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Summary Report:

Remedial Response at Hazardous Waste Sites

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SUMMARY REPORT: REMEDIAL RESPONSE AT HAZARDOUS WASTE SITES

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NOTICE

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ABSTRACT

In response to the threat to human health and the environment posed by numerous uncontrolled hazardous waste sites across the country, new remedial action technologies are evolving and known technologies are being retrofitted and adapted for use in cleaning up these sites. This report identifies and assesses the various types of site response activities which have been implemented, are in progress, or have been proposed to date at uncontrolled hazardous waste sites across the United States. This was accomplished through the combined efforts of JRB Associates (JRB) and the Environmental Law Institute (ELI). A nationwide survey was conducted in which 395 uncontrolled hazardous waste sites across the U.S. were identified where some form of remedial action was planned, was presently ongoing, or has been completed. Each of these sites was assessed and the results are presented herein. Based on these survey findings, JRB and ELI selected a total of 23 sites for which detailed case study investigations have been conducted. Case study reports for each of the 23 sites are presented. These reports include extensive discussions of the remedial responses at each of the 23 sites with respect to technology, cost, and institutional framework. JRB and ELI maintained a specific focus for each of these parameters. JRB's primary focus in these investigations was to assess site response activities from a geotechnical and engineering perspective, while ELI's main objective was to assess these remedial actions from a cost and institutional perspective. Additionally, technological, cost, and institutional data for the 23 case study sites are summarized in several user guidance indices.

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SECTION 1. INTRODUCTION

The Solid and Hazardous Waste Research Division USEPA (Cincinnati, OH) is involved in the research and development of existing and emerging technologies for use in the remediation of uncontrolled hazardous wastes released to the environment. As part of this effort, a two-phased study was conducted involving a nationwide survey of uncontrolled hazardous waste sites and detailed case studies on selected sites. The objective of the nationwide survey was to identify and examine and quantify various types of remedial response actions wich have been implemented, proposed, or are in progress at sites throughout the country.

From the results of the survey, sites were selected for which detailed case studies are prepared. These case studies analyze response actions from the perspectives of technology, cost, planning and management. The case studies documents the specific reasons for the success or failure of applied response action, and determines the limitations and applicability of these technologies, cost control methods, and response planning efforts to other sites.

The survey and case study reports are intended for use by USEPA Regional Officials, State Agencies, industry and commerce, and local authorities involved in selection, evaluation and design of remedial response actions. The data will be useful in the following ways:

- provide an understanding of the remedial process so that future response actions can be developed and implemented in the most efficient way possible
- provide a standard of comparison when evaluating or deciding on response actions for sites with similar problems
- identify cleanup technologies wich may warrant further research
- quantify and document the extent and type of remedial response actions on a nationwide basis
- developing data to aid in cost recovery action promulgated by EPA.

Section 2 describes the methodology used for the nationwide survey, and discusses how the sites were chosen for detailed case studies. The results of the nationwide survey are presented and analyzed in Section 3. Section 4 and 5 focus more specifically on the case studies and analyze the costs of responses and the institutional frameworks for decision making, respectively. Section 6 contains the findings and recommendations concerning the issues discussed in Sections 3, 4, and 5.

SECTION 2

SURVEY AND CASE STUDY METHODOLOGY

2.1 SURVEY METHODOLOGY

The purpose of the survey was to compile a list of completed and on-going remedial response actions at uncontrolled hazardous waste sites across the United States, including landfills, surface impoundments, drum storage facilities, incinerators, and deep well injection sites. This information was compiled systematically through:

- Reviewing in-house literature
- Reviewing data from EPA Municipal Environmental Research Laboratory (MERL) and Office of Emergency and Remedial Response (OERR)
- Contacting appropriate EPA Headquarters and Regional personnel
- Contacting state and local environment and health agency officials
- Contacting Department of Defense officials knowledgeable about restoration work at military bases
- Contacting representatives of trade associations involved in management of hazardous materials and/or spill responses
- Contacting members of private industry specializing in remedial action design and implementation.

A total of 395 uncontrolled hazardous waste facilities across the country were identified at which site responses were either completed, in progress, or in the planning stages. Each of these sites was evaluated according to various criteria, including: the type of hazardous waste management, affected media, type of remedial action, status of remedial action, ease of access for case studies; etc. Sample evaluation summary sheets are shown in Figure 1.

Several data sources were reviewed to develop the list of sites for potential case study analysis. During the data collection activity an effort was made to focus on sites where remedial actions had begun or were in the design stage. Existing data sources included:

- The 1981 survey of remedial action site (EPA Publication No. 430/9-81-05)

SITE NAME AND LOCATION	FACILITY										POLLUTION						[illegible] CATION			WASTE TYPE	SITE CONDITIONS	REMEDIAL ACTION TECHNOLOGY	CONTACT
	TYPE								Status														
	Landfill	Illegal Dump	Drum Storage	Surface Imp.	Injection Well	Incinerator	Spill	Other	Active	Inactive	Ground Water	Surface Water	Air	Soil	Sediments	Food Chain	Current	None	Expected				

Figure 1. Sample Evaluation Summary Sheet

SITE NAME AND LOCATION	DATA AVAILABILITY			COOPERATION EXPECTED			SITE SELECTION RATIONALE	SITE INFORMATION SOURCES
	Good	Fair	Poor	Good	Fair	Poor		

Figure 1. (Continued)

- The Hazardous Waste Site and National Priorities List published by EPA on December 20, 1982

- Publications such as the Groundwater Newsletter, Hazardous Waste Report, Hazardous Materials Intelligence Report, Environmental Science and Technology, and Waste Age

- EPA Field Investigation Team Reports.

Once the data review was completed, a telephone review was conducted in order to verify and add to the data already obtained, as well as to identify new sites. Knowledgeable parties contacted included USEPA Regional Emergency Response coordinators, Regional Land Disposal Branch Personnel, Regional and State On-scene Coordinators, consulting contractors and State and local officials.

Department of Defense (DoD) officials with knowledge of restoration work at military bases were also contacted. The results of the DoD survey effort indicated that remediation activities within the armed forces are in the initial stages. The DoD has established a phased approach for conducting site restoration activities within all branches of the Armed Forces. Presently, each branch of DoD is proceeding at different rates relative to the phase program, and in most cases have conducted initial site assessments but have not initiated site restoration activities.

At this point, the survey methodology had accounted for those uncontrolled hazardous waste sites at which there was some form of public involvement for addressing site response, hence public officials had been able to provide the information. An attempt was made to pursue information regarding private industry site clean-up which had not been provided through the previous literature review and telephone survey. This involved contacting trade associations, industrial officials, cleanup firms and consultants involved in remedial design. Client confidentiality agreements and the sensitivity of many of these cases prevented full cooperation in identifying private industry sites and documenting remedial response action at sites which were identified.

2.2 CASE STUDY SITE SELECTION

On the basis of the survey results, 23 sites were selected for detailed case study investigations. These sites are listed in Table 1. The criteria used to select candidate sites for detailed case study analysis included:

- Availability, accessibility, and completeness of remedial action cost and engineering data

- Availability for field survey activities

- Type of remedial action technology implemented, so that a range of remedial action techniques was investigated

TABLE 1. SITES CHOSEN INITIALLY FOR CASE STUDY INVESTIGATION

Site Name	Location
Anonymous Site A	Northern San Francisco Bay Area, CA
Anonymous Site B	Northern California
Anonymous Site C	DePere, WI
Biocraft	Waldwick, NJ
*Chemical Metals Industry	Baltimore, MD
Chemical Recovery	Romulus, MI
*College Point Site	Queens, NY
*Fairchild Republic Co.	Hagerstown, MD
General Electric	Oakland, CA
*Gallup Site	Plainfield, CT
Goose Farm	Plumsted, NJ
H & M Drum	N. Dartmouth, MA
Houston Chemical Co.	Houston, MO
Howe Chemical	Minneapolis, MN
*Marty's GMC	Kingston, MA
Mauthe	Appleton, WI
Occidental Chemical Co.	Lathrop, CA
PP&L/Brodhead Creek	Stroudsburg, PA
*Quanta Resources	Queens, NY
Richmond Sanitary Service	Richmond, CA
Trammell Crow Co.	Dallas, TX
*University of Idaho	Moscow, ID
Vertac Chemical Corp.	Jacksonville, AR

*Case studies prepared by ELI only

- Type of waste management practice, so that a wide range of technologies common to hazardous waste management was studied

- Whether response was conducted by public or private party

- Types of waste and contaminants present at the facility to ensure that a variety of waste streams and pollutants was included

- Hydrogeologic setting, so that a variety of settings was represented

- Geographic locations to provide a nationwide distribution of sites.

Once sites were collected for detailed case study, field visits were made to gather additional information and to meet with the appropriate Federal, State and private parties and cleanup contractors in order to ensure the development of accurate and complete case history information. Engineering reports, contracts, feasibility studies, and invoices relating to the clean-ups were examined during preparation of each case study. A final case study report for each site is included in Chapter II and follows the format shown below:

SITE NAME, LOCATION
INTRODUCTION
Background
Synopsis of Site Response

SITE DESCRIPTION
Surface Characteristics
Hydrogeology

WASTE DISPOSAL HISTORY

DESCRIPTION OF CONTAMINATION

PLANNING THE SITE RESPONSE
Initiation of Response
Selection of Response Technologies
Extent of Response

DESIGN AND EXECUTION OF SITE RESPONSE

COST AND FUNDING
Source of Funding
Selection of Contractors
Project Costs

PERFORMANCE EVALUATION

SECTION 3

NATIONWIDE SURVEY RESULTS AND TECHNOLOGIES OF SITE RESPONSE

The survey identified 395 hazardous waste sites across the United States where as of December, 1982 some form of remedial activity is planned, is presently ongoing, or has been completed. The survey results are summarized for the 395 sites in Tables 2 through 7. Individual assessments for each of the 395 identified sites are contained in Appendix A.

Tables 2A and 2B show the geographic distribution of the remedial action sites, by state and by EPA Region. Five states: Florida, Michigan, New Jersey, New York, and Pennsylvania account for approximately one-third of all sites identified during the survey. These five states also have the largest number of sites eligible for Superfund monies based on the National Priorities List (NPL). According to that list, however, sites in these five states account for 42 percent of the eligible sites nationwide. This difference in percentage of total sites is due to the fact that our survey only considered Superfund sites at which remedial actions were ongoing or completed while the NPL lists all sites eligible for cleanup under Superfund.

The large number of hazardous waste sites located in these five states is attributed to the fact that these states are highly industrialized. In the past, it was both economical and convenient to dispose of hazardous wastes near the generating source. These states have also been very active in identifying sites and initiating remedial response actions.

Our survey did not identify any sites in Alaska, Hawaii, Nebraska, Nevada or Vermont at which remedial actions were ongoing or completed. However, it should be pointed out that Vermont and Nebraska do have sites which appear on the NPL but remedial response actions have not progressed to the point where they could be included in the survey.

Based on the survey results, Region V had the largest number of sites, followed by Region IV and Region II. According to the NPL the number of sites in these three regions are as follows:

Region	Number of Sites	% of Total
V	144	26
II	123	23
IV	67	12

TABLE 2A. STATE LOCATION OF REMEDIAL ACTION SITES IN 1980 AND 1982

State	Number of Sites (1982)	Percent of Total Identified Nationwide
Alabama	4	1.0
Alaska	0	0
Arizona	6	1.5
Arkansas	4	1.0
California	11	2.7
Colorado	5	1.3
Connecticut	13	3.3
D.C.	1	0.3
Delaware	7	1.8
Florida	27	6.8
Georgia	5	1.3
Hawaii	0	0
Idaho	2	0.5
Illinois	18	4.6
Indiana	10	2.5
Iowa	3	0.8
Kansas	3	0.8
Kentucky	10	2.5
Louisiana	11	2.7
Maine	4	1.0
Maryland	5	1.3
Massachusetts	16	4.1
Michigan	24	6.1
Minnesota	10	2.5
Mississippi	2	0.5
Missouri	11	2.7
Montana	5	1.3
Nebraska	0	0
Nevada	0	0
New Hampshire	7	1.8
New Jersey	25	6.3
New Mexico	3	0.8
New York	26	6.6
North Carolina	10	2.5
North Dakota	8	2.0
Ohio	9	2.3
Oklahoma	2	0.5
Oregon	2	0.5
Pennsylvania	27	6.8
Rhode Island	8	2.0
South Carolina	7	1.8
South Dakota	1	0.3
Tennessee	10	2.5

TABLE 2A. STATE LOCATION OF REMEDIAL ACTION SITES IN 1980 AND 1982 (Continued)

State	Number of Sites (1982)	Percent of Total Identified Nationwide
Texas	9	2.3
Utah	2	0.5
Vermont	0	0
Virginia	5	1.3
Washington	6	1.6
West Virginia	3	0.8
Wisconsin	7	1.8
Wyoming	1	0.3
	395	100%

TABLE 2B. GEOGRAPHIC DISTRIBUTION OF REMEDIAL ACTION SITES BY EPA REGION

EPA Region (States in Region)	Number of Sites	Percent of Total
I (CT, MA, ME, NH, RI, VT)	48	12.2
II (NJ, NY)	51	12.9
III (D.C., DE, MD, PA, VA, WV)	48	12.2
IV (AL, FL, GA, KY, MS, NC, SC, TN)	75	18.9
V (IL, IN, MI, MN, OH, WI)	78	19.7
VI (AR, LA, NM, OK, TX)	29	7.3
VII (IA, KS, MO, NE)	17	4.3
VIII (CO, MT, ND, SD, UT, WY)	22	5.6
IX (AZ, CA, HI, NV)	17	4.3
X (AK, ID, OR, WA)	10	2.5
	395	100%

TABLE 3. WASTE MANAGEMENT PRACTICES EMPLOYED AT IDENTIFIED REMEDIAL ACTION SITES

*NOTE: Percentages do not total 100 because a facility may use more than one method.

Waste Management Practices	Number of Sites	Percent of Total 395 Sites
Landfill	128	32.4
Illegal Dump	54	13.6
Tank/Drum Storage	85	21.5
Surface Impoundments	148	37.5
Injection Wells	9	2.3
Incinerator	13	3.3
Spills/Leaks	42	10.6
Combined Practices	84	21.2
Unknown or Other	48	12.2

TABLE 4. ACTIVITY STATUS OF IDENTIFIED REMEDIAL ACTION SITES

Site Status	Number of Sites	Percent of Total 395 Sites
Active	64	16.2
Abandoned or Inactive (includes spill incidents)	226	57.2
Unknown Status	105	26.5
	395	100%
*Superfund Priority Sites	208	53%

TABLE 5. CONTAMINATED MEDIA (TYPE OF POLLUTION) REPORTED AT REMEDIAL ACTION SITES

*Note: Percentages do not total 100 since many sites reported more than one form of pollution.

Contaminated Medium/ Type of Pollution	Number of Sites	Percent of Total 395 Sites
Ground Water	268	67.8
Surface Water	188	47.6
Soils	130	32.9
Air	70	17.7
Food Chain/Biota	39	9.8
Sediments	20	5.1
Unknown	55	14

TABLE 6. WASTE TYPES/CONTAMINANTS REPORTED AT REMEDIAL ACTION SITES

*Note: Percentages do not total 100 since many sites contain more than one waste type.

Waste Types/Contaminants	Number of Sites	Percent of Total 395 Sites
<u>Inorganics</u>		
Metals	116	29.4
Other Inorganics (e.g., cyanide, ammonia, nitrates)	51	12.9
<u>Organics</u>		
Pesticides/Herbicides (e.g., DDT, dioxin)	43	10.8
Hydrocarbons (oil, fuel, creosote, etc.)	59	14.9
Solvents	109	27.6
Methane Gas	7	1.7
PCBs	51	12.9
Other Organics (e.g., phenols) or Unspecified Organics	89	22.5
<u>Waste Types</u>		
Acids/Caustics	44	11.1
Waste Sludges	59	14.9
Mining and Milling Wastes	6	1.5
Radioactive Wastes	13	3.3
Explosives	8	2.0
Paints, Pigments, Dyes, Inks	18	4.6
Pharmaceutical	5	1.3
Mixed Waste Types	146	36.9
Unknown/Unreported Waste Types	29	7.3

TABLE 7. RESPONSE TECHNOLOGIES EMPLOYED AT SURVEY SITES

*Note: Percentages do not total 100 since more than one remedial action technique has been used at many sites.

Remedial Action	Number of Sites	Percent of Total 395 Sites
Capping/Grading/Revegetation	69	17.5
Surface Water Diversion/Runoff Controls (including spill containment controls, e.g., dikes)	34	8.6
Leachate Collection (e.g., underdrains)	19	4.8
Lining (clay or synthetic)	13	3.3
Drum Removal/Recontainerization	55	13.9
Waste/Contaminated Materials Removal	107	27.1
Waste Recovery/Recycling (solvents, metals)	8	2.0
Contaminant Treatment/On-site Treatment	66	16.7
Encapsulation/Solidification	10	2.5
Ground Water Pumping	29	7.3
Ground Water Containment (e.g., slurry walls)	17	4.3
Ground Water Monitoring	73	18.5
Gas Control	5	1.3
Dredging	5	1.3
Incineration	5	1.3
Other Methods (e.g., new water supply)	28	7.1
Combined Techniques	126	31.8
Unknown (remedial actions planned, but unspecified)	60	15.2

Again, the difference in site distribution between the survey and the NPL is due to the fact that the survey considers sites where remedial actions are ongoing or completed whereas NPL considers all sites eligible for Superfund. It has been estimated that for a typical NPL site, the time span from start of investigation to completion of remedial response will be about 3 to 5 years. Therefore it could be a few years before many of the NPL sites would be included in a survey of ongoing or completed remedial actions.

Table 3 is a compilation of the various types of documented waste management practices employed at the sites identified by the survey. These practices represent the sources of uncontrolled releases of hazardous waste materials to local environments, and they include spill incidents reported at the remedial action sites. Waste management practices documented at the 395 remedial action sites include landfilling, drum and tank storage, surface impoundment treatment and storage, subsurface waste injection, incineration, illegal dumping, and spills. Most of the remedial response actions are associated with three waste management technologies: landfilling, surface impounding and drum storage. This association is to be expected based on the fact that they have been the most common methods for hazardous waste disposal. Nearly 40 percent of all sites identified contained some form of surface impoundments (pits, ponds, lagoons), and one-third of all sites were characterized as landfill sites. Tank or drum storage activities were reported for approximately 22 percent of all sites identified. Approximately 14 percent of remedial action sites were characterized as illegal dumps in the survey literature, however many of those sites reported as landfills or drum storage areas might legitimately be considered as illegal dump sites. Over one-fifth of the sites identified during the survey (21 percent) reportedly used a combination of two or more of the waste management practices considered in Table 3. A number of these sites, for instance, used both land disposal methods (landfills, dumps) and drum storage or liquid waste impoundments to handle hazardous wastes. Spill incidents or leaks (from storage operations, facility process lines, and transportation accidents) accounted for approximately 10 percent of all remedial action sites identified. The use of injection wells or incinerators to dispose of hazardous wastes was reported at less than five percent of the sites. The relatively low percentage of these two disposal methods can be attributed to their limited applicability in treating a broad spectrum of wastes and to limitations on their use in certain geographic areas.

Table 4 gives a breakdown of the sites in terms of their most recently reported activity status. Of the 395 remedial action sites identified, 57 percent are reported as inactive or abandoned sites (including spill sites), while approximately 16 percent are known to be "active" facilities; facilities with identified owner/operators still engaged in their primary activities, whether they be chemical manufacturing firms, military bases, municipal landfills, mining companies, commercial waste management facilities, etc. The actual number of "active" facilities may be far larger than the number identified in this survey. Many of these sites are owned by private industries and information on remedial response actions was considered confidential. Others are located at military bases where remedial response actions have not progressed to the point that they could be included in the survey. Over one-fourth (approximately 27 percent) of all remedial action sites identified lacked sufficient information to determine their current status. It is likely that most of these 103 sites are inactive or abandoned waste disposal facilities.

Table 4 also shows that of the 395 remedial action sites, 208 sites (53 percent) are Superfund priority sites. These sites were drawn from the proposed National Priority List (NPL) of 418 sites eligible for remedial actions under Superfund. These 208 sites represent uncontrolled hazardous waste sites with sufficient data to identify the planned or ongoing remedial actions at the sites. The main sources of this data for the survey were Superfund site descriptions published by EPA/OSWER in December, 1982. Of the 400+ NPL sites, 210 lacked sufficient information on planned or ongoing remedial actions to be included in this survey.

The types of pollution (contaminated media) documented at remedial action sites are summarized in Table 5. Ground water contamination is the most common form of pollution reported at the sites, occurring at nearly 70 percent (268) of the remedial action sites. Approximately half of the sites (nearly 48 percent) have surface water contamination. The prevalence of surface water and ground water contamination problems can be attributed to past widespread practices of disposing of wastes in landfills and impoundments without taking any measures to prevent surface seepage or leaching into ground water. Soil contamination is the third most prevalent form of pollution documented at remedial action sites (33 percent of all sites). Air contamination by methane gas, volatile hazardous compounds, or other toxic gases is reported at about 18 percent of the survey sites. Contamination of sediments and food chain media (livestock, fish, crops) is the least prevalent form of pollution documented at the waste sites. Thus, the survey reveals that contamination of local water resources which may serve as public drinking water supplies (on both municipal and residential scales) continues to be the most critical problem posed by uncontrolled hazardous waste sites. And it is the protection or clean-up of these ground water and surface water supplies that is the focus of most site remediation technologies and strategies.

