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COMPENDIUM OF COST OF REMEDIAL TECHNOLOGIES AT HAZARDOUS WASTE SITES

DRAFT

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A Report to the Office of Emergency and Remedial Response
U.S. Environmental Protection Agency

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SECTION 1

1.0 INTRODUCTION

1.1 OVERVIEW

Response cost information is critical to several aspects of implementation of the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA), known as Superfund. These aspects include:

- o Selecting cost-effective response alternatives
- o Documenting reasonable costs for cost recovery
- o Budgeting for fund balancing

The purpose of this Cost Compendium is to summarize existing cost information for these uses. Actual expenditures and estimated costs are both given to assemble data from all available sources into this one data base. The immediate use of this centralized source of cost information is to provide consistency in various site-specific costing tasks such as: remedial alternative costing called for in the Feasibility Study Guidance Document (FSGD), and budgeting for immediate and planned removals. This compendium should be viewed as the first installment of an ongoing data base, which will be updated periodically as more cost information becomes available from completed Superfund responses. Cost data in this compendium are organized according to related technologies, such as "Ground Water Controls" (see Table of Contents). The cost given are for technologies that have been most commonly used at uncontrolled hazardous waste sites, although some rarely used technologies are given because estimates are frequently given. Commonly used technologies may have been excluded because of the paucity of data. Typically, however, the number of estimates and the depth of background information are often proportional to the frequency of use of the technology. In addition to the organization of cost data according to technologies, several other features of this cost compendium, which merit highlighting are summarized below.

1.2 ACTUAL EXPENDITURES VERSUS ESTIMATES

Most available cost information is from engineering estimates. Few such estimates have been field tested, however. Preliminary comparison of these estimates with actual expenditures has shown significant differences in many cases (ELI/JRB, 1983). Since merging these two types of data would be misleading to the reader, this compendium separates, ex ante, engineering estimates from actually observed expenditures. Although actual expenditure data, which has been "ground truthed", are generally more reliable than estimated cost data, estimates are useful because they broaden the range of site characteristics and technical circumstances for which costs are available. The factors that were included in deriving the cost estimates may reflect a situation that more closely parallels the intended use of the cost data than any of the situations for which actual expenditure data are available.

1.3 FOCUS ON UNIT COST

Data are given in a unit cost form, in terms of dollars per unit operation, such as cost per square foot of slurry wall, or cost per gallon of treated water. Since the units used are important, consideration was given to the selection to ensure that they were useful and/or standardized throughout the industry. English measure only are used for simplicity. These unit costs typically include all related costs such as material, labor, and equipment and other capital costs. Operation and labor costs are given when they are applicable and available.

1.4 INCLUSION OF SUMMARY AND RAW DATA

This compendium organizes cost data into two levels: (1) summary data, and (2) raw data. On the first level, summary data such as range, and when possible, mean and standard error are given. This is simply a summation of the raw data and should be used only for very general cost screening and budgeting. The wide ranges of these data summaries, and the lack of background explanation on this level render it unsuitable for more specific costing purposes. Such specific cost estimation should use raw data, on the second level, which provides more detail on the data compilation. This detail can be used for matching to the circumstances at the site for which it is to be used. The user should compare the site circumstances to the factors given in the raw data to estimate the effect of these factors on the estimated cost.

1.5 FACTORS FOUND TO AFFECT COSTS

A fundamental concept of estimating technology costs is that a variety of factors influence these costs. This compendium discusses these factors for each technology. This brief discussion of the effects of these factors reflects the descriptive detail given for each data source in the table of raw data. For actual expenditure data, the essential site characteristics are typically described. For estimated costs, these site characteristics are drawn from a hypothetical site scenario that is usually established for the purpose of making necessary assumptions for estimating costs. The level of detail available for actual site characteristics and hypothetical site scenarios varied widely.

1.6 CONSTANT 1982 DOLLARS

Since the source data, on which this compendium is based, originated in different years between 1975 and 1982, all costs were indexed to constant 1982 dollars using the Engineering News Record construction cost index. This index relects the weighted cost trend of common labor (74%), structural steel (15%), lumber (9%), and portland cement (2%). Data from 1983 documents were not deflated to 1982 dollars for two reasons. First, most of the actual costs for 1983 were actually incurred in 1982 or estimated for 1982 dollars. Second, the change in the ENR index between 1982 and 1983, is expected to be very small.

1.7 COST OF HEALTH AND SAFETY PROTECTION

One of the key factors affecting the costs of responses at uncontrolled sites is the level of protection for health and safety of on-site workers. The level of hazard determines the type of protective measures the workers must take, which ultimately affects the cost of the response. Many of the data sources used in this compendium, however, did not explicity note health and safety concerns. For actual expenditures, the cost data already include whatever protective measures were taken at the site. Often, however, the available information on the response action did not fully describe the protective measures. This defect may be corrected by further research. For estimates, health and safety assumptions are usually less clear than expenditures. In only one case did the estimator explicitly consider the cost effect of various protective measures.

SCS Engineers recently completed a study on the cost of health and safety protection, for the U.S. EPA Office of Research and Development. For study, six cleanup firms were asked to bid on six hypothetical uncontrolled site scenarios with five levels of personal protection (see Table 1). The key results are presented in Table 2, and more details are given in the SCS report. In using Table 2, several items should be kept in mind. First, the results are from a final draft version of the SCS report. Additional changes may be made to the results. Second, the validity of the results depends on how seriously the bidders took the hypothetical scenarios and whether the bidders were neutral in providing the estimates (i.e., free from motives that may misrepresent the costs). And finally, the technologies in Table 2 do not always match the ones given in this compendium.

TABLE 1

LEVELS OF PERSONAL PROTECTION

1. Level A – requires full encapsulation and protection from any body contact or exposure to materials (i.e., toxic by inhalation and skin absorption).

2. Level B – requires self-contained breathing apparatus (SCBA), and cutaneous or percutaneous exposure to unprotected areas of the body (i.e., below harmful concentration).

3. Level C – hazardous constituents known; protection required for low level concentrations in air; exposure of unprotected body areas (i.e., head, face, and neck) is not harmful.

4. Level D – no identified hazard present, but conditions are monitored and minimal safety equipment is available.

5. No hazard protection – standard base construction costs.

Source: "Interim Standard Operating Safety Guides," EPA, 1982.

TABLE 2.

AVERAGE PERCENT INCREASE FOR TOTAL COSTS AT FOUR DEGREE-OF-HAZARD LEVELS*

Unit Operation	Level D	Level C	Level B	Level A
Surface Water Controls:				
1. Surface Sealing - Sythetic Membrane	114%	119%	122%	124%
2. Surface Sealing - Clay	109%	119%	124%	127%
3. Surface Sealing - Asphalt	--	--	--	--
4. Surface Sealing - Fly Ash	--	--	--	--
5. Revegetation	117%	124%	126%	128%
6. Contour Grading	122%	133%	140%	146%
7. Surface Water Diversion Structures	135%	144%	151%	154%
8. Basins and Ponds	125%	138%	145%	150%
9. Dikes and Berms	150%	173%	176%	186%
Ground Water Controls:				
1. Well Point System	110%	117%	121%	128%
2. Deep Well System	--	--	--	--
3. Drain System	128%	138%	143%	148%
4. Injection System	--	--	--	--
5. Bentonite Slurry Trench	109%	114%	132%	136%
6. Grout Curtain	--	--	--	--
7. Sheet Piling Cutoff	--	--	--	--
8. Grout Bottom Sealing	--	--	--	--
Gas Migration Controls:				
1. Passive Trench Vents	--	--	--	--
2. Passive Trench Barriers	--	--	--	--
3. Active Gas Extraction Systems	--	--	--	--
Waste Controls:				
1. Chemical Fixation (Solidification)	122%	129%	133%	137%
2. Chemical Injection	--	--	--	--
3. Excavation of Wastes/Contaminated Soil	307%	337%	397%	715%
4. Leachate Recirculation	--	--	--	--
5. Treatment of Contaminated Water	119%	121%	126%	128%
6. Drum Processing	201%	228%	264%	317%
7. Bulk Tank Processing	195%	248%	419%	549%
8. Transformer Processing	--+	293%	--+	--+

* Values given include 100 percent for base construction costs.

\+ This unit operation was deemed appropriate for performance only at Level C. Costs at Levels D, B, and A were not provided.

Source: "Worker Health and Safety Considerations: Cost of Remedial Actions at Uncontrolled Hazardous Waste Sites", Draft Final Report, 1983. SCS Engineers for US EPA, Covington, KY

SECTION 2

2.0 SURFACE WATER CONTROLS

2.1 SURFACE SEALING

2.1.1 Definition

Surface sealing (capping) involves covering a site with any of a variety of materials, including clay, asphalt, cement or a synthethic membrane, to prevent surface water infiltration, control erosion, and/or mitigate volatilization from contaminated waste.

2.1.2 Units of Measurement

Cost per unit surface area is used, generally, because area best expresses the functional attribute of a cap. Cost per square yard is used specifically because it is readily converted to acres (X 4,840), sq.ft. ($/9) and cubic yard volume (X depth in yards).

2.1.3 Summary Statistics

2.1.3.1 Expenditures

The actual costs of surface seals ranged from:

$0.92/yd.^{2} - 4" thick, loam

to

$ 15.84/yd.^{2} - 6" thick, clay

The surface seals for which actual costs are given reflect site specific characteristics, such as design parameters and local material availability. The highest cost seal involved an engineered cap with careful quality control for clay/water content. The lowest cost cap was constructed with on-site clay that required only hauling and compacting expenditures.

Operation and maintenance costs involved groundwater monitoring, inspection and, possibly, repair costs. These costs were either accounted for separately or had not yet been encountered in these new caps.

2.1.3.2 Estimates

The eight cost estimates for surface seals ranged from:

$1.32/yd.^{2} - geotextile, level B protection

to

$16.88/yd.^{2} - sand/hypalon/loam

Operation and maintenance costs involving ground water monitoring and cap inspection were generally not included in the estimates. However, the following in O & M costs were included in the Radian estimate:

Item	Cost
Annual Inspection	$500/year
Mowing/Revegetation	$600/year/acre
Erosion control and drainage maintenance	$200/year/acre
Repairs resulting from shrink swell or freeze/thaw forces construction	$200 costs/year

The extremes of the range of estimated costs are represented by a very simple temporary cap at the low end and a more complex, three element cap, intended to be permanent, at the highest cost end.

2.1.4 Factors Found to Affect Costs

2.1.4.1 Expenditures

Generally, the following salient factors affected the surface seal costs:

- Cap material:

  bentonite/clay
  asphalt
  concrete
  synthetic membrane
  loam soil

- o Related material costs:

  top gravel
  gravel bed
  curbs
  membrane anchor soil

- o Dimensional variations:

  thickness
  area covered

The factors affecting the actual costs of surface seals, as outlined above and given in Table 3 are generally divided into "Material variations" and "Dimensional variations". They are presented here only to provide a rough background explanation of the costs for general comparison purposes, and not to specifically delineate the proportional effect of particular cost components. It is not possible to determine from the data if there was a significant general cost difference between clay and asphalt caps. Although the costs at the California site suggest no significant cost difference, other sites had significant cost differences. These differences, however, may have been due to anomolous local material availability or other factors. The number of observations were inadequate to make any clear conclusions. Variations in the costs for related materials may have affected the total costs of the various caps. The cost of the bentonite-soil cap at the California site 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 curbs for run-off control at the California site was not included in the total reported cap cost, but curb installation may have caused a cap cost increase not incurred in the other sites lacking this feature, due to delays for sealing these seams. The use of a synthetic membrane required less heavy construction equipment for deployment, although soil anchors were used. The cap for the New Hampshire site may also be considered an element of revegetation, but it also had a role in soil stabilization.

TABLE 3

SURFACE SEAL EXPENDITURES

(1982 Dollars)

DATA SOURCE	MATERIAL	THICKNESS	COVERAGE	UNIT COST
US EPA ELI/JRB 1981 Maryland	clay	6 inches	data not available	$15.84
US EPA ELI/JRB 1981	gravel over bentonite-soil	6 inches 4-6 inches	17,333 sq.yd.	$10.98
California	asphalt	data not available	15,000 sq.yd.	$11.18
US EPA ELI/JRB 1980 Arkansas	clay	1 foot	11,111 sq.yd.	$10.09

TABLE 3 (continued)

SURFACE SEAL EXPENDITURES

(1982 Dollars)

DATA SOURCE	MATERIAL	THICKNESS	COVERAGE	UNIT COST
US EPA CH_2 M Hill 1981 New York	synthetic membrane	data not available	216,600 sq.yd.	$3.75/sq.yd.
US EPA Weston 1981 New Hampshire	loam soil for revegetation	4 inches	120,520 sq.yd.	$0.92/sq.yd.

Finally, the cap dimensions—thickness and area covered—appeared to affect cap unit costs. Increased cap thickness and area generally added to cap costs by increasing the volume of cap material required and the amount of grading. An exact generalized function for this relationship cannot be determined from the available data. The unit cap cost, however, is also affected by economies of scale.

2.1.4.2 Estimates

Generally, the following factors affected the estimates:

- Component material type:
  - clay
  - soil
  - synthetic liner
  - sand
- Number of components:
  - single component
  - composite
- Dimensional variations:
  - thickness
  - area covered

Generally, cost estimate information (see Table 4) was less detailed than the data for actual cost; however, salient information usually was available. Scenarios from generic engineering-construction cost manual estimates (JRB, SCS, Radian) and feasibility studies were unable to predict unexpected changes occurring during the response.

As in the actual costs, components affecting the costs were generally qualitative and quantitative - "Component material costs" and "Dimensional variation," respectively. Four types of materials were assumed in the various estimates: clay, soil, synthetic liner and sand. The more significant consideration, however, was the number of components assumed for the estimates. Typically, additional component costs in composites were assumed to be additive. Again, the dimensional variations affected both the volume of surface material required and the economies of scale. Increased cap thickness requires more volume per area. By using mobilized grading and compacting equipment at a relatively small additional marginal cost, caps with a larger area had the advantage of greater economies of scale.

TABLE 4

SURFACE SEAL COST ESTIMATES

(1982 Dollars)

DATA SOURCE	MATERIAL	THICKNESS	COVERAGE	UNIT COST
US EPA JRB-RAH 1980	loam over hypalon over sand	8 inches 30 mil. 1 foot	96,800 sq.yd.	$16.88/sq.yd.
US EPA Radian 1982	loam over hypalon over sand	8 inches 30 mil. 1 foot	96,800 sq.yd.	$9.34/sq.yd.
US EPA SCS "landfill" 1980	bituminous concrete	3 inches	66,215 sq.yd.	$6.58-9.13/sq.yd
SCS "impoundment" 1980	bituminous concrete	3 inches	5,597 sq.yd.	$4.67-6.90/sq.yd.

TABLE 4 (continued)

SURFACE SEAL COST ESTIMATES

(1982 Dollars)

DATA SOURCE	MATERIAL	THICKNESS	COVERAGE	UNIT COST
US EPA MERL 1979 New Jersey	bituminous concrete	3 inches	5,597 sq.yd.	$6.49/sq.yd .
US EPA Weston Feasibility Study 1982 New Hampshire	PVC liner	30 mil.	96,800 sq.yd.	$4.50/sq.yd.
US EPA CH_2 M Hill Feasibility Study 1983 New Jersey	earthfill over geotextile	8 inches not given	42,000 sq.yd.	$1.83/sq.yd.
US EPA CH_2 M Hill 1983 Arizona	geotextile	not given	not given	$1.32/sq.yd.

The Radian estimates given Table 5 are based on using the following list of cost components to construct a surface seal, the same specifications were established in the JRB-RAM scenario.

TABLE 5. SURFACE SEAL COSTS: MATERIAL VARIATIONS

Direct Capital Cost Items:	Cost
Topsoil (sandy loam), hauling, spreading, and grading (within 20 miles)	$15/yd.^{3}
Clay hauling, spreading, and compaction	$10/yd.^{3}
Sand hauling, spreading, and compaction	$18/yd.^{3} ($9-12,000/acre)
Portland concrete (4 – 6" layer), mixed, spread, compacted on-site	$9 – 15/yd.^{2}
Bituminous concrete (4 – 6" layer), including base layer	$4.50– 7.25/yd.^{2}
Lime or cement, mixed into 5" cover soil	$2.15 – 3.00/yd.^{2}
Bentonite, material only; 2" layer, spread and compacted	$1.90 yd.^{2}
Sprayed asphalt membrane (1/4" layer and soil cover), installed	$2.00 – 3.40/yd.^{2}
PVC membrane (20 mil), installed	$1.75 – 2.70/yd.^{2}
Chlorinated PE membrane (20–30 mil), installed	$3.25 – 4.30/yd.^{2}
Elasticized polyolefin membrane, installed	$3.10 – 4.15/yd.^{2}
Hypalon membrane, (30 mil), installed	$7.40/yd.^{2}
Neoprene membrane, installed	$7.25/yd.^{2}
Ethylene propylene rubber membrane, installed	$3.60 – 4.70/yd.^{2}
Butyl rubber membrane, installed	$3.60 – 5.10/yd.^{2}
Teflon-coated fiberglass (TFE) membrane (10 mil), installed	$23/yd.^{2}
Fly ash and/or sludge, spreading, grading, and rolling	$1.50 – 2.50/yd.^{2}

Expenditure Sources

- o ELI/JRB Case Studies, 1983
- o State and Federal Superfund Work, 1981 - 1983

Estimate Sources

- o JRB - RAM, 1980
- o Radian, 1983
- o EPA, OERR contractor Feasibility Studies, 1981 - 1983
- o SCS Engineers, 1981

2.2 GRADING

2.2.1 Definition

Grading is the general term for the process of reshaping the ground surface to control surface water run-off and infiltration, as well as to minimize erosion and prepare the site for revegetation or surface sealing. The three basic steps in the process are: hauling, spreading and compacting. The latter two steps are routinely practiced at sanitary landfills. The equipment and methods used in grading are essentially the same for all landfill surfaces, but applications of grading technology will vary on a site-specific basis. Grading is often performed in conjunction with surface sealing practices and revegetation as part of an integrated landfill closure plan.

2.2.2 Units of Measurement

The unit cost is given in dollars per acre because grading is usually performed on the scale of acres.

2.2.3 Summary Statistics

2.2.3.1 Expenditures

No actual expenditure data were available for grading costs at this time.

2.2.3.2 Estimates

The grading cost estimates ranged from:

$4,000/acre
to
$16,205/acre

Operation and maintenance costs involving ground water monitoring and cap inspection were generally not included in the estimates. The following in O&M costs, however, were included in the Radian estimate;

Item	Cost
Annual Inspection	$500/year
Mowing/Revegetation	$600/year/acre
Erosion control and drainage maintenance	$200/year/acre
Repairs resulting from shrink/swell or freeze/thaw forces construction	$200 costs/year

The lower grading cost estimates ($4,000 - 4,720/acre) reflected the costs of on-site hauling, spreading and compacting of a one-foot thick soil layer and a 6 inch sand layer. These estimates assume no material costs for sand or soil. The higher grading cost estimates by SCS also exclude material costs, but include the excavation and grading cost for on-site soil. Additional costs (30%) were included in these estimates to cover overhead and a contingency allowance. The cost for a diversion ditch, included in the SCS estimates, was subtracted, for consistency with the other estimates.

2.2.4 Factors Found to Affect Costs

2.2.4.1 Expenditures

No expenditure data are available at this time.

2.2.4.2 Estimates

The Following salient factors affected grading costs:

Material:

- Source of material
- Type of material

Related or additional costs:

- Soil compaction testing
- Surveying
- Overhead
- Contingency allowance

material costs varied among the estimates detailed in Table 6. The source of the erial was either on-site or off-site, which affected the costs for hauling. The type of material affected the estimate because sand costs more per unit volume to handle soil. Again, however, this estimated difference excludes material costs, and only ides hauling, spreading and compacting.

inclusion of related or additional costs varied among the estimates, and hence cted the costs. The SCS estimates included the following related or additional costs, h were not included in the JRB and Radian estimates:

ted/Additional Costs	Landfill (13.4 acres)	Impoundment (1.16 acres)
eying (2 days)	—	$ 366 - 614
head allowance (25%)	$17,499-20,402	$2,655-3,469
ingency allowance (15%)	$10,502-12,237	$1,593-2,077
Total	$28,001-32,639	$4,614-6,160

ates Sources

- o JRB - RAM, 1980
- o Radian, 1983
- o SCS, 1981

TABLE 6

GRADING COST ESTIMATES

(1982 Dollars)

DATA SOURCE	MATERIAL	COVERAGE	ADDED FILL	UNIT COST
US EPA SCS "Impoundment" 1980	on-site soil	1.16 acres	1.5 feet	$12,563-16,205/acre
US EPA SCS "Landfill" 1980	on-site soil	13.4 acres	1 foot	$7,285-8,469/acre
US EPA Radian 1983	soil sand	not given	not given	$4,000/acre
US EPA JRB-RAM 1980	"fill" sand	15 acres 20 acres	1 foot 6 inches	$4,720

2.3 DRAINAGE DITCHES

2.3.1 Definition

Drainage ditches or trenches intercept overland flow or shallow ground water flow to control surface discharge and/or minimize contributions to ground water contamination. Ditches usually run around the perimeter of a site and may complement ground water or surface water control techniques by collecting water from subsurface drains or off of caps. They may be lined with a clay or synthetic membrane to prevent infiltration or with stone to prevent erosion.

2.3.2 Units of Measurement

Costs are given in dollars per linear foot (LF) because length provides a single simple trench dimension for performing quick estimates.

2.3.3 Summary Statistics

2.3.3.1 Expenditures

No actual expenditure data are available at this time.

2.3.3.1 Estimates

The cost estimates range from:

$1.27 - 2.54/LF (1-foot deep)
to
$6.04/LF (6-feet deep)

The cost estimates seemed to be primarily affected by the volume of soil excavated. The Radian scenario assumed over six times as much soil as the EPA site-specific estimates. The 1 foot deep trench was similar to a shallow french drain since it was filled with gravel.

Operation and maintenance costs such as inspection and repair were inconsistently available. The Radian estimate, however, gave the following estimate:

Item	Cost
Annual Inspection	$500/year
Mowing/Revegetation	$600/year/acre
Erosion control and drainage maintenance	$200/year/acre
Repairs resulting from shrink/swell or freeze/thaw forces construction	$200 costs/year

2.3.4 Factors Found to Affect Costs

2.3.4.1 Expenditures

No expenditure data were available at this time.

2.3.4.2 Estimates

The three primary components affecting the cost estimates were:

- Depth
- Lining
- Overhead and contingency costs

The depth was perhaps the most salient factor affecting cost estimates (Table 7) since it was directly related to the volume of material excavated. Excavation is the primary task of ditch construction, grading and berm construction but it was proportionally included in all estimates.

TABLE 7

DIVERSION DITCH COST ESTIMATES

(1982 Dollars)

DATA SOURCE	LINING	DEPTH	TOTAL COST	UNIT COST
US EPA Radian 1982	none	6 feet	$9,060	$6.04/LF
US EPA SCS (1) "Landfill" 1980	none	6.5 feet	$13,393 - $15,741	$4.39-5.16/LF
US EPA ORD-MERL 1979 New Jersey	gravel and stone filled	1 foot	$8,763	$1.27-2.54/LF

(1) Includes overhead (25%) and contingency allowance (15%).

