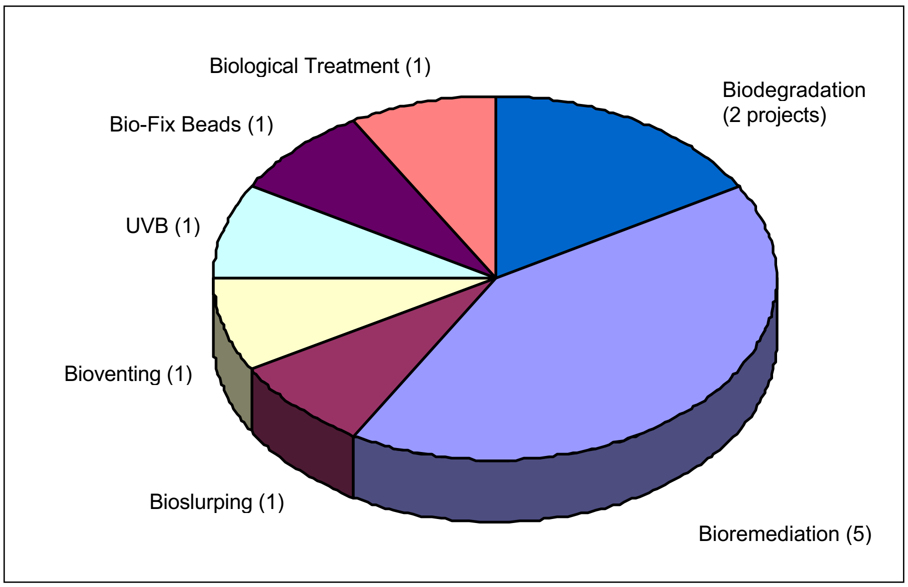


FIGURE 4-2. *IN SITU* BIOLOGICAL TECHNIQUES PER CONTAMINANT CLASS

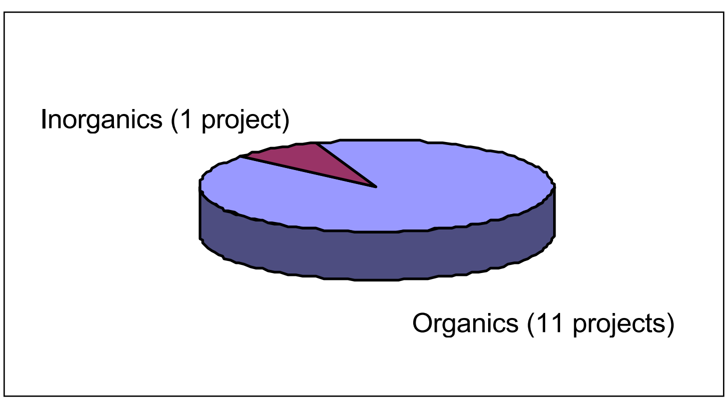


FIGURE 4-3. *IN SITU* BIOLOGICAL TREATMENT TECHNIQUES ORGANIC COMPOUNDS

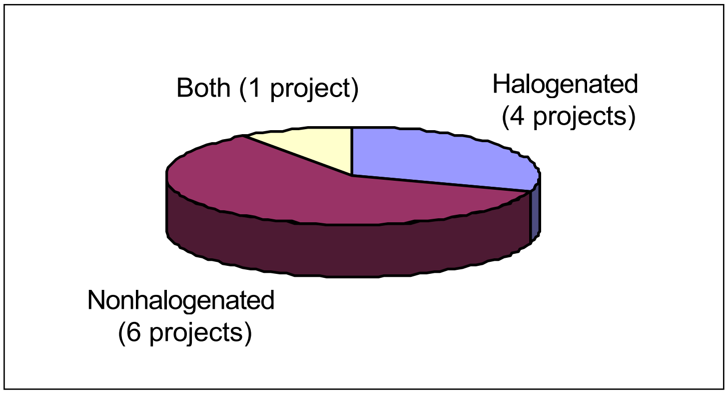
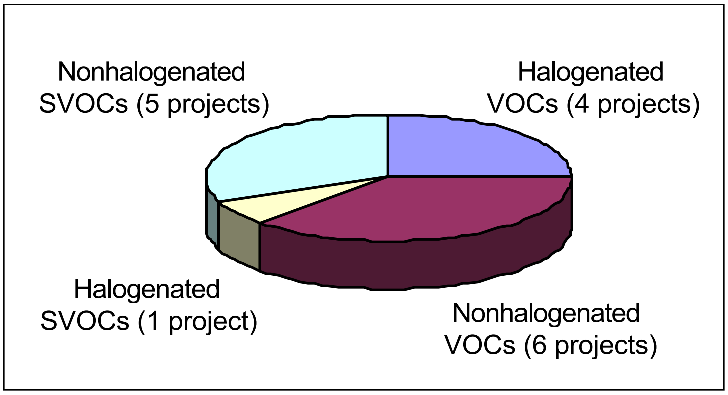
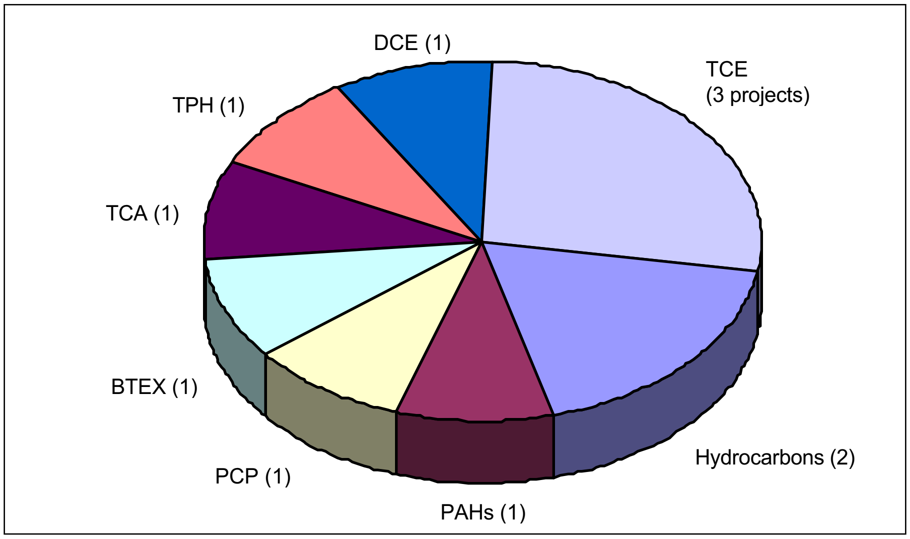


FIGURE 4-4. *IN SITU* BIOLOGICAL TREATMENT TECHNIQUES PER HALOGENATED/NONHALOGENATED ORGANIC COMPOUNDS



NOTE: Several projects involved the treatment of more than one type of contaminant.

FIGURE 4-5. *IN SITU* BIOLOGICAL TREATMENT METHODS SPECIFIC CONTAMINANTS (where indicated)



NOTE: Several projects involved the treatment of more than one type of contaminant.

TABLE 4-1 CONTAMINANTS TREATED vs. REMEDIATION METHOD *IN SITU* BIOLOGICAL TREATMENT TECHNIQUES				
METHOD	**CONTAMINANT**			
	TCE	**Fuels, oils, and nonhalogenated solvents**	**Hydrocarbons**	**Other**
Bio-Fix beads	-	-	-	1 (Heavy metals)
Biodegradation	-	2	-	-
Biological treatment	1	-	-	-
Bioremediation	1	-	-	1 (TCA) 1 (BTEX) 1 (PAHs, PCP)
Augmented subsurface bioremediation	-	-	1	-
Bioslurping	-	-	-	1 (TPH)
Bioventing	-	-	1	-
UVB (in-well vapor stripping)	1	-	-	1 (DCE)

NOTE: Several projects involved the treatment of more than one type of contaminant.

5.0 EX SITU BIOLOGICAL TREATMENT TECHNIQUES

Of the 61 completed North American demonstration projects, 5 involved ex situ biological treatment techniques. Specific methods utilized are shown in Figure 5-1. All of these 5 projects involved the treatment of organic contaminants, with 2 projects involving halogenated organics, 1 nonhalogenated organics, and 2 both halogenated and nonhalogenated organic contaminants (See Figure 5-2). As shown in Figure 5-3, 4 projects involved the treatment of volatile organic contaminants (2 halogenated and 2 nonhalogenated) and 5 projects involved the treatment of semivolatile organics (3 halogenated and 2 nonhalogenated). Figure 5-4 shows the distribution of projects utilizing ex situ biological techniques among specific contaminants. Table 5-1 presents a matrix of ex situ biological remediation methods and the specific contaminants treated via these methods.