Table 6 documents the waste types and chemical contaminants which are of concern at the 395 remedial action sites. Metals (Pb, Zn, Cd, Cu, As, etc.) represent the single most prevalent class of contaminants, reported as pollutants at approximately 30 percent (116) of the remedial action sites. Other inorganic contaminants (e.g., cyanide, nitrates) are reported at approximately 13 percent of the sites.

Organic chemical contaminants include pesticides and herbicides, hydrocarbon fuels and oils, solvents, PCBs, and methane gas. Solvents are the most common organic source of contamination reported at nearly 28 percent of the identified sites. Organic solvents generally sorb poorly to soils and leach readily into ground water and are therefore a major cause of the extensive groundwater contamination problem. Hydrocarbon waste compounds (especially waste oil and creosote) occur at approximately 15 percent of the sites. Polychlorinated biphenyls are a problem at nearly 13 percent of the sites. Pesticide and herbicide compounds (including DDT and dioxin) are documented contaminants at 11 percent of all sites surveyed. Methane gas problems are reported at only 2 percent of the remedial action sites.

In terms of general waste types present at remedial action sites, waste sludges are the most prevalent source of contamination, occurring at almost 15 percent of the sites. Acids and caustic waste types are reported at 11 percent of the sites. Mining wastes, radioactive wastes, explosives, paint and dye-related wastes, and pharmaceutical wastes are all reported at less than 5 percent of the sites. Nearly 40 percent of the remedial action sites contain a combination of two or more waste types or chemical contaminants, presenting the potential for dangerously incompatible or undesirable chemical reactions. For instance, co-disposal of acid wastes and metal-laden wastes is documented at a number of the sites, causing rapid environmental migration of metals to be a major concern. The presence of incompatible wastes also greatly complicates the cleanup of waste sites and often reduces the possible options for remedial actions, particularly those options involving aqueous or in-situ treatment or incineration.

A wide variety of response technologies have been employed (or are planned) at the waste sites identified by the survey (see Table 7). The most commonly implemented remedial action strategy is removal of wastes from the site. This remediation technique was documented at over one-quarter of all the sites (41 percent) identified during the survey. It includes such activities as excavation and off-site transport of contaminated soils and drums and the removal of dewatered or solidified waste sludges from disposal sites.

Another widely used site remediation technique is site capping, grading, and revegetation. This includes the construction of clay caps over landfills, drum burial pits, and dewatered lagoons. It was reported as a preliminary remedial action or site closure activity at 17 percent of the sites. Eight percent of the sites used surface water diversion structures and run-off controls (dikes, berms, trenches, sandbags, etc.) as remedial actions to contain contaminated site runoff and spills.

On-site treatment (16 percent of all sites surveyed) of wastes has also been widely used. In most instances, these techniques correlate well with the high percentage of facilities identified as practicing landfilling, drum storage, or surface impounding as a waste management method. This correlation is based on the following factors:

- Most remedial actions to date have been directed at controlling the immediate threat, i.e. removal of the waste material by landfill and contaminated soil removal, surface impoundment pumping and removal, or drum removal.

- Technologies such as grading/capping, surface water diversions, contaminant removal, and drum removal are in most cases relatively unsophisticated and economic remedial activities when compared with other remedial options.

- In the natural order of implementing remedial actions, removal of the contaminant source is the most likely initial step in performing a staged facility cleanup.

- Complete removal of the source of contamination is the most effective and direct method of reducing or eliminating continued releases of contaminants to the environment.

This category of response actions includes the use of leachate treatment systems, the collection and treatment (via carbon filtration, aeration, etc.) of contaminated well water and surface waters, and in-situ neutralization of impounded acidic or caustic wastes or contaminated soils. These technologies have been widely used in treating industrial wastes in the past. Considerable bench and pilot scale testing has been conducted over the past 10 years to adapt these treatment methods for treating highly variable leachates and to develop mobile units for use in the field.

Groundwater contamination controls including pumping and use of groundwater containment structures such as slurry cut-off walls, and clay-filled trenches have been used at nearly 12 percent of the sites. Pumping accounts for the overwhelming majority of groundwater contamination controls.

Other techniques such as gas control measures, leachate collection drains, encapsulation/solidification and dredging have been used at relatively few of the sites.

Reasons for the more restricted use of these methods include:

- Constraints based on site specific conditions such as waste type, area of contamination, and media contaminated

- Present level of technological development relative to proven field use and successful application in real world situation.

For 15 percent of the sites identified in the survey, specific information on planned remedial actions were unavailable.

A combination of two or more of the individual remedial action technologies shown in Table 7, such as drum removal followed by site capping and ground water monitoring, has been documented as the remedial action strategy at nearly one-third of all the sites surveyed. The 23 sites for which case studies have been prepared parallel these results; at each site a combination of response technologies has been used. These are, of course, dependent upon the site characterization as well as the type of contaminants present. The chosen technologies are in some instances an historical function in that they might have been the most highly developed technology known to exist at the time the remedial response was implemented. The details regarding the site response technologies are discussed in the individual case studies in Chapter II. A summary of the response actions taken at the 23 case study sites is listed in Table 8.

TABLE 8. SUMMARY OF RESPONSE TECHNOLOGIES EMPLOYED AT CASE STUDY SITES

Site Name and Location	Response Technologies
Anonymous Site A San Francisco Bay Area, CA	dike reinforcement, ASPEMIX cut-off walls, interceptor trench, dams
Anonymous Site B Northern California	interceptor trench and sump, carbon treatment, basin dewatering and capping, upgraded drainage system
Anonymous Site C DePere, WI	runoff control via surface drain to surface impoundment, ground water interceptor trench
Biocraft Waldwick, NJ	ground water extraction, biological treatment, reinjection, in-situ aeration
*Chemical Metals Industries Baltimore, MD	drum and tank removal, bulk liquid pumping, soil removal, treatment and disposal, asphalt and clay capping
Chemical Recovery Romulus, MI	asphalt cut-off wall, underdrain system, drain removal, dredging, lagoon waste removal
*College Point Site Queens, NY	pumping waste oil into tanks, solidification with fly ash, filtering of lagoon water, transport and disposal of contaminated materials
*Fairchild Republic Co. Hagerstown, MD	excavation and disposal of contaminated soil, surface water diversions, clay cap, grading, revegetation
General Electric Oakland, CA	Trench drain system, on-site PCB oil/water separation, contaminated soil removal, clay capping
*Gallup Site Plainfield, CT	excavation and removal of drums and contaminated materials, in-situ lime treatment

(continued)

*Case studies performed by ELI only.

TABLE 8. (continued)

Site Name and Location	Response Technologies
Goose Farm Plumstead, NJ	wellpoint collection/spray irrigation/ recharge system, ground water carbon adsorption and aeration, drum excavation, segregation, off-site disposal
H & M Drum N. Dartmouth, MA	excavation of drums and contaminated soil, soil landspreading, interceptor trench, sorbent pillows, drum segregation, off-site disposal
Houston Chemical Co. Houston, MO	pond skimming, PCP/oil recovery, carbon treatment, dredging
Howe Chemical Minneapolis, MN	pesticide-contaminated debris removal, frozen materials thawed in lined lagoon, landspreading liquid wastes, landfarming soils, ground water extraction wells to POTW
*Marty's GMC Kingston, MA	excavation, aeration, capping
Mauthe Appleton, WI	contaminated soils removal, leachate collection trench and treatment system
Occidental Chemical Co. Lathrop, CA	ground water extraction, carbon treatment, aquifer reinjection, excavation and recapping of disposal ditches and lagoon
PP&L/Brodhead Creek Stroudsburg, PA	filter fences in stream, cement-bentonite slurry wall, contaminated soils excavation, recovery wells for coal tar, ground water monitoring
*Quanta Resources Queens, NY	soil removal, solidification, in-situ wastewater treatment
Richmond Sanitary Service Richmond, CA	bay mud subsurface barrier wall dike construction to prevent flooding

(continued)

*Case studies prepared by ELI only.

TABLE 8. (continued)

Site Name and Location	Response Technologies
Trammell Crow Co. Dallas, TX	waste oil sludge solidification by cement kiln dust, on-site landfilling of solidified sludge
*University of Idaho Moscow, ID	excavation and disposal of contaminated materials, backfilling, covering with topsoil and seed
Vertac Chemical Corp. Jacksonville, AR	landfill capping with on-site clay and revegetation of soil cover, clay barrier walls, drum repacking, contaminated soil excavation and containerization, asphalt/clay covering of spill area, basin dewatering and sludge solidification, interceptor trench, herbicide waste recycling

*Case studies prepared by ELI only.

SECTION 4.

COST OF RESPONSES

INTRODUCTION

Documenting expenditures related to the responses at the 23 case study sites was a major focus of the research. This section presents the data in various summarized forms and draws generalizations, to the extent possible, on the actual costs of specific tasks and the factors that affected them. The intent here is to report an illustrative range of costs based on actual expenditures so that they can be compared to future cost models. To this end, remedial response cost estimates from an EPA engineering costing model (Rishel, H.L. et al., 1982) are included in some of the tables for comparison purposes. This engineering cost model uses standard Construction Cost Manuals (Means and Dodge manuals) to estimate component and unit operations of several hypothetical landfill and impoundment scenarios in mid-1980 dollars.

The cost of remedial actions varied greatly depending on the site characteristics. The nature of the contamination, hydrogeological factors, and the perceived level of risk to humans and the environment, were found to influence the costs of responses, even among similar remedial technologies. Estimating the unit costs of remedial actions probably will never acquire the precision of other pollution control measures, such as emission reduction and wastewater treatment, since the uniqueness of each site and the uncertainties associated with most remedial actions hinder generalizations about unit costs. However, the importance of effectively managing remedial work at the nation's uncontrolled sites and the probable scale of future remedial operations calls for the development of some efficient method of estimating these costs. The results here can serve that purpose.

The results of these case studies can be best used with an understanding of the site characteristics and of the limitations of the results. To address the former concern, site characteristics are included in many of the summary tables and charts along with the costs. Of course, for a more complete understanding of the circumstances in which expenditures occurred, it is essential to read the individual case studies. Meanwhile, a careful reading of the "Methodology" sub-section below will provide a general understanding of the factors underlying the data limitations, such as levels of aggregation, sources of information, and quality of documentation.

This remaining section covers the following topics:

- Methodology
- Results
  - total cost by site
  - comparative cost by technology
  - operation and maintenance costs
  - comparison of costs of publicly-funded responses with privately-funded responses

METHODOLOGY

Site Selection

The site selection process is described in Section 3 of this chapter.

Collection of Data

Cost data were generally collected in three stages:

1. Interview preparation
2. Interview and file search
3. Follow-up inquiry and data refinement.

Before the site visits, readily available cost data were obtained through the mail in preparation for interviews with response managers. Researchers also used available information about work performed at the sites to prepare questions and organize the work into discrete unit operations and component tasks.

Interviews and file searches during the site visits were the primary sources of cost data. Invoices, memoranda, letters, proposals and contracts were photocopied. This information was supplemented by interviews with participating personnel who recalled numbers that confirmed invoices, helped aggregate related activities, or related dates and contractors with response activities.

The last phase of data collection was the site visit follow-ups. Phone calls and correspondence were used to refine and verify the data. Again, site contacts were helpful in describing the organization and sequence of events and tasks, and specifying what was or was not included in contractors' invoices.

Categorization of Data

The data base resulting from researching State and Federal agencies, contractors and corporations consists of three forms:

1. Invoices
2. Reports, memoranda and correspondence
3. Interviews.

Cost data were constructed into functional categories by two primary means and supplemented with a variety of sources. The categorization method depended on the type of data available from the source. The first method was the aggregation and summing of specific costs on invoices to determine the total cost of particular operations, such as slurry wall construction. Component costs of the total are detailed in the case study text. Unit costs for items such as ton of waste disposal or square foot of slurry walls were multiplied with the volumes given in as-built engineering reports to verify the total task costs. Where unit costs were unstated, they were derived by dividing the total cost of a particular task by the quantity of material dealt with.

The second categorization method was the correlation of weekly invoice summaries of general cost categories with the activity occurring during that period to estimate the cost of an operation. Weekly invoice summaries were often categorized by items such as labor, equipment, transportation and disposal. These categories were broken down according to each operation contributing to the invoice and the proportion of the weekly total used for that operation. For example, excavation might have been performed for 100% of a given week, and 50% of the labor and 30% of the equipment were devoted to this operation, with the remainder devoted to analytical work. The cost would be further broken down if the daily reports showed that transportation and disposal occurred during two of the seven days included on the invoice for which X% labor and equipment were used for loading and analysis.

These invoice based methods were supplemented with other sources such as interviews, reports, correspondence and contracts. When aggregating specific invoice items, particular item costs were sometimes determined by referring to other file material or the site contacts. The breakdowns of general invoice summaries according to daily reports were often refined by interviewing or corresponding with site contacts about the execution and timetable for particular operations. Private response in-house costs were estimated, when available, by totalling company time sheets or other work records for the appropriate project. Private in-house costs were the most difficult cost data to obtain, usually because of the lack of available records. Data on in-house costs of government responses were sometimes available because such records were kept for cost-recovery purposes.

RESULTS

Total Cost By Site

The total cost of each of the 23 case study site responses is shown in Table 9, and the frequency distribution of the totals is shown in Figure 2. The average cost per site was about $1.5 million, but the standard deviation of $2.3 million and a standard error of $0.48 million shows a wide variation in the costs. The total site response costs ranged from $23,000 to $10.3 million. This range represents a difference of a factor of 448. Seventeen of the 23 responses (74%) cost between $200,000 and $2.0 million. The problem and the primary response at each site are listed in Table 9, with the total cost and the data to describe the most significant site responses characteristics. The relationship between the costs and the site characteristics is detailed in the individual case studies and is summarized in the "Cost by Technology" sub-section below.

The variation in the total costs for the case study responses shows the range of actual site costs, but must be evaluated in light of four characteristics of the data base. These characteristics limit the comparability of costs among the case study sites and with future remedial actions.

The four significant characteristics of the data that had an effect on the total costs of sites are:

- Remedial work was not necessarily completed
- Some hidden or in-house costs were excluded
- Remedial contracting market conditions were dynamic
- Sites were not necessarily statistically representative.

The most important characteristic of these total cost data is that the remedial work performed at the sites was not necessarily complete or final. Significantly, at many of the sites the source of contamination has been partly or completely removed, but the contaminated subsurface has not been dealt with. Additional costs for such sites may involve any or all of the following: hydrogeological studies; ground water withdrawal wells to retard plume migration; treatment systems for extracted contaminated ground water; and future operation and maintenance costs of ground water collection/ treatment systems. In many cases, caps, cut-off walls and subsurface drains will require future expenditures for monitoring and maintenance. Many of the uncertainties regarding total cost stem from uncertainty about the efficacy of the response technologies implemented. Regarding most of the case study sites, however, there is a significant amount of confidence on the part of the companies or agencies involved that the reported costs substantially represent the actual totals for the sites.

The second characteristic of the total site cost data is the exclusion of private or governmental in-house costs from the totals reported for several sites. Estimates of in-house costs were included in each case study whenever possible. However, in the cases where this was not possible, the cost of unaccounted for in-house labor, equipment, and services such as monitoring and management performed by government agencies, were not included in the total site cost.

Figure 2. Distribution Of Total Site Costs

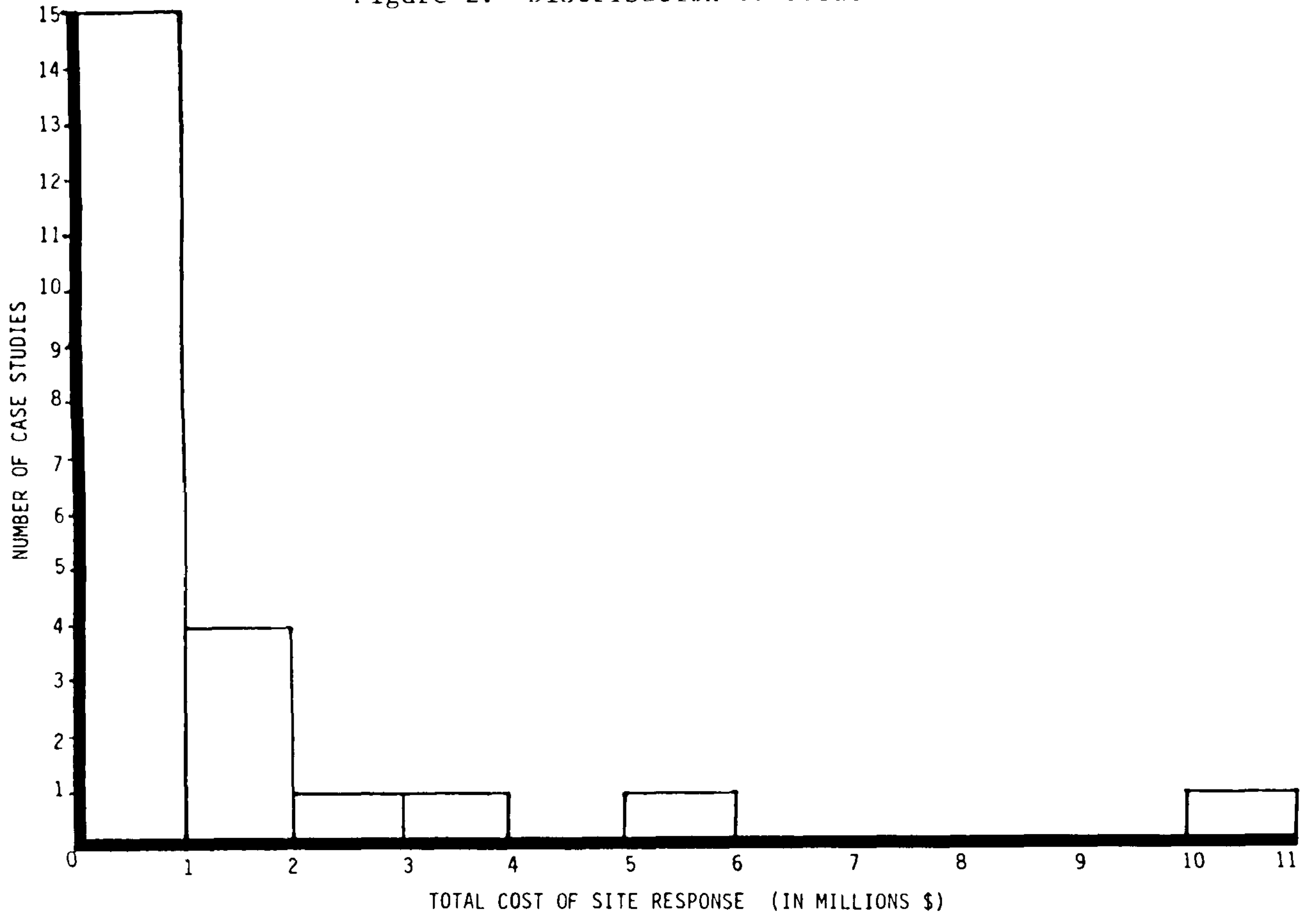

TABLE 9. TOTAL COST BY SITE

Site Name	Date	Problem/Risk (a)	Primary Response Technologies	Quantity	Total Site Cost
Anonymous Site A	1982	pesticide/fertilizer s w discharge adjacent bay	waste water disposal cut-off wall	2.8×10^{10} l 9,637 m^2	$10.3 million
Anonymous Site B	1980	solvents/herbicide gw contamination	subsurface drain leachate treatment	80 m long 3.6-5.2 m deep 82,080-112,320 lpd (b)	$268,217
Anonymous Site C	1981	hexavalent chromium soil, gw contamination	subsurface drain leachate treatment	73 m long 4 m deep 1,040 lpd(b)	$23,000
Biocraft Laboratories	1981	solvents gw, sw contamination	collection/reinjection trenches biodegradation	51,779 lpd (b)	$926,158(c)
Chemical Metals Industries	1981	solvents, metals; gw,sw explosion/fire threat	soil scraping, disposal capping	2,000 drums 91 Mt	$341,349
Chemical Recovery Systems, Inc.	1980	solvents, metals gw contamination	subsurface drain cut-off wall	300 m long 2-3 m deep 1,341 m^2	$1.4 million
College Point	1980	PCB oil; gw, sw, fire threat	oil/soil, solidification/disposal; waste water treatment	2,514 Mt	$1.75 million
Fairchild Republic	1980 1982	hexavalent chromium gw threat	excavation, disposal capping	4,129 Mt 15 cm thick	$450,000

(a) gw = ground water; sw = surface water

(b) lpd = liters per day

(c) Includes significant research and development costs

TABLE 9. (continued)

