DOCKET REPORT

SUPPORTING DOCUMENTS FOR THE REGULATORY ANALYSIS OF THE PART 264 LAND DISPOSAL REGULATIONS

Volume II

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DOCKET REPORT

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APPENDIX A

IX. Regulatory Analysis

A. Executive Order 12291: Regulatory Impact Analysis

Executive Order 12291 requires each Federal agency, "to the extent permitted by law," to prepare and consider a Regulatory Impact Analysis (RIA) in connection with every major rule. The order further requires that a final RIA be transmitted to the Office of Management and Budget (OMB) at least 30 days before the Agency publishes the major rule. EPA has determined that the land disposal regulation promulgated today is a major rule. However, EPA has concluded that the existing facility portion of this rule is exempt from the requirement that a final RIA be submitted to OMB 30 days prior to promulgation. Section 8 of the Executive Order, Exemptions, states that the "procedures prescribed by this Order shall not apply to: ...(2) Any regulation for which consideration or reconsideration under the terms of this order would conflict with deadlines imposed by statute or by judicial order."

Completing an RIA and transmitting it to OMB 30 days before EPA publishes these regulations for existing facilities would conflict with judicial deadlines. A court order in State of Illinois v. Gorsuch (D.D.C., Civil Action No. 78-1689), signed on November 13, 1981, directed EPA to promulgate regulations for existing hazardous waste land disposal facilities on or before February 1, 1982. Although the order was temporarily stayed, the appeals court has now ordered that these regulations be promulgated by July 15, 1982. If EPA were to delay promulgation until completing the RIA and transmitting it to OMB, it would violate the deadline ordered by the Court. Therefore, EPA is exempt from compliance.

D. Individual Unit Costs; E. Closure Analysis; F. Total Costs; G. Industry Analysis; and H. Sensitivity Analysis. The docket for this rulemaking and the EPA regional libraries contain a more extensive report on this analysis.

Although the Agency has not completed its formal benefits analysis for land disposal regulations, it expects these regulations to provide important benefits. First, they will promote economic efficiency. By internalizing the costs of waste management, the regulations promote the allocation of resources to the area of their highest social value through the free market pricing system. Second, they will promote equity. Currently, people living near hazardous waste facilities bear some of the cost of disposal in the form of risk of ground-water contamination and the damages that can result to property values and to health. These regulations will provide a uniform, nation-wide protective floor that requires the owners of hazardous waste facilities to take steps that will reduce the likelihood that populations will be exposed to harmful ground-water contamination. They will thus shift some of the cost of land disposal from those who live near the sites to users of the products that generate the waste.

B. Regulatory Flexibility Act

The Regulatory Flexibility Act (5 U.S.C. 601 *et seq.*) requires each Federal agency to prepare a final Regulatory Flexibility Analysis (RFA) when it promulgates a final rule. (5 U.S.C. 604). The purpose of the RFA is to describe the effects the regulations will have on small entities and examine alternatives that

may reduce these effects. An agency head may delay completing the analysis for up to 180 days after publishing the rule in the Federal Register, if he publishes a finding that the final rule is being promulgated in response to an emergency that makes timely compliance impracticable. (5 U.S.C. 608).

EPA intends to study the impact of today's regulations on small entities. However, as in the case of the RIA, developing an RFA is a difficult and time-consuming task. EPA finds that the court-ordered deadline constitutes an emergency and that completing the RFA by the Court-ordered deadline has not been practicable. EPA will publish the RFA within 180 days of today's publication, in compliance with the Regulatory Flexibility Act.

C. Paperwork Reduction Act

In accordance with the Paperwork Reduction Act of 1980 (44 U.S.C. 3507), EPA will submit the reporting and recordkeeping provisions that are included in this final rule to OMB for approval. They will not become effective until EPA obtains OMB approval. A notice of the effective date of the reporting and recordkeeping provisions of this interim final rule will be published in the Federal Register when OMB approval is obtained.

D. Individual Unit Costs

EPA estimated unit costs using engineering models. A number of engineering models were developed because the unit costs and costs per unit of waste vary significantly with the size and type of unit. The resulting unit costs provide the basis for the total cost of the design and operating standards. Although we show costs for corrective action following, EPA based calculations

of the total cost of corrective action on a facility basis rather than on a unit basis.

1. General Approach. The cost estimation procedure for model units has three components: estimating costs for design and operating changes, estimating costs for a range of corrective action scenarios, and transforming costs into "annual revenue requirements." All cost estimates are in 1981 dollars.

First, to estimate costs for design and operating measures, the steps owners and operators of hazardous waste disposal units might take to comply with the regulations were identified. Since some of these measures were already required under the Interim Status Standards (ISS regulations), the analysis separated these requirements in order to estimate the cost of the additional requirements resulting from this Part 264 rulemaking.[1] The analysis also separated pre-ISS costs for landfills and surface impoundments. The ISS baseline costs used in this analysis do not reflect state requirements.

Where the under-liner requirements of the design and operating standards were applicable, the Agency examined three possibilities: (1) owners and operators would install only the single synthetic liners needed under the regulations, (2) they would install the double liner (synthetic/clay) systems suggested by the guidance, or (3) they would install double synthetic liners to enable them to avoid monitoring the ground water.

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[1] ISS requirements currently in place were used. No adjustments were made to reflect conforming changes to ISS regulations published with today's rule.

EPA began work on an RIA for land disposal facilities before November 13, 1981, but preparing the analysis requires collecting data that are currently unavailable in-house and then analyzing these data. The effort is now in its data gathering stages. When complete, the RIA will examine the need for the regulation, alternative approaches, and the costs, benefits, and distributional effects of the alternative approaches. EPA expects to complete a draft of this analysis in May of 1983, and will consider these results to determine whether any changes to the land disposal standards are warranted.

Within time and data constraints, EPA was able to address some of the analytical requirements of the Executive Order. The Agency prepared preliminary estimates for the range of costs these regulations may impose on regulated units of particular kinds and sizes, on facilities, and for the total costs of the regulations. EPA then allocated these costs to particular waste generating industries and compared them to other economic parameters to obtain measures of the relative significance of the costs resulting from this rule. The results are summarized in D through H of this section:

Second, EPA estimated the costs of corrective action activities using three different timing assumptions for the length of corrective action and two counterpumping strategies reflecting hydrogeologic conditions. Timing will depend on how well units and facilities perform, and on how quickly ground-water quality can be restored. The counterpumping strategy used will reflect the judgments of owner/operators, Regional Administrators and State Directors; technical conditions will affect but not control those decisions.

To keep the total number of cost cases presented manageable, a single set of unit cost estimates and a "median" set of hydrogeologic assumptions were used. The hydrogeologic assumptions were used as averages although they do not necessarily reflect average nationwide conditions. EPA believes that the values used are the best available for estimating total costs, given time and resource constraints. However, actual facility costs in particular cases may be higher or lower than the estimates presented in this section. To present a more complete picture of potential costs, the sensitivity analyses examine the effects of varying key technical assumptions. In addition, the docket report contains a more detailed description of the assumptions used in preparing these estimates, and includes analysis of the sensitivity of results to alternative unit cost assumptions.

Third, the stream of costs over time was converted into "annual revenue requirements" using discounted cash flow analysis. Annual revenue requirements are the added revenues a facility would have to obtain (through increased prices for its products

or for its waste management services) in each year of facility operation, in order to cover the costs of these regulations. This approach provides a consistent basis for presenting and comparing relevant costs. However, it implicitly assumes that future costs can be predicted, and recovered at an even rate over a facility's operating life.[1] Since each facility will face great uncertainty about corrective action costs, and different competitive conditions, revenue requirements estimated using this perfect amortization assumption are not necessarily good predictors of actual pricing behavior under Part 264 regulations.

Because annualizing smooths uneven cash flows, this analysis also reports first year costs to provide an indication of the maximum cash flow burden that facilities could face for design and operating requirements, and for corrective action if necessary.

Costs for regulatory requirements related to bulk and containerized liquids, and the permitting process are not included in the estimates reported here. These costs may be significant, but additional data are needed before reliable estimates can be made. Costs for floodplain standards are addressed in the sensitivity analysis.

2. Design and Operating Standards. To comply with the design and operating standards, new storage and disposal facilities and lateral expansions of existing units must install liners,

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[1] In computing annual revenue requirements a 3% real discount rate and a twenty-year facility operating life were used in all cases.

and in the case of piles and landfills, leachate collection systems. While the regulations do not absolutely require a synthetic liner for landfills, waste piles, and surface impoundments, in nearly all cases, at least a single synthetic liner is the practical result of the regulatory requirement. Those installing double liner systems with a leak detection system between them are exempt from groundwater monitoring and the other requirements of Subpart F. Additionally, waste piles may be placed on a sturdy impermeable base and regularly inspected in lieu of the requirements of Subpart F.

Owners and operators will choose to install the liner system that is most advantageous for them. This will not necessarily lead them to install the lowest cost liner that EPA will allow, since greater investment in the liner system should lower the probability that corrective action will need to be taken. The probability that corrective action will be needed depends on the containment system used, and on hydrogeologic conditions, but EPA is currently unable to quantify these relationships. The Agency believes that some owners and operators will choose each of the different liner systems, reflecting their local hydrogeologic conditions and their differing estimates of the relationship between liner investments and the probability of having to perform

corrective action. To indicate the range of potential liner costs, the cost for each of the liner systems is shown.

3. Corrective Action Costs and Timing. The costs associated with corrective action for a unit or facility depend on when contamination is discovered, the specific contaminants, the magnitude of the plume, and numerous site-specific hydrogeologic factors. The Agency can estimate corrective action costs for simple sets of conditions, but does not know what conditions are actually like for the average of all facilities. For this analysis it was assumed that ground water begins 10 feet down, that plumes reach a depth of 75 feet, and that the aquifer can be characterized by "median" hydrogeologic conditions.[1]

The Part 264 regulations require removal of contamination from ground water, at the "waste boundary" for new plumes, and to the property boundary for existing plumes. For this analysis, EPA chose to make the conservative assumption that corrective action would need to deal with well-established plumes. Cost estimates are based on counterpumping, and include costs for treating pumped water, preparing corrective action plans, and monitoring ground water as required in the regulations.

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1. Plume depths of 75 feet will be typical only for well-established plumes; new plumes will be shallower and less expensive to control. The median hydrogeologic conditions used were hydraulic gradient (change in ground water "elevation") of 5 feet per mile, and transmissivity (flow rate across a one square mile cross-section, per foot of hydraulic gradient) of 100,000 gallons per foot per day. These assumptions result in an aquifer discharge (total ground water flow volume) of 0.5 million gallons per square mile of aquifer cross-section per day.

Costs for corrective action are sensitive to assumptions about when corrective action begins and how long it must continue in order to remove all statistically significant contamination. To bound the range of actual costs an owner or operator could encounter, EPA developed costs for three scenarios: action beginning in year zero and continuing 150 years,[1] action beginning in year zero and continuing for 20 years, and action beginning in year 49 and continuing for 20 years. (The 20 year figure was chosen to match the assumption that operating lives are 20 years.)

The analysis also used two different counterpumping strategies because corrective action costs are also fairly sensitive to the pumping strategy required. Where hydraulic gradients are unidirectional, (i.e., in "simple" cases) recovery wells can be located at the downgradient toe of the plume. This is Strategy 1, and involves minimum costs for a counterpumping program. The simple conditions needed for this approach probably are not very common. Where hydraulic gradients are not unidirectional,[2] another strategy is needed to assure that all contamination is contained. Wells are located inside the plume and pumping is

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[1] The discounted present value of costs incurred over a long but finite future period is essentially identical to the discounted costs incurred in pumping "forever," if costs are incurred as expenditures are made. A corrective action period of 150 years captures about 99% of the costs of continuing the action forever.

[2] This can occur due to complex hydrogeology, the pressure of emplaced wastes on the aquifer, or pumping at off-site wells surrounding the plume.

maintained at a rate sufficient to reverse all gradients in the vicinity of the plume. This is Strategy 2, and it involves higher costs.

The range of cost estimates that results from these alternative assumptions reflects EPA's uncertainty about conditions at actual facilities.[1] To display the alternative cases, the relevant tables have columns displaying each timing scenario discussed above. For each timing case, the range of costs shown reflects cost differences between Strategy 1 and Strategy 2.

To estimate the cost of counterpumping it was necessary to estimate the size of the plumes to be contained. Plume width is

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[1] The unit cost data, hydrogeologic assumptions and algorithms used here to estimate containment costs have been subjected to some peer review and testing, and EPA believes the cost estimates that result from use of this model are the best estimates available at this time. However, the algorithms and data must still be considered to be incompletely verified and validated.

Several key assumptions should be noted. (1) A simplified treatment cost model was used that may significantly underestimate costs for higher concentrations and more complex mixtures of contaminants, and may somewhat overestimate costs for smaller plumes and for treatment of volatiles. (2) Cost estimates are probably less reliable for facilities with small waste piles and the smallest surface impoundments than for other facilities because corrective action costs for plumes of less than one-half acre in area were not modelled. (3) The cost estimating model is directly applicable only within the limits established by the assumptions made to facilitate cost estimation. The use of two counterpumping strategies compensates for this simplification to some extent. (4) In addition, the algorithms do not account for replacement or retirement of wells or treatment facilities. Wells can become unuseable within months, or last for years, depending on corrosivity and other characteristics of the plume. Treatment may be required as long as pumping continues, or may be unnecessary during the latter stages of corrective action. For economic analysis purposes EPA assumed that wells will last for 30 years and that treatment facilities will be in use for as long as remedial action continues.

the most sensitive parameter within the modelling framework used for corrective action cost estimates, and there is reason to expect that unit width serves as a conservative estimate of plume width. If a unit fails because of age, then a general failure across the unit is likely so that the width of the unit might approximate the width of the plume; if a unit fails due to a localized problem or single rupture, then the plume width should be smaller than the unit width. Thus, using unit width as a proxy for plume width should result in a conservative measure of the cost of counterpumping.[1]

Corrective action costs will occur only to the extent that ground water is contaminated and to the extent that protection of the environment requires taking corrective action.

4. Costs for Landfills. Table 1 shows the annual revenue requirements needed to compensate for the cost of Part 264 requirements for on-site landfills of different sizes without corrective action. It covers the annual revenue requirements associated with the cost of required liners, final cover and leachate collection systems. It assumes that waivers are not obtained, and that no landfills currently use any of the features required under Part 264. This tends to overstate costs since there are landfills that are at favorable locations that would qualify for some site specific waivers or include these features.

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[1] When estimating corrective action costs for facilities, EPA assumed that facility width, rather than unit width, approximates the plume width.

TABLE 1
Annual Revenue Per Unit Required to Offset Incremental Costs Due to Part 264 Regulations Without Corrective Action:†
Landfills by Unit Size

Size (MT*/yr)	Single Synthetic Liner per year ($ 000)	Single Synthetic Liner $ per MT*	Double Liner (Synthetic/Clay) per year ($ 000)	Double Liner (Synthetic/Clay) $ per MT*	Double Synthetic Liner per year ($ 000)	Double Synthetic Liner $ per MT*
500	31	62	52	104	43	86
2,000	49	25	94	47	82	41
5,000	79	16	164	33	145	29
7,000	98	14	207	30	184	26
15,000	149	10	323	22	290	19
35,000	277	8	622	18	561	16
60,000	379	6	862	14	779	13
123,000	566	5	1,306	11	1,180	10

† Costs shown are those estimated for on-site landfills in these size categories. They are slightly different from costs estimated for off-site landfills. If costs were based on off-site landfills, double liner (synthetic/clay) costs would be lower than double synthetic liner costs.

* MT indicates metric ton.

Table 2 shows the additional annual revenue requirements associated with corrective action if it is needed.

TABLE 2
Annual Revenue Per Unit Required to Offset Incremental Costs Due to Part 264 Corrective Action Regulations:
Landfills by Unit Size

Size (MT/yr)	Detect Year 0 Pump 150 Years per year ($ 000)	Detect Year 0 Pump 150 Years $ per MT	Detect Year 0 Pump 20 Years per year ($ 000)	Detect Year 0 Pump 20 Years $ per MT	Detect Year 49 Pump 20 Years per year ($ 000)	Detect Year 49 Pump 20 Years $ per MT
500	138 - 198	276 - 396	65 - 95	130 - 190	17 - 24	34 - 48
2,000	149 - 225	75 - 113	71 - 109	36 - 55	18 - 27	9 - 14
5,000	172 - 267	34 - 53	82 - 128	16 - 26	21 - 31	4 - 6
7,000	178 - 275	25 - 39	85 - 132	12 - 19	21 - 32	3 - 5
15,000	194 - 309	13 - 21	93 - 148	6 - 10	24 - 36	2 - 2
35,000	216 - 361	6 - 10	104 - 174	3 - 5	26 - 42	1 - 1
60,000	232 - 391	4 - 6	113 - 190	2 - 3	28 - 46	* - 1
123,000	252 - 422	2 - 3	123 - 206	1 - 2	30 - 50	* - *

* Less than 50 cents.