FIGURE 5-1. EX SITU BIOLOGICAL TREATMENT TECHNIQUES

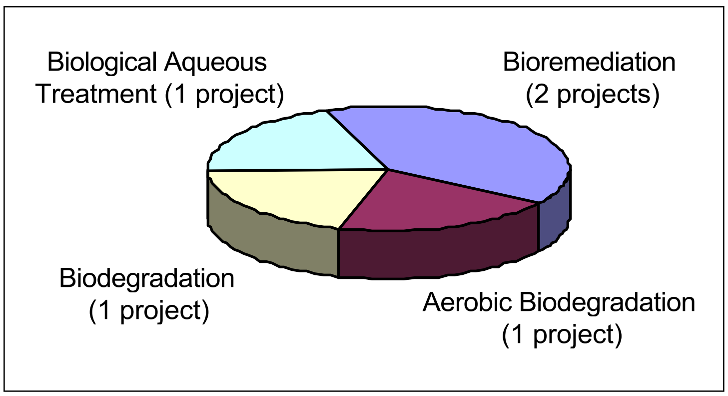


FIGURE 5-2. EX SITU BIOLOGICAL TREATMENT TECHNIQUES ORGANIC CONTAMINANTS

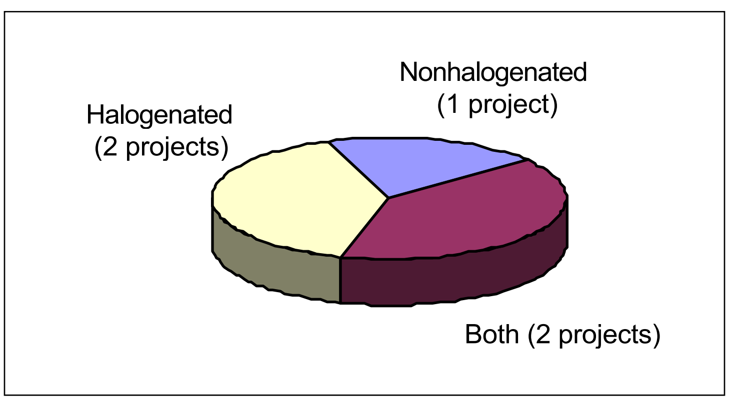
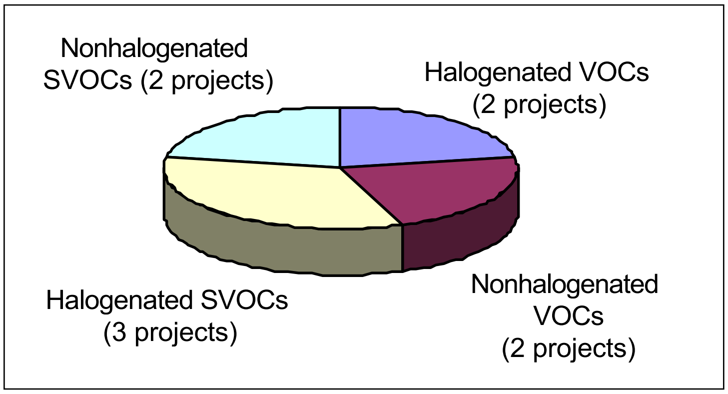


FIGURE 5-3. EX SITU BIOLOGICAL TREATMENT GENERAL CONTAMINANT CATEGORIES



NOTE: Several projects involved the treatment of more than one type of contaminant.

FIGURE 5-4. EX SITU BIOLOGICAL TREATMENT METHODS SPECIFIC CONTAMINANTS (where specified)

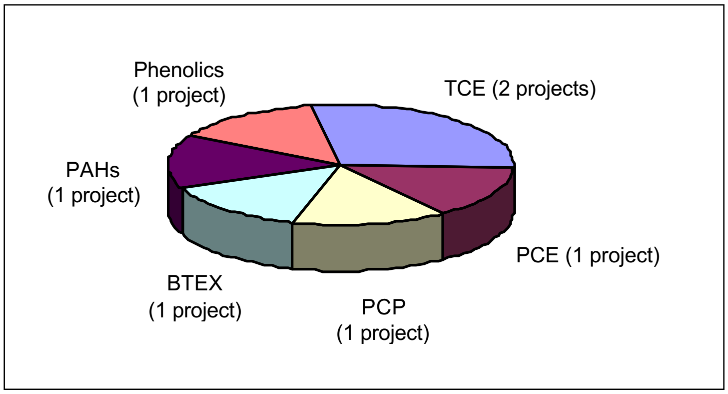


TABLE 5-1
CONTAMINANTS TREATED vs. REMEDIATION METHOD
EX SITU BIOLOGICAL TREATMENT TECHNIQUES

	CONTAMINANT						
METHOD	TCE	PCE	PCP	BTEX	PAHs	Organics	Phenolics
Aerobic degradation	1	1	-	-	-	-	-
Biodegradation	1	-	-	-	-	-	-
Biological aqueous treatment	-	-	1	-	-	-	-
Bioremediation	-	-	-	1	1	-	1

6.0 CONCLUSIONS

- Physical/chemical treatment techniques were demonstrated in over 2.5 times more projects than biological techniques.