Only the EPA-New Jersey site estimate included estimates for the lining subtask. This cost component could become more significant for deeper ditches.

Finally, an overhead allowance (25%) and a contingency allowance (15%) were included for the SCS estimate. The other estimates did not include any surcharges or allowances for health and safety considerations, so these additional costs may be appropriate to include for some sites. The SCS estimated only "grubbing" to clear vegetation from ditches (28,300 sq.ft.) once a year at $378-779.

Estimates Sources

- Radian, 1983
- SCS, 1981
- US EPA, OERR contractor Feasibility Studies

2.4 REVEGETATION

2.4.1 Definition

Establishing a vegetative cover may stabilize the surface of hazardous waste disposal sites, especially when preceded by surface sealing and grading. Revegetation decreases wind and water erosion, and contributes to the development of a naturally fertile and stable surface, and reduces infiltration by enhancing evapotranspiration (i.e., increased loss of soil moisture). It also can be used to aesthetically upgrade the appearance of disposal sites that are being considered for re-use. Short-term vegetative stabilization (i.e., on a semiannual or seasonal basis) also can be used during ongoing remedial actions.

2.4.2 Units of Measurement

Costs are given in dollars per acre because revegetation is usually given in terms of acres.

2.4.3 Summary Statistics

2.4.3.1 Expenditures

No actual expenditure data are available at this time.

2.4.3.2 Estimates

The revegetation cost estimates ranged from:

Capital:	$1,214/acre	(1.76 acre site)
	to	
	$8,000/acre	(20 acre site)

Operation and Maintenance:

$51/acre/year
to
$1,267/acre/year

The range of costs for revegetation reflects the differences in the amount of work needed for different site condition assumptions. The highest cost estimate was for a proposed restoration of a secondary growth temperate deciduous forest, requiring heavy liming to neutralize the highly acidic soil. The lowest cost was estimated for a hypothetically filled and graded on-site fertile soil.

2.4.4 Factors Found to Affect Costs

2.4.4.1 Expenditures

No actual expenditure data were available at this time.

2.4.4.2 Estimates

The following factors were found to affect the revegetation cost estimates:

- Soil:
  - New fill and grading required
  - Terrain impediments (e.g., slope, berms)
  - treatment for fertility
- Vegetation:
  - Grass and/or trees (successional stage), multi-year planting
  - Mulching and/or jute mesh stabilization

Soil cost was not included in the estimates (see Table 8). However, for the New Jersey Feasibility Study, 65,000 cubic yards of off-site fill was expected to be necessary for the 72,600 square yard (15 acre) site (0.9 yards deep). Also, the SCS "landfill" estimate includes excavation, grading and recontouring of the site (27,685 m^3) this was about 60% of the total revegetation cost, including the overhead and contingency. The terrain was assumed to be flat except for the JRB estimate, which assumed 25% sloped terrain and 75% flat terrain. The JRB estimate also assumed a three-year staged planting schedule. The estimates also vary the type of vegetation assumed. Hydroseeding was by far the least expensive vegetation ($0.37/sq. yd.) since it provides fertilizer, lime, and seed in mass application of a sprayed liquid. Trees and shrubbery cost significantly more because of higher material and labor costs of individual hand-planted nursery stock. This

TABLE 8

REVEGETATION COST ESTIMATES

(1982 Dollars)

Data Source	Description	Soil	Size	Capital	Operation & Maintenance
US EPA Feasibility Study 1983 New Jersey	grasses trees: pine & hardwoods	acidic fill cost separate neutralized	15 acres	$8,000/acre	$1,267/acre/year (1)
US EPA JRB - RAM 1980	grasses, mulching 1,000 evergreens 1,000 shrubs	tilled loam	20 acres (5 sloped 15 level)	$6,803	$1,022
US EPA Radian 1982	hydroseeding only (lime, fertilizer, field seed)	not given	not given: assume 17.5 acres	$1,791/acre	$829/acre/year

TABLE 8 (continued)

REVEGETATION COST ESTIMATES

(1982 Dollars)

Data Source	Description	Soil	Size	Capital	Operation & Maintenance
US EPA SCS "Landfill"	grading hydroseed, mulching	fertile soil on-site	13.4 acres	$6,420- $7m889 (2)	$51/acre/year
US EPA SCS "Impoundment" 1980	hydroseed, mulching	fertile soil on-site	1.16 acres	$1,214- $1,827/acre (2)	$81-92/acre/year

(1) First 5 years: $140,000; seconi 5 years: $50,000

(2) Includes overhead (25%) and contingency (10%)

higher stage of plant succession will also vary with the type of stock selected. The Radian report provided the following list of various plant costs (in 1982 dollars), which included materials and installation:

Item	Cost ($)
Topsoil, furnish and spread	
4"	1.43/sq.yd.
6"	1.90/sq.yd.
Sodding, 1-1/2" thick	
Level	2.86/sq.yd.
Slopes	3.74/sq.yd.
Ground Covers	
Pachysandra	1.09/sq.ft.
Vinca Minor	1.11/sq.ft.
Privits, 15" tall planted in hedge row	2.34/LF
Barberry, 15" tall planted in hedge row	3.03/LF
Boxwood 16", tall planted in hedge row	2.84/LF
Trees and Shrubs	
Flowering Crab 8' - 10'	222.12/ea
Hawthorn 8' - 10'	170.90/ea
Junipers, spreading 18" - 24"	33.22/ea
Junipers, upright 4' - 5'	58.63/ea
Yews, spreading 18" - 24"	45.22/ea
Yews, upright 2' - 3'	54.63/ea
Rhododendron 2'	71.16/ea
Fir 8' - 10'	251.16/ea
Hemlock 8' - 10'	283.16/ea
Beech 8' - 10'	222.16/ea
Pine 8' - 10'	249.16/ea
Tulip 8' - 10'	244.16/ea
Maple 1-1/2" diameter	167.11/ea
Maple 2" diameter	197.15/ea
Maple 3" diameter	362.24/ea
Sycamore 4' - 5'	46.22/ea
Gold Locust	69.22/ea

Source: Radian, Inc., 1982

Estimates Sources

- o JRB - RAM, 1980
- o Radian, 1983
- o SCS, 1981
- o US EPA, OERR contractor Feasibility Studies

SECTION 3

3.0 GROUND WATER AND LEACHATE CONTROLS

3.1 SLURRY WALL

3.1.1 Definition

A slurry wall is one of several types of subsurface cut-off walls that prevent leachate formation by redirecting upgradient ground water away from a contaminated area, and/or controlling horizontal leachate movement away from the site. A slurry wall is constructed by filling a trench with a slurry such as bentonite on bentonite-soil-cement during excavation. The backfilled trench has a much lower coefficient of permeability than the surrounding soil and thus creates a barrier to ground water flow.

3.1.2 Units of Measurement

Costs are given in dollars per square foot because square feet reflect the functional area of a cut-off wall. In estimating the cost of a cut-off wall, the length and depth (face area) requirements are usually fixed by the extent of the waste and the depth of the aquiclude. Linear units were not used because they would obscure the effect of thickness on grout curtain costs.

3.1.3 Summary Statistics

3.1.3.1 Expenditures

The slurry wall expenditures ranged from:

$0.25/sq.ft.

to

$31.96/sq.ft.

The lowest cost for a slurry wall was for a privately constructed wall using extensive in-house equipment and labor. The next lowest cost wall was relatively shallow (14 feet deep). The highest cost slurry wall was built partly in contaminated soil on a stream bank. Each scoop of soil required analysis with an organic vapor analyzer and was disposed of at an engineered landfill. The stream bank restricted and delayed access to the construction area.

Operation and maintenance costs involved groundwater monitoring and, possibly, repair. These costs, however, either were accounted for separately or were not yet encountered at the new sites.

3.1.3.2 Estimates

Slurry wall cost estimates ranged from:

$4.50/sq.ft. soil-bentonite
to
$13.86/sq.ft.

The highest slurry wall cost estimate ($11.56/sq.ft.) was for a Wyoming bentonite slurry wall. The lowest estimate was for a competitively bid soil-bentonite slurry wall, for which another contractor was deemed more reliable.

Operation and maintenance costs such as inspection, ground water monitoring, and repair were not included in the estimates.

3.1.4 Factors Found to Affect Cost

3.1.4.1 Expenditures

The following factors primarily affected slurry wall expenditures:

- o Depth.
- o Thickness
- o Wall material
- o Inclusion of related costs:
  - Staging area set-up
  - Contaminated trench soil disposal

Perhaps the most salient factor affecting costs (shown in Table 9) was the wall material. Cement - soil/bentonite walls were the most expensive walls; soil bentonite was in the middle of the cost range, and local clay was the least expensive. Much of the local clay used for the $1.80/sq.ft. California slurry wall was dredged from the adjacent bay. Depth affected costs since a larger excavator (such as a CAT 215 or clamshell instead of a backhoe) was necessary for digging deeper trenches. Once mobilized, however, larger equipment is capable of increasing the trench depth at a reduced marginal cost. Wall thickness was directly proportional to the volume of soil excavated and the volume of slurry mixed into the trench. Since costs are given in terms of dollars per square foot, the cost for this added volume is not precisely reflected in the face-area cost. However, most of the walls had very similar thicknesses, at between 30-36 inches, with two walls varying by two feet. The different thicknesses generally stem from different permeability requirements set forth in a consent decree, or by a state or federal agency.

Related costs played a significant role in at least two cut-off walls. At the Pennsylvania site, a large volume of contaminated trench soil required disposal at an engineered landfill. In addition to these disposal costs, which were included in the operation cost total, the trench construction was slowed by the need to test each excavator scoop with an organic vapor analyzer.

TABLE 9

SLURRY WALL EXPENDITURES

(1982 Dollars)

DATA SOURCE	LENGTH & DEPTH	THICKNESS	MATERIAL	UNIT COST
US EPA ELI/JRB 1981 Pennsylvania	648 feet x 17 feet	1 foot	cement- bentonite	$31.96/sq.ft.
US EPA JRB/ELI 1979 Colorado	1,500 feet x 20 feet	30 inches	85% soil- bentonite; 15% cement	$8.33/sq.ft.
US EPA JRB Florida A (Date unknown)	2,290 feet x 30 feet	30 inches	soil- bentonite	$5.88/sq.ft.
US EPA CH_2 M Hill 1982 New Hampshire	3,500 feet x 60 feet	3 feet	soil- bentonite	$5.64/sq.ft.

TABLE 9 (continued)

SLURRY WALL EXPENDITURES

(1982 Dollars)

DATA SOURCE	LENGTH & DEPTH	THICKNESS	MATERIAL	UNIT COST
US EPA JRB (Date unknown) Louisiana	1,500 feet x 20 feet	3 feet	soil- bentonite	$2.78/sq.ft.
US EPA JRB (Date unknown) Florida B	2,900 feet x 20 feet	3 feet	soil- bentonite	$2.60/sq.ft.
US EPA ELI/JRB (1983 Dollars) California	2,765 feet x 14 feet	5 feet	local clay	$1.42/sq.ft.
US EPA ELI/JRB 1980 Arkansas	2,306 feet x 48 feet	3.2 feet	local clay.	$0.25/sq.ft.

At the Arkansas site the cost given may not reflect the full slurry wall costs since significant in-house labor and equipment were used but not recorded. Other related costs such as site preparation and geotechnical investigations were inconsistently noted as separate or included. Generally, these costs were not included in the slurry wall expenditures.

3.1.4.2 Estimates

The following factors affected the estimated costs for slurry walls:

- o Depth
- o Thickness
- o Material
- o Inclusion of related costs:
  - Geotechnical investigation
  - Overhead and contingencies

Material costs were again the most clear cost factor in the slurry wall cost estimates (Table 10). The highest cost wall ($10/sq.ft.) was the cement-bentonite wall at the New York site. Slurry wall depth seemed to be, at best, a secondary factor. The deepest (130 foot deep) slurry wall at the New Jersey site was the second to lowest estimate while the most shallow (14 foot) slurry wall was the highest estimate.

However, the construction of the 130 foot deep slurry wall would be greatly facilitated by the unlithified coastal plain sediment of New Jersey for which it was proposed. Complete hydrogeological assumptions were not given for all of the estimation scenarios, but a 1980 paper by Ressi di Cervia (see Table 11) gave the following depth-soil condition cost matrix. The slurry wall thicknesses varied less than did those of the wall studied for the actual expenditures. Only one hypothetical slurry wall was over 3 feet thick.

TABLE 10

SLURRY WALL COST ESTIMATES

(1982 Dollars)

DATA SOURCE	LENGTH & DEPTH	THICKNESS	MATERIAL	UNIT COST
US EPA CH_2 M Hill 1983 New York	7,900 feet x 14 feet	over 2 feet	concrete	$10/sq.ft.
US EPA Weston 1982 New Hampshire	3,733 feet x 70 feet (1)	3 feet	soil- bentonite	$8.05/sq.ft.
US EPA Bids 1982 New Hampshire	3,500 feet x 60 feet	3 feet	soil- bentonite	$7.35/sq.ft.
US EPA JRB-RAM 1980	1,000 feet x 40 feet	3 feet	soil- bentonite	$7.08-13.86/sq.ft.

(1) Dimensions assumed for costing
(3,125 feet x 50 feet expected).

TABLE 10 (continued)

SLURRY WALL COST ESTIMATES

(1982 Dollars

DATA SOURCE	LENGTH & DEPTH	THICKNESS	MATERIAL	UNIT COST
US EPA Radian 1982	100 feet x 40 feet	4 feet	soil- bentonite	$6.94/sq.ft.
US EPA CH_2 M Hill 1983 New Jersey Site A	114,715 sq.ft.	24-30 inches	soil- bentonite (5%	$6/sq.ft.
US EPA SCS "Impoundment" 1980	911 feet x 49 feet	3.28 feet	Wyoming bentonite- water (1:12)	$6.49-11.56/sq.ft.
US EPA SCS "landfill" 1980	2,362 feet x 49 feet	3.28 feet	bentonite- water (1:12)	$6.02-10.50/sq.ft.

TABLE 10 (continued)

SLURRY WALL COST ESTIMATES

(1982 Dollars)

DATA SOURCE	LENGTH & DEPTH	THICKNESS	MATERIAL	UNIT COST
US EPA Bids 1982 New Hampshire	3,500 feet x 60 feet	3 feet	soil- bentonite	$5.44/sq.ft.
US EPA CDM, Inc. 1983 New Jersey Site B	4,257 feet x 130 feet	not given	soil- bentonite	$4.88/sq.ft.
US EPA Bids 1982 New Hampshire	3,500 feet x 60 feet	3 feet	soil- bentonite	$4.50/sq.ft.

TABLE 11

SLURRY WALL COSTS: DEPTH EFFECTS

	Slurry Trench Prices In 1982 Dollars Soil Bentonite Backfill (Dollars/Square Foot)			Unreinforced Slurry Wall Prices in 1982 Dollars Cement Bentonite Backfill (Dollars/Square Foot)		
	Depth 30 Feet	Depth 30–75 Feet	Depth 75–120 Feet	Depth 60 Feet	Depth 60–150 Feet	Depth 150 Feet
Soft to Medium Soil N 40	3–5	5–10	10–13	19–25	25–38	38–95
Hard Soil N 40 –	5–9	6–13	13–25	32–38	38–51	51–121
Occassional Boulders	5–10	6–10	10–32	25–38	38–51	51–108
Soft to Medium Rock N 200 Sandstone, Shale	8–15	13–25	25–64	64–76	76–108	108–222
Hard Rock Granite, Gneiss, Schist*	—	—	—	121–178	178–222	222–298

Notes: N = standard penetration value in number of blows of the hammer per foot of penetration (ASTM D1586–67)

*Normal Penetration Only
For standard reinforcement add $8.00 per sq. ft.
For construction in urban environment add 25% to 50% of price

Reference: Ressi di Cervia 1980.

Additional costs were included in at least two of the estimates. Both geotechnical investigation (impoundment: $11,210-23,010; landfill: $4,543-7,694) costs and overhead (25%) and contingency costs (30%) were included in the SCS estimates. Geotechnical investigation and filter cake permeability testing costs were grouped together ($23,600-94,400) in the JRB estimate.

Expenditure Sources

- o ELI/JRB Case Studies, 1983
- o JRB, 1983
- o State and Federal Superfund Work

Estimates Sources

- o JRB - RAM, 1980
- o Radian, 1983
- o SCS, 1981
- o US EPA, OERR, Feasibility Studies.

3.2 GROUT CURTAINS

3.2.1 Definition

Generally, grouting is the pressure injection of one of a variety of special fluids into a rock or soil body to seal and strengthen that body. Once, this fluid gels in the rock or soil voids, it greatly reduces the permeability of, and increases the mechanical strength of the grouted mass. When carried out in the proper pattern and sequence, this process can result in a curtain or wall that can be a very effective ground water barrier. Grouting is rarely used when ground water has to be controlled in soil or loose overburden. The major use of curtain grouting is to seal voids in porous or fractured rock where other methods of ground water control are impractical. The injection process itself involves drilling holes to the desired depth and injecting the grout with using equipment. In curtain grouting, a line of holes is drilled in single, double, or sometimes triple staggered rows (depending on the site characteristics) and injecting the fluid in either descending stages with increasing pressure, or ascending stages with decreasing pressure. The spacing of the injection holes is also site-specific and is determined by the penetration radius of the grout out from the holes. Ideally, the grout injected in adjacent holes should fuse between them. If this process is done properly, a continuous, impervious barrier (curtain) will be formed.

3.2.2 Unit of Measurement

Costs are given in terms of dollars per unit face-area (square feet) because it best reflects the functional area of the grout curtain. The effect of other dimensions on costs is discussed in section 3.2.4 (Factors Found to Affect Costs). Since the units used in existing engineering estimates have varied widely, the effect of using different dimensions is an important consideration for comparing estimates.

3.2.3 Summary Statistics

3.2.3.1 Expenditures

The cost of grout curtains (all-ASPEMIX vibrating beam walls) ranged from:

$ 6.60/sq.ft.
to
$ 14/sq.ft.

The lowest cost grout curtain was the first one installed by a new company. The $14/sq.ft. grout curtain was installed two years later at the same site as the $8.26/sq.ft. wall. The cost differences may reflect the need to recoop the potential earnings foregone for the earlier walls in order to enter the market. Operation and maintenance costs such as inspection, ground water monitoring and, possibly, repair either were accounted for separately or were not yet encountered at the new sites.

3.2.3.2 Estimates

The grout curtain cost estimates ranged from:

$5.50/sq.ft.	ASPEMIX, vibrating beam installation
to	
$75.52/ sq.ft.	phenolic resin, standard injection installation

The order of magnitude difference in cost estimates for grout curtain cost estimates largely seems to reflect the widely varying thicknesses thickesses. The highest estimate was for a 9 foot thick wall; while the lowest (group of four) estimate was for an ASPEMIX wall, which is typically under a foot thick. Operation and maintenance costs such as inspection and ground water monitoring costs were not included in the estimates.

3.2.4 Factors Found to Affect Costs

3.2.4.1 Expenditures

The following factors seemed to affect expenditures:

- o Market entry loss
- o Labor costs

The cost of grout curtains seemed to be primarily affected by market conditions. The industry contacts who supplied the data in Table 12 noted that, compared to the costs shown, the prices will decrease and stabilize in the future now that the firm has penetrated the market. They also noted that the California site cost was significantly affected by the relatively high local labor costs. For instance, a privately built grout curtain in Dallas, for which no data were available, was said to have been less than half the cost of the latest California wall.

3.2.4.2 Estimates

The following factors affected grout curtain cost estimates:

- o Thickness
- o Material composition
- o Installation technique
- o Inclusion of related costs:
  - Geotechnical investigation
  - Overhead and contingency

The most significant cost factor affecting grout curtain cost estimates (Table 13) was the wall thickness. For single row walls this was assumed to be equal to the center-to-center distance of the grout injections, which is equal to the diameter for adjacent injections. The nine foot thick wall, which was expected to be necessary to enclose an impoundment, was the highest estimate.

TABLE 12

GROUT CURTAIN EXPENDITURES

(1982 Dollars)

Data Source	Length x Depth	Thickness	Material	Unit Cost
US EPA ELI/JRB California 1982	2,929 feet x 17 feet	0.83 feet	ASPEMIX (1)	$14/sq.ft.
US EPA ELI/JRB California 1980	2,000 feet x 17 feet	0.83 feet	ASPEMIX (1)	$8.26/sq.ft.
US EPA ELI/JRB Michigan 1980	1,465 feet x 10 feet	1 foot	ASPEMIX	

(1) Asphalt, concrete and sand emulsion installed with vibrating beam

TABLE 13

GROUT CURTAIN COST ESTIMATES

(1982 Dollars)

Data Source	Length x Depth	Thickness	Material	Unit Cost
SCS "Impoundment" 1980	902 feet x 49 feet	9 feet	phenolic resin	$38.94-75.52/sq.ft.
SCS "Landfill" 1980	7,117 feet x 49 feet	5 feet	phenolic resin	$33 - 68.44/sq.ft.
US EPA JRB/RAM 1982	800 feet x 20 feet	3 feet	silicate	$11.54 - 17.17/sq.ft.
US EPA Radian 1982	1,000 feet x 20 feet	3 feet	silicate	$21.80/sq.ft.
			portland cement	$ 11.80/sq.ft.

TABLE 13 (continued)

GROUT CURTAIN COST ESTIMATES

(1982 Dollars)

Data Source	Length x Depth	Thickness	Material	Unit Cost
US EPA ORD - MERL 1979 New Jersey	4,600 feet x 40 feet	3 feet	not given	$6.22 - 10.48/sq.ft.
US EPA 4 bids 1982 New Hampshire	3,500 feet 60 feet	not given (assume 1 foot)	ASPEMIX	$5.50-$6.86/sq.ft.

Comparing the cost estimates based on dollar per linear foot and a dollar per cubic foot basis is useful for discerning the effect of thickness on the estimates. On a cost per linear foot basis the following list shows that the cost ranking is aberrant compared to the depths.

Date	Depth	Unit Cost	Cost Ranking ($/sq.ft.)
1982	60 feet	$ 330 - 412/LF	6
1980	49 feet	$1,908 - 3700/LF	1
1980	49 feet	$1,619 - 3353/LF	2
1979	40 feet	$ 249 - 419/LF	5
1982	20 feet	$ 230 - 340/LF	4 a
1982	20 feet	$ 420/LF	3
1982	20 feet	$ 240/LF	4 b

On this basis the costs show neither an ordinated ranking according to depth, nor does it show an evenness (X= $1,102/LF; SE= $365/LF; n=12) that would suggest that simple length was the most significant cost factor.

Similarly, the effect of thickness and depth on cost can be elucidated by comparing costs on a per volume basis. The following list shows that the cost estimates are relatively even (X= $5.30/cu.ft.; SD= $2.90/cu.ft.; n= 10).