Thus, if a 15,000 MT/year landfill with a double synthetic liner did not contaminate ground water to the extent that corrective action was necessary, the incremental annual revenue requirement would be $290,000 or $19 per metric ton. If contamination were detected immediately resulting in immediate counterpumping for 20 to 150 years, an additional revenue requirement of between $93,000 to $194,000, or $6 to $13 per ton would be added to the basic Part 264 costs (using Strategy 1 counterpumping).

To help put these costs in perspective, costs estimated in the absence of regulations (pre-ISS) range from $11 to $240 per metric ton for the large and small on-site landfills, respectively. ISS incremental cost estimates for these two sizes range from $6 to $128 per metric ton. Prices at commercial landfills in 1981 ranged from $55 per metric ton to $240 per metric ton, depending on the type of waste and whether it was in drums or bulk. This does not include transportation, which averaged about $0.15 per ton mile.

Table 3 shows the costs that existing landfills could incur in the first year as a result of the Part 264 requirements. Potential first year costs for design and operating requirements (D&O) using a double liner (synthetic/clay) and for immediate corrective action are reported separately for Strategy 1 and Strategy 2.[1] In the example discussed above, the first year cost is $305,000 if no corrective action is needed, and an additional $315,000 to $465,000 if counterpumping is undertaken immediately.

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1. First year Part 264 D&O costs are approximately the same as annual revenue requirments because the major incremental cost element in the cost model is the cell liner, which is installed for one cell in each year of the landfill's operating life.

TABLE 3
First Year Costs Per Unit Due to Part 264 Regulations:
Landfills by Unit Size

Size (MT/yr)	Basic Cost: No Corrective Action/ Double Liner* ($ 000)	Corrective Action Cost: Immediate Counterpumping ($ 000)
500	50	185 - 295
2,000	91	205 - 365
5,000	156	255 - 405
7,000	196	265 - 415
15,000	305	315 - 465
35,000	584	375 - 585
60,000	810	425 - 685
123,000	1,226	475 - 795

*(Synthetic/clay)

5. Costs for Surface Impoundments. EPA estimated costs for existing surface impoundments using basically the same methods that were used to estimate the cost for landfills, but varied some features to reflect differences in the regulations and the units affected, and estimated two additional cost cases. It was assumed that surface impoundments close as landfills in all cases. (Costs for units where all waste, liners and contaminated subsoils are removed at closure, and for clay-lined storage impoundments, are not reported.)

The no-corrective-action case was estimated in much the same way as the no-corrective-action case for landfills. However, surface impoundments generate dredged material that must be landfilled;[1] the incremental cost of disposing of this material in a Part 264 landfill rather than in an ISS landfill is counted as a surface impoundment cost in this section.[2] In addition,

1. For this analysis it was assumed that dredged material is disposed of in a 123,000 MT/yr. landfill. Landfill disposal costs vary depending on the type of liner system. It was assumed that the landfill would not need corrective action. If corrective action were necessary, costs would be slightly higher.

2. Because these higher landfilling costs are also included in the landfill cost estimates, landfill and surface impoundment costs cannot simply be added to get total costs.

operators of existing surface impoundments may choose to (1) continue operations without installing liners; (2) close the existing unit and construct a new impoundment lined with one of the three liners described earlier; or (3) retrofit the existing impoundment with any of these three liners. Costs are estimated for all of these cases. The retrofit case includes the costs of disposing of contaminated material from the existing impoundments, and the replacement case includes closure and post closure care costs for existing units. Neither case includes land costs nor the economic costs of disrupted plant operations, which are likely to vary a great deal across sites.

Tables 4, 5, and 6 summarize these results. Costs are reported on the basis of the size of the impoundment rather than per unit of waste because the amount of liquid processed through an impoundment of a given size can be highly variable. The cost for an impoundment will depend on the compliance elements that the unit selects or is required to undertake -- no scenario would include more than one kind of corrective action or more than one kind of alteration.

TABLE 4
Annual Revenue Per Unit Required to Offset Incremental Costs Due to Part 264 Regulations Without Corrective Action: Surface Impoundments by Unit Size

		Retrofit Cases			Replacement Cases		
Size (Acres)	Base Cost ($ 000)	Single Synthetic Liner ($ 000)	Double Liner ($ 000)	Double Synthetic Liner ($ 000)	Single Synthetic Liner ($ 000)	Double Liner ($ 000)	Double Synthetic Liner $ (000)
0.25	4 - 6	9	13	9	19	23	18
0.5	6 - 9	15	22	18	26	31	27
1.0	10 - 16	25	37	34	35	45	42
2.0	16 - 25	48	71	71	59	78	76
5.0	48 - 81	92	148	157	106	153	156
11.0	95 - 157	228	348	374	252	354	367

TABLE 5
Annual Revenue Per Unit Required to Offset Incremental Costs Due to Part 264 Corrective Action Regulations: Surface Impoundments by Unit Size

Size (Acres)	Detect Year 0 Pump 150 Years ($ 000)	Detect Year 0 Pump 20 Years ($ 000)	Detect Year 49 Pump 20 Years ($ 000)
0.25 & 0.5†	122 - 163	58 - 77	15 - 19
1.0	128 - 180	61 - 86	16 - 22
2.0	138 - 198	65 - 95	17 - 24
5.0	149 - 225	71 - 109	18 - 27
11.0	169 - 261	81 - 125	20 - 31

† Costs for plumes associated with surface impoundments smaller than 0.5 acre were not estimated. Cost reported is for a 0.5 acre impoundment.

TABLE 6
First Year Costs Per Unit Due to Part 264 Regulations: Surface Impoundments by Unit Size

Size (Acres)	Basic Cost	Corrective Action Cost†	Facility Alteration††	
	No corrective Action ($ 000)	Counterpumping ($ 000)	Retrofit Liner ($ 000)	Replace Facility ($ 000)
.25	*	159 - 209	123	142
.5	1	159 - 209	226	220
1.0	2	169 - 254	442	390
2.0	3	189 - 299	862	718
5.0	8	209 - 369	2,141	1,765
11.0	18	254 - 399	4,622	3,868

* Less than $500.
† Assumes corrective action is taken in Year Zero.
†† Assumes double synthetic liner

Thus, if a 2-acre surface impoundment did not contaminate ground water to the extent that corrective action was necessary, the incremental revenue requirement would be $16,000 to $25,000 per year, depending on the type of liners used by off-site landfills where the dredged material is disposed of. If the owner chooses to retrofit, the incremental annual cost will be $48,000 to $71,000; if he replaces the impoundment, the incremental annual

cost will be $59,000 to $78,000, depending on the type of liner system installed.

If corrective action is necessary and counterpumping is undertaken immediately, an additional annual revenue requirement of $65,000 to $138,000 would be added to the basic Part 264 cost (under Strategy 1 counterpumping).

The first year cost for the basic requirement is $3,000; if counterpumping is undertaken, the first year cost is $189,000 to $299,000; and if the unit elects to retrofit the first year cost is $862,000.

Current prices that could provide perspective for these costs are not readily observed, because most surface impoundments are on-site. However, it was possible to estimate the total revenue requirements for new impoundments constructed and operated to comply with ISS requirements, using assumptions consistent with those used for Part 264 cost estimates. These annualized revenue requirements ranged from $42,000 for the smallest facility, to $424,000 for the largest, including revenue requirements of $6,000 to $174,000 in the absence of any regulation.

6. Costs for Land Treatment Units. The Agency estimated costs for land treatment units on a model plant basis, as for landfills and surface impoundments, and calculated corrective action costs in an identical fashion (i.e. for action by all facilities in Year Zero or Year 49), though for units of different sizes. It was necessary to make assumptions about the numbers of units that would be required to undertake certain operating modifications under Part 264 rules. EPA assumed that ten percent of land treatment units would require a pH adjustment,

90 percent would require irrigation and a crop cover to control wind dispersal, 25 percent would need to increase their soil monitoring and number of lysimeters. EPA assumed that all units would conduct one waste field test, and that all would close with hazardous consituents in the treatment zone. It was also assumed that ten percent of all units would encounter problems during operation (i.e., they would fail ongoing tests of soil core and soil pore liquids), resulting in operating modifications: three percent of all units (30 percent of those with problems) would adjust their pH, five percent would expand the treatment area, and two percent would reduce their waste loadings. Tables 7, 8, and 9 summarize the results.

TABLE 7
Annual Revenue Per Unit Required to Offset Incremental Costs Due to Part 264 Regulations Without Corrective Action: Land Treatment by Unit Size

Size (Acres)	Basic Cost (No Corrective Action) Per Year ($ 000)	per MT* ($)
1.7	17	48
6.5	19	14
20.1	45	11
74.3	122	8
247.1	361	7

* Based on an average application rate of 206 MT per acre per year. In practice the amount of waste processed per acre is highly variable.

TABLE 8
Annual Revenue Per Unit Required to Offset Incremental Costs Due to Part 264 Corrective Action Regulations: Land Treatment by Unit Size

Size (Acres)	Detect Year 0 Pump 150 Year ($ 000)	Detect Year 0 Pump 20 Years ($ 000)	Detect Year 49 Pump 20 Years ($ 000)
1.7	134 - 187	63 - 89	16 - 22
6.5	154 - 236	73 - 114	19 - 28
20.1	178 - 276	85 - 133	21 - 33
74.3	225 - 371	109 - 180	27 - 44
247.1	285 - 472	140 - 234	34 - 56

TABLE 9
First Year Costs Per Unit Due to Part 264 Regulations: Land Treatment by Unit Size

Size (Acres)	Basic Cost: No Corrective Action ($ 000)	Corrective Action Cost: Immediate Counterpumping ($ 000)
1.7	76	175 - 265
6.5	81	205 - 365
20.1	103	265 - 425
74.3	134	395 - 625
247.1	226	565 - 1,025

Thus, if the operator of an average size (20.1 acre) land treatment unit applies waste at an average rate (206 MT per acre per year) and does not contaminate ground water to the extent that corrective action is necessary, the incremental annual revenue requirement would be $45,000 or $11 per MT. If contamination is detected immediately resulting in immediate counterpumping, $85,000 to $178,000 per year or $21 to $45 per MT would be added to this basic Part 264 cost (under Strategy 1 counterpumping).

As shown in Table 9, the first year cost if no corrective action is needed for this size unit is $103,000. If corrective action is needed immediately, the first year cost increases by $265,000 to $425,000.

To put these costs in perspective, prices for commercial land treatment in 1981 ranged from $5 to $24 per metric ton.

7. Costs for Waste Piles. Waste pile unit cost estimates assume that all existing waste piles would be managed as storage rather than disposal units. Accumulated wastes must periodically be removed and disposed of in a landfill; therefore, the incremental costs of using a Part 264 rather than an ISS landfill are included here as a waste pile cost. (These costs are also reflected in the landfill cost estimates, so unit costs are not additive.) The analysis assumes that all piles are exposed and are at or above grade. Costs for enclosed piles (including the cost of enclosure) could be significantly lower, and costs for below grade piles are likely to be higher (in practice, many large below grade piles would probably close as landfills).

The analysis looked at three alternative compliance paths to reflect the options available to waste pile owners or operators under the regulations: (1) retain the ISS sturdy impermeable base and undertake ground-water monitoring; (2) inspect the ISS base periodically (assumed to mean annually) without ground-water monitoring; or (3) install a new base with a double liner system and leachate collection system and dispense with inspections and ground-water monitoring (until leakage is detected). For waste piles,

it was again assumed that corrective action consists of counter-pumping in Year Zero or Year 49.

Tables 10, 11, and 12 summarize the results. The annual revenue requirements shown in Table 10 include the cost of disposing of the waste pile and base at the time of closure in a Part 264 123,000 MT/yr off-site landfill with a double (synthetic/clay) liner that does not require corrective action.

TABLE 10
Annual Revenue Per Unit Required to Offset Incremental Costs Due to Part 264 Regulations Without Corrective Action: Waste Piles by Unit Size†

	Compliance Option		
Size (000 ft^3)	Ground-Water Monitoring ($ 000)	Base Inspection ($ 000)	Liner and Leachate Collection System ($ 000)
2	15	7	7
10	17	9	9
25	21	13	13
100	27	20	19
500	27	23	17
1,000	26	27	15

† Costs for waste piles sized at 2,000 to 25,000 cubic feet assume a 1 year operating life. Costs for a 100,000 cubic foot pile assume a 2 year operating life, costs for a 500,000 cubic foot pile assume a 10 year operating life, and costs for a 1,000,000 cubic foot pile assume a 20 year operating life. Because operating lives differ, costs as a function of size do not increase monotonically.

TABLE 11
Annual Revenue Per Unit Required to Offset Incremental Costs Due to Part 264 Corrective Action Regulations: Waste Piles by Unit Size†

Size (000 ft^3)	Detect Year 0 Pump 150 Years ($ 000)	Detect Year 0 Pump 20 Years ($ 000)	Detect Year 49 Pump 20 Years ($ 000)
2 - 500	150 - 196	71 - 93	18 - 23
1,000	153 - 207	72 - 98	18 - 24

† Costs for plumes associated with waste piles smaller than 500,000 cubic feet were not estimated. Cost reported is for a 500,000 cubic foot pile.

TABLE 12
First Year Costs Per Unit Due to Part 264 Regulations: Waste Piles by Unit Size

Size (000 ft^3)	Ground-Water Monitoring ($ 000)	Inspect Base ($ 000)	Liner and Leachate Collection System ($ 000)	Immediate Counterpumping ($ 000)
2	44	4	12	*
10	44	4	12	*
25	44	4	12	*
100	44	4	12	*
500	44	4	14	165 - 237
1,000	44	4	17	170 - 265

* Not estimated. Costs for 500,000 cubic foot pile provide an upper bound.

Thus, if the operator of a 100,000 cubic foot waste pile decides to inspect the unit's ISS base rather than monitor ground water or change to a liner and leachate collection and removal system, and does not contaminate ground water, the additional annual revenue requirement is $20,000. If contamination is detected in year zero and counterpumping is necessary, additional annual revenue requirements of $71,000 to $150,000 would be added to the basic Part 264 cost (under Strategy 1 counterpumping).

First year costs for the three Part 264 options are shown in Table 12. Without corrective action, these costs for the unit discussed above are $4,000 to $44,000, depending on the D&O option chosen. Corrective action taken in Year Zero could add up to $165,000 to $237,000 to these costs.

E. Closure Analysis.

This section examines the economics of closing small on-site landfills and shipping wastes to commercial sites and replacing existing on-site surface impoundments. Small on-site landfills may become uneconomic compared to larger commercial facilities as a result of these regulations. Small surface impoundments may close to avoid liability for corrective action (related to past leakage) that could otherwise be imposed through the permit process.

If small landfills choose to close or if small surface impoundments are replaced, a substantial portion of all hazardous waste units will have been significantly affected by these regulations. EPA estimates that there are about 255 small (500

MT/yr. or less) landfills; this represents 44 percent of all landfills. There are about 2,760 small (one acre or less) surface impoundments, or 65 percent of all surface impoundments.

Results of the analysis on small landfill closures indicate that operators of small on-site landfills would in many cases be better off closing and shipping their wastes to off-site commercial facilities for disposal. For small surface impoundments, the economics favor replacing existing units under most circumstances if closure of the existing impoundment eliminates an obligation to undertake corrective action. Each of these issues is summarized below.

Table 13 indicates that under the Part 264 regulations, owner/operators of small on-site landfills could expect their annual revenue requirements to increase by about $62/ton assuming a single synthetic liner design and no corrective action. This is used as the base case. (With a double liner [synthetic/clay], this figure would be $104/ton, or $86/ton with a double-synthetic liner). If corrective action is considered likely, the increases in expected revenue requirements could range from $96 to $458 per ton. These expected cost increases understate the savings that could actually be achieved by closing, since major cost components of ISS like closure, post closure, and financial responsibility, as well as expenses for basic trench or cell construction, could be avoided or recovered if the landfill closed.

These incremental costs (which are conservative estimates of incremental savings from closure) compare with actual 1981 prices for commercial disposal that range from $55/ton to $240/ton.

This sensitivity analysis assumes that prices for commercial services will not change as a result of the Part 264 regulations. This assumption is reasonable if commercial facilities already meet most design and operating standards and do not face corrective action requirements, and if commercial capacity is adequate to meet demand at current prices.