- *In situ* techniques were demonstrated in approximately 59% of the projects detailed. The trend toward *in situ* methods was more prevalent in biological demonstrations, where 71% of projects utilized *in situ* techniques.

- *In situ* and ex situ applications of oxidation processes were the most common physical/chemical treatment methods, utilized in 23% of all physical/chemical demonstration projects.

- Organic contaminants were treated in significantly more projects than inorganics using both physical/chemical and biological techniques (82% and 94%, respectively).

- Physical/chemical remediation techniques were used to treat a greater range of contaminants, including radionuclides and explosives/propellants not treated using biological methods.

- Table 6-1 shows the percentages of projects treated by the various techniques with respect to contaminant category.

    - The percentage of projects utilizing physical/chemical treatment techniques to treat halogenated volatile contamination was 1.5 times greater than the percentage of projects using biological methods. The distribution of projects treating halogenated VOCs was approximately equal for *in situ* and ex situ applications (See Figure 6-1).
    - Nonhalogenated volatiles were treated in approximately equal percentages of physical/chemical and biological projects, but the percentage of *in situ* methods was approximately twice as high as the percentage of projects using ex situ methods (See Figure 6-2).
    - Halogenated semivolatile organics were treated in approximately 1.5 times the percentage of projects demonstrating biological techniques as physical/chemical techniques. The percentage of ex situ applications for halogenated SVOC treatment was twice as high as for *in situ* remediation methods (See Figure 6-3).
    - The percentage of projects demonstrating biological treatment techniques to treat nonhalogenated SVOCs was approximately twice the percentage using physical/chemical techniques, and the percentage of projects using *in situ* methods was approximately twice that of projects using ex situ methods for nonhalogenated SVOCs (See Figure 6-4).
    - The percentage of physical/chemical demonstration projects treating inorganic contamination is 3 times higher than biological methods, while 1.5 times the percentage of projects used ex situ as opposed to *in situ* methods to treat inorganics (See Figure 6-5).

TABLE 6-1 TREATMENT TECHNIQUES USED TO TREAT CONTAMINANT CATEGORIES							
	CONTAMINANT CATEGORY						
	VOCs		SVOCs				
METHOD	**Halogenated**	**Nonhalogenated**	**Halogenated**	**Nonhalogenated**	**Inorganics**	**Explosives/ Propellants**	**Radionuclides**
Physical/ Chemical	57%	43%	16%	20%	20%	2%	5%
Biological	35%	47%	24%	41%	6%	0%	0%
In situ	50%	56%	11%	33%	14%	3%	3%
Ex situ	52%	28%	28%	16%	20%	0%	4%

NOTE: Several projects involved the treatment of more than one type of contaminant.

- Only *in situ* physical/chemical techniques were used to treat explosives/propellants in completed demonstration projects (See Figure 6-6).
- Only physical/chemical remediation methods were used to address radionuclide contamination, with approximately equal percentages of *in situ* and ex situ applications used to treat radionuclides (See Figure 6-7).

- Contaminants most commonly treated in completed demonstration projects were:

  - Chlorinated solvents including PCE, TCE, TCA, DCE, and DCA; and
  - Petroleum hydrocarbon-related contaminants including BTEX, TPH, fuels, oils, hydrocarbons.

Chlorinated solvents made up at least one-third of the contaminants treated using physical/chemical, biological, *in situ*, and ex situ remediation methods (See Table 6-2). Petroleum hydrocarbons made up greater than one-third of all contaminants treated using physical/chemical, biological, and *in situ* methods and approximately one-fourth of the contaminants treated using ex situ techniques.