Date	Thickness	Unit Cost	Cost Ranking ($/sq.ft.)
1980	9 feet	$4.33–8.26/cu.ft.	3
1980	5 feet	$6.61–13.69/cu.ft.	1
1982	3 feet	$7.30/cu.ft.	2
1982	3 feet	$3.80–5.72/cu.ft.	4a
1982	3 feet	$3.90/cu.ft.	4b
1979	3 feet	$203–3.43/cu.ft.	5
1982	1 foot	$5.50–6.86/cu.ft.	6

The mean of the Table 14 costs was $22.60/sq.ft (SD= $20.10; n=10). The data are inadequate to provide any generalization about the relative costs of various grout materials. The scenarios that assumed the use of phenolic resin, however, were the two highest estimates; two silicate wall scenarios were higher than portland cement, and four bids to construct an ASPEMIX wall, composed of an emulsion of asphalt, sand and concrete to be installed with a vibrating beam, was the lowest cost estimate. Since no "control" estimate was available to consider the cost of an ASPEMIX wall if installed with a traditional injection technique, the installation technique cannot be accurately judged as a cost factor. However, the vibrating beam method may be generally less expensive than the traditional injection technique.

Finally, the cost of a geotechnical investigation was included only in the JRB and the SCS estimates. The SCS estimate also included overhead (25%) and contingency allowance (30%).

Expenditure Sources

- o ELI/JRB Case Studies, 1983

Estimates Sources

- o JRB – RAM, 1980
- o Radian, 1983
- o US EPA, OERR contractor bids
- o SCS, 1980

3.3 SHEET PILING

3.3.1 Definition

Sheet piling can be used to form a continuous ground water barrier of driven steel piles. Although sheet piles can also be made of wood or precast concrete, steel is the most effective in terms of ground water cut-off and easy installation. The construction of a steel sheet piling cut-off wall involves driving interlocking piles into the ground using a pneumatic or steam-driven pile driver. In some cases, the piles are pushed into pre-dug trenches. Piles are commonly 4 to 40 feet long and 15 to 20 inches wide. Because of corrosion and "windows" usually present between piles, this method is often considered a temporary stop-gap measure.

3.3.2 Unit of Measurement

Costs are given in terms of dollars per square foot because area best reflects the functional units of a cut-off wall.

3.3.3 Summary Statistics

3.3.3.1 Expenditures

No actual expenditure data for sheet piling cut-off walls were available at this time.

3.3.3.2 Estimates

The cost estimates for sheet piling cut-off walls ranged from:

$8.02/sq.ft.

to

$17.03/sq.ft.

The lowest sheet piling cut-off wall estimate was for the largest site involving 116,228 sq.ft. of sheet piling. This larger wall may have helped reduce the cost by using already mobilized equipment. This effect may have counterbalanced the effect of including related costs that were not included in the JRB-RAM estimate.

3.3.4 Factors Found to Affect Costs

3.3.4.1 Expenditures

No actual expenditure data are available at this time.

3.3.4.2 Estimates

The following components affected the cost estimates for sheet piling cut-off walls:

- o Economies of scale
- o Piling type
- o Inclusion of related costs:
  - Geotechnical investigation
  - Overhead and contingency allowances

As noted above in Comments on the summary statistics, the limited data in Table 14 suggest that economies of scale may be the most significant factor affecting costs. Although local costs may vary this effect, the specialized equipment (pile drivers) and experienced personnel may be able to install sheet piling at decreasing marginal costs as the total area of installed wall increases. This relationship may derive from the fact that mobilization and set-up are relatively more significant elements of the total unit operation for sheet piling than other remedial technologies.

Among the estimate scenarios, the piling types varied both in composition and in thickness. Galvanized steel ($10.48/sq.ft. installed) which provides somewhat greater corrosion resistance, was slightly more expensive than black steel ($9.41/sq.ft. installed). The paucity of data on piling thickness precludes accurate quantification of its relationship to costs. However, this variable may often be dictated by local material availability and geological constraints. Since piles are typically withdrawn and reused, the thickness of the piles may also affect of the reusability and hence the rebate revenue, since a too-thin pile may buckle upon insertion. Since materials may be 80% of the total cost of a sheet piling cut-off wall, the effect of thickness and reusability on the cost may be significant. The cost estimates given Table 14 do not include cost credits for reuse of the piles, but do include varying pile types, as indicated. As noted in Table 14 the cost of a geotechnical investigation ($11,210-23,010) was included only in the SCS "impoundment" estimate. Additional costs for overhead (25%) and contingency allowances (25%) were included in this estimate and the SCS "landfill" estimate.

Estimates Sources

- o JRB-RAM, 1980
- o Radian, 1983
- o SCS, 1980

TABLE 14

SHEET PILING COST ESTIMATES

(1982 Dollars)

Data Source	Lenth x depth	Weight	Piling	Unit Cost
US EPA JRB - RAM 1980	1,000 feet x 20 feet	186 tons	5 guage	$17.03/sq.ft.
US EPA Radian 1982	1,000 feet x 20 feet	Not given	black steel	$9.41/sq.ft.
			galvanized	$10.48/sq.ft.
US EPA SCS (1, 2) "Impoundment" 1980	2,372 feet x 49 feet	487 tons	5 guage	$8.42-12.63/sq.ft.
US EPA SCS (2) "Landfill" 1980	2,373 feet x 49 feet	1,281 tons	PMP-22	$8.02-11.80/sq.ft.

(1) Includes geotechnical investigation ($11210 - 23,010)

(2) Includes overhead (25%) and contingency (25%) allowances

3.4 GROUT BOTTOM SEALING

3.4.1 Definition

Grout bottom sealing is a direct barrier to downward leachate migration. Grout is injected through the fill material to form a bottom underneath the contaminants. The grout is injected horizontally from jets at the bottom of a pipe, which is inserted like a well point, with a pneumatic hammer. A grid of injected grout ideally forms a continguous bottom seal. Grout materials are typically silicate or portland cement.

3.4.2 Units of Measurement

Costs are given in terms of dollars per square foot because area best reflects the functional characteristics of bottom sealing.

3.4.3 Summary Statistics

3.4.3.1 Expenditures

No actual expenditure data are available at this time.

3.4.3.2 Estimates

The grout bottom sealing costs ranged from:

$9/sq.ft.

to

$116/sq.ft.

This wide range of estimates seems to reflect the varying thicknesses given for hypothetical seals. The higher estimate was for a 5.25-foot thick seal vs. a 3.25-foot thick seal for the lower estimate.

3.4.4 Factors Found to Affect Costs

3.4.4.1 Expenditures

No actual expenditure data are available at this time.

3.4.4.2 Estimates

In the scenarios for the grouting estimates, the following components varied:

- o Grout thickness
- o Grout material
- o Coverage
- o Soil, fill type

Of these components, the grout thickness appeared to be directly related to the wide variation in the cost of the two grout seals shown in Table 15. The "landfill" seal was 2 feet (61%) thicker than the "impoundment" grout. Thickness appears to affect the estimates more than does the grout material type. Material costs for phenolic resin are significantly higher than for portland cement grout, but overall, the thicker cement grout has a higher unit area, and a higher unit volume cost ($11- 22/cu.ft. vs $2-5/cu.ft.) than phenolic resin.

Economies of scale may have caused the "landfill" grouting to be less expensive than the impoundment grouting since the scenario assumed ten times as much coverage. Despite this disparity in task size, the geotechnical investigation (impoundment: $11,210-23,010; landfill: $15,104-25,559) and equipment cost were relatively similar.
Overhead (25%) and contingency allowances (40%) were the same for both seals.

Although it is not possible to quantify from the available cost estimates, the effect of injection through heterogeneous, resistant fill and soil probably is a significant cost factor. However, the higher cost of the landfill groutestimate cannot be clearly attributed to this factor since complete information is unavailable.

Estimates Source

SCS 1980

TABLE 15

GROUT BOTTOM SEALING ESTIMATES

(1982 Dollars)

Data Source	Grout Material Thickness	Depth	Coverage	Unit Cost
US EPA SCS "landfill" 1980	cement 5.25 feet	49 feet	559,704 sqft	\$60 - \$116/sq.ft.
US EPA SCS "Impoundment" 1980	phenolic resin 3.28 feet	49 feet	5,038 sqft	\$9 - \$18/sq.ft.

3.5 PERMEABLE TREATMENT BED

3.5.1 Definition

A permeable treatment bed is subsurface wall made of a permeable filtering material. The intent of these treatment beds is to decontaminate groundwater as it flows through the bedding material. The most common functions of these beds is to neutralize acidic ground water, or precipitate metallic ions by using a limestone bed, which increases the pH of the groundwater, thereby reducing the solubility of the metals. The six primary component tasks (generally included in the costs) are:

- o Trench excavation
- o Spreading
- o Well-point dewatering
- o Sheet piling
- o Walers, connectors, struts.
- o Bedding (limestone or carbon).

3.5.2 Units of Measurement

Costs of permeable treatment beds are given in terms of dollars per square foot because it best expresses the functional value of the treatment bed. The width and depth of the leachate plume to be estimated are usually known.

3.5.3 Summary Statistics

3.5.3.1 Expenditures

No actual expenditure data for permeable treatment was available at this time.

3.5.3.2 Estimates

The cost estimate for permeable treatment beds ranged from:

$14/sq.ft. limestone bedding
to
$267/sq.ft. activated carbon bedding

The lowest cost permeable treatment bed was for a limestone bed; while the high estimate was for a bed of granular activated carbon. Operation and maintenance costs, when given, consisted of the following two cost items which depend on site specific variables:

Operation and maintenance Cost Items	Site-specific Variables
(1) Ground water monitoring cost	- contaminants - hydrogeologoy
(2) Replacement cost	- operational lifetime of treatment bed

3.5.4 Factors Found to Affect Costs

3.5.4.1 Expenditures

No actual expenditure data are available at this time.

3.5.4.2 Estimates

The following factors were found to affect the subsurface drain estimates:

- o Bedding Material
- o Size

The estimates made by JRB and Radian shown in Table 16 are very similar except that 17% was added to most of the Radian costs for inflation. However, the same unit cost for limestone and carbon was assumed. For the carbon treatment bed, the bedding cost was the most significant (90%) cost out of the total. For the limestone treatment bed, the most significant cost (75%) was the cost of sheet piling. Conversely, the bedding cost was 7% of the total for the limestone bed; whereas for the carbon bed, the sheet piling was 8% of the total cost.

Although all cost estimates are for the same size treatment bed scenario, the influence of size on unit costs should be noted briefly. First increases in the dimensions of the trench generally will proportionally increase total treatment bed costs. The effect is pronounced by increases in width and depth, and for the more expensive carbon bedding needed to fill the larger trench. A wider carbon trench could potentially be significantly different than any of the estimates given in Table 16. Second, economies of scale could reduce the unit costs of limeston treatment beds over that given in the estimate, since reusable sheet piling, which has significant one-time set up and mobilization costs, is the major (75%) component cost. Also, the marginal unit cost of dewatering decreases as trench size increases.

Estimates Sources

- JRB - RAM, 1980
- Radian, 1983

TABLE 16

PERMEABLE TREATMENT BED COST ESTIMATES

(1982 Dollars)

Data Source	Area	Width	Bed Material	Unit Cost
US EPA JRB - RAM 1980	1,000 feet x 20 feet	4 feet	activated carbon bed	$267/sq.ft
US EPA Radian 1983	1,000 feet x 20 feet	4 feet	coarse size activated carbon	$201/sq.ft.
US EPA JRB-RAM 1980	1,000 feet x 20 feet	4 feet	"gravel and sand sized" limestone	$29/sq.ft.
US EPA Radian 1980	1,000 feet x 20 feet	4 feet	"gravel and sand sized" limestone	$14-14.67/ sq/ft.

3.6 WELL POINT SYSTEM

3.6.1 Definition

Well points are generally used to lower the water table or extract leachate. They differ from drilled and cased deep wells in that they are driven, instead of drilled, into the ground to just below the leachate plume. Groundwater is then piped to a suction header, drawn by a centrifugal pump, to a treatment system. In contrast, deep wells typically use submerisble pumps to pump ground water to a treatment system. For costing purposes, treatment costs are considered separately.

3.6.2 Units of Measurement

Costs are given in terms of dollars per well. The extraction rate (gallons per minute-gpm) and depth should also be considered. Since these characteristics vary with site-specific hydrology, however, costs given below do not factor in pumping rate.

3.6.3 Summary Statistics

3.6.3.1 Expenditures

No actual expenditure data are available at this time.

3.6.3.2 Estimates

The cost estimates ranged from

$803/well

to

$8,284/well

The highest cost estimate (SCS-"impoundment") included the cost of geotechnical investigation, which comprised 50% of the costs. No related costs were included in the lowest estimate (Radian).

3.6.4 Factors Found to Affect Costs

3.6.4.1 Expenditures

No expenditure information are available at this time.

3.6.4.2 Estimates

The following factors affected the cost estimates for the well point systems:

- o Depth
- o Pumping rate
- o Inclusion of related costs:
  - Geotechnical investigation
  - Overhead allowances
  - Contingency allowances

The costs shown in Table 17 are relatively similar. The effect of depth, which was expected to be an important cost factor, did not appear to significantly affect the estimates. Although well point installation is often charged by the depth, well installation was a relatively small cost component compared to pumps and headers. Hence depth affected cost estimates in proportion to the importance of well point installation, which was low compared with the importance of other components such as pumps and headers. The pumping rate, which varied with the size of the pumps and the header system, should affect both capital and operation and maintenance costs. However, no relationship could be identified in the gross data.

The most significant cost factors that could be identified was the inclusion of related costs. Over half of the SCS "Impoundment" estimate was for a geotechnical investigation, that was not included in either of the other estimates. The SCS "Impoundment" and "Landfill" estimates included overhead (25%) and contingency (25%) allowances.

<u>Estimates Sources</u>

- Radian, 1983
- SCS, 1980

TABLE 17

WELL POINT SYSTEM COST ESTIMATES

(1982 Dollars)

Data Source	# Wells; Depth; Diameter	Pumping rate Aquifer depth	Operation & Maintenance	Capital Unit Cost
US EPA SCS 1980 "Impoundment"	5 wells 16 feet deep --	-- --	$9,160- $9,970/year 10,000 kwh	$4,413-$8,284/well (1)
US EPA SCS 1980 "Landfill"	133 wells 16 feet deep --	291-396 gpm --	$10,460- $11,270/year 36,000 kwh	$1,109-$1,855/well (2)
US EPA Radian 1983	50 wells 25 feet 4 inches	500 gpm 10 feet	$70.88/Mgd	$803/well

(1) Includes geotechnical investigation cost (55%)
(2) Includes geotechnical investigation cost (3%)

3.7 DEEP WELL SYSTEM

3.7.1 Definition

Aside from going deeper, deep wells are typically drilled and cased, in contrast to shallower, driven well points. The deep well systems considered in this section are intended to dewater soil at greater depths, for extracting leachate or intercepting ground water flow upradient of a site.

3.7.2 Units of Measurement

Costs are given in terms of dollars per well. Cost per well per foot may also be useful but available cost estimates assume the same depth scenario.

3.7.3. Summary Data

3.7.3.1 Expenditures

No expenditure data was available at this time.

3.7.3.2 Estimates

Cost estimate ranged from

$4,862
to (both wells were at 46 feet deep)
$13,513

These estimates are the low and high end of the ranges of the lowest and highest estimates. It should be noted (see Table 18) that 62% of the lowe estimate and 85% of the high estimate were for (1) geotechnical investigation, (2) overhead allowance (25%); and (3) contingency allowance (30%). On a cost per foot per well basis, the above cost range would be $106-295/foot/well.

3.7.4 Factors Found to Affect Costs

3.7.4.1 Expenditures

No expenditure data are available at this time.

3.7.4.2 Estimates

The following factor affected the cost estimates.

- o Well depth
- o Well diameter
- o Pumping capacity
- o Inclusion of related costs:
    - geotechnical investigation
    - overhead allowance
    - contingency allwance

Variations in well depth are not quantified by the data, but well drilling costs typically vary with depth. Variations in well diameter are also not given in the data, and therefore are not quantifiable, but costs for larger diameter wells are generally proportional because of increases in labor equipment and material costs. Submersible pumping capacity effects on capital costs are difficult to quantify because of the importance of hydrogeology to well yield. Increasing the pump size may have no effect on well yield if the well does not recharge quickly enough to justify the larger pump. Hence, any consideration of cost functions for pumping capacity must regard hyrogeology, pump capacity and well design. Electricity costs for pumping comprised about 5–10% of the operation and maintenance costs. Hence, this cost component, which varies directly with pumping capacity has a relatively small effect on costs compared to the other operation and maintenance cost items-sampling and analysis.

Related costs had the greatest discernible effect on cost estimates since they comprise the majority of both estimates. Table 18 shows the proportion of total capital cost involved in these related components for cost estimates given in Table 19.

TABLE 18.
COMPONENT COSTS OF DEEP WELL ESTIMATES

Estimate source	Geotechnical Investigation	Overhead Allowance	Contingency Allowance	Total
SCS "Impoundment"	30%	25%	30%	85%
SCS "Landfill"	7%	25%	30%	62%

The reason for the significantly higher proportional and absolute cost estimate for the smaller impoundment (1.16 acres, 5 wells) compared to the landfill (13.4 acres, 13 wells) is unclear.

Estimated Sources

- SCS 1980

TABLE 19

DEEP WELL COST ESTIMATES

(1982 Dollars)

Data Source	Depth, diameter, # wells	Pumping	Operation & Maintenance	Capital Cost
US EPA SCS "Impoundment" 1980	46 feet deep 6 inches pvc 5 wells	submersible pumps 574 foot header to 3'deep discharge trench	$9,110-9,920/ year	$7,443 - $13,513/well (1)
US EPA SCS "Landfill" 1980	46 feet deep 6 inches pvc 13 wells	submersible pumps. 1 hp, 984 foot header to gravel filled discharge trench	$9,830- $10,640/year	$4,862 - $7,976/well (2)

(1) Includes geotechnical investigation (30%) overhead (25%) and contingency (30%) allowance.

(2) Includes geotechnical investigation (7%), overhead (25%) and contingency (30%) allowance.

3.8 EXTRACTION/INJECTION WELL SYSTEM

3.8.1 Definition

Extraction/injection wells are usually well points, which are driven into the ground, unlike deep wells which are drilled and cased. A series of extraction and injection wells (well points or cased, drilled wells) is given as the design basis an which to compare costs. Costs for a water treatment system, are is not incuded in this system's cost. This system is sometimes referred to as a leachate recirculation system or plume containment. In addition to ground water decontamination, this system may be used to control leachate migration.

3.8.2 Units of Measurement

Total capital costs are given instead of unit costs for two reasons. First, unlike most other remedial technologies, extraction injection systems are composed of several components that are not readily summarized into a simple unit. Extraction, injection and monitoring wells all comprise roughly equal parts of the system. Capacity in terms of gallons per minute was not used because of its dependence on hydrogeology, and this information was not usually available.

3.8.3 Summary Data

3.8.3.1 Expenditure

No expenditure data was available at this time.

3.8.3.2 Estimates

A range of cost estimates cannot be given since the units of the two estimates were not comparable. See Table 20.

TABLE 20

EXTRACTION/INJECTION WELL COST ESTIMATES

(1982 Dollars)

Data Source	Extraction	Injection	Pumping	Operation & Maintenance	Total Capital
US EPA JRB - RAM 1980	7, six inch well, 35 feet deep pvc casing	7, six inch wells (+ four back up wells pvc casing	4 inch submersible pumps 8 inch transfer pipe, 1,000 feet	Not given	$321,432
US EPA Radian 1983	10, six inch wells (1) average depth 50 feet	six inch wells	submersible pumps 50 gpm per well	$70.88/Mgd electricity and monitoring	Not given (2) ("$37.50/vertical foot")

(1) Based on "50 gpm per well, 500 gpm/site".

(2) Assuming 20 wells, 50 feet deep, total capital cost = $37,500

3.8.4 Factors Found to Affect Costs

3.8.4.1 Expenditure

No expenditure information is available at this time.

3.8.4.2 Estimates

The following factors contributed to the cost estimates of the extraction/injection well systems:

- number of wells
- depth of wells
- diameter of wells
- casing
- submersible pump capacity
- transfer pipe length diameter

The paucity of data precludes quantification of the effects of these factors.

Estimate Sources

- U.S. EPA, JRB-RAM, 1980
- U.S. EPA, Radian, 1983

3.9 EXTRACTION WELLS/SEEPAGE BASINS

3.9.1 Definition

A series of extraction wells is used to collect ground water, and a seepage basin/trench, which is sometimes referred to as "subgrade irrigation" is used to recharge the groundwater. As with the extraction/injection well system above, this system may have a treatment system placed on-line, or it may be used simply to control leachate flow. Treatment costs are not considered in this section. Seepage basins are often applicable in less permeable soil, such as the glacial till, where injection wells provide inadequate infiltration.

3.9.2 Units of Measurement

Total capital cost is given instead of unit costs because, unlike most other remedial technologies, extraction well/seepage basins are composed of several components that are not readily summarized into a simple unit. Extraction and monitoring wells, trench/basin size and pumping/transfer equipment all comprise roughly equal parts of the system. Capacity in terms of gallons per minute was not used because of its dependence on hydrogeology.

3.9.3 Summary Data

3.9.3 Expenditures

The one expenditure found was:

Total capital	$31,269 (9.5 gpm total extraction, two 100-foot long seepage trenches)
Operation and maintenance	$27,500/year

The expenditure was for two extraction trench wells (one 80 x 10 x 4 feet, another 4 x 10 x 16 feet) and two recharge (injection) trenches (100 x 4 x 10 feet).

3.9.3.2 Estimates

The range given in the one estimate source found was:

Total capital:	$33,618 - 53,360
Operation and Maintenance:	$10,856 - 11,812/year

This is actually from a single estimate source that predicts a range for the U.S.

3.9.4 Factors Found to Affect Costs

3.9.4.1 Expenditures

The following factors affected the expenditure

- o Number of wells
- o Size of wells
- o Depth of wells
- o Pumping capacity
- o Seepage basin design

Because of inadequate data and the lack of a comparative site expenditure, quantification of these factors is not possible (see Table 21). However, it should be noted that many of the factors affecting this expenditure are similar to those affecting the subsurface drain, especially the design of the extraction well trench using stone of decreasing size toward the inside of the trench. This increased capital, but probably decreased O & M costs.

3.9.4.2 Estimates

The following factors affected cost estimates:

- o Overhead allowance
- o Contingency allowance
- o Well size and number
- o Pumping capacity

TABLE 21

EXTRACTION WELLS/SEEPAGE BASIN EXPENDITURES

(1982 Dollars)

Data Source	Extraction (trench-well)	Seepage basin	Pumping	Operation & Maintenance	Total Capital
US EPA ELI/JRB 1982 New Jersey	A. 80x4x10 feet-12 inches (1) B. 16x4x10 feet-8 inches pvc TOTAL: 143 cuyd	two trenches: 100x4x10 feet (2) TOTAL: 296 cuyd	9.5 gpm submersible pump	$27,500 (3)	$ 31,269 ($71/cuyd)

(1) Dual media, stone/pebble, filter. Well slotted 2.5 feet.