TABLE 13
Effects of the Incremental Costs of Part 264 Regulations on the Economic Viability of Small On-site Landfills†

	Base Case	Base Case plus Corrective Action	
		Low	High
Incremental Cost for 500 Metric Ton/Year On-site Landfill	$62/ton	$96/ton	$458/ton
Equivalent Distance†† To Ship Waste for Disposal in Commercial Off-site Landfill	0 - 47 miles	0 - 273 miles	1453-2687 miles

† Base case cost assumes single synthetic liner and no corrective action and that increased demand for off-site services does not signficantly raise prices. Low cost assumes that the small landfill undertakes counterpumping under Strategy 1 conditions for 20 years starting in Year 49. High cost assumes that the small landfill undertakes counterpumping under Strategy 2 conditions for 150 years starting in Year Zero.

†† Distance calculated using a range of commercial disposal prices of $55 to $240/ton and a transportation cost of $.15/ton mile.

Under the base case assumptions used in Table 13, it would be advantageous for a firm operating a small on-site landfill to close the landfill and ship its wastes to a commercial facility for disposal if the firm is quoted disposal prices that are at the low end of the actual range. Where the firm faces a price of $55/ton for commercial disposal, it could afford to ship wastes up to 47 miles, assuming a transportation cost of $.15/ton mile. If

the firm is quoted prices closer to $240/ton, it would be more cost-effective for the firm to continue running its landfill.

Where the firm expects that corrective action could be necessary at its landfill, it could close the landfill and ship wastes from 273 to 2687 miles for disposal in a commercial landfill charging $55/ton, instead of bearing the costs and responsibility for corrective action. Where the commerical disposal price is closer to $240/ton, it may be more cost-effective for the firm to continue disposing its wastes on site, but this would depend on the hydrogeologic conditions existing at the site and the expected duration of corrective action.

These economic factors may be offset by concerns over liability potentially associated with sending wastes off site, or by concerns over potential price increases at commercial facilities.

Similar comparisons can be made between the costs of replacing small surface impoundments to limit the possibility that corrective action will be needed, or doing nothing and hoping that corrective action will not be necessary. Actual decisions to close and replace a surface impoundment will be based on individual owner or operators expectations regarding the probability that their impoundments have been leaking or will leak in the future.

Table 14 compares the incremental costs of taking corrective action under various conditions with the costs of replacing 1/4 acre, 1/2 acre and 1 acre surface impoundments.

TABLE 14
Comparison of Corrective Action Costs with
Close/Construct Costs for Small Surface Impoundments

Incremental Annual Revenue Requirements

Impoundment Size	Corrective Action†			Close and Construct††
	In Year Zero for 150 Yrs. ($ 000)	In Year Zero for 20 Yrs. ($ 000)	In Yr 49 for 20 Yrs. ($ 000)	($ 000)
1/4 Acre	126 - 167	62 - 81	19 - 23	19
1/2 Acre	128 - 169	64 - 83	22 - 28	26
1 Acre	138 - 190	71 - 96	26 - 32	35

† Low end of range of Corrective Action costs based on Strategy 1 conditions; high end of range based on Strategy 2 conditions.

†† Assumes double liner design, most expensive of possible systems.

Based on Table 14, it may often be more advantageous to close existing units and construct new ones where it appears likely that this would eliminate the need for corrective action. This may be the case where an impoundment is believed to have been leaking but has not yet resulted in significant contamination at the waste boundary. (In this case, the owner/operator would need to be able to distinguish contamination from the closed and the new unit, perhaps through use of tracers added to new waste or based on the arrangement of monitoring wells.) Of the three corrective action timing cases examined, electing to continue to operate the existing impoundment when corrective action will be necessary is only advantageous under the "best" assumptions, i.e., when action is not needed until Year 49 (the year before owner/operator responsibility ends) and continues for 20 years.

F. Total Costs

EPA estimates that the total annualized cost of these regulations (for existing facilities[1]) could range from $150 to $1,145 million. Details on the components of these cost estimates are reported in table 15.

The broad range covered by these estimates results primarily from the uncertainty regarding the amount of corrective action that will be needed. ISS monitoring will eventually provide an indication of the severity of current environmental problems. Currently, however, EPA is unable to predict reliably the number of facilities able to comply with the ground-water protection standard specified in the regulations. EPA cannot predict when facilities will fail, or how long corrective action will have to continue at a typical site. Data on a host of other site specific factors that will affect the cost of the corrective action are also unavailable. Finally, EPA cannot predict the number of facilities affecting ground water that might be able to avoid corrective action by showing that actual concentrations of Appendix VIII constituents at the compliance point pose no threat to human health or the environment.

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1. We were unable to estimate total costs for new facilities due to the difficulty of projecting the number of facilities that would be affected. Determining incremental costs for a single new facility is difficult in any event, because EPA has not previously estimated the costs of the Part 267 regulations that now apply to these facilities.

To estimate total D&O costs EPA estimated the size distribution of units from the Part A's[1]. For each model unit, EPA multiplied the revenue requirements reported in Individual Unit Costs by the number of units, and summed[2] to obtain an estimate of total D&O costs.

The lower bound estimate of D&O costs assumes that landfills use single synthetic liners, and that waste piles choose to replace the containment system to avoid the need for groundwater monitoring. The upper bound D&O estimates assume that landfills have double synthetic liners, that waste piles monitor ground water, and that surface impoundments are closed and replaced by new units with double synthetic liners.

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1. Complete details are in the docket report. Based on Part A of TSDF permit applications, EPA estimates that there are 573 existing hazardous waste landfills, capable of accepting about 12 million tons of waste per year; 4240 surface impoundments with 11,169 acres of surface area; 241 land treatment facilities with 12,100 acres of operating area; and 608 waste piles with 87 million cubic feet of wastes. Thus, D&O costs are based on 5,662 units. Surveys to verify these estimates are now underway, and it is likely that the final estimates will be lower.

We were unable to simply add the capacities reported on the Part A's, because capacities for some types of units are reported in different units of measure there than the units of measure used in this analysis (i.e., landfills in acre-feet rather than metric tons, and surface impoundments in gallons or liters rather than acres of surface area. In addition, we assumed that the remaining operating life of all units was 20 years. Annual capacity figures for each kind of facility should therefore be viewed as estimates based on available data, rather than as aggregates of reported capacities.

2. In adding costs for units to obtain totals an adjustment was made to avoid double counting the costs of landfilling surface impoundment sludge and wastes removed from piles.

with double synthetic liner systems, and that in spite of these actions, all facilities require immediate corrective action lasting 150 years and using an expensive counterpumping strategy. As the need for corrective action increases, and as owners and operators install more expensive liner systems the total cost of the regulations will increase from the low cost case toward the high cost case.[1]

The lower and upper bound costs are shown in Table 15. The annualized D&O cost for the regulations ranges from $150 to $468 million per year. Depending on the frequency, speed and concentration with which Appendix VIII consituents reach ground water, total incremental annualized costs could be as high as $1,145 million.

G. Industry Analysis

The economic impacts of these regulations will depend in part on how the costs of the regulations are distributed across industries and firms. As described in Total Costs, EPA calculated upper and lower bound cost estimates. These two cost scenarios were then applied to selected industries, in order to obtain a preliminary indication of whether economic impacts might be significant. The industries examined were selected because there were large numbers of on-site land disposal facilities in the industries, or large quantitites of waste shipped off-site, or both.

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[1] Actually, the high cost case does not reflect the highest possible costs and the low cost case does not represent the lowest possible cost that could occur under the regulations, because waivers are potentially available for some requirements and because we use median technical assumptions in determining cost. It is, however, extremely unlikely that the true cost of these regulations will fall outside these boundaries.

TABLE 15
Total Annual Revenue Requirements for Part 264 Regulations:
All Land Disposal Facilities
($ in Millions)

	Baseline (Pre-ISS+ISS)†	Incremental Part 264 Low Estimate	Incremental Part 264 High Estimate
Landfills D&O	301	81	159
Surface Impoundments D&O	534	102	401
(adjustment for landfilled material)	(190)	(57)	(118)
Waste Piles D&O)	16	7	12
(adjustment for landfilled material)	(10)	(3)	(6)
Land Treatment D&O	51	20	20
Corrective Action	-	-	677
TOTAL	702	150	1,145

† The total baseline costs of $702 million includes pre-ISS costs of about $181 million for landfills and $180 million for surface impoundments. Similar data are not available for waste piles and land treatment units. Pre-ISS costs include land, excavation, and infrastructure costs incurred in establishing a land disposal facility. ISS costs include more than "good housekeeping" requirements. Approximately 72 percent of the ISS costs of $341 million included in the baseline are due to ISS closure ($82 million), post closure ($40 million), ground water monitoring ($42 million), and financial assurance ($82 million) requirements.

Upper and lower bound costs were allocated to industries using available information on the use of land disposal of hazardous waste in these industrial sectors. This information is sufficient to allow EPA to identify the industries on which these regulations are most likely to impose significant costs. However, cost estimates for any given industry are highly sensitive to the numbers and sizes of facilities attributed to that industry, and the data base used to derive these factors for individual industries is imprecise.

Table 16 lists the industries EPA examined, and their SIC codes. The range of potential annual revenue requirements is reported and compared to total costs of production, value added, and value of shipments in Table 17. The range of potential first year expenditures is compared to an estimate of annual capital expenditures for each industry in Table 18. Table 19, at the end of this section, provides estimates of the range of potential annual revenue requirements (in excess of pre-ISS costs) for the combination of ISS (Part 265) and Part 264 regulations. In all cases cost ranges reflect the upper and lower bound cases used earlier in this analysis.

These comparisons do not constitute an economic impact analysis at either the industry or firm level. At the industry level, they do provide an initial screening to judge whether economic impacts might be large or small. If the upper bound costs do not appear significant when compared to economic parameters for an

industry, then the analysis indicates that broad and significant economic impacts are unlikely. These comparisons are also useful in identifying those industries where the most significant impacts are likely to occur. However, the high cost case cannot indicate that there will in fact be significant impacts, because costs are probably overstated in the high cost case.

To the extent that economic aggregates such as value added are representative of firms in the industry sectors, the ratios reported here could also provide some insight into potential burdens for "typical" firms in each industry. However, it should be remembered that costs are likely to be overstated in the high cost case[1], and that there are no truly typical firms. Four-digit SIC codes include highly diverse operations with widely varying costs of production, value added and value of shipments per unit of hazardous waste generated. In addition, facilities will use different mixes of on- and off-site disposal for these wastes, and so face different exposure to the regulations.

The docket report contains a full description of the methodology used to construct these tables.

H. Sensitivity Analysis.

The following reports on analysis of the sensitivity of counterpumping costs to the number of units or facilities affected, plume size, technical assumptions about hydrogeology and treatment costs, and the use of a confining slurry wall to reduce pumping

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1. This scenario is appropriate for a firm with a mix of on- and off-site disposal, required to undertake corrective action lasting 150 years at an early date at all of its on-site facilities after having installed the most expensive technology modelled, and simultaneously faced with higher off-site costs due to the need for early corrective action at all available off-site facilities.

TABLE 16
Industries Examined by SIC Codes

Industry Name	SIC Code
Crop Planting and Protection	0721
Oil and Gas Extraction	1300
Wood Preserving	2491
Alkalies and Chlorine	2812
Inorganic Pigments	2816
Industrial Inorganic Chemicals	2819
Plastic Materials and Resins	2821
Synthetic Rubber	2822
Cellulosic Man-Made Fibers	2823
Organic Fibers,Noncellulosic	2824
Medicinals and Botanicals	2833
Paints and Allied Products	2851
Gum and Wood Chemicals	2861
Cyclic Crudes and Intermediates	2865
Industrial Organic Chemicals	2869
Nitrogenous Fertilizers	2873
Phosphatic Fertilizers	2874
Agricultural Chemicals	2879
Explosives	2892
Chemical Preperations, NEC	2899
Petroleum Refining	2911
Lubricating Oils and Greases	2992
Blast Furnaces and Steel Mills	3312
Electro-Metallurgical Products	3313
Steel Wire and Related Products	3315
Gray Iron Foundries	33215
Secondary Nonferrous Metals	3341
Copper Rolling and Drawing	33516
Plating and Polishing, Metal Coating and Allied Services	34719
Motor Vehicles and Bodies	3711
Motor Vehicle Parts and Accessories	3714

TABLE 17

Comparison Of Annual Revenue Requirements Due to Part 264 Land Disposal Regulations to Selected Industry Measures, By SIC Code

(Low and High Cost Cases)

SIC Code	Annualized Cost ($000)	Annualized Cost as a Percentage of: Cost of Production	Value Added	Value of Shipments
0721	322 - 3,309	*	*	*
1300	1,392 - 8,104	*	*	*
2491	774 - 15,572	.16 - 3.17	.38 - 7.61	.13 - 2.58
2812	3,187 - 16,944	.20 - 1.09	.26 - 1.37	.13 - .68
2816	3,204 - 16,318	.44 - 2.26	.68 - 3.49	.31 - 1.57
2819	1,079 - 73,034	.15 - .97	.19 - 1.27	.10 - .64
2821	4,896 - 24,478	.04 - .22	.08 - .41	.03 - .16
2822	2,484 - 10,976	.18 - .78	.46 - 2.03	.14 - .62
2823	1,640 - 7,242	.12 - .53	.33 - 1.46	.11 - .48
2824	1,303 - 7,378	.05 - .27	.08 - .46	.04 - .20
2833	218 - 2,706	.02 - .23	.02 - .19	.01 - .12
2851	996 - 5,739	.03 - .20	.06 - .34	.02 - .14
2861	1,037 - 6,575	1.74 -11.03	2.44 -15.45	1.15 - 7.31
2865	2,517 - 15,885	.12 - .73	.21 - 1.35	.08 - .53
2869	3,756 - 23,435	.04 - .27	.07 - .42	.03 - .18
2873	1,003 - 7,201	.05 - .36	.07 - .49	.03 - .23
2874	151 - 2,347	.01 - .15	.02 - .31	.01 - .10
2879	2,595 - 12,793	.23 - 1.13	.38 - 1.86	.18 - .87
2892	850 - 7,450	.36 - 3.19	.38 - 3.35	.24 - 2.06
2899	1,322 - 7,815	.23 - 1.37	.33 - 1.94	.15 - .90
2911	23,939 -116,687	.02 - .08	.09 - .43	.01 - .07
2992	1,068 - 5,230	.28 - 1.35	.66 - 3.24	.21 - 1.04
3312	8,495 - 37,153	.04 - .19	.10 - .44	.04 - .16
3313	593 - 4,010	.13 - .86	.38 - 2.59	.11 - .76
3315	1,037 - 5,500	.20 - 1.07	.39 - 2.06	.16 - .84
33215	1,327 - 6,998	.12 - .66	.16 - .85	.09 - .48
3341	1,984 - 10,337	.24 - 1.23	.94 - 4.91	.20 - 1.06
33516	4,721 - 20,085	.22 - .92	.79 - 3.37	.19 - .79
34719	6,208 - 31,520	.65 - 3.31	.84 - 4.24	.47 - 2.41
3711	930 - 7,086	.00 - .02	.01 - .07	.00 - .02
3714	716 - 7,042	.01 - .09	.02 - .16	.01 - .07

* Necessary data unavailable

TABLE 18

Comparison of First Year Expenditures Due to
Part 264 Land Disposal Regulations to Yearly Capital Outlays
By SIC Code

(Low and High Cost Cases)

SIC Code	First Year Expenditure ($000)	First Year Expenditure as Percentage Yearly Capital Expenditures
0721	182 - 9,430	*
1300	991 - 38,997	*
2491	474 - 42,900	2.37 - 124.75
2812	995 - 128,807	.25 - 41.58
2816	754 - 152,243	.73 - 141.54
2819	4,556 - 461,702	.72 - 65.01
2821	3,090 - 123,594	.23 - 8.05
2822	590 - 114,029	1.14 - 219.32
2823	869 - 46,052	1.51 - 90.74
2824	435 - 53,985	.11 - 24.31
2833	141 - 8,507	.07 - 3.49
2851	774 - 14,883	.12 - 4.27
2861	333 - 44,958	5.31 - 648.31
2865	698 - 116,540	.84 - 131.04
2869	1,719 - 137,204	.10 - 6.90
2873	376 - 43,233	.04 - 4.17
2874	106 - 7,358	.10 - 4.52
2879	1,115 - 83,884	.78 - 64.21
2892	433 - 31,665	3.03 - 166.98
2899	787 - 31,433	1.97 - 62.38
2911	15,049 - 783,313	.35 - 17.42
2992	863 - 11,883	4.97 - 40.56
3312	6,671 - 81,084	.52 - 3.83
3313	297 - 19,944	.49 - 50.22
3315	889 - 17,563	3.48 - 52.33
33215	949 - 15,039	8.39 - 68.53
3341	1,380 - 23,654	3.31 - 34.61
33516	3,216 - 84,597	1.02 - 105.25
34719	4,424 - 103,817	1.33 - 98.34
3711	155 - 46,625	.02 - 4.68
3714	265 - 29,022	.05 - 4.38

* Necessary data unavailable.