Site Name	Date	Problem/Risk (a)	Primary Response Technologies	Quantity	Total Site Cost
Gallup	1978	solvents, metals gw, sw contamination	excavation, disposal in-situ lime treatment	3,647 Mt	$610,445
General Electric	1981	PCB, trichlorobenzene gw, sw threat	subsurface drain oil/ water separator	126-189 lpd(b)	$1.58 million
Goose Farm	1980 - 1981	solvents, metals, PCB gw, sw contamination	excavation, disposal gw extraction/treatment	3,900 Mt 151,400 lpd	$5.1 million
H & M Drum	1979 - 1981	solvents sw, gw contamination	excavation, disposal	368 Mt	$1.25 million
Houston Chemical	1979	pentachlorophenol sw contamination	soil scraping, disposal water treatment	2,015 Mt 266,670 lpd	$709,428
Howe , Inc.	1979 - 1981	pesticides gw, sw contamination	soil scraping, disposal	1,988 Mt	$470,000
Marty's GMC	1980 - 1981	solvents, PCB's gw, fire threat	excavation, disposal aeration, capping	426 Mt	$557,735
Mauthe	1982	hexavalent chromium sw, gw contamination	excavation, disposal subsurface drain	76.5 Mt	$72,229

(continued)

(a) gw = ground water; sw = surface water

(b) lpd = liters per day

TABLE 9. (continued)

Site Name	Date	Problem/Risk (a)	Primary Response Technologies	Quantity	Total Site Cost
Occidental Chemical	1980-1981	pesticides (DBCP, lindane) gw contamination	excavation, disposal gw treatment	3,559 Mt 1.8-2.7 x 10^6 lpd (b)	$3.91 million
Quanta Resources	1982	solvents, PCB sw, fire, explosion threat	solidification, disposal waste water re. tment	2,387 Mt 10,000 lpd(c)	$2.26 million
Richmond Sanitary	1976-1977	miscellaneous organics sw, air threat	cut-off wall	3,709 m^2 (1.5 m thick)	$111,036
Stroudsburg	1981-1982	sw contamination	cut-off wall recovery wells	1,023 m^2 (0.3 m thick)	$594,500
Trammell Crow	1981	non-hazardous oil	solidification capping	18,925 Mt	$427,527
University of Idaho	1981	pesticides, solvents gw threat	excavation, disposal	625 Mt	$174,897
Vertac	1979 - 1980	solvents, pesticides, dioxin, gw, sw contamination	excavation, disposal, cap, subsurface drain, cut-off wall	--	$2.016 million

(a) gw = ground water; sw = surface water

(b) lpd = liters per day

(c) bulk treatment for 1 1/2 month operation - 630,000 l

Third, the costs for the case study responses were incurred during a period of dynamic conditions in the remedial action contracting market. Increased competition and improved economies of scale from greater utilization of specialized equipment may have tended to decrease costs of the more recent site responses. Further, some responses included costs for research and development of remedial technologies; these costs may not be present in future clean-ups. Also, there were unquantifiable costs of contractors and government officials learning how to carry out remedial actions, which may not be as evident in future clean-ups. However, these factors may have been offset by other pressures that tended to increase costs. For example, changing regulations during the period resulted in more stringent and costly hazardous waste management requirements.

Finally, the site selection procedure did not attempt to assemble a group of 23 sites that were statistically representative of the range of site costs, which is itself still unknown. The site selection criteria affecting the lower end of the cost spectrum were probably less significant than those affecting the upper end. The average total response cost may be an underestimate because the site selection procedure excluded most CERCLA-funded sites, which are generally the largest uncontrolled hazardous waste sites in the country. Also, more costly sites tended to involve litigation that rendered them unavailable for study. Although some sites were studied because of useful unit operations, this was not possible for partially cleaned-up sites involved in enforcement actions because of the confidentiality of the information.

Comparative Cost by Technology

The case studies encountered several primary technologies which are commonly used in remedial actions. Their costs are discussed separately in the following sequence:

- Capping
- Cut-off Walls
- Excavation, Transportation and Disposal
- Site Investigation
- Solidification
- Subsurface Drains
- Water Treatment.

For each technology, its cost is described in terms of its range and component costs. Then the cost is analyzed in three ways: (1) comparison across the sites (when the technology is used at more than one site); (2) identification of site characteristics underlying the costs; and (3) comparison with the engineering cost model by Rishel et al in the 1982 "Costs of Remedial Actions at Uncontrolled Hazardous Waste Sites". The costs for various remedial technologies are compared to those estimated by this engineering costing model to test the accuracy of these estimates in a real world situation. Such comparisons of actual expenditures and estimated costs may generally prove useful for refining future costing models, which can provide an efficient method of planning remedial responses, because data on remedial cost is very limited, and most available cost data is derived from similar cost models.

Generally, the case study cost estimates are of limited comparability because of site characteristics such as waste type and scale of response. However, these factors that limit cost comparisons are discussed briefly in each section to the extent that they were found to affect costs in the case study sites. Also, the usefulness of the expenditures found for generalizing to similar unit operations may be limited.

Capping Cost--

Capping cost data were available for 3 of the 8 case study sites at which capping was used. These costs are given along with significant cost factors and the engineering cost model estimate for comparison in Table 10. The costs include capital costs but not operation and maintenance costs. The costs appeared to be similar, ranging from $0.95 - 1.63/ft^2$ ($10.23 - 17.55/m^2$). The engineering cost model estimate of $0.61 - 0.84/ft^2$ ($6.58 - 9.06/m^2$) was slightly lower, but had a different design than the case study caps. This difference, as well as design differences that affected costs among case study sites, will be considered below to the extent that they provide examples of factors that affect costs.

Although the case study research found insufficient data to determine an average cost for a particular cap or the quantifiable effect of particular cost factors, several cap characteristics that appeared to affect costs are listed in the outline below.

A. Material variations

(1) Cap material
- (a) bentonite/clay
- (b) asphalt

(2) Related material costs
- (1) top gravel
- (2) gravel bed
- (3) curbs
- (4) topsoil and seeding

B. Dimensional variations

(1) Thickness
(2) Area covered

The characteristics of the hypothetical cap (see components below) used for the engineering cost model estimate should be considered in the context of the above outline along with case study cap costs. The following costs were included in the engineering cost model estimate:

TABLE 10. CAPPING COSTS

Site Name	Date	Cap Material	Thickness	Coverage	Unit Cost
Fairchild Republic	1981	clay	6 inches (0.15 m)	(b)	$1.63/ft^2 ($17.55/m^3)
General Electric	1981	gravel/ bentonite-soil	6 inches (0.15 m)/ 4-6 inches (0.1-0.2 m)	156,000 ft^2 (14,493 m^2)	$1.13/ ft^2 ($12.36/m^2)
	1981	asphalt	(b)	135,000 ft^2 (12,542 m^2)	1.15/ ft^2 ($12.26/m^2)
Vertac	1980	clay	1 foot (0.3 m) (a)	100,000 ft^2 (292,681 m^2)	$0.95/ ft^2 ($10.23/m^2)
Engineering cost Model	1980	bituminous concrete	3 inches (0.08 m)	595,953 ft^2 (55,364 m^2)	$0.61 - 0.84/ft^2 ($6.58-9.06/m2)

(a) Reported thickness in proposed design

(b) Data not available

Capital Costs	Dollars	
	Lower U.S.	Upper U.S.
Excavation, Grading and Recontouring of Site -36,208 cu yd (27,685 m^3)	$43,820	$50,790
Excavation and Grading, Soil (for contouring - 22,116 cu yd (16,910 m^3))	$15,190	$17,720
Surface Seal - 595,953 ft^2 (55,364 m^2) Bituminous Concrete Cap - 3 inches (0.08 m)	$168,590	$244,990
Capital Cost (subtotal)	$227,600	$313,500
Overhead Allowance (25 percent)	$56,900	$78,380
Contingency Allowance (35 percent)	$79,660	$109,730
Unit costs	$0.61/ft ($6.58/m^2)	$0.84 ($9.06/m^2)
Total Capital Costs	$364,160	$501,610

Source: Rishel et al. 1981. "Costs of Remedial Actions at Uncontrolled Hazardous Waste Sites", EPA-600/2-82-035.

Details of case study capping costs are given in the individual case studies. The hypothetical cap used for the engineering cost model estimate varied from the case study caps in two characteristics that may be reflected in the relatively lower engineering cost model cost estimate. First, unlike any of the case study caps, the engineering cost model cap was made of bituminous concrete. Second, the hypothetical engineering cost model cap was several times larger than any of the case study caps. Although no realistic material costs could be gleaned from the case study data, the larger engineering cost model cap size may have allowed for greater economies of scale. When necessary equipment such as graders and rollers are mobilized, a relatively small marginal cost would be incurred for any given amount of additional work.

The difference in the material, between bentonite and asphalt, was not shown to significantly affect cap costs. The costs of the two cap types were found to be very similar at the General Electric site. However, this cost similarity may be a result of the second category of material variations: related material costs.

Variations among the costs of cap related materials may have affected the total costs of the various caps. The cost of the bentonite-soil cap at General Electric included the cost of the 6 inch (0.15 m) cover of 3/4 inch (1.9 cm) gravel to prevent erosion of the cap. The cost of the asphalt cap at General Electric included a requisite gravel bed. The cost of curbs for runoff control at General Electric was not included in the total reported cap cost, but their installation may have caused a cap cost increase not incurred in the other sites lacking this feature. Several of the sites for which cap costs were not available used common clean fill for capping. The seeding of soil caps to prevent erosion and restore the site should be included in calculating cap costs.

Finally, the cap dimensions -- thickness and area covered -- tended to affect cap unit costs. Increased cap thickness could generally be expected to add to cap costs by increasing the volume of cap material required. The exact function for this relationship cannot be determined with the available case study data. The total area covered affects the unit cap costs by determining potential economies of scale. Although the engineering cost model included separate calculations for different scales of operation of surface sealing, the cost per unit operation (e.g., dollars per cubic meter) was found to be very similar for vastly different scales of operation. The only remedial technology for which separate scale calculations showed significant economies of scale was well point systems.

Cut-Off Wall Costs--

Although the data may not be adequate to support generalizations about absolute or relative costs of cut-off walls, for the 5 sites surveyed the clay and bentonite slurry walls listed in Table 11 were less costly per unit area blocked off than the ASPEMIX cut-off walls. However, these wall types have significant technical differences that are reflected in the costs. All costs in the table are for capital expenditures and exclude operation and maintenance costs, which would include site monitoring, wall inspection, and possibly, repair or replacement. The unit costs are given in $/area blocked off for comparison because this unit best represents the cost of performing the intended function of cut-off walls. This function is either to divert the flow of ground water to lower the water table below the waste, in the case of an upgradient wall, or to contain a contaminant plume, in the case of a downgradient wall.

Total cut-off wall costs ranged from $56,118 to $976,276. Unit costs ranged from $0.21/ft^2 ($2.26 m^2) to $29.59/ft^2 ($319/m^2). If the two extremes are eliminated, unit costs ranged from $1.42/ft^2 ($15.13/m^2) to $14/ft^2 ($150/m^2).

The hypothetical model cut-off wall engineering cost model estimate is fundamentally different from those studied at the case study sites because of variations in what each includes and how the costs are derived. The

TABLE 11. SUMMARY CUT-OFF WALL COSTS (a)

Site Name	Date	Cut-off Wall Type	Size (depth underlined)	Expenditure	Unit Cost
Anonymous Site A	1980	ASPEMIX (f)	2,000 X 17 X 0.83 ft-34,000ft^2 (510 X 5 X 0.025 m - 3,159 m^2)	$238,000	$7/ ft^2 ($75/m^2)
Anonymous Site A	1982	ASPEMIX (f)	2,929 X 17 X 0.83 ft-69,734 ft^2 (893 X 5 X 0.025 m - 6,478 m^2)	$976,276	$14/ft^2 ($150/m^2)
Chemical Recovery Systems, Inc.	1980	ASPEMIX (f)	1,465 X 10 X 1 ft - 14,650 ft^2 (447 X 3 X 0.3 m - 1,341 m^2)	$83,000	$5.60/ft^2 ($61/m^2)
Stroudsburg (d)	1981	bentonite cement slurry	648 X 17 X 1ft - 11,016 ft^2 (198.6 X 5.2 X 0.3 m - 1023 m^2)	$326,000(d)	$29.59/ft^2 (319/m^2)(d)
Richmond Sanitary Service (c),	1983	local clay	2,765 X 14.3 X 5ft-39,490 sq ft (843 X 4.4 X 1.5 m - 3,709 m^2)	$56,118	$1.42/ft^2 (15.13/m^2)
Vertac	1980	local clay compacted in lifts	NA (b)	NA	$0.21/ft^2 ($2.26/m^2
Engineering cost Model	1980	bentonite slurry	2,306 X 48 X 3.2 feet - 110,688 ft^2 (720 X 15 X 1 m - 10,800 m^2)	$588,130	$5.31-8.93/ft^2 (55-96/m^2)

(a) Costs are of limited comparability; see text.
(b) Reported to be 2 feet (0.6 m) thick by design drawings
(c) Based on Means "Building Construction" Cost Data: 1983.
(d) Includes excavating the trench, transporting and disposing of contaminated soil
(e) Total capital costs
(f) asphalt, sand, concrete, water emulsion.

engineering cost model estimate includes costs for specific related tasks that are not included in the costs for most of the case study cut-off walls. The following cost categories are included in the engineering cost model estimate:

Capital Costs	Lower U.S.	Upper U.S.
Geotechnical Investigation	\$3,850	\$6,520
Slurry Trench Excavation 2,306 X 48 - 110,688 ft^2 (720 X 15 X 1 m - 10,800 m^2) (3 feet (1 m) thick) (includes installation of bentonite slurry)	\$347,760	\$588,710
Bentonite, Delivered - 462 tons (419 Mt)	\$27,830	\$74,200
Capital Cost (subtotal)	\$379,440	\$669,430
Overhead Allowance (25 percent)	\$94,860	\$167,360
Contingency Allowance (30 percent)	\$113,830	\$200,830
Total Capital Costs	\$588,130	\$1,037,620
Unit Cost	\$5.31/ft^2 (\$54.46/m^2)	\$8.93/ft^2 (96/m^2)

Source: Rishel, et al. 1982 "Costs of Remedial Actions at Uncontrolled Hazardous Waste Sites," EPA-600/2-82-035.

Details of case study cut-off wall costs can be found in the individual case study reports. None of the case study site costs include the cost of contingency or geotechnical investigation. If these costs are excluded from the engineering cost model estimate, the engineering cost model estimated unit cost is 4.28 - \$7.56/ft^2 (\$46-\$81/m^2).

The engineering cost model estimates were derived from the Means and the Dodge costing guides along with cost information from Bentonite suppliers. Of the case study sites only the costs for Richmond Sanitary Service relied partly on the Means guide. The costing procedures used for the Richmond Sanitary case study differed from the cost model, however, in that the Richmond Sanitary costs were derived using daily construction progress reports to determine the actual hours of work performed, rather than an assumed number of hours for a similar operation in a non-hazardous setting.

The engineering cost model estimate lies in the middle of the case study cost range. It is over double the costs found for the case study clay and bentonite walls, except for Stroudsburg, for which the total cost figure included excavation, transportation and disposal costs for contaminated trench soil. The engineering cost model estimate is closer to the costs found for

for the ASPEMIX walls.

There were two categories of factors found to affect costs: technical and non-technical. Site characteristics such as waste/wall compatibility, impermeability requirements, and terrain dictate different technical specifications that affect costs. Also, economic factors such as marketing and inflation were found to affect costs. The following outline summarizes the factors found to affect slurry wall costs.

Factors found to Affect Cut-off Wall Costs In Case Studies:

A. Technical Factors
   1. Inclusion of Related Necessary Costs

      (a) Geotechnical Investigation (included in SCS estimate)

      (b) Excavation, transportation and disposal of trench spoils (included in Stroudsburg)

      (c) Subsurface drain

      (d) Staging area set-up (not included in Anonymous A, see case study)

   2. Cut-off wall characteristics

      (a) Permeability

         (i) Waste/wall compatibility, corrosion resistance (Anonymous A and Chemical Recovery Systems, Inc. (CRSI) waste incompatible with clay)

         (ii) Wall thickness variability (compare Anonymous A, CRSI with Richmond, Stroudsburg)

B. Non-technical Factors
   1. Contractor market entry loss investment
   2. Inflation effects

There are four types of related costs that may reasonably be included in the operation costs--(1) excavation, transportation and disposal costs for contaminated trench soil; (2) subsurface drain costs; (3) staging area set up; and (4) geotechnical investigation of these only the first was included in the total cut-off wall costs reported for one case study site Stroudsburg. It was included because it was considered a necessary part of the operation, and separate costs were not available. The subsurface drain costs were excluded from the cut-off wall costs in Chemical Recovery Systems, Inc. (CRSI) because it was useful to consider them separately, despite the fact that it is often a necessary part of the total cost in order to relieve hydraulic pressure on the wall, and prevent ponding. The cost of grading a staging area was included separately in Anonymous A because it was believed to be relatively unique to the terrain because the work was done on a dike.

Another factor limiting the comparison of slurry wall costs with ASPEMIX "grout curtain" costs, is the distinct permeability and installation characteristics of the two walls. The technical specifications of the different walls is such that the slurry wall could not have been used instead of the ASPEMIX wall in some cases for two reasons. First, in bench scale tests with lucite columns, the ASPEMIX walls were found to be less permeable per unit thickness than the clay cut-off walls (10^{-9} vs. 10^{-7} cm/sec). This was primarily due to greater corrosion resistance to waste of the ASPEMIX mixture. In independent bench scale tests, the wastes at Anonymous A and CRSI were found to cause coagulation, corrosion and eventually breakdown of the structured integrity of compacted clay. The lower permeability cut-off walls were required by court or administrative orders at both sites. Hence, the slurry wall was not adequate to meet State requirements.

Second, a standard slurry wall excavation technique would have threatened the integrity of the dike at the Anon A site, and hence could not have been used without substantially reinforcing the dike with new fill. Hence, comparison of the different costs shown for these different types of cut-off wall should be tempered with this consideration about the distinction in installation flexibility. Since this ASPEMIX wall was installed in a raised dike, the company's engineers were concerned that the excavation of the trench necessary for a clay or slurry trench cut-off wall would have threatened the interim integrity of the dike before the wall was completed.

In addition material costs varied between the wall types since the clay and slurry trench cut-off walls were installed with backhoes or excavators to varying thicknesses between 1-5 feet (0.3 - 1.5 m) depending on the characteristics of the wall materials and the site. These variations in thickness were found to cause more cost variations than the relatively fixed thickness of the ASPEMIX walls (4-9 inches (10 - 23 cm)). This difference in cost comparison is related to the secondary issue of how these different walls were found to be priced. The ASPEMIX wall was priced by the unit area (e.g., $/ sq ft), whereas local clay or slurry trench cut-off walls were found to be priced by the unit volume (e.g., $/cu yd). Again, the reason for these pricing unit differences is that ASPEMIX wall thickness is largely fixed between 4 - 9 inches (10 - 23 cm) by the size of the vibrating I-beam used to install the wall, whereas other cut-off wall thicknesses can vary more widely.

As with most excavation work, the cost of compacted clay or slurry trench walls was largely a function of volume of earth moved. The price per unit area costs are derived only for rough comparison purposes for Richmond Sanitary Service, Stroudsburg and Vertac in Table 12. The price per area derived from the volume is multiplied by the thickness (in equivalent units) because this thickness is necessary for each square area of the wall. (e.g., $0.28/cubic foot X 5 feet thick = $ 1.40/ square foot frontage). Again, however, it should be emphasized that the qualitative, technical differences between these walls limit the comparability of these costs.

The excavation volume and the total size of the cut-off wall may have had some effect on unit costs. However, for the case studies any effect of economies of scale on unit cost was apparently overshadowed by other factors. Although the engineering cost model included separate calculations for different scales of operation of cut-off wall construction, the cost per unit operation (e.g., dollars per cubic meter) was found to be very similar for vastly different scales of operation. The only remedial technology for which separate scale calculations showed significant economies of scale was well point systems.

Finally, nontechnical market forces were found to affect the cost of the ASPEMIX, which is a relatively new technology. The second wall at Anonymous A was significantly more expensive than the first wall there or at CRSI. However, the effect of increasing experience and streamlining may help absorb any future price increases. Also, inflation has a common effect on all costs but has an additional effect on the ASPEMIX cost. Since the asphalt component is petroleum based its cost varies as widely as petroleum prices. The engineers at Anonymous A noted that their cut-off wall would have cost significantly less if it was installed before the 1979 oil price increases.

Excavation, Transportation and Disposal--

The costs of excavation, transportation and disposal for the case study sites are given in Tables 12 and 13. Generally, the tables are organized in order of descending costs, and are grouped by RCRA-hazardous waste in Table 12 and PCB wastes in Table 13. Several significant site characteristics are given. Specific site characteristics are detailed in the individual case studies, and are outlined briefly below. The engineering cost model estimates are also given for comparison in each table.