(2) Plywood shoring construction

(3) Conservatively assumed to be 1/3 of water biotreatment operation & maintenance

The overhead had contingency allowance comprised 25% and 20%, respectively, of the total estimated capital cost. Well size and number would be expected to be proportional to the cost, but quantification is not possible without other estimates for comparison (see Table 22). Pumping capacity would also be expected to be proportional to cost, but hydrogeological factors affect this on a site specific basis.

Expenditure Sources

- ELI/JRB Case Studies, 1983

Estimates Sources

- SCS, 1980

TABLE 22

EXTRACTION WELLS/SEEPAGE BASIN COST ESTIMATES

(1982 Dollars)

Data Source	Extraction	Injection	Pumping	Operation & Maintenance	Total Capital
US EPA SCS - "Leachate Recirculation-Landfill" 1980	six deep wells 46 feet deep (drilled, cased)	2,067 x 2x3 feet 6 inch cement pipe, perforated 3/4 inch gravel	six submersible pumps	$9,200-10,010/year $10,856-$11,812/year	$33,618-$53,360 (1)

(1) Includes 25% overhead and 20% contingency allowance

3.10 SUBSURFACE DRAIN

3.10.1 Definition

A subsurface drain is basically a gravel-filled trench capped with a low permeability material. Often, broken tile or perforated pipe is laid along the botton, running into a collection sump or tank. The backside and bottom of the trench may be lined with plastic or clay before being filled with gravel or tile. Subsurface drains are intended to intercept and collect leachate or infiltrating water.

3.10.2 Units of Measurement

The unit costs for subsurface drains are given in dollars per unit length for three trench depth ranges because it facilitates quick cost estimates from a single trench dimension. Trench depth was found to be the greatest single factor affecting costs. The ranges in depth given in the Summary section 3.10.3.1 were determined by the aggregation found for the costs of the different trenches. This may have been caused by technical factors discussed in section 3.10.4, such as type of excavator used and need for sheet piling.

3.10.3 Summary Statistics

3.10.3.1 Expenditures

The expenditures for subsurface drains in three groups of depth ranges were:

Cost per Unit Length		Depth
	$24/LF	3 feet
X =	$370/LF (SE=$208/LF, n=4)	8.5-14.5 feet
	$1,733/LF	22.5 feet

The 2 subsurface drains at the high end of the range involved significant marginal costs for false-starts, delays, and overdesigning. The lowest cost drain was shallow enough that it did not require sheet piling or wooden shoring during construction.

Operation and maintenance costs involve sampling and replacement costs. Drains typically remain unclogged for 10-20 years, but site conditions and drain design affects this operation period. No O&M costs were available for expenditures since they were either accounted for separately, or were not yet encountered and documented.

3.10.3.2 Estimates

Cost estimates for subsurface drains ranged from:

Capital:

$1.94/LF
to
$218/LF

Operation and maintenance:

$10,337/year
to
$11,293/year

This two order of magnitude cost estimate range resulted from included costs and depth variations. The highest cost drain included the cost for a geotechnical investigation, which accounted for 50% of the estimated cost. The lowest cost hypothetical drain was 1-2 feet deep. O&M costs were frequently noted but not consistently quantified.

3.10.4 Factors Found to Affect Costs

3.10.4.1 Expenditures

The following significant factors were found to affect the costs of subsurface drains shown in Table 23.

1. contaminated soil removal
2. trench (filter) length and depth
3. plumbing complexity
4. gravel installation
5. storage tank or sump size

Contaminated soil, which may require secure disposal, may be encountered while constructing the trench or the sump. Excavation of contaminated soil, which 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 the ELI/JRB Wisconsin site #1 where hexavalent chromium contaminated soil was disposed of from the hole excavated for a sump. The PCB contaminated soil at the ELI/JRB California site #1, however, was returned to the drain cap because the system was considered an "Immediate Correction Plan", not a long term remedy. This provision avoided the cost of off-site disposal of the PCB soil.

The importance of the trench length and depth 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 the highest cost site, ELI/JRB California site #1, 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 of the seasonally heavy rains in the Mediterranean climate. The length of the drain at the ELI/JRB Michigan site reflected its purpose of relieving hydraulic pressure on the asphalt emulsion cut-off wall. At the ELI/JRB New Jersey site, 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 the ELI/JRB California site # 1, steel sheet piling was driven into place to support the 30 foot (10 m) deep trenches during construction; whereas at Site 5 no reinforcement was necessary. For the deeper drains at the ELI/JRB California sites #1 and 2 which used steel sheet

TABLE 23

SUBSURFACE DRAIN EXPENDITURES

(1982 Dollars)

Data Source	Length x trench (filter) depth	Width	Sump depth, etc.	Operation and maintenance	Unit Cost-capital
US EPA ELI/JRB 1981 California #1	210 feet (a) x 22.5 (21.5) feet	3 feet	29.5 feet triple level drain pipes	$54,000/ year (b) (1,000-1,500) gallons	$1,733/LF
US EPA ELI/JRB 1980 California #2	261 feet x 14.5 (10) feet	4-6 feet	20 feet + bucket well	$307/year excludes treatment (10 mil. gallon)	$936/LF
US EPA ELI/JRB 1981 New Jersey	280 feet (c) x 10(6) feet	4 feet	no sump pea gravel around pipe; gravel jacket	$89,640 year (b) (19 mil.gal.)	$424/LF
US EPA ELI/JRB 1980 Michigan	990 feet x 8.5(6) feet	not given	rebuilt drain (d)	not given	$85/LF (d)

(a) Three drain arms summed; slotted pvc piping stacked 3 feet apart
(b) Includes water treatment O&M
(c) Three trenches summed: 2 injection, 1 withdrawal
(d) Includes original and renovation costs

TABLE 23 (continued)

SUBSURFACE DRAIN EXPENDITURES

(1982 Dollars)

Data Source	Length x trench (filter) depth	Width	Sump depth, etc.	Operation and maintenance	Unit cost-capital
US EPA ELI/JRB 1981 Wisconsin #2	240 feet x 12 ( ) feet	4 feet	15 feet	$648/year (a) 72,000 gal.	$36/LF
US EPA ELI/JRB 1982 Wisconsin #1	750 feet x 3 (1/3) feet	2 feet	2 sumps: 4 feet 6 feet	not given	$24/LF

piling and the New Jersey, site which used plywood shoring, the cost of shoring was perhaps the most important factor in the different case study drain costs. The available cost data breakdowns are inadequate to quantify this relationship, but the cost difference among these shown in Table 23 suggests its significance.

In addition to trench depth, the filter depth varied among the sites. The depth of the filter affects the amount of stone on gravel fill installed, which is much more expensive than the same volume of backfilling.

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 either drained into a collection sump or as in the case of the New Jersey site, was drained by an extraction pump. At the ELI/JRB California Site #1, 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 the California Site #1, 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 the New Jersey site, 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. The purpose of this relatively complex design was 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 the Michigan site. 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. The New Jersey site was the only site for which leachate storage costs were not included because the collected water was pumped directly into the treatment system. The inclusion of sumps in the other case study site cost 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 types 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.

3.10.4.2 Estimates

The following factors affected the subsurface drain cost estimates shown in Table 24.

- o trench (filter) depth and length
- o storage tank or sump size
- o inclusion of related costs

Trench and filter depth and length had effect on drain estimates similar to that described in the expenditure section above. However, technical details such as the filter/jacket gravel size and the depth of the filter vs. the backfill were less often available for consideration.

A wider variety of storage tanks and sump sizes was found for the estimates scenarios over the actual expenditure sites. In most cases however, no information was available about sump and tank sizes. The influence of this cost factor on total capital costs as well as on operation and maintenance costs from varying storage capacities may be significant.

The SCS estimates were significantly affected by the inclusion of related costs such as:

- geotechnical investigation
- overhead allowance
- contingency allowance

TABLE 24

SUBSURFACE DRAIN COST ESTIMATES

(1982 Dollars)

Data Source	Length x trench (filter) depth	Width	Sump depth, etc.	Operation and maintenance	Unit Cost
US EPA SCS "Impoundment" 1980	197 feet x 16(4) feet (1)	3.3 feet	sump depth not given; cement pipe in drain	$10,337-$11,293/year; 50 gpm	$113 - 218/LF (2)
US EPA SCS "Landfill" 1980	835 feet x 20(13) feet (1)	3.3 feet	depth not given; 4 inch cement pipe in drain	$10,337-$11,293/year; 50 gpm.	$26 - 38/LF
US EPA Radian 1982	1,000 feet x 20(10) feet (1)	4 feet	sump depth not given; perforated pvc in drain	$70.88/Mgd; 50 gpm	$28/LF
US EPA JRB-RAM 1980	3,300 feet (3) x 20(2) feet (1)	4 feet	4 manholes; 2 wet wells; 15 lateral drains (20' each)	not given; 2 x 25 gpm	$15/LF

(1) Trench (filter) depth shows excavated volume vs of gravel installed, respectively

(2) Includes geotechnical investigation (50%)

(3) Includes laterals

TABLE 24 (continued)

SUBSURFACE DRAIN COST ESTIMATES

(1982 Dollars)

Data Source	Length x trench (filter) depth	Width	Sump depth, etc.	Operation and maintenance	Unit Cost
US EPA CH_2 M Hill Feasibility Study 1983	3,250 feet x 15 (?) feet	not given	not given	not available	$5.50/LF
US EPA Feasibility Study 1981 New Jersey	2,495 feet x 1-2 (?) feet	not given	4" slotted	not available	$1.94/LF
US EPA/NYS DEC CH_2 M Hill Bids 1982 New York	3,250 feet x 15(?) feet	not given	not given	not available	$12/LF $11.70/LF $ 7/LF $ 5/LF $ 4/LF

The cost of the geotechnical investigation was included only in the "Impoundment" drain scenario estimate. This element comprised 50% of the total cost of the drain. Overhead (25%) and contingency (25%) allowances were added to both the "Impoundment" and "Landfill" estimates. The variations in the estimated subsurface drain costs from JRB and SCS were caused by a combination of two factors. First, the JRB estimates used unit costs at the high end of the range used by SCS. Second, the JRB estimate included three components not included in the SCS estimates. However, since these items were responsible for only $24.70 of the $694/LF difference (11%) in total unit cost between JRB and SCS, their influence was relatively insignificant. The influence of component unit costs that were included was therefore more significant than the influence of component costs that were not included in the JRB estimates.

Expenditure Sources

- ELI/JRB Case Studies, 1983

Estimated Sources

- JRB - RAM, 1980
- Radian, 1983
- US EPA OERR contractor bids
- SCS 1980

4.0 AQUEOUS AND SOLIDS TREATMENT

4.1 ACTIVATED SLUDGE

4.1.1 Definition

This treatment technology involves introducing organic-laden wastewater into a reactor where an aerobic bacterial culture is maintained in suspension (mixed liquor). The bacteria convert organic materials to carbon dioxide, water, metabolic intermediates and ammonia. Oxygen is supplied to the reactor by mechanical or diffused aeration with air or oxygen-enriched stream. Intimate contact between wastewater, sludge, and oxygen is maintained. A portion of the mixed liquor is continuously passed to a settling tank (clarifier) where sludge is separated from wastewater. A portion of the settled sludge is returned to the reactor to maintain the proper microorganism balance, while the remainder is removed from the system. Typical equipment includes aeration tanks basins, clarifiers, compressors, aerators (diffused or mechanical), and recycle pumps.

4.1.2 Unit of Measurement

Costs are given in terms of dollars per gallon treated. Costs estimates from one source were available only in terms of cost per pound of biological oxygen demand (BOD) reduction. Also, where available, system volume capacity assumptions are given, but cost per unit of mixed organic contaminant reduction estimates were not calculable.

4.1.3. Summary Data

4.1.3.1 Expenditures

The following expenditure was found:

Capital:	$6.3 million/Mgd ($87,514/13,680 gpd)
Operation & Maintenance:	$0.0165/gal.

This system was a nutrient-enhanced biodegradation system, constructed with retrofitted 5,400 gallon milk trailers for aeration and settling tanks. It was not a standard factory constructed activated sludge system, though the cost components were very similar. The operation and maintenance cost includes a relatively small expenditure for nutrient salts ($19.20/day; $0.0014/gallon; 8%). The use of used or salvaged material generally produced significant costs savings over the expected cost for new materials.

4.1.3.2 Estimates

Cost estimates ranged from:

Capital:	$200,000/Mgd to $390,000/Mgd
Operation & Maintenance:	$18,000/Mgd/year to $25,000/Mgd

The compilation of these estimates is unclear from the available data

4.1.4 *Factors Found to Affect Costs*

4.1.4.1 Expenditures

The following factors were found to contribute to expenditures.

- Materials (used and salvaged)
- In- house design and maintenance
- In-house power and process steam
- System flexibility (access holes)

Although no expenditure data is for a newly constructed system available for comparison, the cost of this system given in Table 25 may have been significantly lower than if new equipment and contractor labor had been used. One cost item that increased the capital expenditure, possibly unnecessarily, was the construction of a roller mount and access ports for the pipe air spargers. This system was intended to allow the spargers to be cleaned of biomass buildup without sending a technician into the tank. This maintenance has not been necessary in over 2 years of operating the system (as of August 1983).

4.1.4.2 Estimates

The lack of technical detail about the hypothetical systems for which estimates were given precludes consideration of specific factors affecting the costs (see Table 26).

Expenditure Sources

- ELI/JRB Case Studies, 1983

Estimates Sources

- Radian, 1983
- SCS, 1981

TABLE 25

ACTIVATED SLUDGE EXPENDITURES

(1982 Dollars)

Data Source	Capacity; rate	Aeration	Design	Operation & Maintenance	Direct Capital
US EPA ELI/JRB 1982 New Jersey	0.014 Mgd (1)	20 cfm through stone pipe diffusers	retrofitted milk trailers used for aeration tanks	\$2.89/Mgd(2) \$226/day \$0.0165/gal.	\$6.3 million/Mgd (\$87,514)

(1) Million gallons per day

TABLE 26

ACTIVATED SLUDGE COST ESTIMATES

(1982 Dollars)

Data Source	Capacity; rate	Aeration	Design	Operation & Maintenance	Direct Capital
US EPA Radian "Conventional" 1983	1.0 Mgd (1) 5.0 Mgd 10.0 Mgd	1.1 lb O_2/lb BOD_5 removed	40 year service life detention time 6 hours	\$25,000/Mgd \$24,000/Mgd \$18,000/Mgd	\$390,000/Mgd \$250,000/Mgd' \$200,000/Mgd
US EPA SCS February 1981 1980	7.2 Mgd (1) (5,000 gpm)	Not given	10 year service life	\$358,720/Mgd (2) \$709,180/Mgd	

(1) Million gallons per day
(2) First year O&M.

4.2 AEROBIC, ANAEROBIC, AND FACULTATIVE LAGOONS

4.2.1 Definition

Aerobic, anaerobic and facultative lagoons are large, usually earthen basins, which rely primarily on long retention times for biodegradation of organic wastes.

Aerated lagoons are 6 to 20 feet deep. Aeration devices supply supplemental oxygen and partial mixing. A sludge blanket accumulates on the bottom and undergoes anaerobic decomposition. A non-aerated cell usually follows to allow solids to settle before discharge.

Anaerobic lagoons are deep (20 feet). High organic loadings and an impervious layer of grease promote thermophilic anaerobic digestion. Wastewater enters near the bottom and exits below the surface. Excess sludge is washed out with effluent; waste recirculation is unnecessary.

Facultative lagoons are 3 to 8 feet deep. Wastewater is stratified into aerobic, intermediate, and anaerobic zones because of settling solids and water temperature-density variations. Oxygen in the surface layer is provided by diffuse reaeration and photosynthesis, not aeration devices. The aerated layer also reduces odors.

4.2.2 Units of Measurement

Costs are given in dollars per million gallons per day treated. This cost basis assumes similar treatment effectiveness, as well as the use of extrapolation from total costs.

4.2.3 Summary Data

4.2.3.1 Expenditures

No actual expenditure data are available at this time.

4.2.3.2 Estimates

Cost estimates ranged from

Capital:	$0.08 million/Mgd	(7.2 Mgd)
	to	
	$3.4 million/Mgd	(0.14 Mgd)
Operation & Maintenance:	$0.005 million/Mgd	(10 Mgd)
	to	
	$1.23 million/Mgd	(0.14 Mgd)

The cost estimates reflect widely varying scales of operation assumptions. Large (5-10 Mgd) scale scenarios were at the bottom of the unit cost estimate range, while smaller operations (under one Mgd) were generally the higher estimates. Also, the lower estimates excluded certain related components such as land, pumping and liners.

4.2.4 Factors Found to Affect Costs

4.2.4.1 Expenditures

No actual expenditure data are available at this time.

4.2.4.2 Estimates

The following factors appeared to significantly affect the cost estimates:

- o Scale of operation
  - land, pumping, liner
  - containers and overhead
- o Removal effectiveness
- o Aeration extent
- o Climate

As noted in section 4.2.3.2, the cost estimates were significantly related to the scale of operation of the scenario. This results partly from the economies of scale inherent in larger operations, but it also reflects the nature of these papers for specific technologies, and general construction estimating manuals (see Table 27).

The large hypothetical systems estimated by Radian excluded the costs of pumping, liner and land. These systems were similar in design to those that would be part of a sewage or industrial treatment plant.

A contingency and engineering cost of 30% was included in the New Hampshire Feasibility Study estimate. The inclusion of this cost in the other estimates is unclear from the available data.

The estimates include a variety of contaminant removal effectiveness levels. These levels were generally given in terms of BOD or COD. These may not provide accurate estimates of removal effectiveness for many refractory or highly toxic organics but they provide useful standards for comparison. In cases where removal efficiency information was available, no relationship with total unit costs was apparent. However, for similarly designed systems, removal effectiveness would probably be proportional to cost.

TABLE 27 (ESTIMATES)

ANAEROBIC, AEROBIC AND FACULTATIVE LAGOONS

Data Source	Design	Capacity	Operation & Maintenance(1)	Capital
US EPA OERR 1982 Feasibility Study New Hampshire	AEROBIC 28 day detention period 4 cells, 12 feet deep 3,500 CFM aeration	144,000 gpd (0.14 Mgd)(2)	$1.23 million/Mgd	$3.4 million/Mgd
US EPA Radian 1983	AEROBIC 7 day detention time 88% BOD/COD removal 10 feet deep 30 year service life	1 Mgd 10 Mgd	$0.03 million/Mgd $0.07 million/Mgd	$0.03 million/Mgd $0.02 million/Mgd
US EPA Radian 1983	ANAEROBIC gravity flow, excludes land, pumping, liner 60% BOD removal 50 year service life	1 Mgd 10 Mgd	$0.0125 million/Mgd $0.005 million/Mgd	$0.5 million/Mgd $0.3 million/Mgd
US EPA Radian (coll climate) 1983	FACULTATIVE gravity flow; excludes land, pumping and liner 20 lb BOD_5/acre/day 80% BOD/COD removal	1 Mgd 10 Mgd	$0.015 million/Mgd $0.006 million/Mgd	$1.5 million/Mgd $0.7 million/Mgd

(1) Annual
(2) Million gallons per dav

TABLE 27 (continued)

ANAEROBIC, AEROBIC AND FACULTATIVE LAGOONS

(1982 Dollars)

Data Source	Design	Capacity	Operation & Maintenance(1)	Capital
US EPA Radian (warm climate) 1983	FACULTATIVE gravity flow; excludes land, pumping and liner. 40 lb BOD_5/acre/day 80% BOD/COD removal	1 Mgd 10 Mgd	$0.015 million/Mgd(22) $0.006 million/Mgd	$0.65 million/Mgd $0.35 million/Mgd
US EPA SCS 1981 (mid-1978 dollars)	AEROBIC 70% removal 100 ppm BOD	7.2 Mgd	$0.03 million/Mgd	$0.08 million/Mgd

(1) Annual (2) Million gallons per day (3) First year cost

Finally, the extent of aeration varied among the estimate scenarios. The cost of aeration equipment, in terms of both capital, and operation and maintenance costs, may be significant. This difference in design and cost also significantly affects performance. For example, the hypothetical aerobic system had a presumed efficiency of 88%; whereas the anaerobic system achieved only 60%. This difference suggests the need to quantify costs in terms of dollars per unit of contaminant removed per unit of time when comparing systems for the same waste stream. For facultative systems the climate affects system performance and hence, costs. The system in a warm climate was more effective than the cooler climate system.

Estimates Sources

- Radian, 1983
- SCS, 1983

4.3 ROTATING BIOLOGICAL CONTACTORS

4.3.1 Definition

This system is a form of fixed film biological treatment. A slime layer of microorganisms grows attached to polystyrene or polyvinyl chloride disks 6 to 12 feet in diameter. The disks are mounted vertically on a horizontal rotatable axis in treatment tanks. Rotation of the disks exposes the slime surfaces alternately to both oxygen in the atmosphere and organic matter in the wastewater. Both oxygen and organic matter are adsorbed; the organic material is degraded by aerobic microorganisms. The rotation also mixes and aerates the contents of the tank and causes excess microorganisms to be sloughed off as growth continues. Excess solids are subsequently separated from the effluent in a clarifier. A complete RBC system usually consists of two or more trains of disks with each train consisting of several stages.

4.3.2 Units of Measurement

Costs are given in terms of dollars per million gallons per day treated, when available, for comparison with other water treatment technologies.

4.3.3 Summary Data

4.3.3.1 Expenditures

No actual expenditure data are available at this time.

4.3.3.2 Estimates

The range of cost estimates was:

Capital:	$0.9 million/Mgd	(10 Mgd)
	to	
	$29.6 million/Mgd	(0.144 Mgd)
Operation & Maintenance:	$22,500/Mgd/year	(10 Mgd)
	to	
	$4.6 million/Mgd/year	(0.05 Mgd)

The range of estimates reflects a widely varying scale of operation assumed for the four estimates from two sources. The high estimate is derived from dividing the total (capital or O & M) by the treatment rate, in million gallons per day. Hence this method of scaling up the smaller system estimates may result in multiplication of some fixed costs. The low cost estimates are derived from estimates for very large sewage treatment scale systems. The actual costs can be derived by multiplying the unit cost by the treatment rate.

4.3.4 Factors Found to Affect Cost

4.3.4.1 Expenditures

No actual expenditure data are available at this time.

4.3.4.2 Estimates

The following factors appeared to have significant effects on cost estimates.

- Scale of treatment
- Inclusion of related costs
  - overhead allowance
  - contingency allowance
  - settling tanks, etc.

As noted above in section 4.3.3.2, the scale of treatment operation appeared to significantly affect costs (see Table 28). For this reason the estimate may be of limited comparability since the Radian estimate is for a very large system, compatible with flow rates at a sewage treatment, or large industrial waste plant.

The effect of inclusion of related costs on the estimates is unclear. The New Hampshire Feasibility Study assumed an additional 30% for contractor overhead. Whether these costs are included in the Radian estimate is unclear.