FIGURE 6-1. PERCENTAGE OF PROJECTS TREATING HALOGENATED VOCs

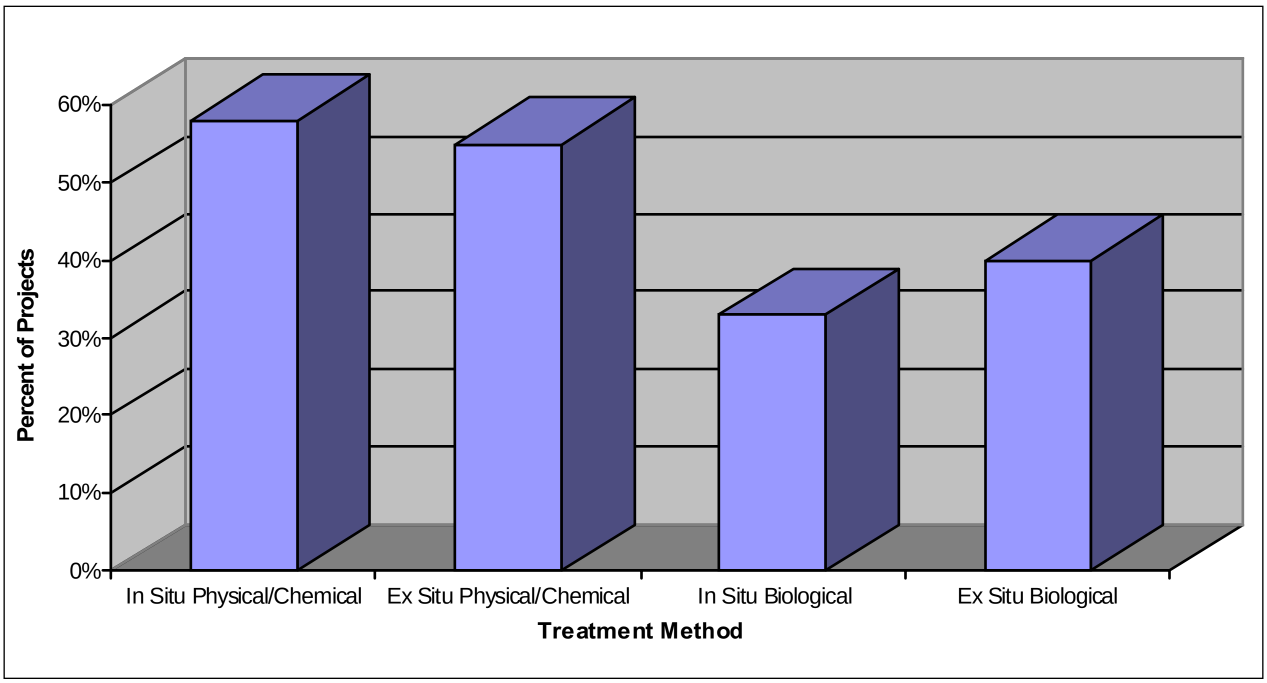


TABLE 6-2. TREATMENT METHODS FOR CHLORINATED SOLVENTS AND PETROLEUM HYDROCARBONS		
METHOD	CONTAMINANT	
	CHLORINATED SOLVENTS	PETROLEUM HYDROCARBONS
Physical/chemical	39%	34%
Biological	35%	41%
In situ	33%	44%
Ex situ	44%	24%

NOTE: Several projects involved the treatment of more than one type of contaminant.