The costs reported cannot be interpreted strictly as being statistically representative, but they illustrate the ranges of costs encountered and the factors that affect the costs, and provide data to compare with the existing engineering cost model estimates. The average unit cost for excavation, transportation and legal disposal of non-PCB, RCRA-hazardous waste for the eight case study sites (11 waste streams) shown in Table 12 for which all three costs were available was \$187.64/Mt (SD=\$97.22) - \$198.64/Mt (SD=\$91.47). The lowest total cost shown of \$48.48/Mt for one contractor at Fairchild Republic Company was for illegal disposal. The average cost of PCB waste excavation, transportation and disposal for the three sites (5 waste streams) in Table 13 was \$415/Mt (SD=\$132/Mt). These costs generally included the cost of personnel protective gear, loading, permitting and other related costs discussed briefly below. They do not include operation and maintenance costs for future site monitoring because all wastes are assumed to be removed, for the purposes of data comparison.

TABLE 12. EXCAVATION, TRANSPORTATION, DISPOSAL COSTS

Site Name	Date	Material	Quantity (c)	Contaminant	Excavation Depth	Excavation	Transportation Distance (a)	Disposal (b)	Total
Occidental Chemical	1981	bottles (f) pallets	562 m^3	pesticides (DBCP, etc.)	4.6 m	$191/$m^3$	$144/$m^3$ (225 km)		$335/$m^3$
Marty's GMC	1981	soil sludge	804 m^3 (d) 151 drums	chlorinated solvents	1-5 m	$ 61/m^3	$149/Mt (825 km)	$92/Mt	$302/Mt
Occidental Chemical	1981	soil (g)	562 m^3	pesticides	4.6 m	$191/$m^3$	$98/$m^3$ (225 km)		$289/$m^3$
University of Idaho	1981	soil sludge	625 m^3	pesticides solvents	4m	$251/ m^3 (409 km)			$251/$m^3$
Occidental Chemical	1981	soil (h)	2,435 m^3	pesticides	4.6 m	$191/$m^3$	$46/$m^3$ (225 km)		$237/$m^3$
Goose Farm	1981	drums soil	3,900 m^3	solvents metals	5-8 m	$44-90/$m^3$	$63/Mt (708 km)	$44/Mt	$151-207/Mt
H & M Drum	1981	drums soil	368 Mt	solvents	--	--	$79/Mt (772 km)	$93/Mt	--
Houston Chemical	1979	soil	2,015 m^3	PCP	0.01-0.015 m	$40-90/$m^3$	$26/Mt (273 km)	$48/Mt	$114-164/Mt
Gallup	1978	drums soil	3,647 Mt	solvents metals	1-4 m	$14/$m^3$	$74/Mt (800 km	$44/Mt	$132/Mt
Engineering cost model Estimate (e)	1980	"landfill"	596,388 m^3 or 324,620 Mt	"hazardous waste"	4 m	$2.38-2.75/$m^3$	$3.18-6.17/Mt(32 km)	$121.26/Mt	$128.57-$133/Mt

(a) One way distance

(b) Land filling unless otherwise noted

(c) standard m^3: Mt landfill ratio=1:1 unless otherwise noted

(d) 470 Mt disposed, m^3: Mt ratio used by contractor=1:.3;211 Mt aerated on-site

(e) Cost model=1.5m^3:1 Mt

(f) CA Class I "extremely hazardous"

(g) CA Class I "hazardous"

(h) CA Class II - I

TABLE 12. (continued)

Site Name	Date	Material	Quantity (c)	Contaminant	Excavation Depth	Excavation	Transportation Distance (a)	Disposal(b)	Total
Quanta Resources	1982	oil	299 m^3	solvents	-- (d)	--	\$99/Mt (1,316 km)	\$22/m^3 incineration	--
Mauthe	1982	soil	76.5 m^3	hexavalent chromium	1.2 m	\$19/m^3	\$ 80/m^3 (365 km)		\$99/Mt
Fairchild Republic	1981	soil sludge	4,129 m^3	solvents chromium	0.6-1.7 m	\$97/m^3 (100 km)			\$97/Mt
Howe	1979	ice soil	1,988 Mt	pesticides	0.3-0.6 m	\$10/m^3	\$37/Mt (225 km)	\$10-25/Mt landfarming	\$57-72/Mt
Fairchild Republic	1980	soil sludge	1,856 m^3	solvents chromium	0.6-1.7 m	\$48.48/ m^4 illegal			\$48.48/Mt
Chemical Metals	1981	soil debris	91 Mt	metals	-- (d)	--	--	\$41/Mt	--
Anonymous Site A	1980	waste water	35,200 Mt		-- (e)	--	\$39.63/ Mt (24 km)		--
Anonymous Site A	1980	waste water	146,000 Mt	carbon fungicide	-- (e)	--	\$31.70/ Mt (80 km)		--
Anon. A	1980	waste water	205,000 Mt	ammonia fertilizer	-- (e)	--	\$5.28-7.93/Mt land farming		
Engineering cost model Estimate	1980	"landfill"	596,388 m^3 324,620 Mt(f)	"hazardous waste"		\$2.38-2.75/m^3	\$3.18-6.17/Mt (32 km)	\$121.26/Mt	\$128.57 - \$133/Mt

(a) One-way distance
(b) Land filling unless otherwise noted
(c) Standard m^3: Mt landfill conversion of 1:1 used unless otherwise noted
(d) surface scraping, no excavation
(e) lagoon emptying
(f) m^3: Mt conversion used by the engineering cost model

TABLE 13. EXCAVATION, TRANSPORTATION, DISPOSAL PCB WASTES

Site Name	Date	Material	Quantity(c)	Contaminant	Excavation Depth	Excavation	Transportation Distance (a)	Disposal (b)	Total
Quanta Resources	1982	oil	147 Mt	PCB	-- (c)	--	\$276/Mt (2,800 km)	\$277/Mt incineration	\$553/Mt
	1982	pumbable sludge	216 Mt	PCB	-- (c)	--	\$267/ Mt (2,285 km)	\$259/ Mt incineration	\$526/Mt
Marty's GMC	1981	soil sludge	63 Mt	PCB	1-5 m	\$61/m^3	\$149/Mt (825 km)	\$228/Mt	\$438/Mt
College Point	1980	flyash/ oil, soil	2,514 Mt	PCB	-- (d)	--	\$81/Mt (644 km)	\$212/Mt	\$264/Mt
Quanta Resources	1982	solidifed sludge	6.5 Mt	PCB	-- (c)	--	\$264/ Mt (644 km)		\$264/Mt
Engineering cost model Estimate	1980	"landfill"	596,388 m^3 or 394,510 Mt	"hazardous waste"	4 m	\$2.38-2.75/m^3	\$3.18-6.17 /Mt(32 km)	\$121.26/Mt	\$128.57-131.59/Mt

(a) One-way distance

(b) Landfilling unless otherwise noted

(c) surface tanks, no excavation

(d) surface scraping

(e) m^3: Mt conversion used by the engineering cost model = 1.5:1

The engineering cost model estimates for excavation, transportation and disposal costs are based on the following capital costs:

Capital Costs	Lower U.S.	Upper U.S.
Total Cost includes:		
780,000 cu yd (596,388 m^3) 357,832 tons (324,620 Mt). Excavation/grading (includes truck loading)	$944,140	$1,094,190
Transportation, 30-ton (27 Mt) dump truck (64 km RT)	$687,040	$1,465,680
Hazardous Waste Surcharge for Excavation and Transportation (50 percent)	$815,590	$1,279,940
Tipping Fee	$39,361,520	$39,361,520
Capital Cost	$41,808,290	$43,201,330
Unit Cost	$53.60/cuyd	$55/cuyd
	($70/$m^3$)	($72/$m^3$)
	$117/ton	$121/ton
	($128/Mt)	($133/Mt)

Source: Rishel et al. 1982. "Cost of Remedial Actions at Uncontrolled Hazardous Waste Sites" EPA-600/2-82-035.

The 50% hazardous waste surcharge in the engineering cost model estimate was proportionally allocated to the excavation and transportation costs for the purpose of calculating unit costs. The hazardous waste surcharge of 50 percent for excavation and transportation includes increased costs due to:

- o Personnel safety equipment
- o Increased labor rest time
- o Equipment modification and decontamination
- o Increased insurance costs
- o Transportation permits.

The m^3: Mt ton conversion of 1.5:1 is based on the given quantities of 596,388 m^3 = 357,832 tons, used for the engineering cost model.

Direct comparison of case study costs with each other and with the cost model estimates is limited by individual site specific characteristics. However, these characteristics represent some of the factors that may affect costs. The outline below lists significant factors found to affect costs at case study sites.

Factors Found to Affect Excavation, Transportation and Disposal Costs in Case Study Sites.

I. Technical

A. Excavation or On-site Transfer
1. Excavation depth
2. Site surface characteristics
3. Waste explosivity
4. Material - liquid/solid/drums
5. Waste quantity

B. Transportation

1. Distance to disposal facility
2. Accessibility to road
3. Material - liquid vs. solid
4. Waste quantity

C. Disposal

1. PCB

a) concentration - over/under 500 ppm
b) material - solid vs. liquid

2. Non-PCB RCRA Hazardous

(a) solid vs. liquid
(b) aqueous vs. organic

II. Non-Technical

A. Community relations
B. Interstate relations
C. Inflation and regulatory factors.

The costs for excavation or on-site transferring of waste were found to be affected by the five factors shown in the above outline. The effect of excavation depth on costs is probably non-linear, since the most significant cost changes resulted from equipment differences. For example, the depth of excavation at University of Idaho, Goose Farm and Marty's GMC necessitated the use of a Caterpillar 235, which is a large, treaded backhoe (excavator), with a 30 foot (10 m) arm, which rents for about $65/hour without crew.

At other sites where the excavation depth was shallower, a smaller, less expensive backhoe such as a Case 580C was used. At sites where only surface scraping was performed, a front loader, which is generally even less expensive, was used. Excavation was performed at a relatively quicker pace, which reduced labor and rental costs, at sites with sandy soil and unconsolidated soil. At Quanta and Anonymous A, no excavation costs were incurred because removal involved pumping liquid waste into trucks from tanks and ponds, respectively. Although no cost information was available for this type of bulkpumping operation, it was believed to be much less expensive than digging or scrapping.

Site surface characteristics probably had a relatively small effect on the excavation costs at most of the case study sites. At Marty's GMC the waste was excavated from a steep embankment. Clean fill was removed from the top of the embankment to prevent its cross-contamination with the wastes buried at the toe during the excavation. This process added slightly to the labor and rental charges. Muddy conditions at Houston Chemical caused some delays in excavation work.

Explosivity of waste affected removal costs at Chemical Metals Industries, where highly explosive zirconium powder was found. This cost is not shown in Tables 12 or 13 because it was internalized by the City of Baltimore, whose bomb squad disposed of the waste. Much more time and care was required for this removal than for other wastes.

The loading costs for liquids were lower than for solids and were generally too low to be significant. But solidification costs for transportation or incineration costs for disposal may have negated this lower cost. Liquid wastes at Quanta and Anonymous A were quickly and continuously pumped into trucks or trains instead of by the bucket load as with contaminated soil. Drum handling was most efficiently performed with a hydraulic drum grappler at Marty's GMC and Goose Farm. This backhoe attachment rented for over $200/day, but reduced labor costs and other equipment charges by speeding up the loading process. The net cost effect is unclear from the available case study data, but the use of this apparatus by experienced removal contractors suggests its economizing value.

Finally, waste quantity may have affected excavation costs through unquantifiable economies of scale. Larger sites such as Fairchild Republic Company and Occidental Chemical could maximize the use of daily rental charges of backhoes because of the greater amount of waste present. However, this effect does not appear to be significant since waste quantity and unit excavation cost do among the case study sites does not appear to be related. Although the engineering cost model included separate calculations for different scales of operation of excavation and removal, the cost per unit operation (e.g., dollars per cubic meter) was found to be very similar for vastly different scales of operation. The only remedial technology for which separate scale calculations showed significant economies of scale was well point systems.

Hazardous waste transportation costs at the case study sites were found to be affected primarily by the four factors given in the above outline. The distance between the removal and disposal sites appeared to be the most significant factor affecting transportation costs. Since PCB waste transportation costs did not appear to vary significantly from non-PCB RCRA waste, transportation costs for both waste types are listed together in Table 14. The average cost for the ten sites for which separate transportation costs were available was $0.16/ton/mile (SD = $0.053/ton/mile) ($0.11/Mt/km SD = $0.03/Mt/km)). The engineering cost model estimate falls within the range of costs found for the case study sites.

The accessibility of the site to major roads was found to affect transportation costs at Occidental Chemical. The contractor stated that a relatively lower price was charged because the site was near a major interstate highway which led to the disposal site. This proximity to the highway minimized the distance travelled on secondary roads and was said to cause less wear and tear on the trucks. This factor may have affected transportation costs at other sites where it was not stated explicitly.

TABLE 14. TRANSPORTATION UNIT COSTS

Site	Unit Weight Cost (divided by)	Distance =	Unit Distance Cost
Marty's GMC	$149/Mt	825 km	$0.18/Mt/km
Goose Farm	$63/Mt	708 km	$0.09/Mt/km
H & M Drum	$79/Mt	772 km	$0.10/Mt/km
Houston Chemical	$26/Mt	273 km	$0.09/Mt/km
Gallup	$74/Mt	800 km	$0.09/Mt/km
Quanta	$99/Mt	1,316 km	$0.06/Mt/km
Howe	$37/Mt	225 km	$0.16/Mt/km
Quanta	$276/Mt	2,800 km	$0.10/Mt/km
Quanta	$267/Mt	2,285 km	$0.11/Mt/km
College Point	$ 81/Mt	644 km	$0.13/Mt/km
Average	--	--	$0.16/ton/mile ($0.11/Mt/Km)
Standard deviation	--	--	$0.053/ton/mile ($0.036/Mt/Km)
Standard error	--	--	$0.017/ton/mile ($0.012/Mt/Km)
Engineering Cost Model Estimate	$3.18 - 6.17/Mt	32 km	$0.09-0.19/Mt/km

The type of waste material affected transportation costs by dictating the transportation method. Liquid wastes were most economically transported in bulk using truck or train tankers. Solid waste was generally transported via truck, which required extra costs for plastic lining and tailgate sealing. Sealing of bulk liquid tanks was quicker because it only required closing and checking valves, instead of the silicon foam or asphalt sealing necessary on dump truck tailgates.

The cost of transportation was also affected by the waste quantity because of its influence on the type of transportation used. Economies of scale were achieved by using bulk tank trucks and rail cars for large quantitites of liquid waste at Quanta and Anonymous A. Rail tankers, which carried several times as much as trucks, provided the lowest unit transportation cost, as shown in the Quanta case study. Economies of scale with solids transportation costs were generally limited by state laws regarding weight per axle. Hence, the five axle, 20 cubic yard (15 m^3) dump truck was generally used.

The most significant factor affecting disposal costs was whether the wastes were PCB contaminated. The cost of disposal for PCB waste was much higher than non-PCB hazardous waste. Among the PCB wastes, waste oil with over 500 mg/l PCB at Quanta was disposed of separately from PCB oil with between 50 - 500 mg/l. The disposal cost alone was the same for waste oil above and below 500 mg/l, but the required separate handling affected other costs because of economies of scale. Liquids from Quanta were disposed of by incineration, at a slightly higher unit cost than solids, which were landfilled.

A wide variation in disposal costs for non-PCB RCRA hazardous waste is shown in Tables 12 and 13. Liquid wastes that were solidified prior to landfilling, such as at Houston Chemical, cost more per excavated weight because the weight and bulk increased due to the added solidification material such as sawdust or lime. Aqueous wastes such as those at Anonymous A had lower tipping rates than the organic wastes at other sites.

The non-technical factors affecting costs are difficult to quantify fully. An increase in disposal cost was encountered at Howe when the community near a proposed incinerator blocked disposal of the waste there, which required a more expensive disposal option to be used. At Quanta, delays and more expensive disposal options were encountered when an out-of-state landfill refused to accept wastes. The city's consultant stated that this problem "had less to do with waste characterization data discrepancies as with inter-state regulatory political factors." Pre-1981 costs were significantly lower than the post - 1981 costs. This may be due to the anticipated RCRA landfill regulations, as well as inflation.

Site Investigation--

All 23 responses studied included some site investigation work, ranging in scale from rapid sampling of surface media during emergencies to detailed hydrogeological surveys. The costs for the variety of investigational work at the 15 sites for which this data was available are listed in Table 15. The percentage of the total site response cost that this investigation cost represents is given for comparison of the scale of work. No engineering cost model estimate of investigation costs estimate is available for comparison. The cost of investigations ranged from $7,643 (N.W. Mauthe) to $1,425,000 (Occidental Chemical Co.). Twelve, or 80%, of the investigations cost less than $131,000. If the investigation cost is expressed as a percentage of the total response cost, the figures range from 4% (Marty's GMC) to 35% (Anonymous C). Nine investigations cost between 8% and 13% of the total response cost. It is important to note that the ratio between investigation costs and total costs is as much a function of the cost of the remedial measures as it is of the cost of investigations.

Because of data limitations such as unquantified costs or limited cost breakdowns, some of the actual investigation costs probably varied from the figures reported in Table 15. As noted in the table, six of the investigation cost figures also include the cost of engineering design for subsequent

TABLE 15. SITE INVESTIGATION COSTS

Site Name	Cost of Investigation	Percentage of Total Response Cost
Anonymous B	$ 23,794	9%
Anonymous C	$ 8,000 (b)	35%
Biocraft	$ 73,948	8%
Fairchild Republic	$ 107,000 (a)	24%
Gallup	$ 61,333	10%
Howe, Inc.	$ 62,536 (a)	13%
Marty's GMC	$ 25,000 (b)	4%
N.W. Mauthe	$ 7,643	10%
Occidental Chemical	$1,425,000 (a)	32%
Quanta Resources	$ 217,395 (b)	10%
Richmond Sanitary	$ 15,000 (a)	14%
Stroudsburg	$ 130,999 (b)	22%
Trammell Crow	$ 50,000 (a)	12%
Univ. of Idaho	$ 18,237	10%
Vertac Chemical	$ 531,000 (a)(b)	26%
Average investigation cost		16%
Standard deviation		9%
Standard error		2%

(a) Includes engineering design costs
(b) There were additional unquantified investigation costs.

remedial measures. Engineering costs may account for 15% to 80% of the reported figures. Also, at five sites noted in the table, there were unreported costs associated with other investigative work that occurred. This work most often was initial sampling performed by in-house employees of government agencies before contractors were hired to perform in-depth investigations.

While the 15 site studies varied widely in scope and complexity, there were a few similarities among them. All studies involved some subsurface investigation, such as soil borings, monitoring wells, or test trenches. All but one (Richmond Sanitary Service) involved sampling and analysis for contaminants. All but one (Anonymous B) were performed by outside contractors.

There were a number of factors that contributed to the wide variation in site investigation costs evident in Table 15. These can be categorized according to sampling factors and analysis factors, which are detailed in the outline below and explained in the text that follows.

Factors Found to Affect Site Investigation Costs in Case Studies

A. Sampling

1. Number of samples

2. Number of sampling points

3. Sampling medium (e.g., air, surface, or subsurface)
4. Wells and borings
    a. depth
    b. diameter
    c. site geology
    d. single or cluster wells
    e. conjunctive use of wells
5. Worker safety requirements

B. Analysis

1. Number of samples analyzed
2. Number of contaminants analyzed for
3. Type of contaminants analyzed for
4. Quality control (e.g., independent split-sample analysis)
5. Laboratory on-site or off-site.

The most significant factors affecting sampling costs were the quantity of samples taken, the number of sampling points, and the medium being sampled. Sampling subsurface media tended to be more costly because it usually required excavation, soil borings, or monitoring wells. Resistivity testing and metal detectors were exceptions to this.

Soil boring and sampling well costs were significantly affected by site geology and the required depth and diameter of the borings. The cost of a well in an investigation was affected further by whether it had a conjunctive use in the site response. For example, if a well was installed for sampling purposes, but later became part of a ground water recovery system, the cost was appropriately distributed between investigational and remedial costs. This was the case at Biocraft and Howe, where wells that were initially installed for monitoring were subsequently retrofitted for extraction pumping or aeration.

Finally, the need at some sites for worker safety measures seemed to increase investigation costs substantially. For example, in the site investigation at Quanta Resources, workers often wore self-contained breathing apparatus or respirators and protective clothing, and air quality was monitored continuously.

The major factors that affected the cost of sample analysis were the number of samples analyzed, the number and type of contaminants analyzed for, and quality control measures such as split-sample analysis by separate laboratories. Additionally, use of on-site laboratories could reduce analysis costs, but in the case of mobile labs, had to be balanced against rental costs. On-site labs generally offer the benefit of rapid turnaround time, which can hasten an investigation and allow the clean-up phase to begin sooner than would be possible if a distant off-site lab were used. Use of a mobile on-site lab at Quanta Resources is an example of this project acceleration.