TABLE 28

ROTATING BIOLOGICAL CONTACTOR COST ESTIMATES

(1982 Dollars)

Data Source	Design basis	Capacity	Operation & Maintenance	Capital
US EPA OERR 1982 New Hampshire	for volatiles removal; follows neutr. and ppt. includes nutrient salt mixing tanks, clarifier dewatering, sludge recycle	0.05 Mgd	$4.6 million/Mgd	$29.6 million/Mgd (2)
		0.144 Mgd	$3.9 million/Mgd	$23 million/Mgd
US EPA Radian 1983	100,000 sq ft of media per shaft 80-90% BOD removal 99% ammonia removal cost excludes 1° and 2° clarifiers	1 Mgd (1)	$32,500/Mgd	$0.9 million/Mgd
		10 Mgd	$22,500/Mgd	$0.9 million/Mgd

(1) Million gallons per day.

(2) Includes engineering & contingency (30%), and contractor's overhead (25%).

(3) Annual

Finally, the exclusion of certain system components from the Radian estimate scenario may have significantly underestimated the cost estimate, compared to that given in the feasibility study. The Radian estimate included only those components strictly used for the rotating biological contactor, excluding settling tanks, clarifiers and chemical mixing unit. Generally, the Radian estimate hypothesized a unit to be retrofitted to a larger primary treatment plant.

Estimates Sources

- Radian, 1983
- US EPA OERR contractor Feasibility Studies

4.4 AIR STRIPPING

4.4.1 Definition

The air stripping process enhances volatilization of volatile organic compounds (VOC) generally by increasing the liquid surface area and the velocity of the air passing by it. Towers and basins have both been used; only towers are considered here. The typical tower is similar in construction and configuration to a water cooling tower. Waste water enters at the top of the tower and flows downward over the packing, which may consist of plastic beads or piping. An induced draft fan draws air in at the lower sides and bottom of the tower and out through the top. Basins, which consist of a temporary swimming pool with a series of spray nozzle across them have been used for leachate stripping, but no separate costs were available for them at this time (August 1983).

4.4.2 Units of Measurement

Costs are given in dollars per million gallons per dav for ready comparison with other water treatment technologies.

4.4.3 Summary Data

4.4.3.1 Expenditures

The one source of actual expenditure data indicated the following costs.

Capital:	$182,540/Mgd (million gallons per day)
Operation & Maintenance:	$9,921 - 11,905/Mgd

No comparison with other site data is possible at this time since this is the only actual expenditure information available (August 1983). This expenditure was significantly lower than those estimated with engineering/construction costing manuals.

4.4.3.2 Estimates

The following range cost estimates for air stripping systems was found:

Capital:	$607,000/Mgd	(1.44 Mgd)
	to	
	$7.3 million/Mgd	(0.0504 Mgd)
Operation & Maintenance:	$89,000/Mgd	(1.44 Mgd)
	to	
	$3.2 million/Mgd	(0.0504 Mgd)

The range given is for two out of the three estimate that were available. The third cost estimate is not shown in the above range because the cost estimate reflects only shipping and set-up costs for a borrowed tower, not construction costs. The above range seems to reflect the economies of scale for varying size systems. The lowest cost system on a unit rate basis ($607,000/Mgd capital; $89,000 O&M) was the largest (1.44 Mgd); while the highest cost system ($7.3 million/Mgd capital; $3.2 million/Mgd) was the smallest system estimated (0.0504 Mgd). Hence, in absolute terms the smallest system had the lowest cost estimate, but on a relative, per million gallons per day, basis, the economies of scale gave a significant cost advantage to the larger systems.

4.4.4. **Factors Found to Affect Costs**

4.4.4.1 Expenditures

The following factors appeared to affect the costs:

- Capacity (VOC reduction and flow rate)
- Blower size

For the system considered (see Table 29), the capacity was estimated to bear almost a straight linear relationship with cost. Hence, on a relative, per rate basis, the cost for different sized systems would be expected to be similar. The Feasibility Study estimated that the cost would increase about the same amount for each of the five towers added.

The VOC reduction was expected to be related to costs, but no quantitative comparison is possible without more expenditure data.

The blower size significantly affected the operation and maintenance (O & M) since most O & M cost was involved in electrical power for the fans. The O & M expenditure was relatively low since power costs in the northwest U.S. were unusually low during the estimation period.

4.4.4.2 Estimates

The following factors seemed to affect the cost estimates

- o Capacity contaminant (reduction and flow rate)
- o Blower size
- o Included costs
- o Packing material

Cost estimates varied directly according to flow rate of the treated effluent (see Table 30). This variation reflected increased tower size, packing volume and pump capacity. However, on a per flow rate basis, of dollars per million gallons per day ($/Mgd), the costs were inversely related to system size. This relationship apparently reflected the varying economies of scale, which seemed to be the most significant factor affecting costs. The least cost system on a unit rate basis ($607,000/Mgd capital; $89,000 O & M) was the largest (1.44 Mgd); while the highest cost system ($7.3 million/Mgd caital; $3.2 million/Mgd O & M) was the smallest system estimated (0.0504 Mgd). Hence, in absolute terms the smallest system was the lowest cost estimate, but on relative per million gallons per day basis, the economies of scale gave a unit cost advantage to the larger system.

TABLE 29

AIR STRIPPING EXPENDITURES

(1982 Dollars)

Data Source	Design	Capacity	Operation & Maintenance (1)	Capital
US EPA OERR CH_2 M Hill Washington 1983	Five towers: 12 feet dia. x 30 feet high; 60 hp blower; 29,000 cfm/tower	5.04 Mgd (3,500 gpm) 95% removal	$9,921- 11,905/Mgd (2)	$182,540/Mgd

(1) Annual cost

(2) Estimated, actual expenditures not yet encountered (8/83)

TABLE 30

AIR STRIPPING COST ESTIMATES

(1982 Dollars)

Data Source	Design	Capacity	Operation & Maintenance (1)	Capital
US EPA OERR - Weston Feasibility Study 1982 New Hampshire	23 foot high tower two 600 cfm blowers 5 hp motors 15 psig steam boiler	0.0504 Mgd (35 gpm) 0.144 Mgd (100 gpm)	$3.2 million/Mgd $2.3 million/Mgd	$7.3 million/Mgd $3.9 million/Mgd
US EPA Radian 1983	20 foot high tower; sch 80 pvc pipe packing, cross-stack; 400 cuft/gallon	0.144 Mgd 1.44 Mgd 80% removal	$286,000/Mgd $89,000/Mgd	$1.07 million/Mgd $607,000/Mgd
US EPA OERR-CH_2 M Hill Feasibility Study 1983 Minnesota	one tower; 12 feet dia. x 300 feet 30 feet high; barrowed from other site; shipping/set up only	average: 1 Mgd. maximum: 2.16 Mgd. 95% removal	$60,765/Mgd $28,131/Mgd	$124,610/Mgd (2) $57,690

(1) Annual cost

(2) "Capital" costs include only shipping of treatment tower from Tacoma, Washington, and set up costs (pad, appurtenances, etc.)

The contaminant reduction effectiveness of the various systems estimated was also reflected in the costs. Since a variety of factors in turn affect removal effectiveness, it is difficult to relate these many factors to costs. These factors and components include: pumping rate (higher rates may create higher dilution resulting in lower percentage removal but higher molar reductions); climate (effectiveness increases with ambient temperature); and heating of treatment stream (may be necessary to offset seasonal cooling or increase effectiveness; significantly increases O & M).

The variation in included costs is especially noteworthv for the system estimated in the Minnesota Feasibility Study. This cost estimate did not include tower construction, but rather only included shipping and set-up of a tower borrowed from the Tacoma, Washington site. Although this system was estimated for a four month operation (while an alternate water was to be installed), the cost given are trebled for annualized comparison. All of the estimates given include engineering overhead, at about 25 – 30%.

Finally, packing types varied among the estimates and had some, unquantifiable effect on costs. The proportion of costs devoted to tower packing is unclear but the costs of different packing materials of varying effectiveness was given in one estimate. ($15/cuft – $95/cuft). Hence, an optimization is necessary when choosing a packing type in order to acheive a given level of removal with a certain system size.

Estimates Sources

- Radian, 1983
- US EPA OERR contractor Feasibility Studies

Expenditure Sources

- State and Federal Superfund work

4.5 CARBON TREATMENT

4.5.1 Definition

Carbon treatment systems generally filter contaminated water through a carbon bed, which selectively adsorbs organic compounds with physical and/or chemical action. When the carbon in the filter reaches breakthrough, that is, when the rate of desorbtion, equals the rate of adsorbtion, the carbon is replaced, and the old carbon is disposed of, destroyed, or regenerated with heat or solvents. Carbon adsorbtion is often used in combination with other treatment technologies such as filtration and flocculation.

4.5.2 Units of Measurement

Costs are given in dollars per million gallons per day, when available. In some cases, where no rate information was available, costs are given in dollars per gallon.

4.5.3 Summary Data

4.5.3.1 Expenditures

Costs for carbon treatment were found to range from:

$ 0.10/gallon

to

$ 0.40/gallon

These costs included system rental, carbon, transportation, and set-up labor and equipment. The higher cost system includes a greater accounting of all of these related costs, while the lower cost system was operated for a short period and did not include carbon disposal or regenerations costs.

4.5.3.2 Estimates

The cost estimates range from:

Capital:	$643,000/Mgd	(complete construction cost)
	to	
	$14,132/Mgd	(set-up of leased system)
Operation and Maintenance:	$11,786/Mgd/year	
	to	
	$1.5 million/Mgd/year	

The wide range of cost estimates reflects variety of included costs. The lowest cost system does not include complete material purchase cost, but rather the rental cost and set-up of the system. The highest estimated cost includes complete material and construction costs.

4.5.4 Factors Found to Affect Costs

4.5.4.1 Expenditures

The following factors affected the expenditures for carbon filtration:

- o Inclusion of pretreatment costs
- o Rental/purchase expenditure

For both expenditures given in Table 31, pretreatment costs are included in the cost given for the carbon treatment system. Although these costs for pretreatment may have been necessary for efficient carbon use, and may comprises a minority of the component costs, it is important to note that they were included. The higher cost system included a settling pool for clarifiying out suspended solid, and an air stripping system for preliminary removal of methylene chloride before running through the four cascade carbon towers. The lower cost system included only pea-gravel and lime for precipitating and filtering out solids.

TABLE 31

CARBON TREATMENT EXPENDITURES

(1982 Dollars)

Data Source	Design	Capacity	Operation & Maintenance	Capital
US EPA ELI-JRB 1980 New Jersey	clarification air stripping four cascade carbon filter	0.25 Mgd 25-150 gpm	$0.30 - 0.47/gallon (1)	
US EPA ELI-JRB 1979 Missouri	pre-gravel/ lime prefilter; three stage carbon 2,400 lb carbon	Not given	$0.13 - 0.23/gallon (1)	

(1) Rented system and related costs.

Both expenditures given are for leased systems. The costs generally included transporting the filter units, set-up, and operating labor. Also, regeneration costs for the lower expenditure (Missouri) did not include carbon regeneration.

4.5.4.2 Estimates

The following factors affected the cost estimates.

- o Size
- o Inclusion of related costs
  - rental/construction
  - carbon regeneration
  - additional prefiltering or treatment

In absolute terms, the total system cost estimates varied directly with size (see Table 32). In relative terms, the cost per million gallons per day treated was relatively more constant, though it varied over one order of magnitude for capital, and three orders of magnitude for operation and maintenance (O & M). No economies of scale effect was apparent since, even from the same data source, cost per million gallons per day of larger systems was sometimes higher than for smaller systems.

The cost of renting a system appeared to be less costly than most construction scenarios in two instances. For the feasibility studies at the Illinois and Minnesota sites, quotes for leased systems were obtained from vendors. These costs included set-up and operation labor, materials and equipment. It is unclear if regeneration costs were included in most examples. For rented systems, it is presumably included in rental costs if a carbon change was not necessary during the lease period, such as in the Minnesota scenario.

Costs for additional prefiltering and treatment, aside from carbon, were included only in two cost estimates. In the second highest cost system estimate, for the New Jersey feasibility study, the costs of sulfur dioxide gas treatment to precipitate out iron, airstripping to remove volatile organics, and neutralization to stabilize the pH were

TABLE 32

CARBON TREATMENT COST ESTIMATES

(1982 Dollars)

Data Source	Design	Capacity	Operation & Maintenance	Capital
US EPA Radian	30 min. contact time;	0.14 Mgd (100 gpm)	$357,000/Mgd	$143,000/Mgd
1983	1 lb per 5,000 gal; off-site regeneration	1.4 Mgd (1,000 gpm)	$250,000/Mgd	$643,000/Mgd
US EPA/NJDEP CDM Feasibility Study (F.S) 1983	SO_2 for Fe ppt. air stripping neutralization (3) 1 lb per 1,000 gall:	2 Mgd (1,389 gpm)	$1.5 million/ Mgd	$473,500/Mgd
New Jersey		7 Mgd (4861 gpm)	$1.3 million/ Mgd	$471,429/Mgd (4) $138,000/Mgd (5)
US EPA CH_2 M Hill (vendor quote for F.S.) 1983	sand filters carbon tanks rented system	0.28 Mgd (200 gpm)	$11,786/Mgd (2)	$346,429/Mgd (1)
Illinois		2.16 Mgd (1,500 gpm)	$222,000/Mgd	$476,852/Mgd
US EPA SCS 1981 (mid 1978 dollars)	pressurized pretreated in situ regeneration	7.2 Mgd (5,000 gpm)	$883,200	$234,600

(1) Includes set-up and breakdown of all major equipment, piping, controls, utility, erection, transportation, carbon and sand. No purchase.
(2) System rental
(3) All costs included
(4) First 5 years
(5) After 5 years.

TABLE 32 (continued)

CARBON TREATMENT COST ESTIMATES

(1982 Dollars)

Data Source	Design	Capacity	Operation & Maintenance	Capital
U.S. EPA CH_2 M Hill Feasibility Study 1983 Minnesota	pressurized system 13 min. contact time 80,000 lb carbon	2.16 Mgd (1,500 gpm)	$82,000/Mgd	$14,132/Mgd (1)

(1) Includes set-up and breakdown of all major equipment, pippin, controls, utility, erection, transportation, carbon and sand. Not purchase.

included. In the SCS II estimate the costs of neutralization and clarification were included. The costs of chemicals and power comprised 90% of the O&M costs for this system.

Expenditure Sources

- ELI/JRB Case Studies, 1983

Estimated Sources

- Radian, 1983
- US EPA OERR contractor Feasibility Studies

4.6 OIL/WATER SEPARATOR

4.6.1 Definition

An oil/water separation skims oil off of water by taking advantage of the immiscibility of these liquids. The two general types of oil/water separators are (1) a floating skimmer-type, and (2) a tank-type coalescing plate separator. Costs are given in this section for the second type. The latter type, which is typically larger, uses a series of horizontal and vertical hydrophilic and hydropholic plates to enhance oil globule flotation. These systems may be used in series with each other and with other treatment technologies, which may provide "polisking" to remove residual low level contaminants.

4.6.2 Units of Measurement

Costs are given in dollars per million gallons per day when data availability make it possible.

4.6.3 Summary Data

4.6.3.1 Expenditure

The one expenditure available was:

Capital:	$289,200	(includes hookup and controls)
Operation and Maintenance:	$50,000/year	(capacity unknown)
	$2.70–4.16/gallon	(1,000–1,500 gallons/month)

The cost per gallon is relatively high because of the low treatment rate. The oil/water mixture is collected into a sump from tight soil with a subsurface drain system.

4.6.3.2 Estimates

The single estimate available was:

Capital:	$91,587	5,000 gpm capacity
	$12,720/Mgd	(7.2 Mgd)
Operation and Maintenance:	$267,456/1st year	
	($0.0001/gallon)	

The assumptions for this system suggest that it is intended as an add-on to a larger treatment system. Appurtenances and control cost are not included as they are for the above expenditure. This causes an underestimate for the capital cost because of the excluded costs and a low estimate for the O&M because the maximum capacity flow rate was assumed for deriving the unit cost.

4.6.4. Factors Found to Affect Costs

4.6.4.1 Expenditures

The following factors affected estimates:

- o Flow rate (utilization of capacity)
- o Inclusion of related costs:
  - appurtenances
  - controls
  - tank housing

Flow rate was probably the most important factor affecting the expenditure (see Table 34). The combination of a locally tight soil with a high organic content, and the natural adhesion of oil to such high organic soil resulted in a very low flow rate of only 1,000-1,500 gallons per month for the California case study site. The effect on operation and maintenance unit costs by flow rate is even more clear. The relatively low flow rate divided into the annual operation and maintenance costs results in a relatively high unit O&M cost.

The expenditure data included a variety of related costs that may not be accounted for in estimates or other expenditures. These related costs are shown in Table 33. They include appurtenance upgrading to connect the lines for the treated effluent to the local POTW, a building to enclose the storage tanks, and a control system for operating the separator. These related fixed costs may be spread among other system components for a larger system in which the oil/water separator is a minor component, such as in a large POTW or complex industrial waste (pre)treatment operation.

TABLE 33. Oil/Water Separator Capital Expenditures

o	Treatment system	$49,200
o	Plumbing modifications on existing tank farm to receive material before treatment to test for treatment need	$ 8,000
o	Tank farm building	$50,000
o	Sanitary sewer system modifications to discharge treated effluent to POTW	$33,000
o	Electrical and instrumental oil recovery system	$117,000
o	Monitoring equipment for POTW discharge	$ 12,000
o	Project management for POTW dishcarge modifications	$ 20,000
	Total	$289,200

TABLE 34

OIL/WATER SEPARATOR EXPENDITURES

(1982 Dollars)

Data Source	Design, capacity	Contaminant	Operation & Maintenance	Capital
US EPA ELI/JRB 1983 California	Coalescing plate separator capacity unknown 1,000-1,500gallons/ month	PCB/oil, 10 c oil in water from french drain sump	$50,000/year ($2.70- $4.16/gallon)	$289,200

4.6.4.2 Estimates

The following factors affected the estimate (Table 35):

- System capacity
- Inclusion of related costs

The unit cost estimate includes only basic material costs and assumes a capacity flow rate and, therefore, was probably an underestimate of an actual installed systems cost. To the extent that this capacity flow rate is an unrealistic assumption, this unit cost is an underestimate.

Since this hypothetical system appears to be intended as an add-on to a large POTW or an industrial (pre)treatment system certain related fixed costs may be excluded or spread among the larger system.

Since the bulk of the flow through an oil/water separator is water rather than oily contaminant, the flow rate variations may overestimate the actual contaminant removal range. Therefore, cost estimates may be made more accurate by calculating the cost per volume of contaminant removed. As with other treatment technologies, however, this contaminant removal cost is very difficult to measure because of the variations in contaminants and removal levels. The removal effectiveness of an oil/water separator is affected primarily by oil drop size; retention time, density differences between the aqueous and the organic phases, and the temperature.

Expenditure Sources

- ELI/JRB Case Studies, 1983

Estimate Source

- US EPA, SCS, 1981

OIL/WATER SEPARATOR COST ESTIMATES

(1982 Dollars)

Data Source	Design, capacity	Contaminant	Operation & Maintenance	Capital
US EPA SCS 1981 (1978 Dollars)	Coalescing plate separator maximum 5,000 gpm (7.2 Mgd)	Not given	1st year = $267,456 ($0.0001/ gallon)	$91,587 ($12,720/Mgd) (simple average cost = $1.98/1,000 gallons)

5.0 GAS MIGRATION CONTROL

5.1 PIPE VENTS

5.1.1 Definition

Pipe vents are vertical or lateral perforated pipe installed in the landfill for controlling gases. They are usually installed at a landfill perimeter on 30 to 60 foot centers and extend down to the water table or the landfill base, sometimes in combination with trench vents for the control of lateral gas migration. Pipe vents are usually surrounded by a layer of coarse gravel to prevent clogging by solids or water. They may discharge passively to the atmosphere or be connected to a negative pressure collection system for possible treatment.

5.1.2 Unit of Measurement

Unit cost is given in dollars per pipe vent. Other units such as depth and diameter are used to describe each pipe vent.

5.1.3 Summary Data

5.1.3.1 Expenditures

No actual expenditure data are available at this time.

5.1.3.2 Estimates

The estimates ranged from:

$445 LS (6 feet deep)
to
$1,310 LS (30 feet deep)

No information was available about the assumptions for the lowest estimate. But the highest (capital) estimate included additional items such as PVC casing and a blower fan, which was not included in the lower estimate.

5.1.4 Factors Found to Affect Costs

5.1.4.1 Expenditure

No actual expenditure data are available at this time.

5.1.4.2 Estimates

The following factors affected the cost estimates for pipe vents:

- o Depth
- o Pipe diameter
- o Casing
- o Ventilation fan size

The factors affecting cost estimates are very similar to those affecting well points, deep wells and monitoring well costs, since construction elements are similar. Well costs are typically proportional to their depth, for both well point type installation and drilled wells. Costs also increase with pipe diameter because of affects on both material, and installation labor and equipment. Some estimates for some cost components were given in terms of dollars/inch diameter/foot depth, indicating that diameter (in inches) and depth (in feet) affect cost at the same function.

Casing (pvc) was included in the JRB and Radian cost estimates, but not the more shallow New Jersey Feasibility Study estimates (see Table 36). This element added $4.50-- 6.50/LF for 4 - and 6 - inch casings, respectively.

The fan affects both capital and operation and maintenance costs. The fan size, and its capital cost estimate was identical for the two sites that included it. The reason for the differing operation and maintenance cost from these sources is unclear.

Estimates Sources

- o JRB-RAM, 1980
- o Radian, 1983
- o US EPA OERR contractor Feasibility Studies
- o US EPA OERR contractor bids

TABLE 36

PIPE VENT COST ESTIMATES

(1982 Dollars)

Data Source	Depth	Diameter	Ventilation	Operation & Maintenance	Capital Unit Cost
US EPA JRB - RAM 1980	30 feet; incl. mushroom cap	pipe: 4 inches pvc casing: 6 inches	one fan/pipe- 0-136 cfm @ 3 inches H_2O	$18/year	$1310each
US EPA Radian 1983	30 feet; incl. mushroom cap	pipe: 3 inches pvc casing: 4 inches	one fan/pipe- 0-136 cfm @ 3 inches H_2O	$85/year	$975 each
US EPA-NH State CH_2M Hill Bids 1982 New Hampshire	Not given	Not given	Not given	Not given	$520 each $500 " $500 "
US EPA CH_2M Hill RI/FS 1983 New Jersey	6 feet 90° elbow + T	4 inch pvc, sch 40	none	none given	$445 each

(1) Includes 800 LF of vent piping; + 10% contingency

5.2 TRENCH VENTS

5.2.1 Definition

Trench vents are deep, narrow trenches backfilled with gravel, forming a path of least resistance through which gases migrate upward to the atmosphere or to a collection manifold. They are typically constructed around the perimeter of a waste area, or across a section of the site to form a barrier against lateral migration of methane (flammable) or toxic vapors. Trenches can be open, or capped with clay and fitted with collection laterals and riser pipes, venting to the atmosphere or connecting to a negative pressure fan or blower.

5.2.2 *Unit of Measurement*

Unit cost is given in terms of dollars per linear foot because it reflects the functional value of mitigating gas migration across an area.