TABLE 19

Comparison Of Annual Revenue Requirements Due to
Part 264 Land Disposal Regulations
And Part 265 Land Disposal Regulations
To Selected Industry Measures
By SIC Code

(Low and High Cost Cases)

SIC Code	Annualized Cost ($000,000)	Annualized Cost as a Percentage of: Cost of Production	Value Added	Value of Shipments
0721	2 - 5	*	*	*
1300	6 - 13	*	*	*
2491	6 - 21	1.24 - 4.25	2.96 - 10.19	1.01 - 3.46
2812	12 - 26	.78 - 1.66	.99 - 2.10	.49 - 1.05
2816	12 - 25	1.65 - 3.46	2.54 - 5.34	1.14 - 2.41
2819	4 - 106	.59 - 1.42	.77 - 1.85	.39 - .93
2821	17 - 36	.15 - .32	.28 - .60	.11 - .23
2822	9 - 18	.64 - 1.25	1.68 - 3.25	.51 - .99
2823	5 - 11	.38 - .79	1.04 - 2.17	.34 - .71
2824	5 - 11	.19 - .41	.31 - .69	.14 - .30
2833	1 - 4	.12 - .34	.10 - .28	.06 - .17
2851	4 - 8	.13 - .29	.21 - .49	.09 - .21
2861	4 - 9	6.35 -15.64	8.91 - 21.93	4.21 -10.37
2865	10 - 23	.45 - 1.07	.84 - 1.98	.33 - .78
2869	15 - 35	.18 - .41	.27 - .62	.12 - .27
2873	4 - 10	.21 - .52	.29 - .71	.13 - .33
2874	1 - 4	.06 - .20	.12 - .42	.04 - .13
2879	9 - 19	.82 - 1.72	1.34 - 2.82	.63 - 1.32
2892	4 - 10	1.63 - 4.45	1.71 - 4.68	1.06 - 2.88
2899	5 - 11	.80 - 1.94	1.13 - 2.74	.53 - 1.28
2911	89 - 181	.06 - .12	.33 - .67	.05 - .11
2992	3 - 7	.77 - 1.84	1.84 - 4.42	.59 - 1.41
3312	23 - 52	.12 - .26	.27 - .61	.10 - .22
3313	2 - 6	.46 - 1.20	1.39 - 3.60	.41 - 1.06
3315	4 - 8	.72 - 1.59	1.38 - 3.05	.57 - 1.25
33215	4 - 10	.37 - .90	.48 - 1.17	.27 - .66
3341	7 - 15	.78 - 1.78	3.11 - 7.08	.67 - 1.53
33516	15 - 31	.69 - 1.39	2.55 - 5.13	.60 - 1.21
34719	21 - 46	2.20 - 4.86	2.81 - 6.22	1.60 - 3.53
3711	4 - 11	.01 - .03	.05 - .11	.01 - .03
3714	3 - 10	.04 - .13	.08 - .22	.03 - .10

* Necessary data unavailable

rates and costs. This section also examines the potential cost of floodplain requirements.

1. Sensitivity of Corrective Action Costs. Total corrective action costs are very sensitive to whether corrective action occurs at individual units within a facility or at the facility as a whole. As described earlier in this preamble, two distributions were used to develop total costs in this analysis. The first distributed individual land disposal units by size and was used to estimate D&O costs on a unit-by-unit basis and to report costs by unit. The second distribution combined individual units to form multi-unit land disposal facilities and was used to estimate total corrective action costs on the basis of total acreage at land disposal sites.

If corrective action costs were to be estimated using the first distribution (on a unit-by-unit basis), instead of on a facility-by-facility basis, total costs reported would be significantly higher. Ranges of corrective action costs using the two distributions are reported in Table 20.

TABLE 20
Comparison of Corrective Action Costs
Using Units and Facilities
($ 000 000)

Scenario	Corrective Action Costs: Detect Year 49 & Pump 20 Years Using Strategy 1	Corrective Action Costs: Detect Year 0 & Pump 150 Years Using Strategy 2
5,662 units	96	1,176
2,424 facilities	51	646

As table 20 shows, if all 5,662 land disposal units were to undertake corrective action individually, counterpumping costs would range from $96 million to $1,176 million per year and would be 80 to 90 percent higher than the total corrective action costs reported in Total Costs.

Both of these estimates depend in part on plume sizes, which in this analysis were necessarily related to the surface areas used for waste management. However, areas used are not directly reported on the Part A of the permit application for some units, and therefore had to be derived. In addition, plumes may be larger than the facility area when corrective action begins due to irregular shapes, the orientation of the facility relative to ground water flow, or site-specific constraints on the location of recovery wells. The 50 percent area add-on used for sites with more than one type of unit deals with some of this imprecision. In any event, corrective action costs are relatively insensitive to plume size, if hydrogeologic conditions are held constant. As reported in table 21, the cost of corrective action for a 25 acre plume is only 28 to 45 percent more expensive than counterpumping for a 5 acre plume, although the size of the plume has increased by 400 percent. Similarly, while a 125-acre plume is 125 times bigger than a 1-acre plume, the counterpumping cost associated with the 125-acre plume is only 1.9 to 2.6 times greater, depending on the strategy used and the timing of corrective action.

TABLE 21
Comparison of Increases in Counterpumping Costs
With Increases in Plume Size

Plume Size In Acres	Counterpumping Cost: Strategy 1 for 20 Years Starting in Year 49		Counterpumping Cost: Strategy 2 for 150 Years Starting in Year 0	
	$ 000	% Change from Previous Value	$ 000	% Change from Previous Value
1	16	-	180	-
5	18	13	225	25
25	23	28	327	45
75	28	22	420	28
125	30	7	466	11

In the corrective action scenario where each unit takes corrective action individually, the average plume size is 7.3 acres. The average plume size increases to 15.6 acres when it is assumed that corrective action is taken on a facility basis. Even this difference, which probably is greater than the range of error in our plume size estimates, has an insignificant effect on total corrective action costs.

2. Sensitivity of Costs to Hydrogeologic Assumptions. EPA examined the effects of alternative assumptions regarding aquifer transmissivity and gradient on corrective action costs for two plume sizes.[1] The Agency found that changing gradient or transmissivity assumptions has almost no effect on costs for small plumes under Strategy 1 conditions. However, for large plumes

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1. In all cases, the small plume (100 ft x 200 ft) is approximately the size of the plume used to estimate corrective action costs for a 1/2 acre surface impoundment. This is two and one-half times as large as the plume size for the smallest (500 MT/yr) landfill modelled. The large plume (1000 ft x 2000 ft) is close in size to the plume used to estimate costs for a 35,000 metric ton per year landfill. A 20 acre surface impoundment would involve about the same size plume.

changing the gradient from 0.5 to 50 feet per mile or changing the transmissivity from 10,000 to 1,000,000 gallons per day per foot can increase the annual revenue requirement calculated for counterpumping by about 50 percent. Under Strategy 2 conditions, the same changes in transmissivity can increase costs for small plumes by 50 percent and costs for large plumes by about 150 percent. Details of this analysis appear in the docket report.

3. Sensitivity of Costs to Treatment Assumptions. All corrective action cost estimates displayed in this preamble assume that the ground water removed through counterpumping is treated in a facility built on site to deal with a simple mix of contaminants in low concentrations. EPA used a simple average of costs for three types of treatment: activated carbon; reverse osmosis; and a treatment train consisting of coagulation, flocculation, sedimentation and filtration. These processes are capable of addressing the bulk of potential ground water contaminants, and except in unusual cases the concentrations of pollutants that are likely to be encountered should be within the ranges that can be treated by these systems.

On balance, these estimates give a reasonable indication of likely costs in average situations. Specific scenarios would need to be addressed to substantially improve on these estimates.

Moving from an average of treatment costs to costs for a single approach can change corrective action costs up or down by a third to a half.

Some cost decreases may be possible if the pumped water contains only volatile pollutants that can be treated through air stripping. Where the volumes of recovered water are very low and the contaminants to be removed are of a suitable kind, pre-engineered treatment equipment can be trucked to the site at some cost savings. Large cost increases are possible if the recovered water contains contaminants in high concentrations, or if the recovered water contains a mixture of contaminants. Mixtures can require use of a combination of the approaches examined here, or use of more complex chemical or biological treatment. (Details are contained in the docket report.)

4. Adding a Slurry Wall to Reduce the Pumping Rate. EPA also examined an alternative strategy for compliance based on use of a confining slurry wall and a surface cover to minimize the amount of pumping and treatment required. This approach removes contamination, but at a very slow rate, so that for purposes of cost calculation, it must be assumed that the plume will exist for a very long time. EPA found that this approach could save money in many cases, compared to pumping at a higher rate over a shorter period of time. The difficulty in using this technique may be in demonstrating that the plume will be effectively contained and removed.

EPA estimated the cost of this strategy for a small plume (100 ft x 200 ft), since slurry wall costs increase more rapidly with plume size than do counterpumping costs. EPA determined that with a slurry wall in place pumping rates would be in the range of 10,000 to 50,000 gallons per year (38 to 189 MT/year). Because these rates are very low relative to what they would be

without the slurry wall (4 to 22 million gallons per year under base case conditions), EPA assumed that the contaminated ground water would be treated in pre-engineered facilities trucked to the site, at a cost of $85 per 1,000 gallons or $22 per metric ton. At this cost, over 250,000 gallons of recovered water--five to twenty-five times the amount expected--could be treated before a slurry wall becomes financially unattractive.

Use of a slurry wall would be even more attractive under pessimistic assumptions regarding gradient and transmissivity, because these changes would not affect the costs of the slurry wall approach. The slurry wall approach would be much less attractive with deeper plumes, and infeasible at depths greater than 150 feet.

5. Costs of Floodplain Standards. The Part 264 regulations require that facilities located in 100-year floodplains be designed, constructed, operated, and maintained to prevent washout of any hazardous waste by a 100-year flood.

Dike costs were only estimated for surface impoundments. It was assumed that impoundments are likely to be located in floodplains because they are often part of systems for treating industrial effluent before it is discharged in surface water. It was assumed that dikes are built around 3 sides of the surface impoundment, that there is a 40' buffer zone between the surface impoundment and the dike, and that dike construction is entirely independent from the surface impoundment.

EPA estimated the costs of constructing dikes of various heights to withstand the effects of a 100-year flood. Actual dike heights are likely to vary with floodplain topographies,

river depths, and heights during 100-year floods. Costs were estimated for dike heights of 2, 3, 5, and 9 meters, but the 3-meter (about 10 feet) height is used as an average cost estimate. Dike widths varied with height and ranged from 14 meters for a 2-meter high dike to 49 meters for a 9-meter high dike. The width of the dike significantly increases the amount of land required for the facility. For example, a 1/4 acre surface impoundment would need to be situated on 1.5 acres to accomodate the buffer zone and a 3 meter dike. Similarly, an 11 acre surface impoundment would require about 16 acres to allow for the buffer area and a 3 meter dike.

Annual revenue requirements for dikes of various heights were estimated in the same way that other D&O revenue requirements were estimated for surface impoundments. Costs for a 3 meter dike ranged from $3,000 for a 1/4-acre surface impoundment to $17,000 for an 11-acre impoundment. For smaller surface impoundments, these costs were about 50 percent of the basic costs of complying with the Part 264 regulations, and roughly 20 to 25 percent of the costs of retrofitting or replacing a facility. For large surface impoundments, a 3 meter dike would add about 15 percent to the basic compliance cost, and about 6 percent to the retrofit or replacement cost.

If it is assumed that all surface impoundments construct 3-meter dikes to protect against washout from a 100-year flood, the total incremental cost would be $29 million.[1]

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[1] Costs were estimated on a unit-by-unit basis for all 4240 surface impoundments. Estimating costs on a facility-by-facility basis for all land disposal sites would increase the total cost reported here by about 75 percent.

X. List of Subjects in 40 CFR Parts 122, 260, 264, and 265

List of Subjects in 40 CFR Part 122

Administrative practice and procedure, Air pollution control, Hazardous materials, Reporting requirements, Waste treatment and disposal, Water pollution control, Water supply, Confidential business information.

List of Subjects in 40 CFR Part 260

Administrative practice and procedure, Confidential business information, Hazardous materials, Waste treatment and disposal.

List of Subjects in 40 CFR Part 264

Hazardous materials, Packaging and containers, Reporting requirements, Security measures, Surety bonds, Waste treatment and disposal.

List of Subjects in 40 CFR Part 265

Hazardous materials, Packaging and containers, Reporting and recordkeeping requirements, Security measures, Surety bonds, Waste treatment and disposal, Waste supply.

Dated: _____

_____
Anne M. Gorsuch
Administrator

A P P E N D I X B

APPENDIX B
UNIT COSTS USED TO DEVELOP BASELINES

This Appendix lists the cost components that were used to develop the cost baselines for landfills, surface impoundments, land treatment areas and waste piles. Costs are listed by type of cost and size of unit. The appendix is organized as follows:

I. Landfill Unit Costs

   a. Capital Costs
   b. Initial Year Costs
   c. Annual Costs
   d. Last Year Costs
   e. Post Closure Costs

II. Surface Impoundment Unit Costs

   a. Capital Costs
   b. Initial Year Costs
   c. Annual Costs
   d. Last Year Costs
   e. Post Closure Costs
   f. Intermittent Costs

III. Land Treatment Unit Costs

   a. Capital Costs
   b. Initial Year Costs
   c. Annual Costs
   d. Last Year Costs
   e. Post Closure Costs

IV. Waste Pile Unit Costs

   a. Capital Costs
   b. Initial Year Costs
   c. Annual Costs
   d. Last Year Costs

I. LANDFILL BASELINE COSTS

a. CAPITAL COSTS ($ 000)
(YEAR 0)

COST COMPONENT	FACILITY SIZE IN METRIC TONS PER YEAR							
	500	2000	5000	7000	15000	35000	60000	123000
Pre-ISS Capital Costs								
Office	31	31	31	31	31	35	35	35
Dewatering Pumps	2	2	2	2	2	3	3	4
Road Gravel	2	3	4	4	5	6	7	9
Revegetation	1	2	3	3	4	5	6	7
Heavy Equipment	30	45	60	70	85	105	200	400
Truck scale	10	10	10	10	10	10	10	15
Water well	3	3	3	3	3	3	3	3
Utilities	10	10	10	10	10	10	10	10
Clearing & Grading	3	6	9	10	14	20	24	36
Subtotal	92	112	132	143	164	197	300	519
ISS Incremental Capital Costs								
Ground-water Wells	30	30	30	30	30	30	30	30
Contingency Equip.	13	13	13	13	13	13	13	13
Subtotal	43	43	43	43	43	43	43	43
ISS BASLINE CAPITAL COSTS	135	155	175	186	207	240	343	562

I. LANDFILL BASELINE COSTS (cont.)

b. INITIAL YEAR COSTS ($ 000)
(YEAR 0)

COST COMPONENT	FACILITY SIZE IN METRIC TONS PER YEAR							
	500	2000	5000	7000	15000	35000	60000	123000
Pre-ISS Initial Yr. Costs								
Land	10	21	34	41	63	99	133	197
Cell Excavation	3	11	27	38	79	189	318	634
Subtotal	13	32	61	79	142	288	451	831
ISS Incremental Initial Yr. Costs								
Detailed Disposal Records*	*	*	*	*	1	2	3	6
Part A Recordkeeping And Reporting	2	2	2	2	2	2	2	2
Waste Analysis Plan	4	4	4	4	4	4	4	4
Ground-Water Monitoring	10	10	10	10	10	10	10	10
Closure/Post Closure Plan	2	2	2	2	2	2	2	2
Systems Design	1	1	1	1	1	1	1	1
Regulatory Review	1	1	1	1	1	1	1	1
Part A Administration	2	2	2	2	2	2	2	2
Inspection	1	1	1	1	1	1	1	1
Training Course Development	12	12	12	12	12	12	12	12
Contingency Plan Development	2	2	2	2	2	2	2	2
Permit								
Offsite	4	4	4	4	4	4	4	4
Onsite	0	0	0	0	0	0	0	0
Runoff Control	7	9	10	11	13	16	18	22
Fencing	6	9	12	13	17	22	26	33
Subtotal								
Offsite	54	59	63	65	71	79	85	96
Onsite	50	55	59	61	67	75	81	92
TOTAL ISS BASELINE INITIAL YR COSTS								
OFFSITE	67	91	124	144	213	367	536	927
ONSITE	63	87	120	140	209	363	532	923

* less than $500

I. LANDFILL BASELINE COSTS (cont.)

c. ANNUAL COSTS ($ 000) (YEARS 1-20)

COST COMPONENT	FACILITY SIZE IN METRIC TONS PER YEAR							
	500	2000	5000	7000	15000	35000	60000	123000
Pre-ISS Annual Costs								
Cell Excavation	3	11	27	38	79	189	318	634
Clerical Labor	13	13	13	13	13	13	26	26
Operating Labor	20	20	20	20	20	40	40	60
Labor Burden	16	16	16	16	16	26	33	43
Supervision	8	8	8	8	8	13	16	22
Fuel	3	4	5	6	9	16	27	46
Electricity	2	2	2	2	3	3	3	5
Equip. Maint. Labor	1	2	2	2	3	4	6	13
Overhead	21	21	21	21	21	33	41	54
Insurance	2	2	2	2	2	2	2	2
G&A	1	1	1	1	1	1	1	1
Fees	21	25	31	35	52	91	135	245
Cell Closure	1	2	6	8	15	39	62	113
Subtotal	112	127	154	184	242	470	700	1264
ISS Incremental Annual Costs								
Runoff Control	7	9	10	11	13	16	18	22
Fencing	6	9	12	13	17	22	26	33
Ground-water Sampling & Analysis	5	5	5	5	5	5	5	5
Recordkeeping & Reporting	*	*	1	1	1	2	3	5
Personnel Training	4	4	4	4	4	6	6	6
Waste Testing								
Offsite	1	3	5	7	12	22	33	57
Onsite	4	4	4	4	4	4	4	4
Cell Closure Costs†								
Offsite	7	18	34	44	73	151	214	336
Onsite	14	34	66	86	143	297	423	656
Subtotal								
Offsite	30	48	71	85	125	224	305	464
Onsite	40	65	102	124	187	352	485	731
TOTAL ISS BASELINE ANNUAL COSTS								
OFFSITE	142	175	225	269	367	694	1005	1728
ONSITE	152	192	256	308	429	822	1185	1995

† Includes fees of 5% for inspection, 10% for engineering, and 15% for contingency.