An additional factor, that seemed to be related to the proportion of site costs spent on investigations, was the role of enforcement actions. The five sites that involved significantly greater shares (20% v. 10%) of investigation resources, were all conducted under intensive enforcement action (Anonymous C - 35%, Fairchild Republic - 24%, Occidental Chemical - 32%, Stroudsburg - 22%, and Vertac Chemical - 28%). Of these, all but Stroudsburg were conducted by private parties. Stroudsburg involved parallel private and government clean-up operations. Of the remaining ten sites, four were cleaned-up privately using a relatively small proportion of investigation costs (8-14%).

Subsurface Drains--

The costs of the subsurface drains used in the case study sites are presented in Table 16. Capital but not operation and maintenance costs are included. The costs are given with significant drain characteristics, along with the engineering cost model estimate for comparison. The subsurface drain costs ranged from $2.78-$71/foot^2 ($30-$768/m^2) for the case study sites. The engineering cost model estimate ranged from $4.88-$9.42/foot^2 ($53-$102/m^2). This wide range of costs results from a variety of individual drain purposes, characteristics, and the inclusion of related costs. These factors are discussed briefly below to the extent that they illustrate cost considerations, following a description of the engineering cost model estimate and an explanation of the unit cost calculation.

The unit costs are given in $/unit area of one side of the trench instead of $/unit length, $/total perimeter area, or $/unit volume of trench, because $/unit area most clearly and accurately conveys the functional cost of the subsurface drains, using the available data. A unit cost per length, as used in the engineering cost model estimate, would exclude from consideration the trench depth which is an important element of the cost and function of the drain. Width of the trench is not included in calculating cost per unit area, since width represents a relatively insignificant proportion of the total area intercepted by a drain. The following costs are included in the engineering cost estimate model given in:

TABLE 16. SUB SURFACE DRAIN COSTS

Site Name	Date	Dimensions - length X depth: on area (a)	Width	Sump depth (s), other characteristics	Total Cost	Unit Cost
General Electric	1981	210 x 22.5ft:4,725 ft^2 (64 x 7m: 439 m^2)	3 ft (1 m)	29.5 feet (9 m) triple level drain (b)	$337,000	$71/foot^2 ($768/m^2)
Anonymous Site B	1980	261 x 12-16 ft: 3,122 - 4,176 ft^2 (80 x 4-5 m:290-387 m^2)	4 - 6ft. (1.3 - 2 m)	20 feet (6 m) + bucket well (e)	$207,046	$50-66/ft^2 $538-710/m^2)
Biocraft Laboratories	1981	280 x 10 ft:2,800 ft^2 (c) (85 x 3 m: 260 m^2)	4 ft (1.3 m)	no sump	$110,000	$39/ft^2 ($420/m^2)
Chemical Recovery	1976, 1980	990 x 7-10 ft: 6,930-9,900 ft^2 (302 x 2-3 m: 644-920 m^2)	--	rebuilt drain (d)	$71,000(d)	$7 - 10/ft^2 ($77-110/m^2)
N.W. Mauthe	1982	750 x 3 ft: 2,250 ft^2 (229 x 1 m: 209 m^2)	2 ft (0.6 m)	2 sumps- 4 feet (1.2 m) 6 feet (2 m)	$18,000	$8/ft^2 ($86/m^2)
Anonymous C	1981	240 x 12 ft; 2,880 ft^2 (73 x 3.7 m: 268 m^2)	4ft (1.3 m)	15 ft (5 m)	$8,000	$2.278/ft^2 (30/m^2)
Engineering cost model	1980	197 x 16 ft: 3,232 ft^2 (60 x 5m : 300 m^2)	3.3 ft (1 m)	--	$ 15,780- 30,450	$4.88-9.42/ft^2 $52.60-101.50/m^2

(a) surface area of one side .

(b) slotted pvc piping stack 1 foot (0.3 m) apart, three arms to sump summed.

(c) three trenches summed, 2 injection, 1 withrawal

(d) includes original and renovation costs

(e) cost includes additional bucket well

Capital Costs*	Lower U.S.	Upper U.S.
Trench Excavation (300 m^3)		
5 m (d) x 1 m (w) x 60 m (L)	$ 400	$ 450
(3,232 ft^2, 300 m^3)		
Cement Pipe (70 m)	$ 570	$ 880
Gravel (70 m^3)	$ 500	$ 760
Sump (1)	$1,100	$1,870
Pump, Submersible (1)	$ 550	$ 900
Capital Costs (subtotal)	$12,620	$24,360
Overhead Allowance (25 percent)	$ 3,160	$ 6,090
Total Capital Costs	$15,780	$30,450
Unit Costs	$ 4.88/ft^2 ($53/$m^2$)	$ 9.42/ft^2 ($102/$m^2$)

*As with case study costs, the model estimates do not include operation and maintenance costs.

Source: Rishel et al. 1982. "Cost of Remedial Actions at Uncontrolled Hazardous Waste Sites." EPA-600/2-82-035.

The cost of the subsurface drains in Table 16 are of limited comparability because of the varied characteristics of the different drains. However, by considering the characteristics of the two basic elements of the drains, trench and sump, the cost variation can be explained. The following factors were found to significantly affect the cost of subsurface drains at the case study sites:

A. Collection Trench
   1. trench length and depth
   2. plumbing complexity
   3. gravel installation

B. Leachate Storage
   1. sump size
   2. tank size.

An additional significant factor regarding both construction cost elements is the potential need for disposing of contaminated soil encountered while constructing the trench or the sump. Excavation of contaminated soil, which sometimes resulted in additional costs for disposal, occurred when trenches were constructed within a contaminated area, rather than at the site perimeter. This additional cost was incurred at Mauthe where hexavalent chromium contaminated soil was disposed of from the hole excavated for a sump. However, at General Electric, PCB contaminated soil was returned to the drain cap because the system was considered an "Immediate Correction Plan", not a long term remedy. This action saved the cost of off-site disposal of the PCB soil.

The importance of the trench size is discussed above in connection with unit cost dimensions. The trench size depended on factors such as waste type, soil permeability, climate and purpose of the system. At General Electric a relatively large three-armed drain system was used because of the relatively tight soil and the strong adhesion of the PCBs to the soil, and because California's Mediterranean climate has seasonally heavy rains. The length of the drain at Chemical Recovery Systems reflected its purpose of relieving hydraulic pressure on the ASPEMIX cut-off wall. At Biocraft the purpose of the relatively small drain at trench A was to collect contaminated water by creating a cone of depression. The size of the drains affected construction costs by dictating different installation methods between the deepest and the most shallow drains. At General Electric steel sheet piling was driven into place to support the 30 foot (10 m) deep trenches during construction, whereas at Mauthe no reinforcement was necessary for the 3 foot (0.3 m) deep trenches. The cost for trench reinforcement necessary for the deeper drains at General Electric and Anonymous B, which used steel sheet piling, and Biocraft, which used plywood shoring, was perhaps the most important factor in the different case study drain costs. The available cost data breakdowns are inadequate to confirm this relationship, but the cost difference among these shown in Table 16 suggests its significance.

The plumbing complexity of the collection pipe running the length of the trench ranged from a single pipe to multi-level pipes. At most of the case study sites a single pipe ran the length of the trench and drained into a collection sump or as in the case of Biocraft, was drained by an extraction pump. A General Electric, three levels of slotted PVC piping were installed in each of three trench arms, with valves into the sump at each level to control the flow from the different oil-lense depths. The cost for design, materials and installation of the trench plumbing part of the system at General Electric was significantly higher than the other case study sites.

The gravel fill installation procedure affected the costs of the drain at one site, where a different design was used. At Biocraft, an outer layer of 1/4 inch (0.6 cm) washed stone was placed around an inner layer of 1 1/2- inch (3.2 cm) stone, which surrounded the collection pipe. This relatively complex design was intended to provide filtration by the outer layer and high collection rates from the coarser inner layer. This added expense was intended to obviate the need for future operation and maintenance costs for clearing the clogged pipe. Reconstruction of a drain installed in 1976 that had become clogged was necessary at Chemical Recovery Systems. Drains at the other case study sites used a single size of stone or gravel.

The second cost item included in the costs of the subsurface drains is for storage of collected water in sumps or tanks. Biocraft was the only site for which leachate storage costs are not included because the collected water was pumped directly into the treatment system. The inclusion of sumps in the other case study site costs assumes that the size and cost of sumps and storage tanks were generally proportional to the size of the collection trench. The storage systems differed in type as well as size. Large prefabricated concrete sumps were used at the end of some drains, whereas steel tanks or pipes were used at others.

Solidification--

Some form of waste solidification was performed in 5 of the case study responses. Of these, only one, Trammell Crow, involved on-site solidification plus on-site landfilling. At the other 4 sites, Marty's GMC, Houston Chemical, College Point and Quanta, various materials were used to solidify wastes for off-site landfill disposal.

The cost and method of solidification in all 5 of these responses were affected by the nature of the waste, particularly its viscosity, and the price, proximity and availability of solidification materials. Of the 5 sites, only the data for Trammell Crow permit the solidification cost to be distinguished from other tasks performed. The total cost of the Trammell Crow project was $427,527, which included $50,000 for a feasibility study. The project involved mixing, at a ratio of about 1:1.5, 25,000 yd^3 (1.9 x 104 m^3) of oil sludge with 41,000 tons (3.7×10^4 m^3) of kiln dust in a landfill constructed on-site. About a quarter of the kiln dust was fresh; the remainder was stale, which had a lower absorption capacity than fresh kiln dust.

The other 4 sites involved a variety of solidification materials. At College Point, New York City officials purchased fly ash from municipal incinerators to solidify PCB-contaminated oil for off-site disposal. The ratio of fly ash to oil ranged from 5:1 to 99:1. At Quanta Resources, the clean-up contractor used lime to solidify non-pumpable RCRA-hazardous sludge at a ratio of 1:1. At Marty's GMC, Massachusetts officials mixed 18 drums of liquid waste with solid waste and soil for off-site landfilling. At Houston Chemical, in the course of scraping and removing soil contaminated with pentachlorophenol (PCP), it was necessary to use sawdust from a nearby sawmill to solidify watery mud before trucking it off-site.

Waste Water Treatment Costs--

The costs for water treatment at eight case study sites and the comparable engineering cost model estimate are listed in order of decreasing unit cost in Table 17. These costs include either: operation and maintenance costs for permanent systems constructed on-site; labor, material and rental costs for temporary on-site systems; prices charged by contractors for water sent to commercial industrial waste treatment plants; or the prices charged by publicly owned treatment works (POTWs) for accepting waste water. Capital costs generally are not included because they are not always applicable and because calculation of amortization is not possible because of uncertainty about operational lifetimes. The cost of withdrawing ground water is not included in these costs but is discussed briefly with other factors below to the extent that it influenced treatment costs. Unit cost information may be more appropriately expressed in terms of price per unit of contaminant removed, but adequate data was inconsistently available for this level of data

TABLE 17. CONTAMINATED WATER TREATMENT COST (a)

Site Name	Date	Treatment Technology	Primary Contaminant	Quantity Treated	Expenditure	Unit Cost
General Electric	1981	On-site advanced oil/ water separator	PCB/oil	1,000-1,500 gallons (3,785-5678 l)/ month	\$4,167/month	\$2.70-4.6/gal (\$0.73-1.10/l)
Quanta Resources	1982	Off-site Commercial Treatment	Cyanide	9,425 gallons (35,674 l)	\$12,724	\$1.35/gallon (\$0.036/l)
Goose Farm	1980	On-site carbon, clarification, air stripping	mixed solvents, PCB	7.8 x 10^6 gallons (2.9 x 10^9 l) over 6 month period	\$2 - 3 million	\$0.26-0.40/gal (b) (\$0.068-0.10/l)
Houston Chemical	1979	On-site carbon, pea gravel/lime filtration	Pentachlorophenol (PCP)	2 x 10^6 gallons (8 x 10^6 l) over 1 month period	\$200,000-350,000	\$0.10-0.18/gal (\$0.026-0.048/ l)
Biocraft Laboratories	1983	On-site Biodegradation	methylene chloride, butanol, acetone	13,680 gallons (51,779 l)/day	\$226.53/day	\$0.0165/gal (\$0.0044/l)
Mauthe	1982	Off-site POTW (c)	hexavalent chromium	273,000 gallons (1.03 x 10^6 l)	\$2,275	\$0.008/gallon (\$0.002/l)
Howe, Inc.	1979	Off-site POTW (c)	Pesticides (atrazine, alachlor)	9 x 10^7 gallons (3.4 x 10^8 l) over 5 month period	\$50,169	\$0.00056/gallon (\$0.00015/l)
Occidental Chemical	1982	On-site Granular Activated Carbon (reverse pulse)	Pesticides (DBCP)	1.5-2.6 x 10^8 gallons (6.8-9.8 x 10^8 l)/year	\$133,320-370,800/year	\$0.0005-0.0011/ gallon (\$0.00013-0.00029/l)
Engineering cost model	1980	On-site "Chemical, biological and/or physical"	"contaminant"	4.3 x 10^7 gallons (1.6 x 10^8 l)/year	\$51,900-94,340/year	\$0.0012-0.0022/gal. (\$0.00032-0.00058/l)

(a) Operation and maintenance, or rental cost

(b) Includes ground water recovery cost

(c) Publicly Owned Treatment Works

analysis. The engineering cost model estimate reflects the operation and maintenance cost for a generalized "chemical, biological, and/or physical treatment" system constructed permanently on-site at a total capital cost of $669,900 - $1,134,050.

The following operation and maintenance costs are included in the engineering cost model estimate:

Operation and Maintenance Cost*	Lower U.S.	Upper U.S.
Operating Cost (3 operators) (2,080 hr/yr ea.) (6,240 hr/yr total)	$39,300	$81,740
Power Cost (electricity) (32,000 kwh/yr)	$$1,600	$ 1,600
Chemical cost (16,922/ day) X 260 days/year	$11,000	$11,000
Total O & M Costs	$51,900	$94,340
Unit operation & maintenance cost	$0.0012/gallon ($0.00032/1)	$0.00032/gallon ($0.00058/1)

*For treating (116,443 gallons (440,740 1) of contaminated ground water/day at a medium size site of 13 acres (5.41 ha).

Source: Rishel et al. 1982 "Costs of Remedial Actions at Uncontrolled Hazardous Waste Sites," EPA 600/2-82-035.

Details of case study water treatment costs can be found in the individual case study reports. The component tasks in the engineering cost model estimate do not appear to differ significantly from those included in the cost for case study sites. The cost estimated by engineering cost model is between the two case study costs incurred for water discharged to POTW's. The technical characteristics of the hypothetical system used for the engineering cost model estimate were not described.

Direct comparison of the case study costs with each other and with the engineering cost model estimates is limited by individual site characteristics. However, these characteristics can indicate some factors that may affect costs. The significant factors that influenced treatment costs in the case studies are listed in Table 17 and are outlined below.

Factors Found to Affect Water Treatment Costs in Case Studies.

A. Technical Factors

1. Nature and degree of contamination
   a. Treatability
   b. Solubility
   c. Concentration
   d. Diversity of contaminants

2. Variations in type of treatment processes selected
    a. Carbon
    b. Biological
    c. Physicochemical secondary treatment (POTW)
    d. Other individual treatments (e.g., air stripping, fabric filtering)
3. Variations among particular processes
    a. Level of treatment
    b. On-site/off-site
    c. Efficiency
    d. Treatment system capacity
    e. Collection limitations
    f. Climate

B. Non-technical Factors

1. POTW rate system
2. Use of existing system
3. Rental vs. purchase of treatment system
4. Market competition by treatment contractors
5. Inflation.

The cost factors are organized into three categories of technical factors and several non-technical factors. The choice of treatment process was usually dictated by the nature and extent of contamination. For example, high concentrations of a refractory contaminant like cyanide at Quanta precluded the exclusive use of a standard POTW or on-site filtering and clarification.

The three technical categories in the outline are separated to distinguish between the contaminant characteristics and the actual choice of the treatment alternative. The variation in cost of a particular process was often related to general site and contaminant characteristics such as the required extent of treatment in terms of volume and concentration reduction. These categories help identify the specific cost factors found in the case studies.

Before considering the costs found for different treatment processes, the data in Table 17 should be clarified by highlighting the highest and lowest treatment costs found in the case studies because of the apparent anomalies they represent. These cost variations were affected by characteristics of the particular system at the site, not the type of process.

The unit treatment cost at General Electric was relatively high because of a combination of high operation and maintenance costs and low volume of treated wastes. The unit operation and maintenance cost was unusually high at General Electric because the capacity of the treatment system was several times the volume actually treated. The volume of water treated was low because the tight soil minimizes the recharge into the sump from the subsurface drain, which served the purpose of containment by creating a cone of depression.

The unit treatment cost at Occidental Chemical was relatively low largely because of the very large volume of water being treated. The operation and maintenance cost figures that were used for calculating the additional unit cost at Occidental in Table 17 are incomplete because the system currently is being modified to achieve the contaminant level reduction ordered by the state. In addition, no written documentation of these relatively low costs were not obtained. Data on the actual cost of the adequately effective system, with its double carbon contactors, were not available. In addition, the unit cost of operation and maintenance of the treatment system at Occidental was relatively low because of the high efficiency of the state-of-the-art reverse pulse bed. This system was apparently designed to take advantage of the economies of scale of the system. The large volume of water treated reflects the purpose of the system, which was to reclaim a contaminated aquifer as well as contain a contaminant plume.

Excluding General Electric and Occidental Chemical, the treatment costs in Table 17 were primarily a function of the type of treatment sytem used. In order of decreasing cost the following treatment system types were found: (1) off-site commercial treatment; (2) on-site carbon filtration with additional treatment; (3) on-site biodegradation; (4) off-site publicly-owned treatment works (POTW). The process types were generally dictated by the nature and extent of contamination. Only wastewater with low concentrations of treatable contaminants could go to POTWs. Biodegradation was not considered effective with PCB or cyanide contaminated wastewater. The type of treatment processes used at Goose Farm and Houston were also used at Quanta, but cyanide waste was considered incompatible with the other wastes in the system. Finally, marginal cost increases were incurred at Goose Farm for additional treatment tasks for additional contaminants.

The very large gap in costs between various on-site treatment systems (carbon filtration, neutralization/precipitation and flocculation, biological treatment, etc.) and off-site POTWs may suggest a general pattern that is applicable to other uncontrolled hazardous waste site remedial actions. POTWs may be capable universally of providing relatively inexpensive water treatment of contaminated, pumped leachate if the water has an adequately low concentration of nonrefractory contaminants. This cost differential may be due to the advantages of very long term amortization, in-place capital and labor, and general economies of scale. Certainly, subsidies from the federal and local governments has some impact on this cost differential, but internalization of these costs will probably still allow for significant cost savings from the use of POTWs where it is possible to attain adequate treatment levels.

Within each of these process types, several factors were found to significantly affect treatment costs. The level of contaminant reduction affected the cost of the treatment system at Occidental. The number of carbon contactors is being doubled to achieve the reduction agreed upon with the state. Off-site treatment for cyanide wastewater at Quanta necessitated additional costs of loading and unloading, as well as outside contractor costs. The relatively low carbon usage rate at Occidental shows how process efficiency can affect costs. Typically, carbon costs are a major component of this process type. However, the reverse pulse bed used at Occidental minimized this rate for a given level of treatment. The effect of treatment system capacity on costs was encountered at both General Electric and Occidental. Although large for the treatment needs encountered, the system at General Electric was significantly smaller than Occidental and could not capitalize on potential economies of scale. Also, POTW costs are typically low because of the small marginal load increase in their total load caused by the addition of wastewater from a site.

Collection limitations generally affected the numerator of the unit cost formula - i.e., the quantity of water treated. At Quanta, wastewater collection was facilitated by the water's accessibility above ground in diked areas, pits and tanks. At General Electric, the volume of water was limited because the tight soil minimized the recharge of the sump from the subsurface drain.

At Goose Farm, climate affected the treatment cost by increasing the down-time cost of the mobile on-site system and by necessitating cold-weather system modification. The system operated on-site during the winter when freezing weather conditions impaired its functions.

The five non-technical factors are interrelated, but are distinguished on the outline to highlight factors of particular sites, some of which are not listed on Table 17 because of insufficient treatment cost data. Most non-technical factors affected the internalization of costs among different parties.

At Anonymous C (not on Table 17), the POTW cost was based on the volume of water used by a customer, not on discharge. Hence, the contaminated ground water added no marginal cost to the discharge fee. At another site, Anonymous B, additional costs for the water treatment were not encountered because of available capacity at an existing on-site system. At two of the sites listed in Table 17, Goose Farm and Houston Chemical, mobile rented treatment systems were used. The costs of purchased systems often excluded in-house costs for operation and maintenance overhead, which were explicitly included in the cost of rented systems. At Occidental, the project manager and treatment system company engineer believed that market competition was significant in reducing the cost of the treatment system. Because of a desire to increase its market share of the new ground water treatment market, the contractor minimized its profit to obtain the contract.