FIGURE 6-2. PERCENTAGE OF PROJECTS TREATING NONHALOGENATED VOCs

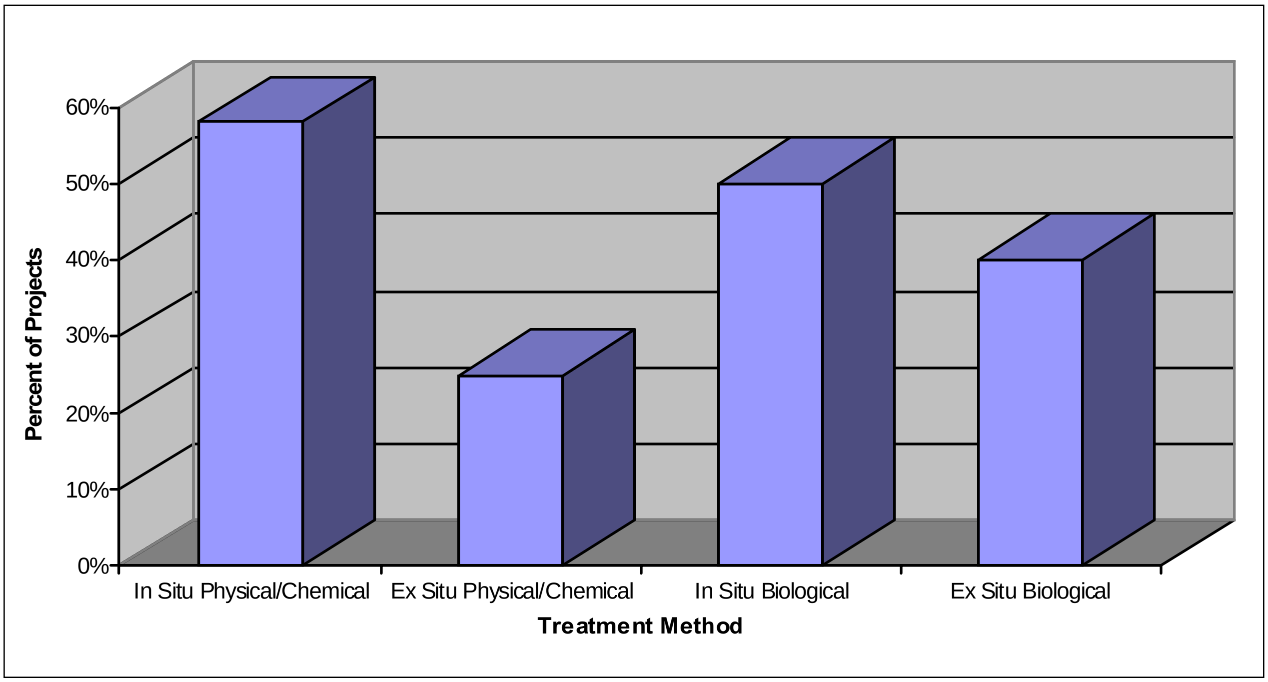


FIGURE 6-3. PERCENTAGE OF PROJECTS TREATING HALOGENATED SVOCs

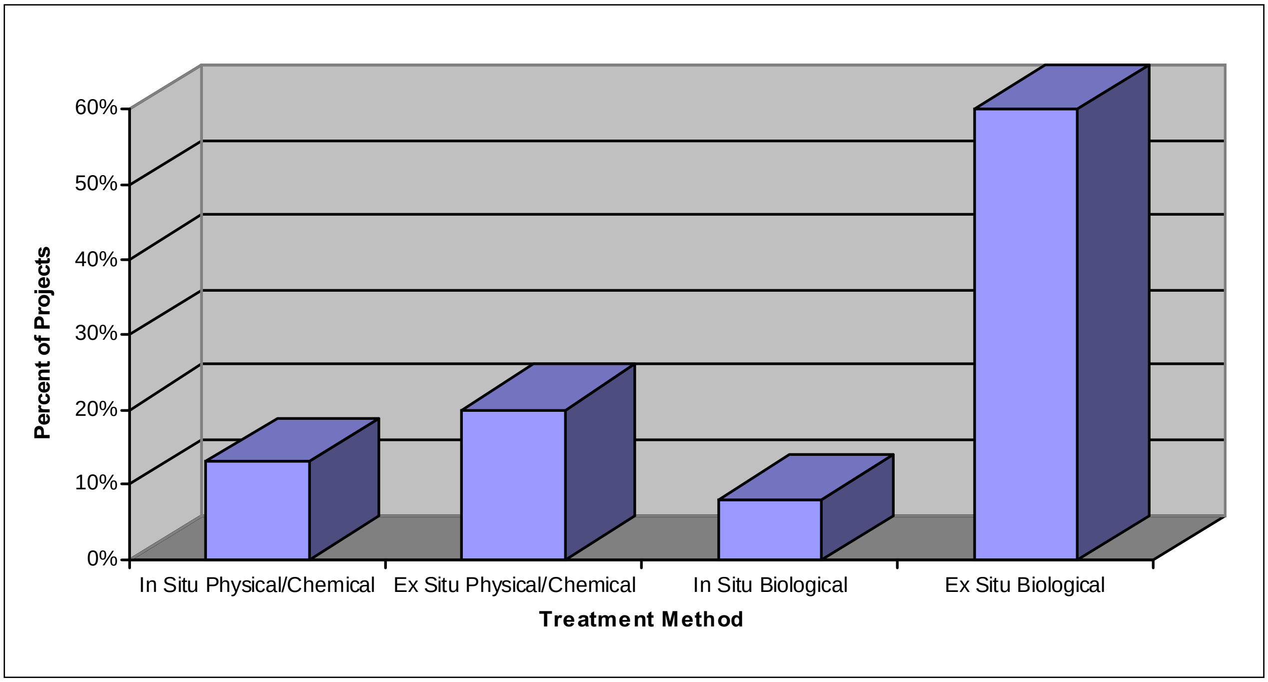