I. LANDFILL BASELINE COSTS (cont.)

d. OTHER LAST YEAR COSTS ($ 000)
(YEAR 20)

COST COMPONENT	FACILITY SIZE IN METRIC TONS PER YEAR							
	500	2000	5000	7000	15000	35000	60000	123000
Pre-ISS Last Year Costs								
Subtotal	-	-	-	-	-	-	-	-
ISS Incremental Last Yr. Costs								
Decontamination & Certification	2	2	3	3	3	6	7	8
TOTAL ISS BASELINE LAST YEAR COST	2	3	3	3	3	6	7	8

I. LANDFILL BASELINE COSTS (cont.)

e. POST CLOSURE COSTS ($ 000) (YEARS 21-50)

COST COMPONENT	FACILITY SIZE IN METRIC TONS PER YEAR							
	500	2000	5000	7000	15000	35000	60000	123000
ISS Capital Costs								
Replanting (year 21)	*	*	1	1	2	5	9	19
Fence Replacement (year 36)	1	2	4	4	7	13	18	30
Damage Correction (year 35)	*	1	2	2	5	11	19	38
Leachate Monitoring & Disposal	*	1	3	4	9	22	38	77
ISS BASELINE CAPITAL COSTS	1	4	10	11	23	51	84	164
ISS Annual Costs								
Inspection	5	5	5	5	5	5	5	5
Mowing	*	*	*	*	*	1	2	4
Routine Maintenance (erosion repair, etc)	*	*	*	*	*	*	1	1
Fertilizer	*	*	*	*	1	2	3	7
Ground-water Sampling & Anlaysis	4	4	4	4	4	4	4	4
30% Contingency & Administrative	3	3	3	3	3	4	4	6
ISS BASELINE ANNUAL COSTS	12	12	13	13	14	16	19	27

* less than $500

II. SURFACE IMPOUNDMENT BASELINE COSTS

a. CAPITAL COSTS ($ 000) (YEAR 0)

COST COMPONENT	FACILITY SIZE IN ACRES					
	1/4	1/2	1	2	5	11
Pre-ISS Capital Costs						
Excavation	4	12	20	45	139	314
Access Road	1	2	2	3	4	6
Clearing & Grading	1	1	1	1	2	3
Revegetation	-	-	-	1	1	1
Inlet/Outlet	5	5	5	5	5	5
Fees (at 5%, 10% & 15%)	4	7	9	18	50	108
Subtotal	15	27	37	73	201	437
ISS Incremental Capital Costs						
Ground-water Wells	30	30	30	30	30	30
Fencing	9	12	16	21	32	46
Contingency Equipment	13	13	13	13	13	13
Subtotal	52	55	59	64	75	89
TOTAL ISS BASELINE CAPITAL COST	67	82	96	137	276	526

† Includes fees of 5% for inspection, 10% for engineering, and 15% for contingency.

II. SURFACE IMPOUNDMENT BASELINE COSTS (cont.)

b. INITIAL YEAR COSTS ($ 000) (YEAR 0)

COST COMPONENT	FACILITY SIZE IN ACRES					
	1/4	1/2	1	2	5	11
Pre-ISS Initial Yr. Costs						
Land	4	6	8	15	26	46
Subtotal	4	6	8	15	26	46
ISS Incremental Initial Yr. Costs						
Part A Recordkeeping And Reporting	2	2	2	2	2	2
Waste Analysis Plan	4	4	4	4	4	4
Ground-Water Monitoring	10	10	10	10	10	10
Closure/Post Closure Plan	2	2	2	2	2	2
Systems Design	1	1	1	1	1	1
Regulatory Review	1	1	1	1	1	1
Part A Administration	2	2	2	2	2	2
Inspection	1	1	1	1	1	1
Training Course Development	12	12	12	12	12	12
Contingency Plan Development	2	2	2	2	2	2
Subtotal	37	37	37	37	37	37
TOTAL ISS BASLINE INITIAL YR COSTS	41	43	45	52	63	83

II. SURFACE IMPOUNDMENT BASELINE COSTS (cont.)

c. ANNUAL COSTS ($ 000) (YEARS 1-20)

COST COMPONENT	FACILITY SIZE IN ACRES					
	1/4	1/2	1	2	5	11
Pre-ISS Annual Costs						
Subtotal	-	-	-	-	-	-
ISS Incremental Annual Costs						
Ground-water Sampling & Analysis	5	5	5	5	5	5
Recordkeeping & Reporting	3	3	3	3	3	3
Personnel Training	4	4	4	4	6	6
Waste Testing	4	4	4	4	4	4
Annual Report						
Regular Inspections	*	*	*	*	*	*
Subtotal	16	16	16	16	16	16
TOTAL ISS BASELINE ANNUAL COSTS	16	16	16	16	16	16

* less than $500

II. SURFACE IMPOUNDMENT BASELINE COSTS (cont.)

d. OTHER LAST YEAR COSTS ($ 000) (YEAR 20)

COST COMPONENT	FACILITY SIZE IN ACRES					
	1/4	1/2	1	2	5	11
Pre-ISS Last Year Capital Costs						
Fill/Compact/Slope †	9	29	47	110	335	900
Revegetation †	3	6	9	18	41	89
Subtotal	12	35	56	128	376	989
ISS Incremental Last Yr. Capital Costs						
Fill/Compact/Slope †	21	33	88	172	420	853
Subtotal	21	33	88	172	420	853
TOTAL ISS BASELINE LAST YEAR CAPITAL COSTS	33	68	144	300	796	1842
Other Pre-ISS Last Year Costs						
Subtotal	-	-	-	-	-	-
Other ISS Incremental Last Year Costs						
Decontamination & Certification	2	2	2	2	2	3
Subtotal	2	2	2	2	2	3
TOTAL ISS BASELINE OTHER LAST YEAR COSTS	2	2	2	2	2	3

† Includes fees of 5% for inspection, 10% for engineering, and 15% for contingency.

II. SURFACE IMPOUNDMENT BASELINE COSTS (cont.)

e. POST CLOSURE COSTS ($ 000) (YEARS 21-50)

COST COMPONENT	FACILITY SIZE IN ACRES					
	1/4	1/2	1	2	5	11
ISS Capital Costs						
Replanting	*	*	*	*	1	2
Fence Replacement	*	1	1	1	3	5
Damage Correction	*	*	*	1	2	5
Leachate Monitoring & Disposal	*	*	*	1	2	5
ISS BASELINE CAPITAL COSTS	1	1	2	3	8	17
ISS Annual Costs						
Inspection	2	2	2	2	2	2
Mowing	*	*	*	*	*	*
Routine Maintenance	*	*	*	*	*	*
Fertilizer	*	*	*	*	*	1
Ground-water Monitoring	1	1	1	1	1	2
30% Contingency & Administrative	1	1	1	1	1	2
ISS BASELINE ANNUAL COSTS	5	5	5	5	6	8

* less than $500

II. SURFACE IMPOUNDMENT BASELINE (cont.)

f. INTERMITTENT DREDGING QUANITITES (METRIC TONS)

YEAR DREDGE OCCURS	FACILITY SIZE IN ACRES					
	1/4	1/2	1	2	5	11
0						
1	500					
2		1,100	2,400	5,000		
3	500					
4	500	1,100				
5			2,400		21,400	
6	500	1,100				49,000
7	500			5,000		
8		1,100	2,400			
9	500					
10	500				21,400	
11		1,100	2,400	5,000		
12	500					49,000
13	500	1,100				
14			2,400			
15	500	1,100		5,000	21,400	
16	500					
17		1,100	2,400			
18	500					49,000
19	500	1,100		5,000		
20			2,400			

* Pre-ISS intermittent dredging costs, and ISS incremental dreging costs depend on the estimated pre-ISS and ISS per ton disposal cost.

III. LAND TREATMENT BASELINE COSTS

a. CAPITAL COSTS ($ 000) (YEAR 0)

COST COMPONENT	FACILITY SIZE IN ACRES				
	1.7	6.5	20.1	74.3	247.1
Pre-ISS Capital Costs	-	-	-	-	-
Subtotal	-	-	-	-	-
ISS Incremental Capital Costs					
Ground-water Wells	30	30	30	30	30
Fencing	10	18	32	61	111
Contingency Equipment	13	13	13	13	13
Runoff Control	9	14	21	38	65
Subtotal	62	75	96	142	219
TOTAL ISS BASELINE CAPITAL COST	62	75	96	142	219

III. LAND TREATMENT BASELINE COSTS (cont.)

b. INITIAL YEAR COSTS ($ 000) (YEAR 0)

COST COMPONENT	FACILITY SIZE IN ACRES 1.7	6.5	20.1	74.3	247.1
Pre-ISS Initial Yr. Costs	-	-	-	-	-
Subtotal	-	-	-	-	-
ISS Incremental Initial Yr. Costs					
Part A Recordkeeping And Reporting	2	2	2	2	2
Waste Analysis Plan	4	4	4	4	4
Ground-Water Sampling & Analysis	10	10	10	10	10
Closure/Post Closure Plan	2	2	2	2	2
Systems Design	1	1	1	1	1
Regulatory Review	1	1	1	1	1
Part A Administration	2	2	2	2	2
Inspection	1	1	1	1	1
Training Course Development	12	12	12	12	12
Contingency Plan Development	2	2	2	2	2
Detailed Disposal Records	*	*	*	1	3
Subtotal	37	37	37	38	40
TOTAL ISS BASLINE INITIAL YR COSTS	37	37	37	38	40

III. LAND TREATMENT BASELINE COSTS (cont.)

c. ANNUAL COSTS ($ 000) (YEARS 1-20)

COST COMPONENT	FACILITY SIZE IN ACRES				
	1.7	6.5	20.1	74.3	247.1
Pre-ISS Annual Costs					
Subtotal	-	-	-	-	-
ISS Incremental Annual Costs					
Annual Report	*	*	*	*	*
Ground-water Sampling & Analysis	5	5	5	5	5
Recordkeeping & Reporting	3	3	3	3	3
Personnel Training	4	4	4	6	6
Regular Inspections	*	*	*	*	*
Soil core, soil pore liquid, pH, and surface water analysis	50	50	50	50	50
Subtotal	62	62	62	64	64
TOTAL ISS BASELINE ANNUAL COSTS	62	62	62	64	64

* less than $500

III. LAND TREATMENT BASELINE COSTS (cont.)

d. OTHER LAST YEAR COSTS ($ 000) (YEAR 20)

COST COMPONENT	FACILITY SIZE IN ACRES				
	1.7	6.5	20.1	74.3	247.1
Pre-ISS Last Year Costs					
Subtotal	-	-	-	-	-
ISS Incremental Last Year Costs					
Decontamination & Certification	6	6	6	6	6
TOTAL ISS BASELINE LAST YEAR COSTS	6	6	6	6	6

III. LAND TREATMENT BASELINE COSTS (cont.)

e. POST CLOSURE COSTS ($ 000) (YEARS 21-50)

COST COMPONENT	FACILITY SIZE IN ACRES				
	1.7	6.5	20.1	74.3	247.1
ISS Capital Costs					
Wind Dispersal Control	-	-	13	13	67
ISS BASELINE CAPITAL COSTS	-	-	13	13	67
ISS Annual Costs					
Soil Pore-Liquid Monitoring	15	15	15	15	15
Ground-Water Monitoring	5	5	5	5	5
Wind Dispersal Control	*	*	24	90	300
ISS BASELINE ANNUAL COSTS	20	20	44	110	320

* Less than $500.

IV. WASTE PILE BASELINE COSTS

a. CAPITAL COSTS ($ 000)
(YEAR 0)

COST COMPONENT	FACILITY SIZE IN 000 OF CUBIC FEET					
	2	10	25	100	500	1000
Pre-ISS Capital Costs	-	-	-	-	-	-
Subtotal	-	-	-	-	-	-
ISS Incremental Capital Costs						
Fencing	2	3	4	6	10	13
Contingency Equipment	13	13	13	13	13	13
Runoff Control	4	5	6	9	15	20
Base/Liner	3	8	16	39	115	181
Subtotal	22	29	39	67	153	227
TOTAL ISS BASELINE CAPITAL COST	22	29	39	67	153	227

IV. WASTE PILE BASELINE COSTS (cont.)

b. INITIAL YEAR COSTS ($ 000) (YEAR 0)

COST COMPONENT	FACILITY SIZE IN 000 OF CUBIC FEET					
	2	10	25	100	500	1000
Pre-ISS Initial Yr. Costs	-	-	-	-	-	-
Subtotal	-	-	-	-	-	-
ISS Incremental Initial Yr. Costs						
Part A Recordkeeping And Reporting	2	2	2	2	2	2
Waste Analysis Plan	4	4	4	4	4	4
Closure/Post Closure Plan	2	2	2	2	2	2
Systems Design	1	1	1	1	1	1
Regulatory Review	1	1	1	1	1	1
Part A Administration	2	2	2	2	2	2
Inspection	1	1	1	1	1	1
Training Course Development	12	12	12	12	12	12
Contingency Plan Development	2	2	2	2	2	2
Subtotal	27	27	27	27	27	27
TOTAL ISS BASLINE INITIAL YR COSTS	27	27	27	27	27	27

IV. WASTE PILE BASELINE COSTS (cont.)

c. ANNUAL COSTS ($ 000) (YEARS 1-20)

COST COMPONENT	FACILITY SIZE IN 000 OF CUBIC FEET					
	2	10	25	100	500	1000
Pre-ISS Annual Costs	-	-	-	-	-	-
Subtotal	-	-	-	-	-	-
ISS Incremental Annual Costs						
Annual Report	*	*	*	*	*	*
Waste Testing	4	4	4	4	4	4
Personnel Training	4	4	4	4	4	6
Regular Inspections	*	*	*	*	*	*
Subtotal	8	8	8	8	8	10
TOTAL ISS BASELINE ANNUAL COSTS	8	8	8	8	8	10

* less than $500

IV. WASTE PILE BASELINE COSTS (cont.)

d. LAST YEAR COSTS ($ 000)
(YEAR 20)

COST COMPONENT	FACILITY SIZE IN 000 OF CUBIC FEET					
	2	10	25	100	500	1000
Pre-ISS Last Year Costs	-	-	-	-	-	-
Subtotal	-	-	-	-	-	-
ISS Incremental Last Year Costs						
Removal of Pile & Base	*	1	3	7	23	38
Disposal of Pile & Base[1]	4	12	26	85	355	670
Subtotal	4	13	29	92	378	708
TOTAL ISS BASELINE LAST YEAR COSTS	4	13	29	92	378	708

* Less than $500.