Operation and Maintenance Costs--

All but four of the 23 case study sites will require some ongoing operation and maintenance (O&M) expenditures. At one site where no future O&M is expected by the state or the developer, Trammell Crow, non-hazardous sludge was solidified and landfilled over thick clay and shale. No monitoring wells have been installed or are planned. At the other three sites, College Point, Houston Chemical and Howe, emergency surface or subsurface removal and disposal operations were performed, and no follow-up monitoring is being performed.

The lack of ground water and soil monitoring, and the incurred costs, may be somewhat characteristic of immediate, complete removal actions. Institutionally, funds for monitoring sites where all wastes were to have been removed may not be justifiable since all of the wastes were to have been removed. In addition, a party contending that all of the wastes have been removed, may not find it in its own best interests to authorize monitoring that may provide data indicating an ineffective removal. This potential dilemma suggests the need for some distinction between remedial and monitoring authorities.

The other 19 sites are expected to require future O&M in two forms. First, varying amounts of monitoring well sampling and analysis will be performed at all 19 sites. Second, four of these sites will also require ongoing water treatment expenditures, for withdrawn ground water. These costs include only expected O&M and exclude potential future costs for maintenance such as repairing failed cut-off walls or clearing clogged subsurface drains.

The four sites at which future ground water treatment costs are expected are Biocraft, General Electric, Mauthe and Occidental. At Mauthe, the contaminated ground water is being treated at a POTW for a relatively low cost. For example, the O&M cost at Mauthe for treating the contaminated water from the subsurface drain amounts to $235 per 3,000 gallon (11,355 l) truckload for pumping and transportation ($210), and treatment ($25) or about $36,660 for 156 truckloads per year. The O&M costs for treatment at the three sites where permanent water treatment systems were built ranged from 6-21% of the capital costs for the systems (see Table 18).

TABLE 18. COMPARISON OF O&M VS. CAPITAL COSTS FOR PERMANENT ON-SITE WATER TREATMENT SYSTEMS (1982 COSTS)

Site	Operation & Maintenance	CAPITAL	Percent O&M Capital
Biocraft Laboratories	$82,683/year	$926,158(a)	9%/year
General Electric	$50,000/year	$846,200	6%/year
Occidental Chemical	$133,320 - 370,800/year	$1.735 million	8-21%/year

(a) includes significant research and development costs

The operation and maintenance cost data for sampling and analysis of ground water from monitoring wells were not available for most of the sites. These costs appeared to vary among the sites depending on the monitoring work performed. Different amounts of monitoring were often required for ensuring that the site response is performing as expected. Many of the variables affecting these costs are discussed in the "Comparative Cost by Technology: Site Investigation Costs" subsection above. For follow-up monitoring O&M, the most important factors found to affect costs at all of the sites were the frequency of sampling and the number of samples taken on each round (replicates times number of wells). These costs were routinely internalized into the operating budgets at operating facilities. For example, at Biocraft, in-house laboratory technicians have been trained to sample and analyze wells on a weekly basis. At the University of Idaho, site wells are sampled and analyzed by students as part of a lab class in hydrogeology. These procedures eliminate the higher cost of an outside consultant to perform the sampling and analysis. The amount of sampling costs depended on the remedial technology implemented. At sites using a cut-off wall or subsurface drain, more monitoring O&M was performed than at sites where removal was performed, especially where the removal was performed quickly before ground water contamination could occur.

Public vs. Private Clean-ups

Of the 23 responses studied, 11 were funded and executed by state, local, or federal agencies, 11 were funded and executed by private firms, and one, Gallup, was privately funded but executed by a state agency. Analysis of the costs of, and the variables affecting, the 23 responses gives no indication that government executed clean-ups tended to be more or less cost-effective than privately executed clean-ups. In particular no pattern of unit costs for similar operations could be discerned. While it is possible that such a difference exists, the highly individual nature of each site prevents a valid comparison of relative costs.

Numerous factors influencing costs limit the comparability of the responses. No two sites or responses were alike. While the sites and response technologies can be grouped in general classes, variables such as site geology, accessibility, weather, nature and extent of contamination, and site-specific design of responses, make each case unique.

There were hidden or unquantifiable costs in many of the case study responses. Many of the private sites made use of existing capital resources and personnel, the cost of which were not included in the reported total response costs. For example, at Anonymous B, a private site, there was a wastewater treatment plant already on-site to treat contaminated effluent from a subsurface drain. In contrast, at Houston Chemical, a government-funded site, it was necessary for EPA to pay for rental and operation of a mobile water treatment system. Even when in-house personnel cost data were available, these figures usually did not include the additional costs of overhead and profit that would have been incurred if similar labor were hired from outside the firms. This finding suggests that, generally, when scrutinizing costs of private responses, the role of in-house resources should be determined.

All but one of the government executed clean-ups involved emergency responses, while only one of the private clean-ups did. Consequently, government agencies necessarily incurred additional expenses associated with rapid mobilization, limited planning time, and limited site data.

It is clear that in some government executed responses, institutional factors increased costs. Such factors included delayed or interrupted funding, citizen opposition to selected responses, and pressure to begin clean-ups before adequate data were available or before weather conditions were favorable. However, private clean-ups suffered delays and added costs as well. Many of the private clean-ups involved a protracted period of negotiation or litigation with government agencies before there was agreement on the nature and extent of response. In addition, some private parties had internal funding or decision making disagreements among different levels or divisions of their corporate structures, which may have delayed and added costs to the responses.

SECTION 5

PLANNING AND MANAGEMENT OF RESPONSES

INTRODUCTION

This section summarizes institutional and decision making aspects of the 23 clean-ups studied and examines the degree to which the responses were affected by factors generally thought to be significant in hazardous waste site clean-ups. These factors are:

- The basis for initiation of responses;
- Public interaction with clean-ups;
- The basis for the extent of the responses;
- The role of federal and state statutes in the execution of clean-ups; and
- Methods of hiring contractors to perform the clean-ups.

The following sections state the findings regarding the significance of the above factors, and then summarize the results that led to the findings. It is important to note that these 23 cases were not intended to be a statistically representative sample; rather, they were selected for their illustrative value.

BASIS FOR INITIATION OF RESPONSES

The reasons for initiating clean-ups were significant in that they often determined whether responses were considered emergencies, and influenced the choice of response technologies. Among the 23 sites studied, the responses were initiated to protect humans, agricultural biota, or natural biota from exposure to contaminants via surface water, ground water, air, or direct contact. Table 19 summarizes the primary exposure routes, contaminants, and threatened populations that were the basis of response initiation at each site and notes the clean-ups that began as emergency responses.

Emergency Response Designation

Twelve of the 23 responses began as designated emergency actions, although most of these continued into a remedial phase addressing threats that were more long-term. In general, the emergency sites were initially considered imminent hazards either because they threatened to release contaminants catastrophically, e.g., by fire, explosion, or flood, or because they had already caused environmental damage or drinking water contamination. The remainder of the sites were believed to pose less immediate threats.

Contaminants

The sites studied contained a broad range of contaminants. At 20 sites, the predominant contaminants were organic compounds such as pesticides, solvents, PCBs, phenols, and mixtures such as coal tar and petroleum refining sludge. At 3 sites, the predominant contaminant was hexavalent chromium. Most of the sites contained combinations of substances, often numbering dozens of different contaminants at a single site. At only 3 sites was contamination limited to a single substance. PCBs were present at 6 sites, usually mixed with oil.

Potential Exposure Routes

Surface and ground water were the primary routes of contaminant migration and potential exposure. All of the sites contained multiple routes. Surface water was a route at 17 sites, and ground water at 16 sites. Other exposure routes included air, at 6 sites, and direct contact, at 10 sites.

Population at Risk

At all but four sites, the primary reason for response initiation was an imminent or potential threat to human health. Eight sites were situated in rural areas, where the potentially affected human population was relatively low. Seven sites were situated in commercial/industrial areas, where residences were relatively far from the sites. Finally, 8 sites were situated in areas that were either predominantly residential, or were mixed residential/commercial/industrial. At the 4 sites where human health was not directly at risk, contamination most often threatened aquatic environments used by humans for recreation.

Four of the sites threatened agricultural biota such as cropland, pasture, or gardens. Fifteen sites threatened or actually damaged natural biota, most often aquatic life. Threats to natural biota at seven of these sites also represented threats to recreational resources, most often fishing, boating, and swimming.

TABLE 19. BASIS FOR INITIATION OF RESPONSE

Site Name	Contaminants	Potential Exposure Routes: surface water	ground water	air	direct contact	Population at risk: human	agricultural biota	natural biota	Emergency response
1. Anonymous A	pesticide, ammonia waste water	X						X	
2. Anonymous B	pesticides, solvents	X	X			X		X	
3. Anonymous C	hexavalent chromium	X	X		X	X	X	X	
4. Biocraft	butanol, methylene chloride	X	X			X		X	
5. Chemical Metals Industries	various organics, metals	X		X	X	X			X
6. Chemical Recovery Systems	various organics, PCB, vinyl cloride	X	X	X		X			
7. College Point	PCB oil	X		X	X	X		X	X
8. Fairchild Republic	total and hexavalent chromium, various organics		X			X			
9. Gallup	various metals, organics	X	X			X		X	X
10. General Electric	PCB, trichlorobenzene		X		X	X		X	
11. Goose Farm	various organics, metals, PCB's	X	X			X		X	X
12. H & M Drum	various organics		X		X	X			X
13. Houston Chemical	pentachlorophenol	X					X	X	X
14. Howe, Inc.	pesticides	X	X	X	X	X		X	X
15. Marty's GMC	solvents, paint sludge, PCB		X	X	X	X		X	X
16. N.W. Mauthe	hexavalent chromium	X	X		X	X		X	X
17. Occidental Chem.	pesticides (DBCP)		X			X	X		
18. Quanta Resources	PCB oil, chlorinated solvents cyanide	X		X	X	X			X
19. Richmond Sanitary	various organics, metals	X		X		X		X	
20. Stroudsburg	coal tar	X	X					X	X
21. Trammell Crow	oil sludge	X			X	X			
22. Univ. of Idaho	mixed solvents, pesticides		X			X	X		
23. Vertac Chemical	dioxin, phenols, various organics	X	X		X	X		X	X

PUBLIC INTERACTION WITH CLEAN-UPS

Almost half of the sites were first reported to authorities by private citizens, but local citizens were not significantly involved in decision making in most of the responses studied. Ten of the clean-ups received attention from the news media, ranging from occasional progress reports to highly sensational editorials. Four sites involved town meetings or public hearings regarding the clean-ups. These sites were: Chemical Recovery Systems, Inc., Howe, Inc., Marty's GMC, and Occidental Chemical. Public attention usually focused on ensuring that a response was initiated, rather than on specific aspects of the clean-ups.

At one site, however, public opinion did have a significant effect on the nature and cost of the remedial actions. During the Howe, Inc. clean-up, state officials proposed six different options for disposal of contaminated materials before finding a method that was acceptable to the public. The disposal method ultimately chosen was substantially more costly than others proposed.

Of the 23 sites studied, few clean-up operations were reported to have had a significant direct impact on the health or activities of local populations. Five of the responses included closing residential, municipal, or commercial drinking water wells and providing alternative water supplies. At only one site, Goose Farm, were there reports of ill health effects among nearby residents as a result of the clean-up, apparently caused by air emissions from excavated wastes stored on-site.

BASIS FOR THE EXTENT OF RESPONSES

The goal of all 23 responses was to clean up the sites to eliminate or mitigate the threat to public health or the environment. In some responses specific physical standards (e.g., parts per million of hexavalent chromium), based on pre-existing design or performance standards from statutes, regulations or scientific studies, were used to achieve this goal. Other responses used no specific physical standards, relying instead on the clean-up managers' evaluation of the effectiveness of the work based upon their "best professional judgement." The research on the 23 responses indicates that specific physical standards were valuable management tools for selecting response technologies and determining when clean-up work was completed.

In addition to clean-up standards, another factor affected decisions about the extent of response: the manner in which the standards were selected. The researchers identified three major ways in which these standards were chosen: through judicial or administrative process; by voluntary agreement; and selection by the government agency conducting the response.

Every case study attempted to identify the factors, such as clean-up standards used and the way they were selected, that actually influenced decisions, as reported by the decision makers and those closely connected to the response actions, in order to provide a realistic picture of how response actions were defined and terminated. The following discussion groups the case studies according to these factors. Table 20 presents these factors in summary form.

TABLE 20. EXTENT OF RESPONSE

SITE NAME	EMERGENCY RESPONSE (a)	REMEDIAL ACTION					
		Source of Standards			Manner of Selecting Standards		
		Best Professional Judgement	Pre-existing Standards		Judical or Administrative Process	Voluntary Agreement	Government Remedial Action
			Design	Perfor-mance			
1. Anonymous A			X	X	X		
2. Anonymous B		X				X	
3. Anonymous C		X		X	X		
4. Biocraft		X		X	X		
5. Chemical Metals Industries	X						
6. Chemical Recovery System, Inc.			X	X	X		
7. College Point	X	X		X			
8. Fairchild Republic		X				X	
9. Gallup	X						
10. General Electric (b)		X		X	X	X	
11. Goose Farm	X	X					X
12. H & M Drum	X						
13. Houston Chemical	X	X					X
14. Howe, Inc.	X	X					X
15. Marty's GMC	X	X					X
16. N.W. Mauthe	X	X					X
17. Occidental Chemical (b)		X		X	X		
18. Quanta Resources (b)	X	X		X			
19. Richmond Sanitary			X		X		
20. Stroudsburg (b)	X	X				X	X
21. Trammell Crow		X				X	
22. Univ. of Idaho		X				X	
23. Vertac Chemical (b)	X	X	X	X	X		

(a) source of standards for emergency phase was always best professional judgement, and manner of selecting standards was either judicial or administrative process, voluntary agreement, or procedures followed by governments in conductin responses.

(b) denotes cases having more than 1 response action.

Emergency Responses

Twelve of the 23 case studies involved emergency response actions in some form or another. Responses were classified as emergency operations based on how the people involved with the clean-up described the situation, not with reference to any criteria or guidelines such as those contained in CERCLA or the National Contingency Plan. Three cases were rather straight forward emergency removal operations that were terminated when the threat of fire, explosion or release was mitigated: Chemical Metals Industries, Gallup, and H&M Drum. In eight other cases, the emergency response work overlapped some planned removal or remedial actions: Goose Farm, Howe, Mauthe, Stroudsburg, Vertac, Quanta, College Point, and Houston Chemical. For example, although Goose Farm was labelled as an emergency response, the emergency work was followed by ground water treatment, which is usually associated with a longer term response. In Stroudsburg, the emergency containment measures were followed by construction of a slurry wall and ultimately by a plume recovery action, which generally are used in remedial actions. Despite the fact that some emergency responses were followed by planned removal or remedial actions, each emergency response itself appeared to be defined and terminated based on the best professional judgment of the responsible on-scene personnel, given the available data about contaminants and health and environmental risks.

In three emergency response cases, Houston Chemical, Howe, Inc., and Marty's GMC, the government authorities performing the response actions established explicit standards for themselves regarding the extent of response. In Houston Chemical, for example, EPA and the U.S. Coast Guard accepted the level of 10 ug/l for pentachlorophenol (PCP), supplied by the Missouri Department of Conservation, as the criterion for abatement of the long term threat. This level was based on the department's research, which included bioassays on bluegill for PCP and a review of U.S. Fish and Wildlife Service data on the effects of PCP on fish, and constituted the department's best professional judgment as to the appropriate clean-up level.

Remedial Actions

The extent of remedial actions in the case studies can be viewed from two perspectives: the source of standards used for response and the manner by which those standards were selected. Standards often were closely related to the extent of remedial actions because they defined when a clean-up was considered effective or complete. Sources of standards were important because they often determined how clearly and precisely the standards were expressed, and how justifiable or defensible the standards would be if called into question. The manner by which the standards were chosen was important because it determined who had authority to set and modify the standards, and it affected the time required to decide upon a course of action.

Source of Standards

Two important categories of standards emerged in this research: best professional judgment and pre-existing standards. These are discussed below.

Best professional judgment

Best professional judgment represents a professional's decision about the extent of clean-up needed at a particular site in light of the circumstances surrounding the response. This type of judgment might be based on visual observations about the extent of contamination, generally accepted scientific studies about the effects of specific levels of toxic substances on organisms, or the past experience of response personnel. Best professional judgments could be exercised by a single person or represent the consensus of experts involved in the responses, as where the On-Scene Coordinator (OSC) consults with government officials and private parties. An example of this sort of clean-up standard is Fairchild Republic Company, where the parties used their best professional judgment, based on visual observations and composit soil sample analysis, to determine that the practical extent of excavation of contaminated materials had been reached.

Pre-existing standards

Pre-existing standards can be tailored to the features of a given site and serve as benchmarks for clean-ups. They also can make response actions consistent with federal and state environmental laws, such as the National Pollution Discharge Elimination System (NPDES) of the Federal Water Pollution Control Act (FWPCA). Pre-existing standards can be subdivided into two classes, design standards and performance standards. An example of the use of a design standard is the Richmond Sanitary Services landfill, where an Administrative Order directed the company to construct a cut-off wall and dikes in accordance with California design requirements for hazardous waste land disposal facilities. Another case, Anonymous C, is an example of the use of a performance standard. In that case, the company was required to continue collecting contaminated ground water in an interceptor trench and disposing of it in a sanitary sewer system until discharge monitoring showed a trend indicating that total and hexavalent chromium were below the discharge limits set by the Wisconsin Pollutant Discharge Elimination System.

Manner of Selecting Standards

Standards were chosen in three basic ways: through judicial or administrative processes, by voluntary agreement, and by governmental procedures followed in the course of response actions conducted by government agencies.

Judicial or Administrative Process

In eight cases, decisions about the extent of response were made through a formal legal process, involving either litigation that resulted in the entry of a judicial order or a consent decree, or litigation or negotiation that resulted in an administrative order. These formal legal orders tended to include general goals of protecting public health and the environment as well as specific directives for remedial action, such as installing a slurry wall or a French drain. These orders might require the parties to exercise best professional judgment or comply with pre-existing standards or both. They also might establish a framework whereby the parties could propose and decide upon future remedial action plans, as in the case of Vertac Chemical Corporation. The research on these clean-ups indicated that judicial and administrative orders significantly affected decisions about the extent of response, not only by setting the standards utilized but also by formalizing the decision making process, which had the advantages of greater clarity and assurances of compliance but the disadvantage of greater delay.

Voluntary Agreement

Another way one can analyze the extent of response is by distinguishing between those cases where the decisions were made within the formal legal process and those cases where the decisions are made outside of such a process. An example of decision making without litigation is Anonymous B, where the state informally approved a company's remedial plan, allowed the company to proceed with its remedial action, and then evaluated the results and agreed that the response was adequate. Trammell Crow is similar in that the state examined and agreed with the company's proposal to solidify the oil sludge, although this case differs somewhat from Anonymous B because the state did have to grant formal approval of the company's closure plan for its on-site landfill.

Government Remedial Action

Where the responsible private party was unable or unwilling to conduct a remedial action, the local, state or federal government, or some combination of these, had to decide what was the appropriate extent of response. In 11 of the 12 emergency responses, as discussed above, government authorities conducted the work, and in these cases they determined the necessary extent of response. Further, in all of these 11 emergency responses, the government authorities had to determine whether a remedial action, if any was necessary, should follow certain emergency or interim measures and what type of remedial action would be appropriate. At 6 sites, government authorities carried out what appeared to be remedial actions after the emergency work was completed. It should be noted that in some emergency response ands remedial actions, the government authorities selected only the technology to be employed and not the extent to which that technology would be used to clean up a site, while in others they made both decisions.

INTERFACE OF KEY FEDERAL AND STATE LAWS WITH RESPONSES

The response actions studied in this research dealt with a number of federal and state environmental laws. These laws, which included statutes as well as regulations, were quite varied in nature, which makes it difficult to generalize about the response actions. Generally speaking, most of the responses were affected by laws governing hazardous substances or laws protecting water resources, but not by laws protecting air quality per se, although air pollution was often an important concern. Table 21 presents the laws that affected the 23 responses.