FIGURE 6-4. PERCENTAGE OF PROJECTS TREATING NONHALOGENATED SVOCs

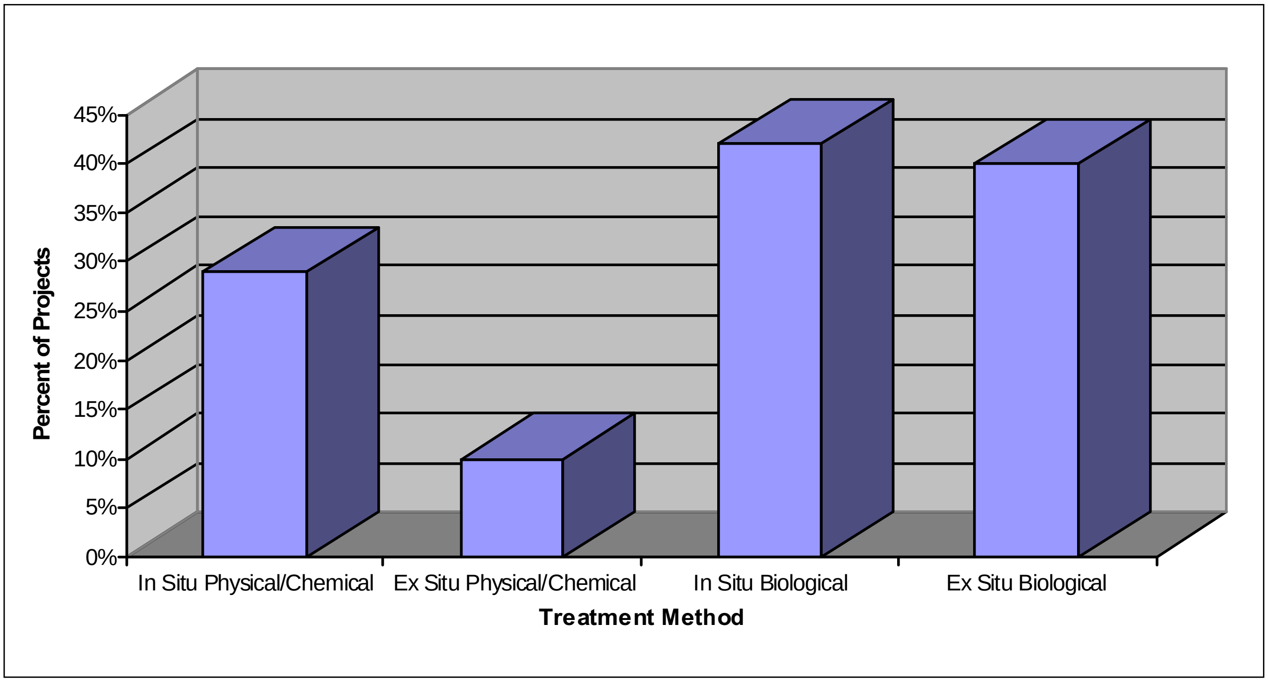


FIGURE 6-5. PERCENTAGE OF PROJECTS TREATING INORGANICS