5.2.3 Summary Data

5.2.3.1 Expenditures

No actual expenditure data are available at this time.

5.2.3.2 Estimates

The cost estimates for trench vents ranged from:

$35/LF (20 feet deep)
to
$646/LF (20 feet deep)

The highest cost estimate included significant costs for sheet piling, geotextile trench lining and well point dewatering of the excavated trench, none of which were included in any of the other three estimates. The lowest estimate was a simple passive trench vent with no piping or fan ventilation.

5.2.4 Factors to Affect Costs

5.2.4.1 Expenditures

No expenditure data are available at this time.

5.2.4.2 Estimates

The following factors were found to affect the trench vent cost estimates:

- o Trench size
- o Pipe vent size
- o Ventilation for size
- o Inclusion of related costs:

  sheet piling
  geotextile lining
  overhead allowances
  contingency allowances
  well point dewatering

Trench depth seemed to have the most significant effect on costs (see Table 37). The 20-foot deep scenario used for the JRB-RAM estimate required sheet piling, which, despite reuse assumptions, comprised 81% of the total capital cost. Also, wellpoint dewatering (14% of total capital cost) was considered necessary for this deep trench vent.

Pipe vents which were added to the trench vent designs estimates. Varied among the estimates given. The pipe vents for the highest and lowest estimates were not specified, and not included, respectively. However, length of the laterals and risers for the two SCS "Landfill" estimates was congruent; only the pipe diameter varied. This did not appear significantly affect costs.

TABLE 37

TRENCH VENT COST ESTIMATES

(1982 Dollars)

Data Source	Trench Size	Pipe vents	Ventilation fan	Operation & Maintenance	Capital unit cost
US EPA JRB - RAM 1980	500 feet (l) x 20 feet (d) x 4 feet (w)	laterals and risers= 500 feet	none	not given	$646/LF (1)
US EPA SCS-active control "Landfill" 1980	3,068 feet (l) x 12 feet (d) x 4 feet (w)	risers- 951 feet x 4 inches laterals - 3,068 feet x 8 inches	2 hp 1,250 cfm	$7,015 - $13,777/year	$41 - 63/LF
US EPA SCS-gravel trench vent "Landfill" 1980	3,068 feet (l) x 12 feet (d) x 4 feet (w)	risers- 951 feet x 6 inches laterals-3,068 feet x 12 inch	none	$897 - $1,888/year	$40 - 87/LF
US EPA SCS-gravel trench vent "Landfill" 1980	3,068 feet (l) x 20 feet (d) x 4 feet (w)	none	none	$130 - $283/year	$35 - [illegible]2/LF

(1) Includes sheet piling construction and geotextile lining

For the one estimate for which a ventilation fan was included, the operation and maintenance costs were significantly higher by an order of magnitude than the other estimates for which these costs were estimated, presumably to cover electricity and maintenance costs.

Geotextile trench lining (12% of total capital costs) was included only in the JRB-RAM estimate, which assumed $2.38/sq ft for hypalon.

The SCS estimates included allowances for overhead and contingencies as follows:

Estimate Scenario	Overhead	Contingency
Active control	25%	30%
Passive control	25%	20%
Gravel trench	25%	15%

Estimates Sources

- JRB-RAM, 1980
- SCS, 1980

5.3 GAS BARRIERS

5.3.1 Definition

Typically, a synthetic membrane is used in combination with other technologies to form a barrier against horizontal or vertical gas migration. Clay or concrete slurry walls and grout curtains may also perform a similar function, but at a higher cost; these technologies are usually reserved for ground water barriers. Synthetic membranes may be installed during construction of a trench vent or a subsurface drain, which both involve digging a trench. The cost of the trench and other tasks may be derived from the section on that conjunctive technology. Similar barriers to vertical migration may be taken from the surface sealing section. For material costing purposes, synthetic membranes may need to be doubled to prevent punctures from gravel and stones. Also, an additional several feet should be allowed for the membrane at the top of the trench to allow for proper anchoring. Trench bottoms should also be lined.

5.3.2 Unit of Measurement

Costs are given in terms of dollars per square foot because it best expresses the functional value of gas barriers.

5.3.3 Summary Data

5.3.3.1 Expenditures

No expenditure data are available at this time.

5.3.3.2 Estimates

The cost estimates ranged from:

Capital	$0.39/sq.ft.	asphaltic concrete
	to	
	$3.00/sq.f.t	hypalon (36 mil)
Operation and Maintenance	$900/year	(24 four hour inspections/year)

The information source does not explicitly state whether installation as well as material costs are included in these estimates.

5.3.4 Factors Found to Affect Costs

5.3.4.1 Expenditure

No expenditure data are available at this time.

5.3.4.2 Estimates

The following factor primarily affected gas barrier cost estimates:

- o Installation
- o Material type
- o Material amount

The inclusion of installation costs is the most important factor affecting these cost estimates. Although the estimates references drew data from the same sources. Table 38 shows that there are significant differences that may have been caused by the inclusion/exclusion of installation costs.

The material types and amount affected cost estimates, but inadequate data was available to quantify these effects.

Estimates Sources

- JRB-RAM, 1980
- Radian, 1983

TABLE 38

GAS BARRIERS COST ESTIMATES

(1982 Dollars)

Barrier Material	Design assumptions	JRB - RAM, 1980	Radian, 1983	Operation & Maintenance(1)
Synthetic liners:				
Hypalon	36 mil thickness	$0.71-0.77/ sq.ft.	$2.40-3/sq ft	
Teflon	10 mil thickness	$2.62/sq.ft.	$2.22/sq ft	
Geotextile backing	heavy weight, 2 layers	$1.77-2.36/ sq.ft.	$1.50-2/sq ft	
Gunite	4 inch, layer with wire mesh	$5.45-$9.91/ sq.ft.	$5.50-10.30/ sq ft	$900 - 1,062/year
Asphaltic concrete	4-6 inch layer including base	$0.39-0.66/ sq.ft.	$0.33-0.56/ sq ft	
Clay	Material cost, hauling, backfill by dozer, vibratory compaction every 6 inches for trench vent only.	$0.51/cu.ft.	$0.43/cu ft	

(1) Operation and maintenance cost estimated by Radian only

5.4 CARBON ADSORPTION (GAS)

5.4.1 Definition

Carbon filters are added to vents to collect gaseous contaminants (typically volatile organics) from the vent gases. Large gas filtration systems (10,000 and 100,000 cfm - roughly 1,000 cu.ft. of carbon) used in manufacturing processes are available, but this section includes information on relatively small systems (7 cu. ft. of carbon) for passive venting systems.

5.4.2 Units of Measurement

Costs are given in terms of dollars per filter. Units such as carbon filter volume of air filtered or amount of contaminant collected are important for describing a given filter unit, when available.

5.4.3 Summary Data

5.4.3.1 Expenditures

One expenditure for carbon gas filtration was available:

$188/filter

This cost does not include the cost of the used 55 - gallon drums that were retrofitted, or the labor cost of filling these drums with carbon. Only the material cost for the granular activated carbon is included. Each of four improvised filters was saddled over the vents to the 5,400 gallon activation and settling tanks used to biodegrade butanol and acetone from contaminated groundwater, using a wooden pallet.

Operation and maintenance costs include carbon testing and regeneration/replacement costs.

5.4.3.2 Estimates

One estimate was available from price quote sheets (this may be considered similar to expenditures except that no record of an expenditure is available).

$635/vent sorb (for orders of 1-3)

This cost is for a commercial carbon filter, which is very similar to the improvised filter for which costs are given above. Related costs of construction (drum cutting, filling, painting) are included in the delivered cost.

5.4.4 Factors Found to Affect Costs

The following factors affected the cost of the carbon vent adsorber (see Tables 39 and 40):

- Size
- Related costs
- Flow rate

The size of the filters affected only the cost of the activated carbon filler, since the drums used were reconditioned waste barrels. The containment structure would affect costs at a relatively small incremental proportion of the cost, since the carbon costs (roughly $1.00/lb) is a more significant cost factor.

As noted above, and in the comments section, the expenditure includes only material costs for the carbon. The vent filters were mounted on the cylindrical tanks using wooden pallets, and in-house labor was used to retrofit and fill the drum canisters. Hence, the cost of these related components would be expected to increase the cost of a factory-built carbon filter, as noted below.

TABLE 39

GAS TREATMENT EXPENDITURES

(1982 Dollars)

Data Source	Filter Size	Contaminant	Operation & Maintenance	Total Cost
US EPA ELI - JRB New Jersey 1982	55 gallon drum (1)	butanol acetone	not available	$188/each (2)

(1) Retrofitted use drum (2) Includes carbon cost only

TABLE 40

GAS TREATMENT COST ESTIMATES

(1982 Dollars)

Data Source	Filter Size	Contaminant	Operation & Maintenance	Total Cost
Industry vender quote (1983)	55 gallon drum	not given	not given varies with contaminant concentration	$635 each

The flow rate affects costs in general, because of the specific costs of a fan and the higher rate of adsorbtion. The fan would not only add to the capital cost but would add to the operation and maintenance costs in two important ways. First, the fan itself would require electricity and maintenance to keep running. Second, the higher rate of adsorbtion would increse the necessary frequency of replacement for the filter. The paucity and similarity of available data obviates contrast of factors between sources. However, the following brief listing of factors is appropriate.

- Filter size
- Flow rate (use of ventilation fan)
- Contaminant concentration

Of these, flow rate is probably the most important independent factor.
Neither of the passive-type vent filters for which costs are given above included costs for a fan, which would significantly increase operation and maintenance costs. JRB Remedial Action Manual (Rogoshewski, et al., 1980) included the relationship shown in Figure 1. The hypothetical system for which these costs were estimated is a large carbon filtration unit, several orders of magnitude larger than the vent-sorbs noted above.

Expenditure Sources

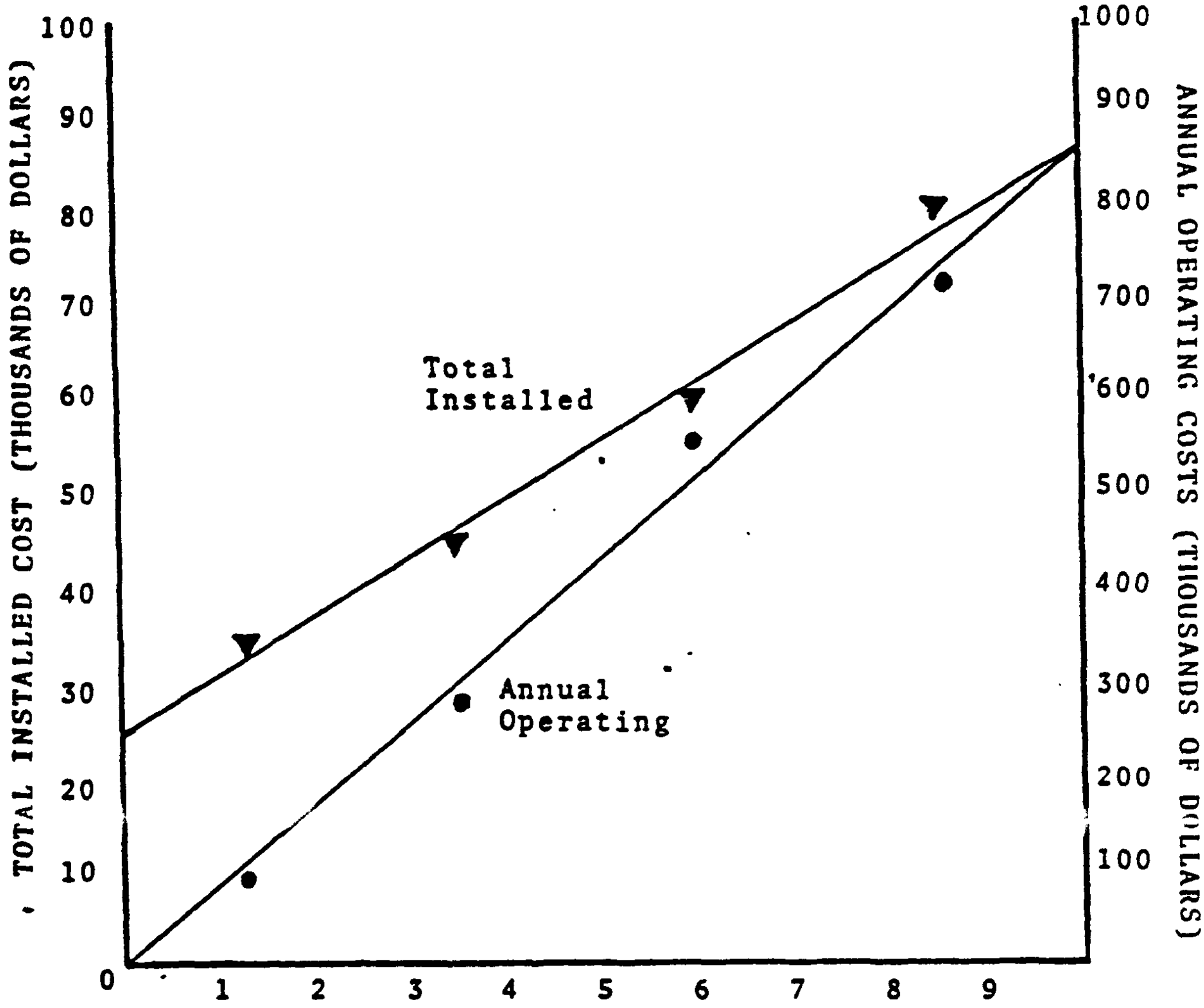
- ELI/JRB Case Studies, 1983

Estimates Sources

- US EPA OERR contractor bids

FIGURE 1. CAPITAL AND OPERATING COSTS

FOR NONREGENERATIVE CARBON GAS VENT FILTER



FLOW RATE (X1000 CUBIC FEET PER MINUTE)
OF VENT GAS CONTAINING 50 PPM TRICHLOROETHYLENE

SOURCE: CALGON, 1980

6.0 MATERIAL REMOVAL

6.1 EXCAVATION/REMOVAL TRANSPORTATION AND DISPOSAL/TREATMENT

6.1.1 Definition

Excavation, transportation and disposal costs are grouped here because, (1) similar factors affect all three tasks, and (2) some actual expenditure data are available only in terms of the three aggregated tasks. Excavation refers to the work necessary to load the hazardous material, ready for transport from its found position. (This may involve significant digging and waste classification, or only surface scraping.) Transportation involves hauling loaded materials off-site to a disposal/treatment facility. Disposal treatment may include landfilling, incineration or treatment.

6.1.2 Units of Measurement

Cost are given in dollars per cubic yard (cuyd) because it serves as a standard soil excavation measure. A cubic yard is assumed to weigh one ton, which is a common assumption at landfills. In several cases disposal and transportation costs are given in terms of dollars/ton because haulers and landfills used weight measures.

6.1.3 Summary Statistics

6.1.3.1 Expenditures

The following ranges of excavation/removal, transportation and disposal/treatment expenditures were found:

Excavation/Removal:	$15 - $460/cuyd
Transportation:	$29 - $145/cuyd
Disposal Treatment:	$17 - $356/cuyd

These cost elements cannot necessarily be summed, since the extremes of the ranges are derived from different sources with different scenarios and assumptions. Hence, summing the three unit operations from the highest and lowest cost sites, results in the following site total

Excavation, Transportation and Disposal :
$4.70 – $884/cuyd

For excavation/removal, the lowest cost site (Texas–$6.06/cuyd) required only pumping a liquid into a tank truck, while the highest cost site reflected the use of boats and level A protective gear to retrieve floating pails from a canal. For transportation, the salient reasons for the lowest cost site were unclear, but at the highest cost site (Massachusetts –$145/cuyd), a relatively high demurrage (compensation for delay) was charged because of sample analysis delays. The disposal/treatment cost varied greatly with the waste compatibility. The lowest disposal cost (New York City – $17/cuyd) was charged for oil heavily contaminated with highly volatile solvents, which facilitated incineration. The highest disposal cost (Florida – $356/cuyd) was for disposal of extremely caustic "super tropical bleach" (calcium oxide-chlorinated lime), which required treatment and neutralization prior to disposal. Operation and maintenance costs may involve ground water monitoring and, possibly, site inspections or security to prevent future illegal dumping, which is often repeated at former sites. These costs were either accounted for separately, or were not encountered for the sites.

6.3.1.2 Estimates

The following ranges of cost estimates for excavation/removal, transportation, and disposal/treatment were found:

Excavation/removal:	$0.85 – 4.09/cuyd
Transportation:	$1.67 – 94.40/cuyd
Disposal/treatment:	$ 12 – 283.20/cuyd
Site Total:	$222.87 – 379.37/cuyd

For excavation/removal, the lowest estimates (SCS "impoundment" - $0.85 - 1.27/cuyd) a front-end loader was assumed to be feasible, while for the highest estimate (SCS "landfill" - $3.42-4.09/cuyd) assumed an excavator scenario for the deeper excavation. The low transportation estimate was an extrapolation from a construction-engineering manual, while the high estimate reflected actual bids from different types of hauling firms. Disposal costs varied from $12/cu.yd. at a sanitary landfill, to $283.20/cu.vd. for contaminated sediment at an engineered landfill.

No operation and maintenance costs were assumed for the excavation/removal, transportation and disposal/treatment cost estimates.

6.1.4 Factors Found to Affect Costs .

6.1.4.1 Expenditures

The following technical factors were found to affect the costs of excavation/removal, transportation and disposal/treatment:

Excavation or On-site Transfer:

1. Excavation depth
2. Site surface characteristics
3. Health and Safety requirements
4. Material - liquid/solid/drums
5. Waste quantity

Transportation:

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

Disposal:

1. PCB Waste
   (a) Concentration-over/under 500 ppm
   (b) Material-solid vs. liquid

2. Non-PCB RCRA Hazardous Waste
   (a) Solid vs. liquid
   (b) Aqueous vs. organic

In addition, the following primary non-technical factors affected costs:

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

The effect of excavation depth on the costs shown in Tables 41 and 42 is probably non-linear, since the most significant cost changes resulted from equipment differences. For example, the depth of excavation at the Case Study sites in Idaho, New Jersey and Massachussetts #1 necessitated the use of a Caterpillar 235, which is a large, treaded backhoe, with a 30 foot (10 m) arm, which rents for about $70/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 and unconsolidated soil. At the New York City #1 and California #2 Case Study Sites no excavation costs were incurred because removal involved pumping liquid waste into trucks from tanks and ponds, respectively. Site surface characteristics probably had a relatively small effect on the excavation costs at most of the case study sites. At Case Study Massachussetts #1 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 that were buried at the toe of the slope during the excavation. This process added slightly to the labor and rental charges.

TABLE 41

EXCAVATION EXPENDITURES

(1982 Dollars)

Data Source	Material	Quantity	Contaminant	Excavation Depth	Excavation Removal	Trans. (Distance)	Disposal Treatment(1	Total
US EPA OERR 1982 Florida	liquid; 5 gal. pails	18.7 cuyd; 757 pails	Ca oxide chlorinated lime	surface	$460/cuyd	$0.17/cuyd/mi. (2 trucks) $68/cuyd (4)	$356/cuyd	$18,155 (2,4) $884/cuyd
US EPA ELI/JRB 1981 Calif.	bottles, pellets	430 cuyd	pesticides (DBCP, etc.)	15 feet	$158/cuyd	$119/cuyd (140 miles)		$276/cuyd
US EPA ELI/JRB 1981 Mass.	soil sludge	1,052 cuyd and 151 drums (3)	chlorinated solvents	3-15 feet	$ 51/cuyd	$145/ton (513 mi.)	$90/ton	$285/ton
US EPA ELI/JRB 1981 Idaho	soil sludge	817 cuyd	pesticides solvents	13 feet	$207/cuyd (254 mi.)			$207/cuyd

(1) Landfilled unless other wise noted
(2) Total cost includes other tasks
(3) 615 cuyd disposed; cuyd:ton ratio used by contractor= 1:1.3; 276 cuyd aerated on-site
(4) If 400 miles assumed

TABLE 41 (continued)

EXCAVATION EXPENDITURES

(1982 Dollars)

Data Source	Material	Quantity	Contaminant	Excavation Depth	Excavation /Removal	Trans. (Distance)	Disposal/ Treatment(1	Total
US EPA ELI/JRB Mass. 1981	drums soil	481 cuyd	solvents	surface	Not Available	$77/cuyd (480 miles)	$91/ton	--
US EPA ELI/JRB 1979 Missouri	soil	2,635cuyd	pentachloro-phenol	surface	$39-87/ cuyd	$29/cuyd (170 miles)	$61/ton	$110-159/cuyd
US EPA ELI/JRB 1978 Conn.	drums soil	4,770 cuyd	solvents metals	3-13 feet	$15/cuyd	$92/ton (497 mi.)	$55/ton	$164/ton
US EPA ELI/JRB 1982 NYC	oil	229 cuyd	solvents	surface	Not Available	$89/ton (818 mi.)	$17/cuyd (2)	--

(1) landfilled unless otherwise noted (2) Incineration

TABLE 41 (continued)

EXCAVATION EXPENDITURES

(1982 Dollars)

Data Source	Material	Quantity	Contaminant	Excavation Depth	Excavation /Removal	Trans. (Distance)	Disposal/ Treatment(1)	Total
U.S. EPA OERR 1982 Indiana	liquids sludges	2,500 gal. 27 cuyd. Tot.=55 cuyd	solvents still bottoms adhesives metals PCb (4)	surface	$89/cuyd	Not Available	$28/cuyd (2) (landfill, recycle)	$10,362 (3)
U.S. EPA 1982 OERR Texas	liquid	99,000 gallons	xylene	surface	$0.03/gal. vacuum truck	Not Available	Not Available	$3,186 (3)
US EPA ELI/JRB 1981 Calif.	soil	3,185 cuyd	pesticides	15 feet	$158/cuyd	$38/cuyd (140 miles)		$195/cuyd
US EPA ELI/JRB 1981 New Jersey	drums, soil	5,101 cuyd	solvents metals	15-26 feet	$37-74/ cuyd	$62/cuyd (440 miles)	$43/ton	$124-171/cuyd

(1) Landfilled unless otherwise noted

(2) Partially recycled

(3) Total cost includes other tasks

(4) Under 50 ppm

(1982 Dollars)

TABLE 41 (continued)

EXCAVATION EXPENDITURES

(1982 Dollars)

Data Source	Material	Quantity	Contaminant	Excavation Depth	Excavation /Removal	Trans. (Distance)	Disposal/ Treatment (1)	Total
US EPA ELI/JRB 1982 Wisc.	soil	100 cuyd	hexavalent chromium	4 feet	$15/cuyd	$61/cuyd (227 miles)		$76/ cuyd
US EPA ELI/JRB 1980 Calif.	waste-water	46,037 cuyd 9.3 x 10^6 gal	pesticides class I (3)	pumped from lagoons	$35.75/cuyd (15 miles)			$35.75/ cuyd
US EPA ELI/LRB 1980 Calif.	waste-water	190,950 cuyd; 38.6 x 10^6 gal	carbamate fungicide class II-I (3)	pumped from lagoons	$28/cuyd (50 miles)			$28/ cuyd
US EPA ELI/JRB 1980 Calif.	waste-water	268,114 cuyd 54.2 x 10^6 gal.	ammonia fertilizer	pumped from lagoons	$4.70-7/cuyd (60 miles) (2)			$4.70-7/ cuyd

(1) Landfilled unless otherwise noted
(2) Landfarmed, US EPA subsidized project
(3) State waste category

TABLE 41 (continued)

EXCAVATION EXPENDITURES

(1982 Dollars

Data Source	Material	Quantity	Contaminant	Excavation Depth	Excavation /Removal	Trans. Distance	Disposal	Total
US EPA OERR 1982 Arizona	liquid	10,000 gal.	sulfuric acid	leaking tank	$0.70/ gal. $141/cuyd vacuum truck	$2.56/mile/ truckload	$0.40/gal $80/cuyd landfill	$17,000 (1)

(1) Total includes other tasks

Table 42

PCB EXCAVATION EXPENDITURES

(1982 Dollars)

Source	Material	Quantity	Contaminant	Excavation Depth	Excavation /Removal	Trans. (Distance)	Disposal Treatment(1	Total
US EPA ELI/JRB 1982 N.Y.C.	OIL	163 tons	PCB (3)	surface tanks	Not Available	$248/ton (1,740 mi.)	$249/ton (2)	$498/ton
	pumpable sludge	240 tons	PCB (3)	surface tanks	Not Available	$240/ton (1,420 mi.)	$233/ton ton (2)	$473/ton
US EPA ELI/JRB 1981 Mass.	soil sludge	82 tons	PCB (3)	3-15 feet	%51/cuyd	$145/ton (513 miles)	$221/ton	$425/ton
US EPA ELI/JRB 1980 N.Y.C.	flyash/ oil, soil .	2,793 tons	PCB (3)	surface	Not Available	$86/ton (400 mi.)	$226/ton	$313/ton

(1) Landfilling unless otherwise noted (2) Incineration (3) 50-500 ppm

Table 42 (continued)

PCB EXCAVATION EXPENDITURES

(1982 Dollars)

Data Source	Material	Quantity	Contaminant	Excavation Depth	Excavation /Removal	Trans. (Distance)	Disposal/ Treatment	Total
US EPA ELI/JRB 1982 N.Y.C	solidified sludge	7 tons	PCB	surface tanks	not available	$238/ton (400 miles)		$238/ton

Muddy conditions at the Missouri Case Study site caused some delays in excavation work. However, at the US EPA, OERR cleanup in Florida, the pails were in a canal, which required that technicians retrieve them by boat, while in full level A protective gear.