TABLE 21. INTERFACE WITH KEY FEDERAL AND STATE LAWS

SITE NAME	FEDERAL STATUTES AND REGULATIONS									STATE STATUTES AND REGULATIONS - BY FUNCTION									
	CERCLA	RCRA		TSCA		FWPCA				RESPONSE FUNDING		HAZARDOUS WASTE(a)				WATER QUALITY			DRINKING WATER
	Response Authority- §104	Injuction	Hazardous Waste Characteristics	§6(d) Ruling- Imminent Hazard: Transfer Ban	PCB Requirements	Injuction	Ambient Water Quality Standards	NPDES Permit	Spill Fund §311	Spill Fund	Emergency Appropriation	Ihjunction	Waste Discharge Requirements- Land Disposal Facility	Disposal Requirements	Closure Plan Plan	Injunction	Ambient Quality Standards	Effluent Discharge Levels	Threat of Con- tamination of Well
1. Anonymous A													X						
2. Anonymous B								X						X					
3. Anonymous C														X				X	
4. Biocraft																	X		X
5. Chemical Metals Industries	X								X										
6. Chemical Recovery Systems																	X		
7. College Point					X				X										
8. Fairchild Republic														X	X				
9. Gallup														X					
10. General Electric					X		X	X						X					
11. Goose Farm	X								X	X									
12. H&M Drum										X	X								X
13. Houston Chemical									X										
14. Howe, Inc.										X									
15. Marty's GMC					X					X									X
16. N.W. Mauthe					X					X				X				X	X
17. Occidental Chemical								X						X				X	X
18. Quanta Resources								X										X	
19. Richmond Sanitary													X						
20. Stroudsburg	X								X										
21. Trammell Crow			X												X				
22. University of Idaho																			X
23. Vertac Chemical		X		X		X	X	X				X		X		X	X	X	

Laws significantly affected clean-ups in three important ways. First, federal or state laws gave government agencies the authority to initiate responses and provided funding for the work. The best example of this sort of law, of course, is CERCLA. Second, laws affected response actions because they provided the basis for governments to prompt private emergency response or remedial efforts through enforcement. When a company was charged with violating RCRA, the FWPCA, and several state statutes, as in the Vertac case, the litigation led to the initiation of certain emergency response and remedial actions at the site as well as the beginning of studies to determine the need for further action. Third, laws affected response actions because they contained design or performance requirements that were used as standards to determine the extent of response.

Many laws that applied to response actions are not discussed here because they did not affect the responses significantly or directly. For example, the federal Hazardous Materials Transportation Act governed the transport of some materials from sites to licensed disposal facilities, as did the more general federal and state laws regulating trucks, but in no response examined in this research did these laws significantly shape the planning or execution of a clean-up.

Funding and Initiation of Government Responses

Two federal statutes, the CERCLA (Superfund) and the FWPCA, provided money and response authority for several sites. Clean-up under the response authority (section 104) of CERCLA occurred in three cases, Chemical Metals Industries (CMI), Stroudsburg and Goose Farm, where emergency response actions were triggered by the release or threat of release of hazardous substances. For example, the situation at CMI posed an imminent threat of fire or explosion, and the federal government, with the cooperation of the state and local governments, conducted an emergency removal operation. All three sites involving CERCLA also were funded in part by the section 311 spill fund of the FWPCA. Emergency action under the FWPCA was triggered by the discharge or threat of discharge of hazardous substances into navigable water. One site, Houston Chemical, was funded and cleaned up solely under the authority of the FWPCA.

State statutes provided funds and response authority for cleaning up several sites. Two states, New Jersey (Goose Farm) and Wisconsin (Mauthe) had spill funds that paid for all or part of the government emergency response actions. Two other states, Massachusetts and Minnesota, were faced with several sites requiring emergency responses and enacted a series of emergency appropriations to pay for the clean-ups at H&M Drum and Howe, respectively. After passing its emergency appropriation, Massachusetts enacted a special hazardous waste clean-up fund, which provided money for work at Marty's GMC and for part of the response at H&M.

A pattern emerged in the research concerning the funding of responses by federal and state governments. While the cases involving federally funded response actions had a high degree of overlap between CERCLA and FWPCA monies, the cases where state funds were used had much less overlap between state and federal funds. Only 1 out of 5 state funded cases, Goose Farm, also used federal money. This pattern suggests that the federal and state governments tended to fund emergency responses exclusively. Often either a state provided the clean-up funds, in which case the federal government provided none, or the state provided little or no money, in which case the federal government provided it under CERCLA or the FWPCA.

Initiation of Private Response

The enforcement of federal and state environmental laws prompted the initiation of all of the private responses studied except one, Trammell Crow. Enforcement took several forms: litigation in court that resulted in a consent decree, injunction or other judicial ruling; negotiations with or proceedings before an administrative agency that led to an administrative order or administrative consent order; or an administrative ruling by an agency directed at a particular company. These legal measures were important because they prompted the initiation of response actions, specified clean-up standards and goals, and once the required activities were completed, often served as the basis for terminating responses. Further, the legal orders and rulings provided a means of ensuring that follow-up monitoring of the sites would be done and that any needed future remedial work could be compelled readily.

Federal enforcement efforts fell under three statutes: the Resource Conservation and Recovery Act (RCRA), the Federal Water Pollution Control Act (FWPCA), and the Toxic Substances Control Act (TSCA). All three statutes were relied upon in various proceedings against Vertac Chemical Corporation, for example, along with several state laws. The EPA sued Vertac for violating RCRA as well as the FWPCA's ambient water quality standards and NPDES effluent discharge levels. The agency also sought and obtained injunctive relief based on RCRA and the FWPCA. While several remedial actions had already been completed at the Vertac site, some of which were required by an earlier state administrative order, the EPA's lawsuit led to the company's initiation of several specific remedial actions, as well as engineering studies about the effectiveness of past remedial actions and the need for future on-site and off-site actions.

One enforcement measure taken under TSCA that prompted the initiation of a private response was found in the case study research, and also involved Vertac. The EPA Administrator issued a section 6(d) ruling, the first of its kind, that directed the company not to transport drums containing 2,4-D still bottoms, which were contaminated with dioxin, from the plant site for disposal. This ruling occurred during the period in which Vertac was taking various response actions required by the prior injunction and state administrative order, and forced Vertac to change its disposal plans from off-site disposal to incineration or chemical destruction and recycling.

State enforcement efforts under hazardous waste, water pollution and public health laws were found more frequently than federal efforts in the 23 case studies. In 7 cases, a state administrative order was entered that specified what clean-up work had to be done: Anonymous A, Anonymous C, Biocraft, General Electric, Occidental Chemical, Richmond Sanitary, and Vertac. The circumstances in which administrative orders were made varied considerably in terms of how the situation was brought to an agency's attention, whether the agency formally charged a company with violating the law or simply told the company that it had to comply with certain requirements, and whether response work began before or after entry of the order.

Two cases, Chemical Recovery Systems, Inc. (CRSI) and Gallup, involved lawsuits brought by state agencies in state courts. These two lawsuits prompted the initiation of private response actions in different ways. In CRSI, the suit was settled by a consent decree that stated what sort of remedial actions the company would take (e.g., construct a slurry wall according to explicit specifications). The Gallup suit was brought by the state against Mr. Gallup, the site owner, who pleaded nolo contendre and agreed to reimburse the state for its clean-up costs. In Vertac, the state followed its administrative order by joining the U.S. EPA in a suit against the company that was brought in federal district court, not state court. The state and EPA first obtained an injunction that required Vertac to take certain actions, then eventually settled the case by a consent decree that specified further remedial work.

State hazardous waste laws provided the basis for many of the state lawsuits and administrative proceedings. In Vertac, for example, both the administrative order and the state's complaint in the lawsuit were brought under the enforcement authority established in the Arkansas hazardous and solid waste management laws. California's hazardous waste management law governing operating land disposal facilities was enforced by orders issued by the Regional Water Quality Control Board in two responses: Richmond Sanitary Service and Anonymous A. State hazardous waste laws governing disposal were also enforced in 4 cases, Occidental Chemical, General Electric, Fairchild Republic and Anonymous C. In Fairchild Republic, for example, a contractor hired to do the excavation and removal work was prosecuted and convicted in state court of illegally disposing of contaminated materials from the Fairchild Republic site. In Anonymous C, the company itself was charged with illegal disposal of chromium at its plant.

State water laws were the basis for several enforcement actions. Biocraft and Vertac involved administrative orders prompted by charges that the companies had violated ambient quality standards or effluent discharge limits. As discussed above, in CRSI and Gallup, state agencies brought suit in state courts, alleging violations of water laws. In Vertac, the state sued in federal district court along with EPA, alleging that the company had violated Arkansas ambient water quality standards and effluent discharge limits, in addition to the alleged violations of the hazardous waste laws. This case was settled by a consent order.

State laws concerning public drinking water supply wells led to the initiation of remedial measures in 5 cases, H&M Drum, University of Idaho, Marty's GMC Occidental Chemical, and Biocraft. In H&M Drum and University of Idaho, state agencies were concerned with the distance between a hazardous waste site and a drinking water supply well. In H&M, the state Department of Environmental Quality Engineering ordered the town of Dartmouth to close a well near the dump site as a precaution, but several months later advised the town that it could reopen the well. When it closed the well, the town had to take the response measure of obtaining alternative drinking water supplies. In the University of Idaho case, the City of Moscow proposed to install a drinking supply well near the university's dump site, and the state Department of Health and Welfare required the university to conduct a study of potential health hazards posed by the site. This requirement was one of the factors that led to the initiation of remedial action at the site. Marty's GMC and Occidental Chemical were cases where state authorities closed drinking water wells due to contamination, while at Biocraft the state closed a well because of the threat of contamination. The closing of wells in these latter 3 cases was part of the initial response measures, which were carried out by the state at Marty's GMC and by private companies at Biocraft and Occidental Chemical.

Laws Affecting Implementation of Responses

One of the most important ways in which laws affected clean-ups was by serving as sources of standards that were imposed upon remedial actions, as dicsussed above in the "Basis for Extent of Response" section. Often a judicial or consent order would take design or performance standards found in federal or state laws, whether or not they were being enforced in that particular case, and require that the responsible party comply with them. This had the result of making the sites consistent with the state or federal regulatory frameworks.

Two cases in California involving land disposal facilities showed how pre-existing standards can affect remedial actions. The California Administrative Code contains provisions governing discharge requirements of solid waste disposal facilities as they relate to surface and ground water quality. These Administrative Code regulations were promulgated by the State Water Resources Control Board under the authority of the California Water Code, and provide that Regional Water Quality Control Boards (RWQCB's) can establish the particular manner by which a land disposal site shall meeet waste discharge requirements. The RWQCB's can prescribe for particular facilities various design and performance standards relating to land discharge, surface water controls, subsurface drainage facilities, waste well construction, and site closure plans. A RWQCB imposed both design standards and waste discharge requirements upon companies in two cases, Anonymous A and Richmond Sanitary Service. In Anonymous A, the RWQCB required that the company install barrier walls that had a permeability of less than 10^{-6} cm/sec and permitted no discharge, pursuant to the requirements for a Class II-1 hazardous waste disposal facility. Similarly, in Richmond Sanitary Service, the RWQCB set design standards based on state Class I hazardous waste disposal facility regulations (5 foot cut-off wall with permeability of less than 10^{-8} cm/sec, specifications for height of dike, etc.) as well as performance standards for run-off discharge. These detailed design and performance standards were applied in remedial actions in order to upgrade the two facilities so that they would comply with California's regulations for land disposal facilities.

Design standards in less explicit form were used in two other remedial actions, Trammell Crow and Fairchild Republic, where particular closure plans were submitted to state authorities for approval. In Trammell Crow, the on-site landfill for solidified oil sludge was treated as a Class II industrial waste landfill. The company submitted the closure plan to the Texas Water Resources Board, which had authority over it pursuant to the Texas hazardous waste law, and the Board approved it. However, no detailed design or performance specifications such as those found in the California cases were imposed. In Fairchild Republic, the situation was similar in that the closure plan was submitted for state approval, with the difference that what was approved was the closure of an excavated area rather than a landfill containing hazardous substances. Hence, there were few ways in which the state could impose specific design and performance standards at Fairchild Republic, other than for backfilling and capping.

In addition to hazardous waste laws, water pollution control laws provided standards for several response actions. Effluent discharge limits contained in National Pollutant Discharge Elimination System (NPDES) permits were used directly or indirectly as performance standards in 5 responses. State effluent discharge limits were also used in two of these cases, Vertac and Occidental Chemical. In two other cases, Anonymous C and Quanta Resources, only state effluent discharge limits were used.

Vertac is an example of the direct use of a NPDES permit. In this case, the company already had a NPDES permit for its plant for process wastewater, but had exceeded the levels for some pollutants. State and federal authorities required the company to undertake remedial actions at the plant site to reduce the discharges to within permit levels. Cases where NPDES permits served indirectly as clean-up standards are Anonymous B, General Electric, College Point, and Quanta Resources. In General Electric, for example, the state indirectly based the pretreatment standard for the plant on the federal ambient water quality criterion for PCB. This standard was influenced by the capacity of the local publicly owned treatment works (POTW) that received the discharge, which had a NPDES permit.

Government authorities used effluent discharge limits as performance standards even when companies did not have a NPDES permit and the permit held by a POTW was not the primary concern. At Anonymous C, ground water had to be pumped out and properly disposed of until a trend emerged in the contaminant levels (less than 0.5 mg/l for total chromium and less than 0.05 mg/l for hexavalent chromium) that fell within the Wisconsin Pollutant Discharge Elimination System. At Occidental Chemical, the state used the "action level" that had been set specifically for dibromochloropropane (DBCP) contamination in ground water as the effluent discharge limit for treated water to be discharged into a deep saline aquifer below the plant. In this way, DBCP was used as a surrogate criterion for other contaminants.

In one case, Biocraft, the administrative consent order set specific performance standards for cleaning up the site using ambient water quality standards. The order required the company to operate its decontamination system until the ground water met the explicit contaminant standards or until the state determined that the system was incapable of achieving those clean-up standards.

One final way in which laws provided standards in these response actions concerned TSCA. At College Point, General Electric, Marty's GMC, and Quanta Resources, the managers of the clean-ups were specifically aware that TSCA governed PCB in waste oil in excess of 50 ppm, and conducted the response actions accordingly in terms of removing, transporting and disposing of contaminated materials. The effect of TSCA was to provide an alternative set of performance standards for these responses, since PCB wastes had to be handled differently than non-PCB wastes.

Another way in which TSCA provided a performance standard occurred in the Vertac case, where the EPA Administrator issued a section 6(d) ruling. This ruling was directed specifically at Vertac and prohibited the company from transporting dioxin-contaminated 2,4-D still bottoms off-site for disposal. In forcing the company to change its remedial plan regarding disposal, the ruling drew a line between permissible and non-permissible performance.

SELECTION OF CONTRACTORS

The researchers found that the ways in which private parties and governments selected contractors for clean-up work differed in three main respects: (1) the procedures by which contractors were chosen; (2) the criteria used to select contractors; and (3) the types of contracts used. Table 3 groups the data into these three categories, and then divides the data further into numerous subcategories.

The data seem to suggest that government authorities tended to use sole source selection procedures, to rely heavily on the technical qualification of contractors as a criterion for selecting firms, to use time and materials contracts, and to allow subcontracting. It also appears that private companies also used sole source selection procedures frequently, but tended to use bidding procedures more often, to make selections based on a more balanced set of criteria, and to favor lump sum and unit price contracts as a way of controlling costs. However, these generalizations should be tempered by the fact that 10 out of 11 government responses were considered to be emergency removal actions. When time is of the essence, it appears more plausible to select qualified contractors quickly. Since in most emergency situations little is known about the actual nature and extent of contamination, a time and materials contract may seem not only expedient but necessary. Subcontracting also seems more appropriate when a response might encounter hazardous situations that require rapid mobilization of special services.

The private cases, in contrast, were primarily remedial actions where the companies had enough time to determine the scope of the needed responses. More preliminary investigations were conducted and remedial action plans developed. Usually, government authorities participated in the investigative and planning phases of the work. As a result, the private firms were in a better position to know what had to be done, and could use bidding procedures, balanced criteria for selection, and lump sum or unit price contracts to control costs. In light of the differences between the types of response actions then, it does not appear that the data will support many broad generalizations about the respective abilities of the private and public sectors to select appropriate contractors and control response costs. The comparison of private and public approaches should take into consideration the types of response actions involved.

The data on selection of contractors were taken from interviews from on-scene coordinators, contracting personnel and, where available, from copies of contracts, proposals and contractor selection guidelines. Table 22 is intended to show which response actions fall into the listed categories. Many

TABLE 22. SELECTION OF CONTRACTORS

	SITE NAME	SELECTING CONTRACTORS						CRITERIA FOR SELECTION										TYPE OF CONTRACT						
		Open Competitive Bid	Request for Bids from Pre-selected Group	Sole Source	Informal	Pre-existing Contract	Emergency Procurement	Lowest Bid	Bid in Competitive Range	Experience and Technical Qualifications	Past Experience with Firm	Reputation	Proximity to Site	Familiarity with Site	Guarantee of Technology	Management Responsibility	Technical Approach of Proposal	Subcontract Let by Contractor	Lump Sum	Time and Materials	Cost Plus Fixed Fee	Unit Price	Price List on File-By Contractor	Ceiling
PRIVATE RESPONSE ACTION	1. Anonymous A			X					X	X			X		X			X	X			X		
	2. Anonymous B	X	X	X							X									X				
	3. Anonymous C			X	X			X		X			X											
	4. Biocraft			X	X				X	X	X	X		X						X				
	5. Chemical Recovery Systems			X						X		X		X	X				X					
	6. Fairchild Republic	X		X				X	X			X						X	X			X		
	7. General Electric(b)																							
	8. Occidental Chemical	X	X	X	X								X	X					X					
	9. Richmond Sanitary			X							X			X										
	10. Trammell Crow	X				X		X		X									X		X	X		
	11. Vertac Chemical	X	X	X	X			X	X	X	X	X	X	X					X	X	X	X		X
GOVERNMENT RESPONSE ACTION	1. Chemical Metals Industries			X						X	X		X					X	X	X			X	
	2. College Point			X						X		X						X		X				X
	3. Gallup			X						X	X		X					X	X	X		X		X
	4. Goose Farm		X	X			X	X		X								X		X				
	5. H&M Drum	X		X		X				X							X	X		X				X
	6. Houston Chemical			X			X			X			X					X		X			X	
	7. Howe, Inc.			X		X	X		X	X			X					X		X		X		X
	8. Marty's GMC	X		X		X		X		X		X				X	X	X		X			X	X
	9. N.W. Mauthe		X		X			X									X							
	10. Quanta Resources	X					X		X	X		X				X	X			X				X
	11. Stroudsburg		X	X			X		X	X	X					X	X			X				
	12. Univ. of Idaho		X					X		X									X			X		

TABLE 22. (continued)

DESCRIPTION OF CATEGORIES

Procedure for Selecting Contractors

Open Competitive Bid - where public announcement of job or RFP is made and any interested party can respond.

Request for Bids from Pre-selected Group - where the responsible party seeks bids from firms that were pre-selected based on criteria such as prior experience, technical qualifications, general reputation, etc.

Sole Source - where the responsible party hires a particular firm without any bidding by other firms.

Informal - where the responsible party selects and hires a firm without following express procedures or guidelines ; contract could be oral or written.

Pre-existing Contract - where the responsible party had an ongoing contract with a firm to provide various services at a site or particular services at similar sites.

Emergency Procurement - where the responsible party, usually a government agency, has special procurement powers for emergency response actions.

Criteria for Selection

Lowest Bid - the lowest price quoted for the work to be performed. Used primarily in procedures involving competitive bidding or bidding by pre-selected group, and where lump sum or fixed price contracts are used.

Bid in Competitive Range - bid was not lowest but among the lowest; other criteria may have a role in the decision.

Experience and Technical Qualifications - a firm's experience with the proposed kinds of response work; its technical expertise to do the job.

Past Experience with Firm - the responsible party's prior dealings with a firm in similar work situations.

Reputation - what is generally and informally known about a firm's competence, professional standards and management capability.

Proximity to Site - how far a firm has to travel to work on-site or how far materials have to be transported from the site to a facility for treatment or disposal.

Familiarity with Site - usually based on previous experience working on-site for the responsible party or working with local geology; may include knowledge of plant operations, hydrogeology, previous remedial actions, etc.

Guarantee of Technology - contractual guarantee that technology, e.g., a slurry wall, will meet stated specifications.

Responsiveness to RFP - how well a proposal responded to the responsible party's Request for Proposals, which usually describes the known or expected contamination or threat.

Management Responsibility - how well a firm can organize and manage a task; whether it can be depended on to complete its work in a professional manner. This may include financial responsibility and solvency as well.

Technical Approach of Proposal - how well a firm analyzed a situation and proposed a course of action, from an engineering, chemical or scientific standpoint.

Type of Contract

Subcontract Let by Contractor - contract made between a primary or general contractor having broad authority for a response and a subcontractor for specific tasks.

Lump Sum - a contract that states a total price for given activities, e.g., $60,000 for a ground water study.

Time and Materials - where the contractor bills the responsible party for the labor of its personnel as well as for the contractor's costs of procuring consumable equipment and materials; this may or may not have a ceiling.

Cost Plus Fixed Fee - a contract whereby the contractor is paid all of its direct costs of the work, such as purchase of consumable equipment, as well as a fee that could be a lump sum, percentage of total construction cost, etc.

Unit Price List on File - by Contractor - some responsible parties, usually government agencies, keep a price list of the costs for labor and materials submitted by various contractors, so that the responsible parties can more readily estimate costs and select contractors; the price list may be incorporated into the contract.