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[1] Pre-ISS disposal costs not estimated. ISS disposal costs assume disposal in a 123,000 MT offsite landfill at a cost of $15.30 per ton.

A P P E N D I X C

APPENDIX C

PART 264 ENGINEERING COSTS FOR LANDFILLS, SURFACE IMPOUNDMENTS, WASTE PILES AND LAND TREATMENT AREAS

This appendix contains tables listing the engineering cost estimates for the Part 264 designs described in Chapter IV for landfills, surface impoundments, waste piles, and land treatment areas. These cost estimates were used to calculate the incremental annual revenue requirements and first year cash requirements of the Part 264 regulations. Costs for landfills, surface impoundments, and waste piles were developed by Pope-Reid Associates, Inc. Costs for land treatment areas were developed by K.W. Brown.

DETAILED ENGINEERING COSTS
FOR A SINGLE SYNTHETIC LINER DESIGN
OFF-SITE LANDFILLS (On-site Clay)
($1000)

	FACILITY SIZE (MT/Year)							
	500	2000	5000	7000	15,000	35,000	60,000	123,000
Liner								
Excavation	2.2	7.8	18.5	25.6	52.6	120.6	202.0	402.5
Synthetic membrane	4.9	11.3	21.9	28.4	46.3	93.3	131.5	202.5
Run-on/run-off control system	0.7	1.1	1.6	1.8	2.3	3.3	3.9	4.9
Leachate collection system								
Drainage tiles	0.2	0.4	0.9	1.1	1.7	3.5	4.6	6.3
Liner buffer-sand	1.6	3.9	7.8	10.3	17.0	34.9	49.5	76.8
Gravel	1.2	2.9	5.9	7.8	13.1	27.2	38.8	60.6
Sump and pump	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
LINER SUBTOTAL	22.8	39.4	68.6	87.0	145.0	294.8	442.3	765.6
Final Cover								
Fill and slope	0.1	0.5	1.6	2.4	5.2	16.1	27.6	53.8
Run-off control	0.6	0.9	1.3	1.4	1.9	2.7	3.2	4.0
Vegetation	0.3	0.9	1.9	2.6	4.4	9.2	13.2	20.5
Topsoil	1.7	4.1	8.1	10.6	17.6	36.4	51.5	79.7
Sand drainage layer	1.2	3.2	6.7	8.9	15.1	32.0	45.8	71.5
Compacted clay layer	1.6	4.2	8.8	11.8	19.9	42.2	60.3	94.0
COVER SUBTOTAL	5.5	13.8	28.4	37.7	64.1	138.6	201.6	323.5
TOTAL	28.3	53.2	97.0	124.7	209.1	433.4	643.9	1089.1
Plus								
Engineering Fees @ 15%	4.3	8.0	14.5	18.7	31.4	65.0	96.6	163.4
Inspection Fees @ 5%	1.6	3.0	5.6	7.2	12.0	24.9	37.0	62.6
Contingency @ 25%	8.5	16.1	29.3	37.6	63.1	130.9	194.4	328.8
TOTAL PART 264 DESIGN COST:	42.7	80.3	146.4	188.2	315.6	654.2	971.9	1643.9

DETAILED ENGINEERING COSTS
FOR A SINGLE SYNTHETIC LINER DESIGN
ON-SITE LANDFILLS (Off-site Clay)
($1000)

	FACILITY SIZE (MT/Year)							
	500	2000	5000	7000	15,000	35,000	60,000	123,000
Liner								
Excavation	2.2	7.8	18.5	25.6	52.6	120.6	202.0	402.5
Synthetic membrane	4.9	11.3	21.9	28.4	46.3	93.3	131.5	202.5
Run-on/run-off control system	0.7	1.1	1.6	1.8	2.3	3.3	3.9	4.9
Leachate collection system								
Drainage tiles	0.2	0.4	0.9	1.1	1.7	3.5	4.6	6.3
Liner buffer-sand	1.6	3.9	7.8	10.3	17.0	34.9	49.5	76.8
Gravel	1.2	2.9	5.9	7.8	13.1	27.2	38.8	60.6
Sump and pump	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
LINER SUBTOTAL	22.8	39.4	68.6	87.0	145.0	294.8	442.3	765.6
Final Cover								
Fill and slope	0.1	0.5	1.6	2.4	5.2	16.1	27.6	53.8
Run-off control	0.6	0.9	1.3	1.4	1.9	2.7	3.2	4.0
Vegetation	0.3	0.9	1.9	2.6	4.4	9.2	13.2	20.5
Topsoil	1.7	4.1	8.1	10.6	17.6	36.4	51.5	79.7
Sand drainage layer	1.2	3.2	6.7	8.9	15.1	32.0	45.8	71.5
Compacted clay layer	5.3	13.8	28.9	38.6	65.2	138.1	197.4	307.7
COVER SUBTOTAL	9.2	23.4	48.5	64.5	109.4	234.5	338.7	537.2
TOTAL	32.0	62.8	117.1	151.5	254.4	529.3	781.0	1302.8
Plus								
Engineering Fees @ 15%	4.8	9.4	17.6	22.7	38.2	79.4	117.1	195.4
Inspection Fees @ 5%	1.8	3.6	6.7	8.7	14.6	30.4	44.9	74.9
Contingency @ 25%	9.7	19.0	35.3	45.8	76.8	159.8	235.8	393.3
TOTAL PART 264 DESIGN COST:	48.3	94.8	176.7	228.7	384.0	798.9	1178.8	1966.4

DETAILED ENGINEERING COSTS
FOR A DOUBLE LINER (SYNTHETIC/CLAY) DESIGN
OFF-SITE LANDFILLS (On-site Clay)
($1000)

	FACILITY SIZE (MT/Year)							
	500	2000	5000	7000	15,000	35,000	60,000	123,000
Liner								
Excavation	3.7	11.1	24.8	33.7	65.8	147.0	239.1	459.7
Synthetic membrane	5.4	12.1	23.1	29.8	48.1	95.8	134.5	206.2
Run-on/run-off control system	0.8	1.2	1.7	1.9	2.4	3.4	4.1	5.1
Leachate collection system								
Drainage tiles	0.2	0.5	1.1	1.5	2.4	5.4	7.3	10.5
Liner buffer-sand	1.8	4.3	8.3	10.8	17.7	35.8	50.6	78.2
Gravel	2.5	6.1	12.2	16.1	26.8	55.2	78.6	122.3
Sump and pump	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Clay	2.9	6.3	11.9	15.2	24.6	49.1	68.9	105.8
LINER SUBTOTAL	29.3	53.6	95.1	121.0	199.8	403.7	595.1	999.8
Final Cover								
Fill and slope	0.1	0.5	1.6	2.4	5.2	16.1	27.6	53.8
Run-off control	0.7	1.0	1.4	1.5	2.0	2.8	3.3	4.1
Vegetation	0.4	0.9	1.9	2.6	4.4	9.2	13.2	20.5
Topsoil	2.3	5.1	9.5	12.2	19.6	39.2	55.0	83.9
Sand drainage layer	1.2	3.2	6.7	8.9	15.1	32.1	45.8	71.5
Compacted clay layer	1.6	4.2	8.8	11.8	19.9	42.2	60.3	94.0
COVER SUBTOTAL	6.3	14.9	29.9	39.4	66.2	141.6	205.2	327.8
TOTAL	35.6	68.5	125.0	160.4	266.0	545.3	800.3	1327.6
Plus								
Engineering Fees @ 15%	5.3	10.3	18.8	24.1	39.9	81.8	120.1	199.1
Inspection Fees @ 5%	2.0	3.9	7.2	9.2	15.3	31.4	46.0	76.3
Contingency @ 25%	10.8	20.7	37.7	48.4	80.3	164.6	241.6	400.8
TOTAL PART 264 DESIGN COST:	53.7	103.4	188.7	242.1	401.5	823.1	1208.0	2003.8

DETAILED ENGINEERING COSTS
FOR A DOUBLE LINER (SYNTHETIC/CLAY) DESIGN
ON-SITE LANDFILLS (Off-site Clay)
($1000)

	FACILITY SIZE (MT/Year)							
	500	2000	5000	7000	15,000	35,000	60,000	123,000
Liner								
Excavation	3.7	11.1	24.8	33.7	65.8	147.0	239.1	459.7
Synthetic membrane	5.4	12.1	23.1	29.8	48.1	95.8	134.5	206.2
Run-on/run-off control system	0.8	1.2	1.7	1.9	2.4	3.4	4.1	5.1
Leachate collection system								
Drainage tiles	0.2	0.5	1.1	1.5	2.4	5.4	7.3	10.5
Liner buffer-sand	1.8	4.3	8.3	10.8	17.7	35.8	50.6	78.2
Gravel	2.5	6.1	12.2	16.1	26.8	55.2	78.6	122.3
Sump and pump	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Clay	9.4	20.6	38.9	49.8	80.6	160.6	225.5	346.2
LINER SUBTOTAL	35.8	67.9	122.1	155.6	255.8	515.2	751.7	1240.2
Final Cover								
Fill and slope	0.1	0.5	1.6	2.4	5.2	16.1	27.6	53.8
Run-off control	0.7	1.0	1.4	1.5	2.0	2.8	3.3	4.1
Vegetation	0.4	0.9	1.9	2.6	4.4	9.2	13.2	20.5
Topsoil	2.3	5.1	9.5	12.2	19.6	39.2	55.0	83.9
Sand drainage layer	1.2	3.2	6.7	8.9	15.1	32.1	45.8	71.5
Compacted clay layer	5.2	13.8	28.9	38.6	65.2	138.1	197.3	307.8
COVER SUBTOTAL	9.9	24.5	50.0	66.2	111.5	237.5	342.2	541.6
TOTAL	45.7	92.4	172.1	221.8	367.3	752.7	1093.9	1781.8
Plus								
Engineering Fees @ 15%	6.9	13.9	25.8	33.3	55.1	112.9	164.1	267.3
Inspection Fees @ 5%	2.6	5.3	9.9	12.7	21.1	43.3	62.9	102.4
Contingency @ 25%	13.8	27.9	52.0	67.0	110.9	227.2	330.2	537.9
TOTAL PART 264 DESIGN COST:	69.0	139.5	259.8	334.8	554.4	1136.1	1651.1	2689.4

DETAILED ENGINEERING COSTS
FOR A DOUBLE SYNTHETIC LINER DESIGN
OFF-SITE LANDFILLS (On-site Clay)
($1000)

	FACILITY SIZE (MT/Year)							
	500	2000	5000	7000	15,000	35,000	60,000	123,000
Liner								
Excavation	3.1	9.9	22.6	30.9	61.2	138.0	226.5	440.3
Synthetic membranes (2)	11.4	25.2	47.4	60.9	97.9	194.1	271.9	416.0
Run-on/run-off control system	0.8	1.2	1.7	1.9	2.4	3.4	4.0	5.0
Leachate collection system								
Drainage tiles	0.2	0.4	1.1	1.5	2.4	5.4	7.3	10.5
Liner buffer-sand	3.9	8.9	17.1	22.1	36.1	72.6	102.4	122.3
Gravel	2.5	6.1	12.2	16.0	26.8	55.2	78.6	157.9
Sump and pump	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
LINER SUBTOTAL	33.9	63.7	114.1	145.3	238.8	480.7	702.7	1164.0
Final Cover								
Fill and slope	0.1	0.5	1.6	2.4	5.2	16.1	27.6	53.8
Run-off control	0.7	1.0	1.3	1.5	2.0	2.8	3.3	4.1
Vegetation	0.3	0.9	1.9	2.6	4.4	9.2	13.2	20.5
Topsoil	2.1	4.7	9.0	11.7	18.9	38.3	53.8	82.5
Sand drainage layer	1.2	3.2	6.7	8.9	15.1	32.0	45.8	71.5
Compacted clay layer	1.6	4.2	8.9	11.8	19.9	42.2	60.3	94.0
COVER SUBTOTAL	6.0	14.5	29.4	38.9	65.5	140.6	204.0	326.4
TOTAL	39.9	78.2	143.0	184.2	304.3	621.3	906.7	1490.4

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DETAILED ENGINEERING COSTS
FOR A DOUBLE SYNTHETIC LINER DESIGN
ON-SITE LANDFILLS (On-site Clay) (Continued)
($1000)

	FACILITY SIZE (MT/Year)							
	500	2000	5000	7000	15,000	35,000	60,000	123,000
Plus								
Engineering Fees @ 15%	6.0	11.7	21.4	27.6	45.6	93.2	136.0	223.6
Inspection Fees @ 5%	2.3	4.5	8.2	10.6	17.5	35.7	52.2	85.7
Contingency @ 25%	12.0	23.6	43.2	55.6	91.9	187.6	273.7	449.9
TOTAL PART 264 DESIGN COST:	60.2	118.0	215.8	278.0	459.3	937.8	1368.6	2249.6

DETAILED ENGINEERING COSTS
FOR A DOUBLE SYNTHETIC LINER DESIGN
ON-SITE LANDFILLS (Off-site Clay)
($1000)

	FACILITY SIZE (MT/Year)							
	500	2000	5000	7000	15,000	35,000	60,000	123,000
Liner								
Excavation	3.1	9.9	22.6	30.9	61.2	138.0	226.5	440.3
Synthetic membranes (2)	11.4	25.2	47.4	60.9	97.9	194.1	271.9	416.0
Run-on/run-off control system	0.8	1.2	1.7	1.9	2.4	3.4	4.0	5.0
Leachate collection system								
Drainage tiles	0.2	0.4	1.1	1.5	2.4	5.4	7.3	10.5
Liner buffer-sand	3.9	8.9	17.1	22.1	36.1	72.6	102.4	122.3
Gravel	2.5	6.1	12.2	16.0	26.8	55.2	78.6	157.9
Sump and pump	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
LINER SUBTOTAL	33.9	63.7	114.1	145.3	238.8	480.7	702.7	1164.0
Final Cover								
Fill and slope	0.1	0.5	1.6	2.4	5.2	16.1	27.6	53.8
Run-off control	0.7	1.0	1.3	1.5	2.0	2.8	3.3	4.1
Vegetation	0.3	0.9	1.9	2.6	4.4	9.2	13.2	20.5
Topsoil	2.1	4.7	9.0	11.7	18.9	38.3	53.8	82.5
Sand drainage layer	1.2	3.2	6.7	8.9	19.9	32.0	45.8	71.5
Compacted clay layer	5.3	13.8	29.0	38.5	65.2	138.1	197.3	307.7
COVER SUBTOTAL	9.7	24.1	49.5	65.6	110.8	236.5	341.0	540.1
TOTAL	43.6	87.8	163.6	210.9	349.6	717.2	1043.7	1704.1

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DETAILED ENGINEERING COSTS
FOR A DOUBLE SYNTHETIC LINER DESIGN
ON-SITE LANDFILLS (Off-site Clay) (Continued)
($1000)

	FACILITY SIZE (MT/Year)							
	500	2000	5000	7000	15,000	35,000	60,000	123,000
Plus								
Engineering Fees @ 15%	6.5	13.2	24.5	31.6	52.5	107.6	156.5	255.6
Inspection Fees @ 5%	2.5	5.0	9.4	12.1	20.1	41.2	60.0	98.0
Contingency @ 25%	13.2	26.5	49.4	63.7	105.5	216.5	315.1	514.4
TOTAL PART 264 DESIGN COST:	65.8	132.5	246.9	318.3	527.7	1082.5	1575.3	2572.1

DETAILED ENGINEERING COSTS
FOR A SINGLE SYNTHETIC LINER DESIGN
SURFACE IMPOUNDMENTS
($1000)

	FACILITY SIZE (Acres)					
	0.25	0.50	1	2	5	11
Liner						
Excavation	5.2	10.9	22.5	46.3	162.3	365.5
Run-on/run-off control system (Berm)	0.8	1.1	1.6	2.2	3.4	5.0
Soil layer	0.9	1.8	3.6	7.0	17.5	38.2
Synthetic membrane	10.3	19.5	37.1	71.6	173.8	374.1
Leachate collection system						
Drainage tiles	0.3	0.5	0.7	2.6	6.5	13.6
Liner buffer-sand	3.7	7.0	13.7	26.8	66.1	143.6
Sump and pump	12.0	12.0	12.0	12.0	12.0	12.0
LINER SUBTOTAL	33.2	52.8	91.2	168.5	441.6	952.0
Final Cover						
Fill and slope	5.3	11.4	25.0	55.4	190.0	490.9
Run-off control	2.9	3.9	5.4	7.5	11.7	17.3
Vegetation	1.3	2.4	4.4	8.4	19.9	42.5
Topsoil	12.0	22.7	43.5	84.4	205.1	444.1
Compacted clay layer	16.8	31.8	60.9	118.1	287.1	621.5
COVER SUBTOTAL	38.3	72.2	139.2	273.8	713.8	1616.3
TOTAL	71.5	125.0	230.4	442.3	1155.4	2568.3
Plus						
Engineering Fees @ 15%	10.7	18.8	34.6	66.4	173.3	385.2
Inspection Fees @ 5%	4.1	7.2	13.2	25.4	66.4	147.7
Contingency @ 25%	21.6	37.7	69.6	133.5	348.8	775.3
TOTAL PART 264 DESIGN COST:	107.9	188.7	347.8	667.6	1743.9	3876.5