Health and safety requirements and costs were rarelv documented and hence, their actual effects on costs are not accurately quantifiable. Since the relative effects of these requirements are potentially greater for excavation/removal than from other technologies, their approximate effect warrants brief recapitulation here.
Given the following level of personal protection:

1. Level A – requires full encapsulation and protection from any body contact or exposure to materials (i.e., toxic by inhalation and skin absorption).
2. Level B – requires self-contained breathing apparatus (SCBA), and cutaneous or percutaneous exposure to unprotected areas of the body (i.e., neck and back of head) is within acceptable exposure standards (i.e., below harmful concentrations).
3. Level C – hazardous constituents known; protection required for low level concentrations in air; exposure of unprotected body areas (i.e., head, face, and neck) is not harmful.
4. Level D – no identified hazard present, but conditions are monitored and minimal safety equipment is available.
5. No hazard – standard base construction costs.

Source: "Interim Standard Operating Safetv Guides," EPA 1982

The following levels of productivity have been assumed for other estimates:

Site Level	Productivity	Equipment
A	10% - 15%	50%
B	25% - 50%	60%
C	25% - 50%	75%
D	50% - 70%	--
E	70% - 100%	--

Source: CH_2 M Hill, Inc.

This productivity effect is already reflected in the expenditure data, but inadequate technical data was available to detail the protection levels for each site.

The loading costs for liquids were lower than for solid, 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 the New York City #1 and California #2 Case Study sites were quickly and continuously pumped into trucks or trains instead of by the bucket load as with contaminated soil and sludge. Drum handling was most efficiently performed with a hydraulic drum grappler at the Case Study Massachussetts #1 and New Jersey sites. 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 an economizing value.

Finally, waste quantity may have affected excavation costs through unquantifiable economies of scale. Larger sites such as the Maryland and California #1 Case Study sites 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 among the case study sites does not appear to be related.

Transportation -

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 43. The average cost for the twelve sites for which separate transportation costs were available was $0.17/ton/mile (SD = $0.04/ton/mile).

TABLE 43. TRANSPORTATION EXPENDITURES

Data Source (1)	Unit Weight Cost (divided by)	Distance =	Unit Distance Cost
ELI/JRB-Massachussetts #1	$135/ton	513 miles	$0.26/ton/mile
ELI/JRB-New Jersey	$ 57/ton	440 miles	$0.13/ton/mile
ELI/JRB-Massachussetts #2	$ 72/ton	480 miles	$0.15/ton/mile
ELI/JRB-Missouri	$ 24/ton	170 miles	$0.14/ton/mile
ELI/JRB-Connecticut	$ 67/ton	497 miles	$0.13/ton/mile
ELI/JRB-N.Y. City #1	$ 90/ton	818 miles	$0.11/ton/mile
ELI/JRB-Minnesota	$ 34/ton	140 miles	$0.24/ton/mile
ELI/JRB-N.Y. City #1	$250/ton	1,740 miles	$0.14/ton/mile
ELI/JRB-N.Y. City #1	$242/ton	1,420 miles	$0.17/ton/mile
ELI/JRB-N.Y. City #2	$ 94/ton	400 miles	$0.19/ton/mile
EPA,OERR-Florida	$ 68/ton	400 miles (2)	$0.10/ton/mile
EPA,OERR-Arizona	$ 38/ton	400 miles (2,3)	$0.17/ton/mile

(1) assume 1 cuyd = 1 ton unless specified other wise by contractor or hauler.

(2) assumed; actual distance unknown

(3) 15 cu yd/3,000 gallon truckload assumed

The accessibility of the site to major roads was found to affect transportation costs at the California Case Study site #1. 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.

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 silicon foam or asphalt sealing necessary on dump truck tailgates. Relative costs of transporting roll off dumpsters was not distinguishable. The cost of transportation was also affected by the waste quantity by influencing 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 sites New York City #1 and California #2 Case Study sites. Rail tankers, which carried several times as much as trucks, provided the lowest unit transportation cost, as shown by the New York City #1 Case Study site. 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) tractor-trailer dump truck was generally used.

Disposal/treatment -

The most significant factor affecting disposal costs was whether the wastes were PCB contaminated. The disposal of cost for PCB waste was roughly double the disposal cost for non-PCB RCRA hazardous waste. Among the PCB wastes, waste oil with over 500 mg/1 PCB at the New York City Case Study Site #1 was disposed of separately from PCB oil with between 50-500 mg/1. The disposal cost alone was the same for waste oil above and below 500 mg/1, but the required separate handling affected other costs because of economies of scale. Liquids from this site 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 Table 41. Liquid wastes that were solidified prior to landfilling, such as the ELI/JRB Missouri

case study site, cost more perexcavated weight because the weight and bulk increased due to the added solidification material such as sawdust or lime. Aqueous wastes such as those at Case Study California site #2 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 Case Study Minnessota site when community opposition blocked five initial proposals, which required a more expensive disposal option to be used. At the Case Study New York City site #1 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" (CH_2 M Hill, 1982). Pre-1981 costs were significantly lower than the post-1981 costs. This may have been primarily due to the anticipated RCRA landfill regulations, and secondarily to inflation.

6.1.4.2 Estimates

The following factors affected the cost estimates for excavation/removal, transportation, transportation and disposal/treatment:

- o Excavation:
  - depth
  - method
- o Transportation:
  - distance
  - contractor
- o Disposal:
  - Method

Generally, the factors affecting estimates (Table 44) were similar to those the affecting the expenditures, which was of significantly less technical detail was available for the estimates scenarios.

Excavation –

Excavation cost estimates seemed to reflect primarily varying depths. The SCS "impoundment" estimate and the New Jersey RI/FS assumed that a frontloader would be adequate to scrape up the contaminated soil and topsoil, respectively. In the analgous estimates scenarios, however, the need for a shovel excavator to dig deeper caused

Table 44

EXCAVATION COST ESTIMATES

(1982 Dollars)

Data Source	Material	Quantity	Contaminant	Excavation Depth	Excavation /Removal	Trans. (Distance)	Disposal/ Treatment(1)	Total
US EPA JRB-RAM 1980	sediments	10 cuyd	not given	not given	$1.77/cuyd	$94.40/cuyd (200 miles)	$283.20/ cuyd	$379.37/ cuyd
SCS "impound." 1980	soil, sludge	4,368 (2) cuyd	"hazardous"	not given	$0.85-1.27/ cuyd $44.84-67.26	$1.67-4.39/ ton (20 miles)	$214.17/ ton	$216.69-219.23/ ton (2)
SCS "landfill" 1980	soil	780,000 cuyd	"hazardous"	not given	$3.42-4.09/cuyd	$5.27-11.96 cuyd (20 miles)	$214.17/ ton	$222.87-230.23/ ton
US EPA CH2MHill 1983 New Jersey	topsoil fill.	100 cuyd 51,876 cuyd	none; solvents, Hg, Be	not given	$2.49/cuyd $1.18/cuyd	not given	not given	--

(1) Landfilled

(2) SCS assumes one cuyd = 1.89 tons

Table 44 (continued)

'EXCAVATION COST ESTIMATES

(1982 Dollars)

Data Source	Material	Quantity	Contaminant	Excavation Depth	Excavation /Removal	Trans. (Distance)	Disposal/ Treatment(1	Total
US EPA/ NJ DEP Dames & Moore 1982 N.J.	soil, sediment	not available	solvents	not available	not available	$17.50/ton .32/ton/mi. (55 miles)	$12-20/ cuyd; sanitary landfill	---
US EPA/ NJ DEP Dames& Moore 1982 N.Jersey	soil, sediment	not available	solvents	not available	not available	$17.50/ton (100 miles)	$30-50/ ton/mi. interme-diate landfill	---
US EPA/ NJ DEP Dames & Moore 1982	soil, sediment	not available	solvents	not available	not available	$70/ton (400 miles)	$60-80/ cuyd engineered landfill	---
US EPA SCS 1983	not given	not given	not given	not given	not given	$52-76 $0.13-19/ cuyd (2) (see text)	not given	---

(2) Assumption: 20 tons/truckload, 400 miles

higher estimates. In all cases the excavation cost estimates were about an order of magnitude lower than the expenditures given above. The reason for this difference may be that excavation of hazardous material does not simply add costs to the estimate for additional tasks such as health and safety protection requirements. But, rather it necessarily affects all tasks involved in excavation such as reduced labor productivity while to of encumberances from protective gear and delays due to waiting for analyses. Standard Construction-Engineering manual estimates (see examples Table 45) fail to consider adequately the effect of these factors.

TABLE 45.

ESTIMATES FROM ENGINEERING CONSTRUCTION MANUALS

Item	Design Basis:	Cost
Excavation with dragline	3/4 yd bucket, 90 swing, rating 33 yd/hr	$2.47/cuyd
	1.5 yd bucket, 90 swing, rating 65 yd/hr	$1.76/cuyd
Excavation with backhoe	Hydraulic, crawler mounted 1 yd bucket, rating 45 yd/hr	$2.17/cuyd
	1.5 yd bucket, rating 60 yd/hr	$1.96/cuyd
	2 yd bucket, rating 75 yd/hr	$1.93/cuyd
	3.5 yd bucket, rating 150 yd/hr	$1.48/cuyd
	Wheel Mounted 0.5 yd bucket, rating 20 yd/hr	$3.95/cuyd
	0.75 yd bucket, rating 30 yd/hr	$2.92/cuyd
Excavation with clamshell	0.5 yd bucket, rating 20 yd/hr	$4.34/cuyd
	1 yd bucket, rating 35 yd/hr	$2.93/cuyd

Source: Radian, Inc., 1983

Transportation -

The transportation cost estimates ranged from $1.42 - 94/ton as shown in Table 46. The distance strongly affected the cost of transportation for a ton of waste. The cost estimates per ton per mile are given in Table 46. They ranged from $0.07 - 0.51/ton/mile. The mean was $0.25/ton/mile (SE=$0.04/ton/mile, n=10), which was almost twice the average expenditures found for transportation. However, the distances assumed for the estimates were significantly lower (3.6 times) than those found to be necessary for actual sites. (average distance found for transportation expenditures = 618 miles, SD=485 miles; average distance assumtion given for transportation estimates = 168 miles, SE=65, n = 7).

TABLE 46. TRANSPORTATION COST ESTIMATES

Data Source	Unit Weight Cost	(divided by)	Distance	=	Unit Weight Distance Cost
JRB-RAM	$94/ton		200 miles		$0.47/ton/mile
SCS "impoundment"	$1.42-3.27/ton		20 miles		$0.07-0.19/ton/mile
SCS "landfill"	$4.47-10.14/ton		20 miles		$0.22-0.51/ton/mile
New Jersey # 2 RI/FS #2	$17.50/ton		35 miles		$0.32/ton/mile
New Jersey RI/FS #2	$17.50/ton		100 miles		$0.18/ton/mile
New Jersey RI/FS #2	$70/ton		400 miles		$0.18/ton/mile
SCS 1983	$52-76/ton		400 miles(1)		$0.13-0.19/ton/mile

(1) Assumed: 400 miles, see text.

The hauling cost estimates were also found to depend on the type of transporter as shown Table 47. These specific costs are not necessarily representative but do show a pattern of relative costs.

TABLE 47

AVERAGE TRANSPORTATION COSTS BY TYPE OF TRANSPORTER

Type of Transporter	Unit distance cost/"truckload"	Unit weight distance cost (1)
Treatment, Storage, and Disposal Facilities Providing Service to Customers	$2.67/mile ($1.66/km)	$0.13/ton/mile ($0.09/Mt/km)
General Freight Transportation Companies Which May Haul Hazardous Waste on Request	$3.60/mile ($2.24/km)	$0.18/ton/mile ($0.12/Mt/km)
Hazardous Waste Transportation Companies Specializing in Hazardous Waste	$3.70/mile ($2.30/km)	$0.19/ton/mile ($0.13/Km)

Source: SCS Engineers, 1983.
(1) Assume 20 tons (18 Mt)/truckload

Disposal/Treatment

The most salient factors affecting disposal cost estimates was the method used in the disposal cost estimates from the RI/FS from the New Jersey site shown a doubling of disposal cost for each increase in landfill security. However, since hazardous waste cannot be safely or legally disposed of in a sanitary landfill, this cost is inappropriate to compare with other estimates for engineered landfills. Also, the other estimates are significantly higher than the actual costs found. Table 48 shows price quotes from a sample of disposal/treatment firms.

Expenditure Sources

- ELI/JRB Case Studies, 1983
- State and Federal Superfund work

Estimates Sources

- JRB – RAM, 1980
- Radian, 1983
- US EPA OERR contractor Feasibility Studies
- SCS 1980

Table 48

AVERAGES OF HAZARDOUS WASTE MANAGEMENT QUOTED PRICES FOR ALL FIRMS IN 1980 AND FOR NINE MAJOR FIRMS IN 1981* (in 1982 Dollars)

TYPE OF WASTE MANAGEMENT	TYPE OF FORM OF WASTE	UNIT COST 1980	UNIT COST 1981
INCINERATION	clean liquids high BTU value	$0.65/gal $131/cuyd	$0.13/gal (1) $26/cuyd
	liquids		$0.59/gal $119.90/cuyd
	solids; heavy toxic liquids	$2.12/gal $429.50/cuyd	$2.43/gal $490/cuyd
CHEMICAL TREATMENT	acids/ alkalines	$0.21/gal $42.50/cuyd	$0.24/gal $47.50/cuyd
	cyanides, heavy metals (2)	$1.30/gal $262/cuyd	$1.76/gal $355/cuyd
DEEP WELL INJECTION	oily waste water	$0.13/gal $26/cuyd	
	toxic waste water	$0.88/gal $179/cuyd	
LANDFILL	Drum	$35.40/55 gal. drum	$45.90/55 gal. drum
	Bulk	$53/ton	$67.50/ton
LAND TREATMENT	All	$0.07/gal $14/cuyd	

(1) Some cement kilns and light aggregate manufacturers are now paying for waste

(2) Highly toxic waste

Source: U.S. Environmental Protection Agency. "Review of Activities of Major Firms in the Commercial Hazardous Waste Management Industry: 1981 Update". SW-894.1. May 1982.

6.2 HYDRAULIC DREDGING

6.2.1 Definition

Hydraulic dredges are used to remove liquid, slurry, or semi-solid (sludge) wastes from improperly constructed or improperly sited disposal sites. Once removed, the wastes can be pumped to treatment and dewatering facilities, or transported to acceptable nearby land disposal sites.

6.2.2 Units of Measurement

Costs are given in dollars per cubic yard because it provides a useful standard measurement that is comparable to excavation.

6.2.3 Summary Statistics

6.2.3.1 Expenditure

No expenditure data are available at this time.

6.2.3.2 Estimates

The hydraulic dredging cost estimates ranged from:

$3.54/yd^3	Contractor dredging only
to	
$1.25/yd^3	Includes related fixed costs: sheet piling, silt curtain, coffer dam etc.

The lowest cost estimate includes only contractor prices for the dredging and pumping phases of the operation.

6.2.4 Factors Found to Affect Costs

6.2.4.1 Expenditures

No data was available at this time.

6.2.4.2 Estimates

- Equipment type
- Pumping system capacity
- Sludge density
- Transportation of slurry
- Inclusion of related costs

The most important factor affecting costs was the inclusion of related tasks. The Feasibility Study for the Illinois site included a variety of necessarily related tasks that are listed in Table 49. These tasks accounted for $119 cuyd of the total $125/cu.yd. unit price (see Table 50). Assuming similar included costs, other site specific and equipped factors also affect costs.

The equipment assumptions varied with the site condition scenario. Land based, floating and barge-mounted hydraulic dredges represent increasing costs for varying depths and waterway sizes. The JRB-RAM and Radian estimates did not specify the dredger type, but the Illinois feasibility study assumed a barge-mounted dredger.

TABLE 49.

ADDITIONAL RELATED COST ITEMS ESTIMATED FOR HYDRAULIC DREDGING-
EPA OERR, CH_2 M HILL, ILLINOIS, 1983.

Task/Cost Item	Quantity	Unit Cost	Total
Pipeline to lagoon	1,200 LF	$11.97/LF	$14,364
Sheet pile caisson - double ring-13400 SF PS 27	181 tons	$23.36/ton	$422,816
Remove sheet - pile cofferdam	181 tons	$11.68/ton	$211,408
Replace existing piles & floating docks	690 LF	$195/LF	$134,550
New boat hoisting facility	1LS	$15,000	$15,000
Sediment control - 2 x silt curtain	600 LF	$ 95/LF	$ 57,000
			$855,138

$855,138/7,200 cuyd = $119/cuyd related costs + hydraulic dredging ($6.12/cuyd) = $125/cuyd

Table 50

HYDRAULIC DREDGING COST ESTIMATES

(1982 Dollars)

Data Source	Quantity/design	Contaminant	Pumping Distance	Cost
US EPA JRB-RAM 1980	694/yd^3/day suction or cutter head	Not specified	1,000 ft	\$3.54 - 5.90/yd^3
EPA - OERR CH_2 M Hill Feasibility Study Illinois	925/yd^3/day	PCB contaminated sludge	900 ft	\$6.12/yd^3 (excludes significant fixed and related costs)
US EPA Radian 1983	Not specified	Not specified	1,000 ft	\$4-8/yd^3

The system capacity likely affected unit costs through economies of scale. Inadequate data were available to quantify or confirm this effect.

The sludge density affects unit costs because, after dewatering, low density sludge may yield less contaminated sediment volume than a higher density sludge. This effect must be considered in light of the higher suction rate possible with a lower density sludge, however.

Sludge transportation variations affected costs, since the JRB-RAM and Radian scenarios assumed that only piping would be necessary; whereas the Illinois feasibility study assumed the need for a barge-mounted hopper as well as a pipeline.

Estimated Sources

- JRB-RAM, 1980
- Radian, 1983
- US EPA, OERR contractor Feasibility Studies

6.3 MECHANICAL DREDGING

6.3.1 Definition

Mechanical dredging with draglines, clamsheels, or backhoes is used to remove contaminated sediments from shallow streams, rivers, lakes, and other basins of water. The stream is usually diverted with temporary cofferdams; the sediments are dewatered, excavated, then loaded onto haul vehicles for transport to a disposal site.

6.3.2 Units of Measurement

Costs are given in dollars per cubic yard because it provides a useful standard measurement that is comparable to excavation.

6.3.3 Summary Statistics

6.3.3.1 Expenditures

No expenditure data are available at this time.

6.3.3.2 Estimates

Mechanical dredging cost estimates ranged from

$1.37
to
4.09/yd^3

The range reflects varying equipment assumptions derived from a single estimate source. The low end involves a simple backhoe, while the high end a clam shell. Mobilization and demobilization costs for the backhoe added $1.50. Hauling and disposal costs of the dredge material was not included (see excavation, transportation and disposal).

6.3.4 Factors Found to Affect Costs

6.3.4.1 Expenditures

No expenditure data are available at this time.

6.3.4.2 Estimates

The following factors appeared to affect the cost estimates from mechanical dredging:

- o Equipment
  - Use of Barge
  - Excavation method (backhoe, clam shell, or dragline)
- o Site condition
  - Depth of sediment
  - Water table

Additional costs: Barge
Sheet piling (pile driver)

Since mechanical dredging is most suited to dredging shallow water, the cost will rise in proportion to the depth of the water and the size of the dredging surface. The use of a barge would double or triple the unit cost for mechanical dredging; hence, the accessibility of the sediments has a significant effect on costs. Also, wet excavation may require sheetpiling or a cofferdam to support the dredging.

Table 51 shows the estimated cost for these additional tasks and the pile driver is shown to be significant.

The basic dredging equipment costs varied with the scenario (see Table 52). Dredging using a hydraulic backhoe (1–3.5 cuyd bucket) the lowest cost scenario, was $1.37–2.10/cuyd. Intermediately, a dredging operation with a 0.75–1.5 cuyd dragline was estimated at $1.64–2.43/cuyd. The highest cost scenario was estimated with a 0.5–1 cuyd clamshell at $2.74–4.09/cuyd.

TABLE 51

ADDITIONAL COSTS TO BASIC MECHANICAL DREDGING

Barge-mounted dragline or clamshell, hopper dumped, pumped 1000' to shore dump		$5.31-7.67/yd^3$
Sheet piling, steel, high strength (55,000 psi); temporary installation (pull and salvage):	20' deep 25' deep	$9.72/ft^2$ $7.82/ft^2$
Pile driver; mobilize and demobilize:	50 mile radius 100 mile radius	$ 6,726 total $11,151 total

Source: EPA, Manual for Remedial Actions at Waste Disposal Sites

625/6-82-006

Estimate Source

o JRB-RAM, 1980

Ta 52

MECHANICAL DREDGING COST ESTIMATES

(1982 Dollars)

Source	Volume	Contaminant	Site Dimension	Unit Cost
US EPA JRB-RAM 1980	10 yd^3	unspecified	7.5 feet x 30 feet stream bed	\$1.37 - 4.09/yd^3

6.4 DRUM REMOVAL, TRANSPORTATION AND DISPOSAL/TREATMENT

6.4.1 Definition

Drum handling includes excavation in cases where the drums (bucket, pails, containers etc.) were buried; or, simply staging, overpacking and loading for transport. Transportation involves hauling loaded material to an off-site disposal treatment facility. Disposal/treatment may include landfilling and/or other technologies such as neutralization, solidification or treatment. These are combined here because the cost for all three tasks are often combined into a unit price.