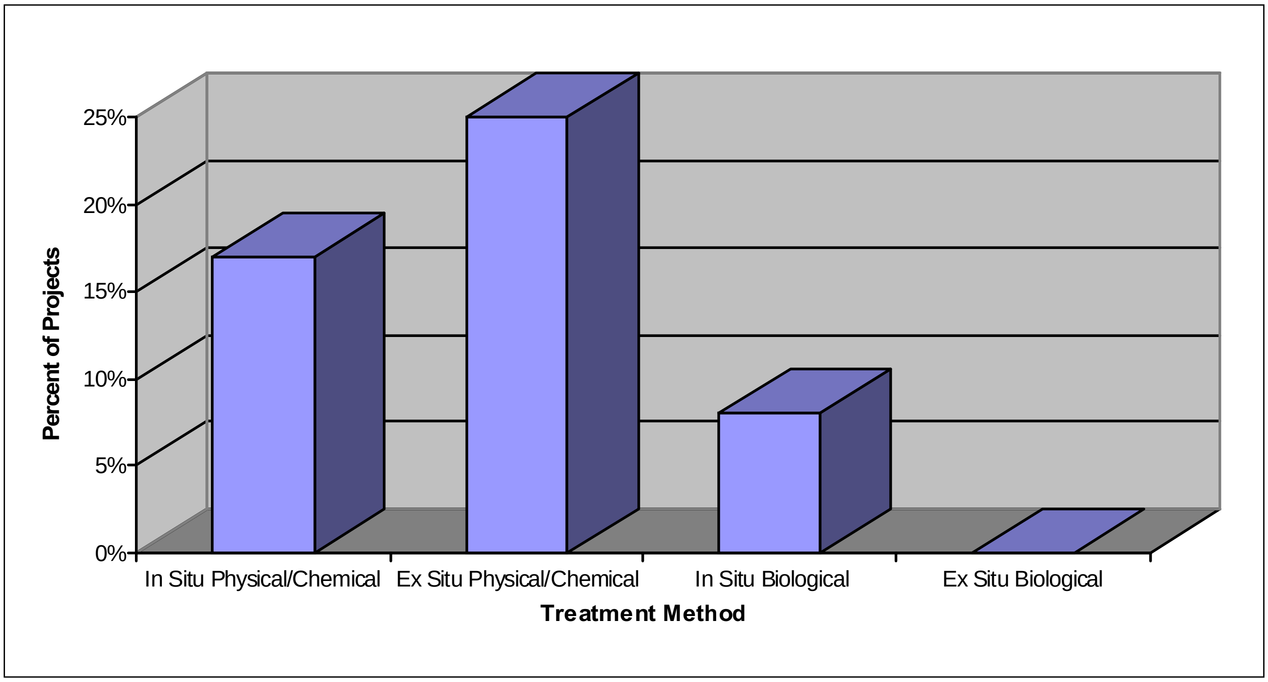


FIGURE 6-6. PERCENTAGE OF PROJECTS TREATING EXPLOSIVES/PROPELLANTS

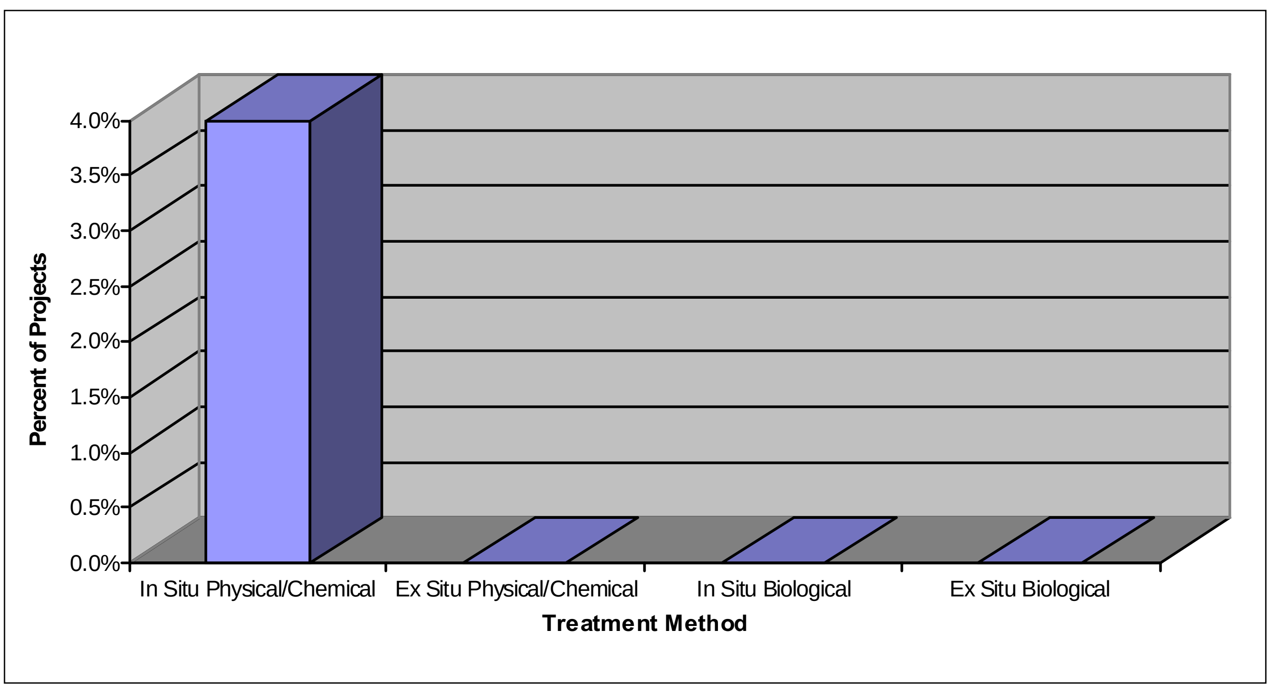


FIGURE 6-7. PERCENTAGE OF PROJECTS TREATING RADIONUCLIDES