DETAILED ENGINEERING COSTS
FOR A DOUBLE LINER (SYNTHETIC/CLAY) DESIGN
SURFACE IMPOUNDMENTS
($1000)

	FACILITY SIZE (Acres)					
	0.25	0.50	1	2	5	11
Liner						
Excavation	7.7	15.5	31.4	63.3	203.3	453.6
Run-on/run-off control system (Berm)	0.8	1.2	1.6	2.2	3.4	5.0
Soil layer	0.9	1.8	3.6	7.1	17.5	38.2
Synthetic membrane	10.4	19.5	37.1	71.6	173.8	374.1
Leachate collection system						
Drainage tiles	0.3	0.5	0.7	2.6	6.5	13.6
Liner buffer-sand	5.6	10.7	20.8	40.5	99.7	216.1
Sump and pump	12.0	12.0	12.0	12.0	12.0	12.0
Clay	13.0	24.0	45.1	86.2	207.8	445.4
LINER SUBTOTAL	50.7	85.2	152.3	285.5	724.0	1558.0
Final Cover						
Fill and slope	5.3	11.4	25.0	55.4	190.0	490.9
Run-off control	2.9	3.9	5.4	7.5	11.7	17.3
Vegetation	1.3	2.4	4.4	8.4	19.9	42.5
Topsoil	12.0	22.7	43.5	84.4	205.1	444.1
Compacted clay layer	16.8	31.8	60.9	118.1	287.1	621.5
COVER SUBTOTAL	38.3	72.2	139.2	273.8	713.8	1616.3
TOTAL	89.0	157.4	291.5	559.3	1437.8	3174.3
Plus						
Engineering Fees @ 15%	13.3	23.6	43.7	83.9	215.7	476.2
Inspection Fees @ 5%	5.1	9.1	16.8	32.2	82.7	182.5
Contingency @ 25%	26.9	47.5	88.0	168.8	434.0	958.2
TOTAL PART 264 DESIGN COST:	134.3	237.6	440.0	884.2	2170.2	4791.2

DETAILED ENGINEERING COSTS
FOR A DOUBLE SYNTHETIC LINER DESIGN
SURFACE IMPOUNDMENTS
($1000)

	FACILITY SIZE (Acres)					
	0.25	0.50	1	2	5	11
Liner						
Excavation	6.6	13.6	27.7	56.3	186.6	418.0
Run-on/run-off control system (Berm)	0.8	1.1	1.6	2.2	3.4	5.0
Soil layer	0.9	1.8	3.6	7.0	17.5	38.2
Synthetic membranes (2)	22.4	41.3	77.6	147.9	354.9	758.9
Leachate collection system						
Drainage tiles	0.3	0.5	0.7	2.6	6.5	13.7
Liner buffer-sand	5.9	11.2	21.4	41.4	101.1	218.2
Gravel	3.1	5.8	11.3	21.9	53.7	116.2
Sump and pump	12.0	12.0	12.0	12.0	12.0	12.0
LINER SUBTOTAL	52.0	87.3	115.9	291.3	735.7	1580.2
Final Cover						
Fill and slope	5.3	11.4	25.0	55.4	190.0	490.9
Run-off control	2.9	3.9	5.4	7.5	11.7	17.3
Vegetation	1.3	2.4	4.4	8.4	19.9	42.5
Topsoil	12.0	27.7	43.5	84.4	205.1	444.1
Compacted clay layer	16.8	31.8	60.9	118.1	287.1	621.5
COVER SUBTOTAL	38.3	72.2	139.2	273.8	713.8	1616.3
TOTAL	90.3	159.5	295.1	565.1	1449.5	2196.5
Plus						
Engineering Fees @ 15%	13.5	23.9	44.2	84.7	217.4	329.5
Inspection Fees @ 5%	5.2	9.2	17.0	32.5	83.3	126.3
Contingency @ 25%	27.3	48.1	89.1	170.6	437.6	663.0
TOTAL PART 264 DESIGN COST:	136.3	240.7	445.4	852.9	2187.8	3315.3

DETAILED ENGINEERING COSTS
FOR A DOUBLE SYNTHETIC LINER DESIGN
WASTE PILES -- ISS AND PART 264 REQUIREMENTS
($1000)

	Facility Size (cu ft)					
	2,000	10,000	25,000	100,000	500,000	1,000,000
Liner						
Run-on/run-off control system	2.7	3.5	4.2	5.7	8.7	10.6
Clearing, grubbing, excavation	0.3	0.8	1.6	3.9	11.4	18.0
Synthetic membranes (2)	1.6	4.7	8.9	22.1	64.4	101.6
Leachate collection system						
- Drainage tiles	0.9	1.6	2.0	3.1	7.2	11.3
- Sand	0.4	1.2	2.3	5.7	16.7	26.4
- Wet well and sump pump	6.0	6.0	6.0	6.0	6.0	6.0
Miscellaneous						
Wind dispersal prevention	0.1	0.2	0.4	0.9	2.6	4.1
Fence and gate	1.9	2.8	3.7	5.4	8.8	10.8
SUBTOTAL	13.9	20.8	29.1	52.8	125.8	188.8
Fees						
Engineering and inspection @10%	1.4	2.1	2.9	5.3	12.6	18.9
Contingency @10%	1.5	2.3	3.2	5.8	13.8	20.8
TOTAL	16.8	25.2	35.2	63.9	152.2	228.5

DETAILED ENGINEERING COSTS
FOR A DOUBLE SYNTHETIC LINER DESIGN
WASTE PILES -- CLOSURE REQUIREMENTS
($1000)

	Facility Size (cu ft)					
	2,000	10,000	25,000	100,000	500,000	1,000,000
Closure						
Remove waste and containment system	0.2	0.6	1.2	3.5	12.8	22.9
Fees						
Inspection/testing @5%	0.01	0.02	0.06	0.2	0.6	1.1
Contingency @10%	0.02	0.06	0.1	0.4	1.3	2.4
SUBTOTAL	0.23	0.7	1.4	4.1	14.7	26.4
Disposal						
At secure landfill	3.5	13.1	29.3	101.9	458.8	887.9
TOTAL	3.73	13.8	30.7	106.0	473.5	914.3

DETAILED ENGINEERING COSTS
FOR A STURDY IMPERMEABLE BASE DESIGN
WASTE PILES -- ISS OR PART 264 REQUIREMENTS
($1000)

	Facility Size (cu ft)					
	2,000	10,000	25,000	100,000	500,000	1,000,000
Liner						
Run-on/run-off control system	2.9	3.9	4.7	6.6	10.2	12.4
Clearing, grubbing, excavation	0.4	1.2	2.3	5.6	16.4	25.9
Impermeable base	2.0	5.6	10.9	26.8	78.5	123.6
Miscellaneous						
Wind dispersal prevention	0.1	0.2	0.4	0.9	2.6	4.1
Fence and gate	2.2	3.3	4.3	6.3	10.4	12.9
SUBTOTAL	7.6	14.2	22.6	46.2	118.1	178.9
Fees						
Engineering and inspection @ 10%	0.8	1.4	2.3	4.6	11.8	17.9
Contingency @ 10%	0.8	1.6	2.5	5.1	13.0	19.7
TOTAL	9.2	17.2	27.4	55.9	142.9	216.5

DETAILED ENGINEERING COSTS
FOR A STURDY IMPERMEABLE BASE DESIGN
WASTE PILES -- CLOSURE REQUIREMENTS
($1000)

	Facility Size (cu ft)					
	2,000	10,000	25,000	100,000	500,000	1,000,000
Closure						
Remove waste and containment system	0.4	1.1	2.2	5.8	19.5	33.4
Fees						
Inspection/testing @5%	0.02	0.06	0.1	0.3	1.0	1.7
Contingency @10%	0.04	0.1	0.2	0.6	2.1	3.5
SUBTOTAL	0.5	1.3	2.5	6.7	22.6	38.6
Disposal						
At secure landfill	5.3	18.4	39.4	126.8	531.6	1,002.3
TOTAL	5.8	19.7	41.9	133.5	554.2	1,040.9

DETAILED ENGINEERING COSTS
FOR A STURDY IMPERMEABLE BASE DESIGN
WASTE PILES -- INSPECTION REQUIREMENTS
($1000)

	Facility Size (cu ft)					
	2,000	10,000	25,000	100,000	500,000	1,000,000
Inspection						
Waste removal (minimum is $200)	0.2	0.2	0.2	0.9	4.3	8.5
Inspection and reporting	0.1	0.1	0.1	0.1	0.1	0.1
TOTAL	0.3	0.3	0.3	1.0	4.4	8.6

A P P E N D I X D

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Geraghty & Miller, Inc.

CONSULTING GROUND-WATER GEOLOGISTS AND HYDROLOGISTS

May 27, 1982

Environmental Protection Agency
Office of Solid Waste
Washington, D.C.

Gentlemen:

This information is a documentation of Geraghty & Miller, Inc.'s analytical efforts in support of EPA's estimation of costs of containment of plumes of contamination. The "working papers" which provide explanations of the technical basis of the cost estimates, are solely for use in support of EPA's regulatory analysis. They are not considered to be in suitable form for general publication.

The conceptual basis of the document was developed in a series of team problem definition meetings with Sobotka and Company, Inc., and Public Interest Economics Center with the purpose of augmenting EPA's positon in benefits assessment. As such, the format and coverage of the information reflect the results of these meetings and are intended to form the basis for estimating costs of containment nationwide.

Sincerely,

GERAGHTY & MILLER, INC.

Jeffrey S. Mahan
Senior Scientist

COST ESTIMATES FOR CONTAINMENT OF PLUMES OF CONTAMINATED GROUND WATER

WORKING PAPERS DEVELOPED FOR
THE UNITED STATES ENVIRONMENTAL
PROTECTION AGENCY UNDER:

CONTRACT NO.: 68-01-5838
SUBCONTRACT NO. 28

MAY 1982

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PREFACE

The cost estimates presented in this draft document were prepared at the request of the EPA in support of their benefits estimation activities related to regulations promulgated under RCRA.

The format in which costs are presented (e.g., Capital and Annual Operation and Maintenance) was selected to conform to the analytical requirements of the EPA. Both Capital (K) and Operation and Maintenance (O&M) costs are presented in 1981 dollars unless otherwise specified. Due to the level of generalization required for policy use, cost estimates developed in this project should be considered as "model costs" or approximations based on the conditions/caveats described in the text. As a result, significant variations in actual containment costs can be realized at specific sites. Unit costs are presented, where appropriate, to provide maximum flexibility in the use of the model costs.

The cost estimation algorithms and resultant model costs are based on Geraghty & Miller, Inc. s experience and contact with related industry (e.g., drillers, equipment manufacturers, and slurry wall contractors). A formal

validation procedure has not been performed, however, and will be required to assure confidence in the model outputs. This procedure would involve a review of Geraghty & Miller, Inc., and other projects where these containment techniques are applied.

Estimates of treatment costs and surface infrastructure requirements were developed in conjunction with SCS Engineers. Data on treatment facility construction and O&M costs were derived principally from the an EPA document, "Estimating Water Treatment Costs," by Gumerman, Culp, and Hansen (1979) of Culp, Wesner and Culp. Principal findings and assumptions in these areas are presented in Appendices D and E.

Additional analytical efforts will be required to fully utilize model costs in regulatory policy analysis. This may include developing distributions of cost on the basis of regional variations in ground-water recharge, aquifer dicharge, plume characteristics and other data base requirements noted in the text.

Every effort was made in this document to develop transparent and reproducible cost estimates. However, since numerous computational algorithms were applied, round-

ing error and lack of resolution in graphically derived support data can result in ± 5 percent computational error. Therefore, when attempting to verify aggregated cost estimates, this type of variation should be anticipated.

In addition to thorough technical documentation, a glossary of terms is presented in Appendix A in order to acquaint the reader with frequently used technical terms.

INTRODUCTION

The purpose of this study is to develop model cost estimates for containment of plumes of contaminated ground water encountered in the process of EPA regulatory compliance. It is commonly recognized that site-specific plume and hydrogeologic conditions are highly variable and greatly influence containment costs. For this reason, a range of costs were generated over a range of site conditions.

Little effort was applied in developing an "average" cost or plume condition, as this is largely a function of specific scenarios to be studied by EPA. Summary cost tables presented in this introduction should not be considered as typical, but as examples of costs that would be incurred for the conditions defined, given the assumptions and caveats. Subsequent efforts will be required to establish statistical distributions for plume sizes, depths, and other significant driving variables in order to fully utilize the cost matrices in this study.

Total containment costs and corresponding support data are presented for various scenarios in Appendices B through I. Source data for unit costs were derived from the published literature and appropriate industry sources as

indicated in the list of references. The costs are primarily developed to be useful to EPA in comparing selected containment cost elements within techniques and to a lesser extent among techniques. A rigorous cost comparison of techniques is possible, but would require further manipulation of the cost data such as capitalization of the O&M costs or an expression of capital costs over an appropriate time-stream. However, additional assumptions such as longevity of structural controls such as walls and wells and the time-frame for operating recovery well or drain systems are required to develop comparable life-cycle costs for fluid isolation and removal systems.

Conceptual Approach

Containment costs are developed through a model approach where plume and hydrogeological conditions are substantially simplified. Cost estimates are not based on empirical data or actual case studies. This should be done in a formal validation effort in order to more fully support the study results.

A series of cost estimation algorithms are developed for a range of plume and hydrogeological conditions.

These algorithms are primarily computational rules and conventions for calculating containment requirements. Costs are presented in table form to best reflect the influence of the primary driving variables. For example, the driving variables specified in the background cost matrices include:

- Plume dimensions - width x length x depth
- Hydraulic gradient (I)
- Transmissivity (T)
- Aquifer discharge (Q)
- Treatment requirements

Sensitivity analyses are presented graphically to indicate key driving variables or conditions affecting total containment costs (Appendices G, I).

Overview of Plume Characteristics

Most ground-water contamination incidents are local phenomena affecting only the uppermost aquifers. The area over which ground-water quality is significantly degraded is typically less than a mile or two long and a half a mile wide with pollutants moving at an average rate of less than one foot per day. These conditions are reflected in the model plume sizes studied in the project.

Ranges/options for plume related variables considered in the cost estimation models include:

- Plume dimensions
  - width: 100 to 2000 feet
  - length: 200 to 10,000 feet
  - depth: 25 to 200 feet
- Hydraulic gradient
  - .5 to 500 feet/mile
- Aquifer transmissivity
  - 1000 to 1,000,000 gallons/day/foot
- Aquifer discharge
  - .05 to 5 mgd/mile

These characteristics impact the cost and the relative effectiveness/efficiency of the containment techniques costed herein. In addition, factors such as plume depth and strength of earth materials determine the feasibility of certain techniques (e.g., drains and slurry walls are limited to shallow depths and materials that can be excavated).

Concentrations of contaminants are not explicitly considered in the cost algorithms, except in the recovery well approach, where treatment costs assume low concentrations of contaminants. Similarly, the algorithms do

not consider the mobility of contaminants within aquifers which can affect the period of operation of a recovery well system.

Other factors of significance such as institutional constraints and land values are not factored into the costs. Excavation or other source removal requirements related to the contaminant source are not considered in the cost model.

Overview of Containment Techniques

This study focuses solely on the containment of contaminants in aquifers through fluid removal and isolation systems. The objective of these systems is not to clean-up or rehabilitate, for the rehabilitation of aquifers contaminated by selected chemicals is often not economically or technically feasible. A number of techniques for clean-up have been applied or are under development, but are likely to be applicable under limited conditions, and attempts at clean-up are not widespread. In this study, the two principal techniques considered for achieving containment by halting migration are:

- Fluid removal systems that use wells or drains to recover and, if needed, treat contaminated ground water.