Ceiling - the upper limit of a responsible party's liability on a contract, regardless of whether it is fixed price, time and materials, etc.; disbursement limits or temporary limits on spending authority are not included in this category.

response actions involved more than one contractor. When this occurred, each process by which a contractor was selected is marked on the table. For example, in Fairchild Republic Company, three contractors were hired by the company, and one contractor hired several subcontractors. The engineering contractor was hired on a sole source, lump sum contract and the two excavating and hauling contractors were hired based on separate competitive bidding procedures, one as lowest bid and one as a bid in the competitive range that was from a contractor known to be reputable. The table lists all of the contractor selection issues: competitive bid, sole source, bid in competitive range, reputation, and subcontract. This way of presenting the data enables one to identify how many times a particular issue, such as competitive bidding, appears in the 23 case studies. To find the selection process used for a certain contractor in a given response action one can turn to the "Selection of Contractors" secton of that case study.

The case studies are also divided into private and government response actions in this table. This allows one to compare the selection procedures, criteria for selection, and types of contracts used by the private sector with those used by the public sector. For example, one can compare the number of cases where competitive bidding was used in private versus public response actions, which are 5 and 3 occasions, respectively, or the number of cases where a time and materials contract was used, 3 and 10, respectively. Such a format provides a general idea of how public and private entities select contractors for response actions.

Procedures for Selecting Contractors

The most common procedure used was the sole source method, which was found in 18 of the 23 case studies. Competitive bidding was the next most common with 8 appearances, followed closely by requests for bids from pre-selected contractors at 7 appearances. When combined the two bidding categories account for 15 of the 23 case studies. Pre-existing contracts, informal selections and emergency procurements were found at about one-half the frequency of the two bidding or the sole source categories.

Criteria for Selection

The criteria of experience and technical qualifications were the most commonly used basis for selecting contractors, appearing in 17 of 23 case studies. Lowest bid and proximity to site were next, with 8 occurrences each, followed by past experience with a firm and reputation (7 each), familiarity with site (5), and technical approach of the contractor's proposal (4). The remaining criteria, guarantee of technology and management responsibility, appeared twice each.

Type of Contracts

Three principal types of contracts were encountered in this research: time and materials (13 cases), lump sum (9 cases), and unit price (7 cases). Two cases involved cost plus fixed fee contracts and three cases had contracts using a contractor's price list that was on file with a government agency before the response began. Two characteristics of contracting were frequently found: the use of ceilings and the letting of subcontracts by primary or general contractors. In 8 cases, contracts that contained ceilings were used, and these often were time and materials contracts. Subcontracts appeared in 10 cases.

Private and Government Response Actions Compared

The data in Table 3 show some differences in the way private and public parties selected contractors for response actions. Some of the more noteworthy points of comparison are discussed below.

Procedures for Selecting Contractors

Private and public responses appeared to use selection procedures with roughly the same frequency. For example, of 11 private actions, 5 used competitive bidding, 4 used bidding from pre-selected groups and 9 used sole source methods, compared to 12 government responses, which used 3 open bids, 3 bids from pre-selected groups and 9 sole source contracts. Some differences in selection procedures can be explained in terms of the different responsibilities of government versus private response authorities. Government actions included 5 cases involving pre-existing contracts and 3 cases using emergency procurement procedures, two features that are fairly common with agencies charged with the responsibility for responding to emergency situations. Only one private response involved a pre-existing contract, and in that case the contract was for a broad range of engineering services relating to construction at the site. Informal selection of contractors occurred in several private actions but in no public actions, probably due to government procurement requirements.

In three cases, Quanta Resources, Marty's GMC and H&M Drum, the state hired a management consulting firm to establish criteria for selecting contractors by competitive bidding and to evaluate proposals. The state then hired the contractor recommended by the consulting firm. A similar procedure occurred in Trammell Crow, where a private company that owned the site had an engineering consulting firm, which had developed the remedial action plan, evaluate contractors' competitive bids. The company hired the contractor recommended by the engineering firm.

Criteria for Selection

All government response authorities stated that they selected contractors based at least in part on the firms' experience and technical qualifications, while only half of the private response authorities did so. The next most common criterion used by governments was proximity to the site (4 cases), followed by lowest bid, past experience with a firm, and the technical approach of proposals (3 cases each). Bids in the competitive range and reputation each appeared in three cases. These data suggest that government agencies always looked at a contractor's technical expertise, but that in less than half of the cases they also looked at other factors such as lowest bid, bid in competitive range, etc.

Private companies directing response actions used these criteria with a more even frequency. Cost considerations seemed to be more important in these actions: lowest bids appeared in 5 of 11 cases and bids in the competitive range in 4 cases. Four cases involved selections based on past experience with the contractor or the contractor's reputation. The contractor's familiarity with the site appeared in 5 cases. Proximity to the site appeared 4 times and technical approach of the proposal only once. An interesting criterion, contractual guarantee of technology, was found in two private responses. One criterion, management responsibility, apparently related to a more formalized screening of contractors because it never appeared in the private response cases. On the whole, it seems that private firms used several criteria with about the same frequency, but that no single criterion was used in every case.

Type of Contract

Government agencies used time and materials contracts in 10 of 12 response actions, compared to only 3 of 11 occurrences in the private cases. Contracts included ceilings in 6 government cases and 2 private cases; each time a ceiling was used, the contract was for time and materials, whether public or private. Government authorities allowed primary or general contractors to let subcontracts in 8 cases, whereas only 2 private cases involved subcontracts. Private companies seemed to use lump sum and unit price contracts more often than governments. Private responses had 6 lump sum and 4 unit price contracts, as compared to government responses, which had 3 lump sum and 3 unit price contracts. Two private cases involved cost plus fixed fee contracts and two government contracts incorporated contractors' price lists that were already on file. Thus, it appears that private companies used types of contracts that could provide more certainty about and control over response costs, while government authorities used less controllable forms, such as time and material contracts, but often sought to control costs by imposing ceilings. Also, private firms tended to do their contracting directly with all contractors, regardless of how minor or specialized the services were, while government officials were more willing for primary contractors to subcontract for specialized work.

SECTION 6

FINDINGS AND RECOMMENDATIONS

The findings and recommendations in this section are based on general observations from the broad-based research for the nationwide survey and detailed case studies. They are useful for defining and understanding the nature of hazardous waste problems and site response activities in the United States today. These conclusions are also useful for planning future site response activities or improving those response activities which have already taken place, in the most cost-effective and technically sound manner possible.

The following subsections present the findings and recommendations based on the nationwide survey, followed by the findings and recommendations based on the 23 case studies.

NATIONWIDE SURVEY FINDINGS AND RECOMMENDATIONS

A number of conclusions can be drawn from the nationwide survey results regarding the nature of uncontrolled hazardous waste sites in the United States and the remediation technologies implemented at the sites. The most significant conclusions include the following:

- More than one-half of the 395 sites identified are abandoned or inactive facilities.
- More than one-half of the 395 sites identified are Superfund priority sites.
- Surface impoundments and landfills are the most common waste management practices employed at the identified sites.
- Metals and solvents are the two most prevalent types of contaminants found at the sites identified through this survey.
- Ground water and surface water are the media types most frequently contaminated at the identified sites.
- Almost one-third of the remediation programs implemented at the sites involved a combination of remedial action techniques.
- The most common remediation technique implemented to date has been the removal of waste and contaminated materials from the identified sites.

- EPA Regions IV and V contain the greatest concentration of uncontrolled hazardous waste sites where remedial actions are either planned, ongoing, or completed.

This survey has been valuable in assessing the number of uncontrolled hazardous waste sites across the country where remedial response actions have been completed, are ongoing, or are in the planning stages, as well as what types of technologies are being implemented. It is anticipated that the information provided by this survey and the accompanying case study reports will serve as a guide for future clean-up efforts from both a technical and a managerial perspective. Additionally, this information is a measure of the development and implementation of remedial response actions through 1982. It is recommended that this information be used as a comparative measure with future studies of this kind in order that members of both government and industry can identify the options which are available to them and the general direction in which hazardous waste site response is taking in the United States.

FINDINGS AND RECOMMENDATIONS BASED ON 23 CASE STUDIES

The findings and recommendations in this subsection are based on general observations from the research for the 23 case studies. To some extent, the National Contingency Plan addresses the issues raised here; the recommendations simply focus on more specific considerations that merit attention in the management of remedial actions. The three issues discussed here are:

- Technology selection
- Planning the extent of responses
- Documentation of responses.

Technology Selection

Findings

Upon careful examination of the remedial response technologies chosen at the 23 case study sites, it is evident that decisions were based on various factors such as:

- Objective of response
- Site specifications/characterization
- Available technologies
- Engineering standards
- Long term effectiveness
- Cost
- Regulatory compliance
- Public interest
- Economic return on investment.

Because no decision could be based solely on one factor, at each site, all or a combination of these factors were considered to some extent. Of primary importance was the objective of the site response--what was the purpose for choosing the response technology? Keeping this in mind, technology selection had to be quite site specific, hence the best technology chosen for a site was contingent upon site specifications and characterizations. This not only included the nature and type of contamination present, facility type, and status of operation (active, inactive, or abandoned), but it also included the physical characteristics of the site such as hydrogeologic setting, surface characteristics, climate, and proximity to drinking water supplies, residential areas, unique environments, etc.

Once these factors had been outlined, decision makers determined what technologies were available to them. Generally this involved evaluating several technologies because there were frequently a number of technologies which could have remedied a specific problem and/or because the nature of the problems at the case study sites were multi-fold. For instance, a ground water contamination problem not only involved responding to the actual ground water contamination itself but also involved responding to the cause of the contamination to prevent further problems.

By determining the technology options available, decision makers could then examine the engineering and design standards relevant to a particular site, thus judge which responses were technologically feasible. Another consideration from the engineering perspective was that of long term effectiveness--how useful would this response activity be in years to come? In some instances, it was evident that this was a major concern and that technologies have been implemented where long term monitoring is in effect. In other instances it was evident that this was not a major concern and therefore long term monitoring has not been implemented.

Also of major concern in selecting response technologies was cost. The technology options in most instances were evaluated not only for their ability to remedy hazardous waste problems, but also for their cost feasibility. In the long term, high cost technologies can prove ineffective because maintenance and upkeep on a complex system can be too costly. If a facility operator does not have the ability to keep such a system in optimum working condition, then the response cannot be successful. These case studies have shown that technology selection has been in many cases based on compromises between technical and economic feasibility.

In addition, selection of site response technologies, as these case studies have shown, is based on compliance with the intent of Federal and State regulations to the extent possible. This includes compliance with the intent of RCRA, CERCLA, OSHA, etc. during selection and implementation of remedial response actions. For instance, at sites where wastewater treatment systems were installed, systems were designed to ensure that the treated wastewater was within compliance with the National Pollutant Discharge Elimination System (NPDES) prior to discharge into a tributary.

Another factor considered at some of the sites was that of public interest. Because of the overall sensitive nature of hazardous waste issues, technology selection in some instances took public interest into consideration. For example, at one site plans for implementation were designed so that construction could be halted if a threat to human health was evident because of high winds. In other cases, design plans submitted by private companies to State officials were explained to citizens' groups who had the opportunity to comment on the plans.

The most successful of the response actions at the case study sites were those that took into consideration all of these selection considerations. This could be ensured through a systematic approach to technology selection.

Benefits

It is essential that the remedial actions selections process evolve around a systematic approach tailored to achieve the objectives of the remediation effort. The ultimate benefit of such an approach is the creation of an effective management scheme for remedial action selection. By implementing an organized management approach several inherent problems observed in the case studies evaluation may have been avoided. For example, at several sites, had a clear definition of the objectives of the remedial actions been established, then the extent of the response and degree of clean-up could have been developed (i.e., in the action of an emergency removal or the initial stage of a long term remedial activity). By setting remedial actions objectives (scope of work to be performed) several communication, costs, and technology selection problems are avoided or reduced.

It is more likely that implemented action will succeed if a system exists for selecting remedial alternatives which factors in elements such as site characteristics, cost, response objectives, and other key decision elements. For example, in the case of an emergency action little time is available for evaluating and selecting the type of remedial action. However, if a series of reference charts were available which outlined the positive and negative aspects for implementing various alternatives, then the decision maker could quickly compare the site specific conditions with the limiting factor for each remedial option. Using this gross comparison he could then select the most feasible option and as a result reduce the risk of making a poor selection.

The benefit of remedial actions design guidance is realized most during the implementation and long term performance of the action. Once a remedial alternative has been selected there exists a need to design the action so as to meet or exceed the performance standard specified in the response objectives. It is necessary that guidance be provided which describes the baseline design requirements for the various remedial actions (i.e., where to key slurry walls, how large drain pipes should be, and what chemicals are effectively treated by carbon absorption). With these baseline design requirements available the planner is able to develop construction specifications which will assure effective implementation of remedial actions.

Recommendations

The National Contingency Plan has established a process for planning site responses. Within section 300.67 guidelines are provided on criteria and screening methodologies for selecting remedial alternatives. However, no specific guidance is provided on the steps or tools for conducting a remedial action selection analysis. It is recommended that a methodology be developed for selecting remedial actions at uncontrolled hazardous waste sites on the basis of site characteristics and anticipated level of response. This should provide the user with mechanisms for evaluating candidate remedial actions by considering the following:

- Media to be controlled
- Characteristics of the contaminants
- Objective of the remedial action
- Design and application limitations and advantages of the remedial actions
- General cost feasibility
- Compliance with regulatory requirements
- Development of a post-remedial action monitoring plan.

A systematic procedure illustrating the steps for collecting and evaluating the supporting data needs to be created in order to perform an evaluation of the factors listed above. Briefly, these steps should include identification of the problem; evaluation of the extent and nature of contamination; collection of site specific data and determination of remedial options; comparison of remedial options with site-specific characteristics, costs, and regulatory requirements; development of preliminary recommendations for remedial actions; and recommendations of a post-remedial action monitoring plan.

Planning the Extent of Responses

Findings

In many of the responses studied, decision makers did not establish specific physical standards regarding the extent of response before beginning clean-up work, or in some cases, before completing clean-up work. Reasons for this include: time constraints in emergency responses; uncertain funding; and lack of data on the extent of contamination or feasibility of achieving a predetermined standard. This lack of standards sometimes was an obstacle to effective planning and management of responses, making it difficult to project the amount of funding that would be required and to choose the most appropriate response technologies.

Many of the responses examined, however, demonstrated that it is possible to establish specific physical standards regarding the extent of remedy prior to initiation of responses. Decision makers often used or adapted existing standards for pollutants, referring to drinking water standards, effluent discharge standards, crop tolerance limits, suggested no-adverse-response levels, and others. These standards, however, were not always stated clearly at the outset of the responses.

Benefits of Setting Response Standards

Goals expressed in terms of specific standards are basic tools of effective management. Standards regarding the extent of response, established before clean-up work starts, allow response managers to select the most appropriate technologies and predict demands on funding. As responses are performed and completed, response managers can use the standards to evaluate the performance of technologies and decide whether further work is needed. The primary benefit of specific standards as discussed here is as management tools in individual responses. The policy questions of the most appropriate sources of standards, or their applicability across sites, are beyond the scope of this study.

Recommendations

It is essential that response managers establish, after site investigation and prior to beginning clean-up work, explicit clean-up standards defined by specific physical parameters. The standards should be incorporated into the Remedial Action Master Plan (RAMP) and should serve as the basis for planning and managing the clean-up. However, it should be recognized that standards may have to be modified later, as technical limitations become apparent or new data become available. The Remedial Action Master Plan should specify, to the extent possible:

- Acceptable levels of contaminants allowed to remain in the soil, ground water, surface water, or air after a clean-up is complete
- Acceptable uses of the site or site environs after completion of clean-up
- If remedial structures or devices are installed on-site, the amount of time they will be maintained or operated
- The methodology that will be used to evaluate the performance of the remedial measures and determine if the standards have been met.

Documentation of Responses

Findings

The case study research found that the documentation of both government and private responses was often not conducive to retrospective analysis of the response. Consequently, a substantial amount of the researchers' time was invested in reviewing files and conducting interviews in order to determine the task-specific costs, bases for decisions, and technical details of responses. It became apparent during the research that, if lessons are to be learned from future hazardous waste site responses, clean-ups will have to be documented in a manner that provides ready access to the relevant data without such a great expenditure of resources. The most useful documentation would be a summary report similar to the On-Scene Coordinator's (OSC's) reports required for responses under section 311 of the FWPCA, but would provide more specific details on costs, decision making, and performance of technology.

Benefits of Improved Documentation

Cleaning up hazardous waste sites is a new field in science, engineering, and public policy. Consequently, little data are readily available on the performance and costs of remedial technologies and on management of clean-ups. Such data will be required for effective planning of the large number of clean-ups that State and Federal agencies will manage in coming years. While the case studies in this report provide useful reference points for costs, technologies, and decision making, data and experience from a much larger sample of sites will be required to improve the cost-effectiveness of the diverse range of future clean-ups.

A central file of summary reports on site investigations and clean-ups detailing task-specific costs, performance of technologies, and decision-making would assist:

- Planning and management of future clean-up
- Cost-recovery litigation
- Clean-up negotiations with responsible parties
- States' management of their own clean-ups.

The data file would aid in planning and management of individual clean-ups. By reviewing the costs and performance of past site investigations and responses, decision makers would be better able to evaluate bids and proposals, select contractors, and predict the cost and duration of the various tasks that comprise a clean-up. The data file could continue to assist decision makers during clean-ups by providing examples of solutions to unanticipated problems in past responses.

The summary reports would assist cost recovery litigation by providing coherent explanations and justifications for expenditures and decisions associated with individual cases being litigated, and by facilitating comparison of costs of litigated clean-ups with similar sites in order to justify expenditures.

The data file would assist in clean-up negotiations with responsible parties. By reviewing the range of costs of similar previous clean-ups, government negotiators would be better able to estimate the costs of clean-ups, thereby strengthening their negotiating positions.

Finally, the data file would improve the States' ability to perform or contribute to remedial actions by giving them access to a nationwide pool of experience with remedial action management, costs, and technologies.

Recommendations

The National Contingency Plan (NCP) discusses the need to provide documentation of responses under CERCLA and the FWPCA, and is a useful starting point for guidance on what such documentation should include. Under Subpart F, which addresses hazardous substance responses, section 300.69

requires that adequate documentation be maintained, but does not specify the content and format, and does not require an OSC report for each response. Under Subpart E, which addresses oil removal, sections 300.54 and 300.56 are somewhat more specific, but even if they were applied to hazardous substance responses, they would not provide sufficiently detailed and accessible data on costs and institutional aspects of clean-ups. Section 300.54 refers to documentation requirements under 33 CFR section 153. In section 153.415(c), the OSC is required to provide in a summary report an estimate of the cost of each function performed by each agency and contractor. This is an important requirement and should be applied to hazardous waste responses as well.

Section 300.56 of the NCP provides a specific outline for OSC reports on oil spill responses, but does not require all of the institutional and cost data that would be useful in hazardous waste clean-ups under CERCLA. While oil spill clean-ups involve relatively well-known technologies and costs which do not require detailed summary documentation for research purposes, data from hazardous waste clean-ups should be made more readily available.

The following two recommendations are intended to make the most efficient use of government resources for management of uncontrolled hazardous waste site remedial actions.

1. Hazardous substance responses should be summarized in a report similar to the OSC report outlined in section 300.56 of the NCP, but with the additions suggested in the Sample Protocol (see Example 1). In order to maximize accessibility of the data, the reports should be available in a central file and should be cross-referenced according to relevant factors such as: type of contamination; type of remedial technology; and type of site, including geological and surface characteristics.

2. Contractors hired for responses should be required to include specific information in invoices, aggregated by task, regarding the amount and type of equipment and materials used, and amount and type of labor. Quantities of materials should be expressed in standard units; for example, quantities of waste transported should be expressed in tons or cubic yards, in addition to truck loads. Actual unit costs should be expressed where applicable. If a contractor produces a summary report, the report should include a task-specific accounting of that contractor's costs, in addition to the technical information normally provided. If the cost of a contractor's work deviated from an initial estimate, the contractor should explain and document the reason for the deviation.

The OSC summary report outlined below would simply provide for information that is already documented, in most cases, to be assembled in the most useful format:

Example 1. SAMPLE PROTOCOL FOR HAZARDOUS SUBSTANCE RESPONSE SUMMARY REPORTS

I. Summary of Events, including chronology

II. Description of site investigation, including explanation of basis for type and extent of investigation performed

III. Basis for initiation of response

(a) threatened populations, including distance from site

(b) type of contaminants

(c) contaminant pathways

IV. Basis for selection of contractors and description of contracting method

V. Basis for selection of response technology

VI. Basis for planned extent of response

VII. Description of technical details of response, organized by task and sub-task, including the amount of time it took to complete each task.

(a) description of site

(b) quantities of waste

(c) dimensions, quantities, or design specifications of materials or equipment used in the response

(d) schematic diagrams of remedial measures

VIII. Cost of response

(a) initial cost estimate prior to response, and basis for estimate

(b) actual cost breakdown by task

(i) site investigation cost

(ii) cost of each remedial task

(A) unit costs

(B) expected future costs, particularly operation, maintenance and monitoring

(iii) administrative costs

(c) factors affecting costs

(d) reasons for variance of actual cost from initial estimate

IX. Evaluation of effectiveness of response, in light of planned extent

X. Problems encountered

XI. Recommendations

XII. Bibliography of significant documents related to response

*USGPO: 1984-759-102-889