6.4.2 Units of Measurement

Costs are usually given in terms of dollars per drum (bucket, pail, containers, etc.) for comparison purposes. However, these costs may include other component tasks such as overpacking and adjacent contaminated soil, as noted.

6.4.3 Summary Statistics

6.4.3.1 Expenditures

The following ranges of expenditures were found from drum removal, transportation and disposal/treatment:

Drum removal:	$60–1,168/drum
Transportation:	$15–261/drum (30–480 miles)
Disposal/treatment:	$36–360/drum

These cost elements cannot necessarily be summed, since the extremes of the ranges are derived from different sources with different scenarios and assumptions.

Site Total: $60–1,528/drum

Some of the costs for the above three tasks may have been combined in the new data. For the removal costs, the high expenditures may reflect the use of overpacking and containerization. Transportation cost of a drum likely varied with distance, but distance information was rarely available. Some of the disposal costs given also include contaminated soil disposal expenditures for bulk soil disposal. Operation and maintenance costs may include groundwater monitoring and, possibly, site inspections or security to prevent future illegal dumping, which is often repeated at former sites. These costs were either accounted for separately, or were not encountered for the sites.

6.4.3.2 Estimates

No handling cost estimates data are available at this time.

6.4.4 Factors Found to Affect Costs

6.4.4.1 Expenditures

The following factors were found to affect drum removal expenditures given in Table 53 in the Raw Data section.

Removal -	Waste type Drum condition Drum size Drum situation, depth Adjacent soil contaminant Demurrage Economies of scale
Transportation -	Distance
Disposal -	Waste type

Removal - The waste types found at the Michigan, California #2, Florida, Vermont and Philadelphia sites seemed to have had a significant effect on the removal costs. In all cases, the cyanide, caustic soda, ethyl ether (highly flammable), aromatic hydrocarbons and super tropical bleach (calcium oxide-chlorinated lime), required that Level A or B protective gear, treatment (solidification or neutralization) and recontainerization be added to the removal costs. In addition, careful management of these more hazardous waste generally increased the time necessary for the various elements of the operation such as labor and equipment. In adequate technical detail was available, however, to quantify its effect.

Poor drum condition increased removal costs because it necessitated overpacking. In cases where waste had leaked out increased costs were incurred for transferring the waste and emptying and crushing the drums. A variety of drum sizes are given in Table 16. Overpacking 30 and 55 gallon drums required 55 and 80 and gallon overpacks at increased costs.

Most drums were removed from the surface. The drum removals requiring excavation did not cost significantly more than the surface drums suggesting that the added costs of backhoes and drum grapplers were less significant than other cost items such as treatment or protective gear necessary for high risk waste. Also, a drum of an unidentified liquid floating in a Los Angeles. California river required additional costs for a boat, but was not significantly more expensive than other surface removal.

The extent of adjacent soil contamination varied among the sites given. In some cases the total cost included removal of bulk soil, but the unit cost is derived by dividing only this total by the intact or overpacked drums. Hence, the removal cost per drum may be an overestimate in some cases. For the ELI-JRB sites in New Jersey, Connecticut, and Massachusetts, the drums were emptied, crushed and bulked along with contaminated soil necessitating a bulk volume unit cost. More analysis of technical details is necessary to reaggregate these costs.

Based on two observations the economies of scale appeared to affect the unit costs of removal. First, there was a general inverse relationship between the total site costs and the unit cost per drum. Second, certain minimum costs were charged for component tasks such as mobilization of technicians and equipment. M minimum charges also apply to transportation as noted in the discussion of Excavation cost factors in the previous section. However, the Michigan site cost for transportation ($2/truck/mile; $60 one truck, 30 miles) was lower than many minimum hauling charges.

Transportation - Inadequate information was available to compare cost per mile of transportation, but the effect of distance, as well as the rates can be expected to be similar to those found in the above Excavation section. Demurrage was not found to significantly affect the costs since it was explicitly charged only at the Philadelphia site ($50 out of $1,410-4%).

Disposal - Although the reasons for the widely varying disposal costs were unclear because of inadequate technical detail availability, they parallel these given in the material removal section.

6.4.4.2 Estimates

No cost estimate data are available at this time.

Expenditure Sources

- o ELI/JRB Case Studies, 1983
- o State and Federal Superfund work

Table 53

DRUM HANDLING EXPENDITURES

(1982 Dollars)

Source	Material	Quantity	Contaminant	Excavation Depth	Excavation /Removal	Tans. (Distance)	Disposal/ Treatment	Total
US EPA OERR Date unknown Phila.	solid	0.6 cuyd.	caustic soda	surface	$400/drum $1,468/ cuyd (2,4)	$230/drum	$75/drum	$1,410 (1)
US EPA OERR Date unknown Calif. #1	liquid	one 55 gal. drum	unidentified	surface	$686/drum (5)	not available		$686/ drum
RI DEM US EPA 1981 Rhode Island	drums soil	4,500 unknown	solvents	average 20 feet (3-35 feet)	$363/ drum	$ 106/drum		$469/ drum
US EPA OERR Date unknown Florida	one, 30 gal. pail	0.15 cuyd	Calcium-	surface	$129/drum	$10.20/mile	$300/drum	$453 (1)

(1)Total cost may include other tasks
(2)Overpacking
(3) 50-500 ppm; minor component
(4) drum = 0.27 cuyd
(5) cost may include transportation and disposal

Table 53 (continued)

DRUM HANDLING EXPENDITURES

(1982 Dollars)

Data Source	Material	Quantity	Contaminant	Excavation Depth	Excavation /Removal	Trans. (Distance)	Disposal/ Treatment(1)	Total
US EPA OERR 1982 Florida	liquid; 5 gal. pails	18.7 cuyd; 757 pails	Ca oxide chlorinated lime	surface	$460/cuyd	$0.17/cuyd/mi (2 tucks) $68/cuyd (4)	$356/cuyd	$18,155 (2,4) $24/pail ($884/cuyd)
ELI/JRB 1981 New Jersey	drums, soil	5,101 cuyd	solvents metals	15-20 feet	$34-69/ cuyd	$57/cuyd (440 miles)	$40/ton	
ELI/JRB Conn. 1978	drums soil	4,770 cuyd	solvents metals	3-13 feet	$11/cuyd	$67/ton (494 mi.)	$40/ton	$119/ton
ELI/JRB Massach. 1978	drums	481 cuyd (3)	solvents	surface	Not Available	$71/cuyd (480 miles)	$84/ton	--

(1) Landfilled unless otherwise noted
(2) Total cost may include other tasks
(3) 615 cuyd disposed; cuyd: ton ratio used by contractor = 1:1.3; 276 cuyd aerated on-site
(4) If 400 miles assumed

7.1.4 Factor Found to Affect Cost

7.1.4.1 Expenditures

No actual cost data available at this time.

7.1.4.2 Estimation

The following factors affected sewer line replacement cost estimates:

- o Pipe size
- o Pipe composition
- o Depth of excavation

Pipe size and depth seemed to be most directly related to the cost of sewer line replacement costs. The cost of excavation, which is a major component of sewer line replacement, was affected by the depth and size of the pipe. The cost of the new pipe, which is the major material cost factor, was largely a function of the pipe size and composition. Since reinforced concrete pipe was assumed for both estimates, cost estimates vary mostly with size.

<u>Estimates Sources</u>

- o JRB-RAM, 1980
- o Radian, 1983

Table 54

SEWER LINE REPLACEMENT COST ESTIMATES

(1982 Dollars)

Data Source	Design	Pipe Type	Pipe Dia.	Unit Cost
US EPA JRB - RAM 1980	Inspection, excavation section removal, pipe and bedding replacement backfill and compaction	reinforced concrete	36 inch 42 inch 48 inch 54 inch 60 inch	$55.46/LF $68.44/LF $87.32/LF $107.38/LF $141.60/LF
US EPA Radian 198[illegible]	Inspection, excavation section removal, pipe and bedding replacement,backfill and compaction	reinforced concrete	36 inch 42 inch 48 inch 54 inch 60 inch	$53.90/ LF $66.60/ LF $85/LF $104.50/LF $137.90/LF

7.2 SEWER LINE REPAIR

7.2.1 Definition

Sewer lines contaminated by migrating leachate may be reconditioned in place if pipe damage is limited. The procedure includes interior inspection, cleaning (mechanical, hydraulic or chemical means) and repair of damaged sections. The upgradient source of contamination is assumed to have been removed or encapsulated for the purpose of this section.

7.2.2 Units of Measurement

Costs are given in dollars per linear foot (LF) because it provides a simple and standardized measure of sewer lines.

7.2.3 Summary Statistics

7.2.3.1 Expenditures

The only expenditure for cleaning and flushing contaminated sewer lines was:

$15/LF.

The cost per foot for cleaning sewer lines was the same for all piping sizes, which ranged in diameter from 10–21 inches. No cost comparison was possible since only one actual expenditures was.

7.2.3.2 Estimates

Sewer Line recondition cost estimates for 12 – inch diameter pipe ranged from:

$5.75
to
$15.30/LF

Cost estimates for repair included cleaning, interior inspection and internal grouting repairs for 12 inch diameter pipe in average condition. Higher estimates were expected for larger diameters and/or more extensive grouting. Disposal costs of removed contaminated material were not included in these estimates.

7.2.4 Factors Found to Affect Cost

7.2.4.1 Expenditures

The paucity of expenditure data precludes quantification of component costs and the factors affecting total unit costs (see Table 55).

7.2.4.2 Estimates

The following factors affected cost estimates for sewer line reconditioning (see Table 56):

- o Diameter of piping
- o Extent of damage

Although the paucity of data hinders quantification of the cost factors, the above two factors appeared to directly affect the level of effort required for repair, and hence, the cost. The extent of the damage was probably the primary factor affecting costs since it was directly related to the amount of repair that was required. The size of the pipe was less directly related to costs, but still affected the area to be repaired.

These costs of contaminant handling and disposal were not included in the estimates and must be considered as a site specific factor.

Estimates Sources

- o JRB - RAM, 1980
- o Radian, 1983

Table 55

SEWER LINE REPAIR EXPENDITURES

(1982 Dollars)

Data Source	Design	Total Length	Pipe Dia.	Unit Cost
US EPA CH_2 M Hill 1983 New York	Cleaning and Flushing	29,426 feet	10 - 21 inches	$15/LF

Table 56

SEWER LINE REPAIR COST ESTIMATES

(1982 Dollars)

Data Source	Design	Length	Pipe Dia.	Unit Cost
US EPA JRB - RAM 1980	Cleaning, T.V. inspection and grout repairs	not specified	12 inches	$5.90/LF (1)
US EPA Radian 1982	Cleaning, T.V. inspection and grout repairs	not specified	12 inches	$5.75/LF (1)

(1) Average Cost; cost will vary with pipe diameter and extent of grouting repairs.

7.3 WATER LINE REPAIR

7.3.1 Definition

Municipal water lines, contaminated by infiltration of contaminated groundwater, may be repaired and reconditioned if damage and potential health hazards are limited. Upon inspection and location of faulty sections, cleaning procedures, followed, in more complicated instances, by pipe relining, can rehabilitate an effected system. This work may be done in place, withour costly excavation.

7.3.2 Units of Measurement

Costs are given in dollars per linear foot (LF) because if provides a simple and standardized measure of water main lines.

7.3.3. Summary Statistics

7.3.3.1 Expenditures

No actual cost data was available at this time

7.3.3.2 Estimates

Cost estimates for water main repair ranged from:

$26/LF 8" diameter
to
$35.50/LF 24" diameter

Restoration of 24 inch diameter concrete pipe was in the same range as smaller diameter iron pipe. Included in the cost per linear foor estimate was provision for preliminary T.V. inspection.

7.3.4 Factors Found to Affect Costs

7.3.4.1 Expenditure

No actual cost data are available for water main repair.

7.3.4.2 Estimates

The following factors affected cost estimates for water main rapair:

- o Pipe size
- o Extent of damage and contamination
- o Accessibility

Pipe size was the primary factor which directly affected the cost estimates for repair (see Table 58). Site specific factors such as accessibility of damaged sections and degree of contamination and damage would directly affect costs, but the cost estimate data were inadequate to quantify these factors.

Estimates Sources

- o JRB-RAM, 1980
- o Radian, 1983

Table 57

WATER LINE REPAIR COST ESTIMATES

(1982 Dollars)

Data Source	Design	Line Type	Pipe Dia.	Unit Cost
US EPA JRB - RAM 1980	In-Place cleaning, and cement relining of pipes	ductile iron ductile iron concrete	8 inch 12 inch 24 inch	\$29.50/LF \$35.40/LF \$29.50/35.40/LF
US EPA Radian 1983	In-Place cleaning and cement relining of pipes	ductile iron ductile iron concrete	8 inch 12 inch 24 inch	\$28.75/LF \$34.50/LF \$28-34.50/LF

7.4 WATER MAIN REPLACEMENT

7.4.1 Definition

Water main replacement involves the excavation and removal of extensively damaged and contaminated water pipe sections and bedding, sleeving new sections with Polyethelene sheet and relaying them. This is followed by backfilling and compaction of the trench. Preliminary investigation by inspection and analysis is required prior to the replacement procedure.

7.4.2 Units of Measurement

Costs are given in dollars per linear foot (LF) because it provides a simple and standardize measure of water lines.

7.4.3 Summary Statistics

7.4.3.1 Expenditures

No actual cost data are available at this time.

7.4.3.2 Estimates

Water line replacement cost estimates ranged from:

$ 58.50/LF	8" diameter
to	
$119.18/LF	24" diameter

These estimates covered all basic pipe replacement costs including preliminary inspection procedures. Costs were generally proportional to pipe size.

7.4.4 Factor Found to Affect Cost

7.4.4.1 Expenditures

No actual cost data are available for water line replacement.

7.4.4.2 Estimation

The following factors affected water line replacement cost estimates (see Table 59):

- Pipe size
- Depth of excavation

Pipe size and depth seemed to be most directly related to the cost of water line replacement costs. The cost of excavation, which is a major component of water line replacement, was affected by the depth and size of the pipe. The cost of the new pipe, which is the major material cost factor, was largely a function of the pipe size. No significant cost difference between iron and concrete pipe was shown by the limited available data.

<u>Estimates Sources</u>

- JRB - RAM, 1980
- Radian, 1983

Table 58

WATER LINE REPLACEMENT COST ESTIMATES

(1982 Dollars)

Data Source	Design	Material	Size (Dia.)	Unit Cost
US EPA JRB - RAM 1980	Inspection, excavation, old line removal, Polyethylene sleeving, pipe laying, backfill, and compaction	Iron Iron Iron Concrete	8 inch 12 inch 16 inch 24 inch	$60.8/LF $71.98/LF $95.58/LF $119.18/LF
US EPA Radian 1983	Inspection, old line removal, Polyethylene sleeving, pipe laying, backfill, and compaction	Iron Iron Iron concrete	8 inch 12 inch 16 inch 24 inch	$58.50 /LF $70.00/ LF $93.00/ LF $116,00/LF

8.0 ALTERNATIVE WATER SUPPLIES

8.1 NEW WATER SUPPLY WELLS

8.1.1 Definition

New water wells usually involve drilled rather than driven wells, and are cased with a pvc sleeve. The cost of providing and operating a pump, and the cost of storage tanks may also be included in the operation.

8.1.2 Units of Measurement

Costs are given in dollars per linear foot depth because it provides a standard unit for comparison within the water well industry.

8.1.3 Summary Data

8.1.3.1 Expenditures

No expenditure data was available at this time.

8.1.3.2 Estimates

The single cost estimate found for new well installation was:

Capital: $462/LF

Operation and
Maintenance: $265/year

The capital cost estimate covers labor, equipment and materials. However, preliminary geologic investigation costs required for well siting were not included. The operation and maintenance figure has been calculated for a well 200 feet deep.

8.1.4 Factors Found to Affect Costs:

8.1.4.1 Expenditures

No data was available at this time.

8.1.4.2 Estimates

Due to the limitations of well cost estimation data (see Table 59), no comparison of cost factors can be made. As noted above, however, well depth and diameter as well as hydrogeologic site conditions are general determinants in total costs for well installation.

Estimates Sources

US EPA, OERR contractor Feasibility Studies.

Table 59

NEW WELL COST ESTIMATES

(1982 Dollars)

Data Source	Design	Depth	Operation & Maintenance	Capital
US EPA Radian 1973 (1978 dollars)	4 inch diameter pvc casing submersible pump 5gpm	200 feet	$265/year	$46.25/LF ($9,250 Total)

8.2 WATER DISTRIBUTION SYSTEM

8.2.1 Definition:

Water distribution systems consist of network of pressurized pipes connecting individual households with existing water sources such as mains or reservoirs and municipal hydrants to a common water source. For this section no source costs for wells or reservoirs are assumed, only connection costs are given.

8.2.2 Units of Measurement

Costs are given in dollars per household connected as this is a common factor in the available data and allows an approximation of the numbers of people sewed by a new water system.

8.2.3 Summary Data

8.2.3.1 Expenditures

The range of expenditures was:

$1,091/household

to

$10,714/household

The costs components of the higher expenditure include fire hydrants and all appurtenances; while the lower cost system did not include these costs. operation and maintenance costs, which may be significant, were not available.

8.2.3.2 Estimates

No estimates data are available at this time.

8.2.4 Factors Found to Affect Costs

8.2.4.1 Expenditures

The following factors were found to affect the costs of new water distribution systems (see Table 60):

- Size (pipe length/diameter)
- Inclusion of related costs

The inclusion of related costs was probably the most important factor that affected costs. The higher cost system included design work and fire hydrants along all streets connected. The lower cost system included only the basic domestic water supply connection construction costs. The two systems shown vary somewhat in size, in terms of both length and diameter. The lower cost Minnesota system connected houses that were closer together than the California system. Also the California system was built to allow for connection of more houses in the future, by using oversized mains that exceeded present system needs. Operation and maintenance costs, which may be significant, are not included. Also excluded is the fee usually charged by a municipality for a connection.

8.2.4.2 Estimates

No estimates data are available at this time.

Table 60

WATER DISTRIBUTION COST ESTIMATES

(1982 Dollars)

Data Source	Design	Units served	Total Cost	Unit Cost
US EPA ELI/JRB 1979 Minnesota	domestic water distribution system	11 houses	$12,000	$1,091/house
US EPA ELI/JRB 1982 California	Includes construction, services, fire hydrants	28 houses fire hydrant system	$200,000 $300,000	$7,143-10,714/house

ANNOTATED REFERENCES

CH_2 M Hill, December 1982. "Draft Engineering Services Report/Quanta Resources Clean-up" Reston, Va. For New York City Department of Environmental Protection. Invoices and daily logs were used to assemble actual removal expenditures.

ELI/JRB Environmental Law Institute, Washington, D.C. and JRB Associates, McLean, Va. Case Studies of Remedial Responses at Hazardous Waste Sites. 1983. Invoices, corresponddence, reports and vouchers were used as part of this compilation of 23 case studies around the U.S.

JRB - RAM, 1980. These cost estimates were drawn from the "Manual for Remedial Actions at Hazardous Disposal Sites" Draft final report by JRB Associates, McLean, Va. June 20, 1980. This manual was subsequently published by U.S. EPA as the "Manual for Remedial Actions at Hazardous Wastes Sites." EPA 625/6-82-006. Cincinnati, Ohio, 1982, and again by Noyes Publishing Company, Englewood Cliffs, New Jersey, 1983. The initial draft final report was used because it contained the greatest cost detail. These estimates were drawn principally from construction estimation manuals such as (1) the Means Manual (Godfrey, R.R. (Ed.), 1980, Building Construction Cost Data 1980, 38th Annual Edition, R.S. Means Company, Inc.; (2) Dodge Manual (McMahon, L.; Pereira, P. (Ed.) 1979. 1980 Dodge Guide to Public Works and Heavy Construction Costs. McGraw-Hill Information Systems Co., New York, N.Y.; (3) Richardson Rapid Construction Cost Estimating System (Richardson Engineering Services, 1980); and supplemented with a large number of price quotes drawn directly from industry and commercial sources. Hypothetical site scenarios are given for many of the technologies.

Radian, 1983. These estimates are drawn from the last section of "Evaluating Cost-effectiveness of Remedial Actions at Uncontrolled Hazardous Waste Sites" - Draft Methodology Manual by the Radian Corporation, Austin, Texas, January 10, 1983. These estimates were indexed to constant dollars for March 1982. Many of the estimates were derived from EPA's "Handbook for Remedial Action at Hazardous Waste Sites." EPA 625/6-82-006. Cincinnati, Ohio, 1982. This source

was always supplemented or supplanted by many other estimation sources, including specialized papers for specific technologies, and general construction estimating manuals.

SCS (Engineers), 1980. These cost estimates came from "Costs of Remedial Response Action at Uncontrolled Hazardous Waste Sites" by SCS Engineers, Long Beach California, April 1981. According to this methodology: "For the most part the 1980 Means (Godfrey, R. (Ed.) 1979. Building construction cost data: 1980. Robert Snow Means Company, Inc. Kingston, MA. and Dodge Guides McMahon, L., Pereira, P. (Ed.) 1979. 1980 Dodge Guide to Public Works and Heavy Construction Costs.; McGraw-Hill Information Systems Co. New York, N.Y. were used to obtain the costs needed."

SCS (Engineers), 1981. These cost estimates are derived from Cost Comparison of Treatment and Disposal Alternatives for Hazardous Materials (EPA - 600/52-80-188) published in February 1981 by the US EPA Municipal Environmental Research Laboratory. The estimate compilation was performed by SCS Engineers for a greater Chicago area scenario using the 1978 Means Construction Cost Manual. Hence, mid-1978 costs were originally estimated. For comparison purposes these cost estimates were converted from simple average costs, and the raw data on capital and operation and maintenance costs were used in stead.

US EPA, OERR contractor Bids. Losing bids for Superfund work are used here as estimated costs since they did not serve as the basis for actual construction. However, these estimates reflects a higher level of detail than many other estimates since specific local capabilities are considered. Most of the cost estimates are from 1982 and 1983 estimates.

US EPA, OERR contractor Feasibility Studies. Cost estimates from feasibility studies are generally drawn from non-bid estimates from contractors. Most of these cost estimates are from 1982 and 1983.

US EPA, OERR State and Federal Superfund Work. Records from initial Superfund work, such as bid and change order reports, and spread sheet printouts. All sites are numbered for anonymity, but state locations are given because of its relevance to cost factors such as labor and materials, and site characteristics such as climate.