Table 1. Total Containment Costs for Three Remedial Options Under Median Hydrogeologic Conditions[a]

Remedial Option	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)															
	100 x 200		100 x 500		500 x 1000		500 x 2500		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
	K	O&M	K	O&M	K	O&M	K	O&M	K	O&M	K	O&M	K	O&M	K	O&M
Fluid Isolation With Slurry Wall and No Land Surface Treatment	240	10	495	10	1041	10	2255	10	2045	10	4567	10	3963	10	8845	10
Fluid Isolation With Slurry Wall and Surface Sealing	253	10	528	10	1361	10	3053	10	3325	10	7682	10	8963	10	21565	10
Strategy 1[b] Fluid Removal Without Treatment	74	15	80	15	120	15	160	15	183	16	251	16	297	19	449	20
Strategy 1[b] Fluid Removal With Reverse Osmosis Treatment	118	39	124	39	250	63	290	63	398	81	466	81	637	109	789	110
Strategy 2[c] Fluid Removal Without Treatment	75	15	103	18	140	19	229	24	192	22	353	33	329	29	766	54
Strategy 2[c] Fluid Removal With Reverse Osmosis Treatment	205	63	353	92	540	119	979	184	792	165	1553	253	1329	224	2766	354

[a] Plume Depth: 75 feet
Transmissivity: 100,000 gpd/ft
Gradient: 5 feet/mile
Aquifer Discharge: 0.5 mgd/mile

[b] Strategy 1 involves locating recovery wells or drains near toe of plume that is migrating in only one horizontal direction

[c] Strategy 2 involves locating wells or drains inside a plume that is migrating in all horizontal directions

Fluid isolation systems that use slurry walls, and if needed, treatment or modifications to the land surface to contain the contaminated ground water and limit additional recharge.

Other techniques such as insitu chemical or biological treatment, pressure grouting, contaminant dilution, deep injection well disposal, etc., are limited in application and performance data and are not addressed.

Summary of Costs

The model costs developed in this study are presented in detail in Appendices F and H with supportive data and cost sensitivities presented in the other Appendices. A brief summary of costs representing "mid-range" scenarios is presented in Table 1. It is clear from the analysis that capital costs are higher for fluid isolation wall systems than fluid removal systems. However, operation and maintenance costs are higher in fluid removal systems due to treatment, pumping and servicing requirements.

Overview of Assumptions

In order to develop containment costs on a model basis, a number of simplifying assumptions related to plume and aquifer conditions were required. Those related to aquifer conditions include:

- Aquifers are single layers of homogeneous and isotropic porous media.
- Aquifers are unconfined with a water table as the upper boundary of the aquifer.
- Aquifer transmissivity is constant in both space and time.
- Under pre-response conditions, the water table is everywhere 10 feet below land surface.
- Aquifers are bounded below by impermeable earth materials at constant depths from land surface.
- In lateral directions from the plume, aquifers have no physical or political boundaries.
- The aquifer matrix is a consolidated but poorly-cemented material which can be drilled, excavated, or otherwise penetrated with equipment specified for each containment technique.

Further assumptions relating to plume conditions include:

- Plumes are single-phase homogeneous fluid mixtures of ground water and leachate.
- In plan view, plumes are assumed to have ellipical shapes with minor/major axes ratios of 1:2 or 1:5.
- Plumes encompass the surface source of the leachate and extend away from the source in the direction of the local hydraulic gradient.
- Plumes are located in the general vicinity of metropolitan areas; however, the land surface above plumes is accessible for engineering construction activities.

Additional assumptions related to control measures are presented in the respective chapters.

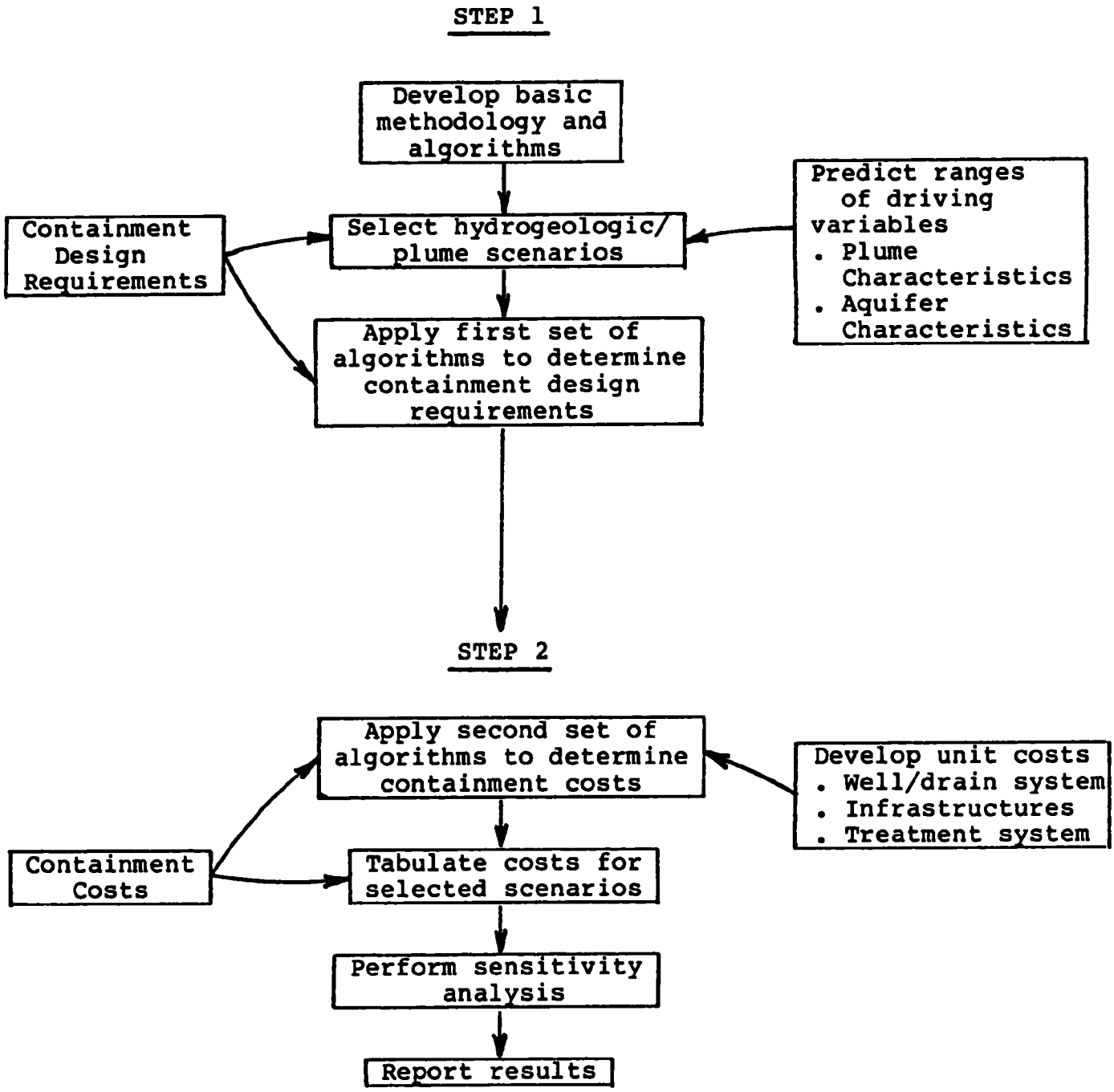
COST OF CONTAINMENT BY FLUID REMOVAL/TREATMENT

Model costs for containment by removal and treatment of plume fluids were determined with the sequence of work-tasks shown in Figure 1. As shown, there are basically two major steps in estimating the cost for containment. The first step is to determine containment design requirements by applying a set of algorithms for selected scenarios based on plume and aquifer characteristics. Containment design requirements are the number, size, and capacity of various engineered structures needed to remove, transport, and treat contaminated fluids. In the second step, a conceptual design and cost estimate are developed for the structures. This is accomplished by developing unit costs for the structures and applying a second set of algorithms for the selected scenarios.

A sensitivity analysis was performed in order to find the most sensitive variables affecting costs and to serve as a basis for discussing how the basic assumptions affect total costs. The analysis was qualitative and based on visual inspection of graphs of cost versus the driving variables.

FIGURE 1

SEQUENCE OF TASKS FOR COSTING CONTAINMENT BY FLUID REMOVAL/TREATMENT SYSTEMS



Containment Design Requirements

The containment design requirements are basic design data which include the number, size, and discharge capacity of various engineered structures. The structures considered in this study include recovery wells and drains, infrastructure pipelines, roads, powerlines, etc., and three treatment options.

The design requirements for recovery wells are the location and total number of wells of a particular depth having a calculated discharge capacity. Design requirements for recovery drains include the location, length, and calculated discharge capacity for each drain. The well/drain location is primarily a function of the pre-response plume movement and the corresponding containment strategy. Size and discharge capacity are determined with hydraulic models that translate into mathematical algorithms.

Design requirements for infrastructures are the number, spacing, and individual discharge capacity of each well or drain in the system along with plume width and length. More details about design considerations and costs of infrastructures are presented in Appendix D. Design requirements for treatment would normally include total

discharge from wells or drains and the identity and concentration of contaminants in the waste stream. For this study, however, the latter two are replaced with the assumption that the contaminants are treatable and can be removed by techniques such as activated carbon filtration, reverse osmosis, or coagulation/floculation/sedimentation/filtration as described in Appendix E.

General Approach

Containment requirements are determined through the use of simple, conceptual plume and aquifer models with a set of simple mathematical algorithms. The methodology used involves the selection of driving variables and scenarios within a set of well defined assumptions. Two physical containment strategies were developed and resultant computational algorithms were used to tabulate design requirements.

Selected classes of driving variables include plume and aquifer characteristics and engineering constraints as shown in Figure 2. Within the major components affecting costs is a hierarchy of variables that become more specific and quantifiable at lower levels of the diagram with specific driving variables identified along the lowest level of the diagram.

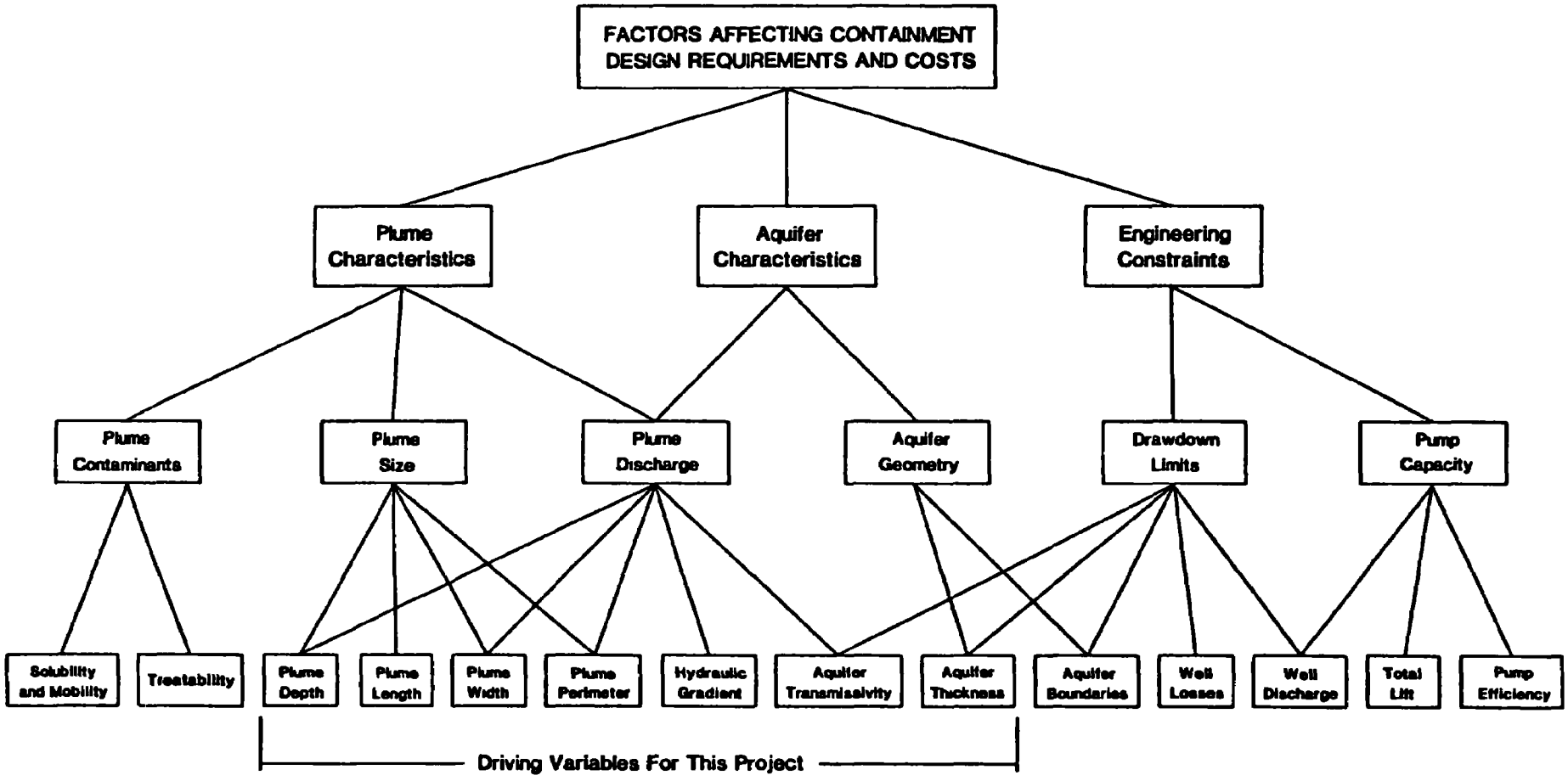


FIGURE 2. Factors Affecting Containment by Fluid Removal/Treatment Systems

Driving variables were assigned a range of values to represent site conditions that could be encountered in the United States mainland. Other variables shown on the figure were held constant or handled through caveats because of their smaller relative importance, and the budgetary constraints of this study. The possible effects on costs resulting from this is addressed through sensitivity analyses.

As mentioned, a series of assumptions were developed in parallel with the selection of driving variables and are fundamental in establishing the containment strategies. In fact, two basic assumptions with respect to hydraulics represent the basis of our strategies. First, a uniform hydraulic gradient is assumed where the plume elongates in the direction of flow. This "favorable" situation is a principal requirement in the Strategy 1 containment approach.

Secondly, a radially-directed gradient is assumed with the plume spreading in all directions. This "least favorable" situation of radial-plume movement requires a Strategy 2 containment method. These two extremes bracket all possible cases of horizontal plume movement within a single aquifer. The development of containment costs by

fluid removal for these two extremes theoretically establishes the range of costs likely to be encountered. Details of Strategies 1 and 2 are presented in the following subsections.

For the purpose of determining the containment design requirements, a scenario is defined by four driving variables in Figure 2. These variables and the number of values assigned to each are as follows:

- Four Hydraulic gradients
- Four Aquifer transmissivities
- Eight Plume sizes (length x width)
- Five Plume depths

The total number of possible scenarios that can be created is numerous and includes some situations not likely to be encountered in nature. There are potentially 16 combinations of gradient and transmissivity; however, only 10 combinations create aquifer discharges that, in our opinion, are realistic.

Strategy 1

Strategy 1 is developed to deal with the most favorable plume migration condition where there is a unidirectional gradient operating parallel to the major axis of a plume.

This strategy takes advantage of the unidirectional gradient by locating recovery wells or drains at the downstream end, or "toe" of the plume, a short distance inside the plume boundary. Technical assumptions applying to the various mathematical models used in both Strategy 1 and 2 calculations are outlined in Table 2.

Figure 3 shows an example of Strategy 1 conditions where a single recovery well is used to contain a plume that is migrating in a unidirectional flow field. The recovery well must produce at least the same amount of volumetric discharge occurring in that part of the aquifer which encompasses the plume. In Figure 3, this would be the quantity of water flowing per unit time between the flow lines that bound the sides of the plume. On a specific site, this "plume discharge" would be estimated with the Darcy equation:

$$Q_p = TIW$$

where,

Q_p = Plume discharge, $[L^3/T]$

T = Aquifer transmissivity, $[L^2/T]$

I = Hydraulic gradient, [dimensionless]

W = Width of plume, [L]

TABLE 2

HYDRAULIC MODEL ASSUMPTIONS

- Wells or drains are completed to the lower impermeable boundary of the aquifer and produce water from the entire saturated thickness of the aquifer.

- For predicting drawdowns around pumping wells, all the assumptions inherent with the Theis (1935) equation, as modified by Cooper and Jacob (1946), are in effect.

- After 100 days of pumping at a constant rate from each well or drain, the hydraulic system has reached steady state, i.e. the drawdowns caused by pumping will stabilize and no longer change.

- Transmissivity does not change due to reductions in saturated thickness of the water-table aquifer near pumping wells.

- Additional drawdown due to well losses are assumed to be negligible.

- Transport mechanisms involving mechanical dispersion and chemical diffusion are negligible.

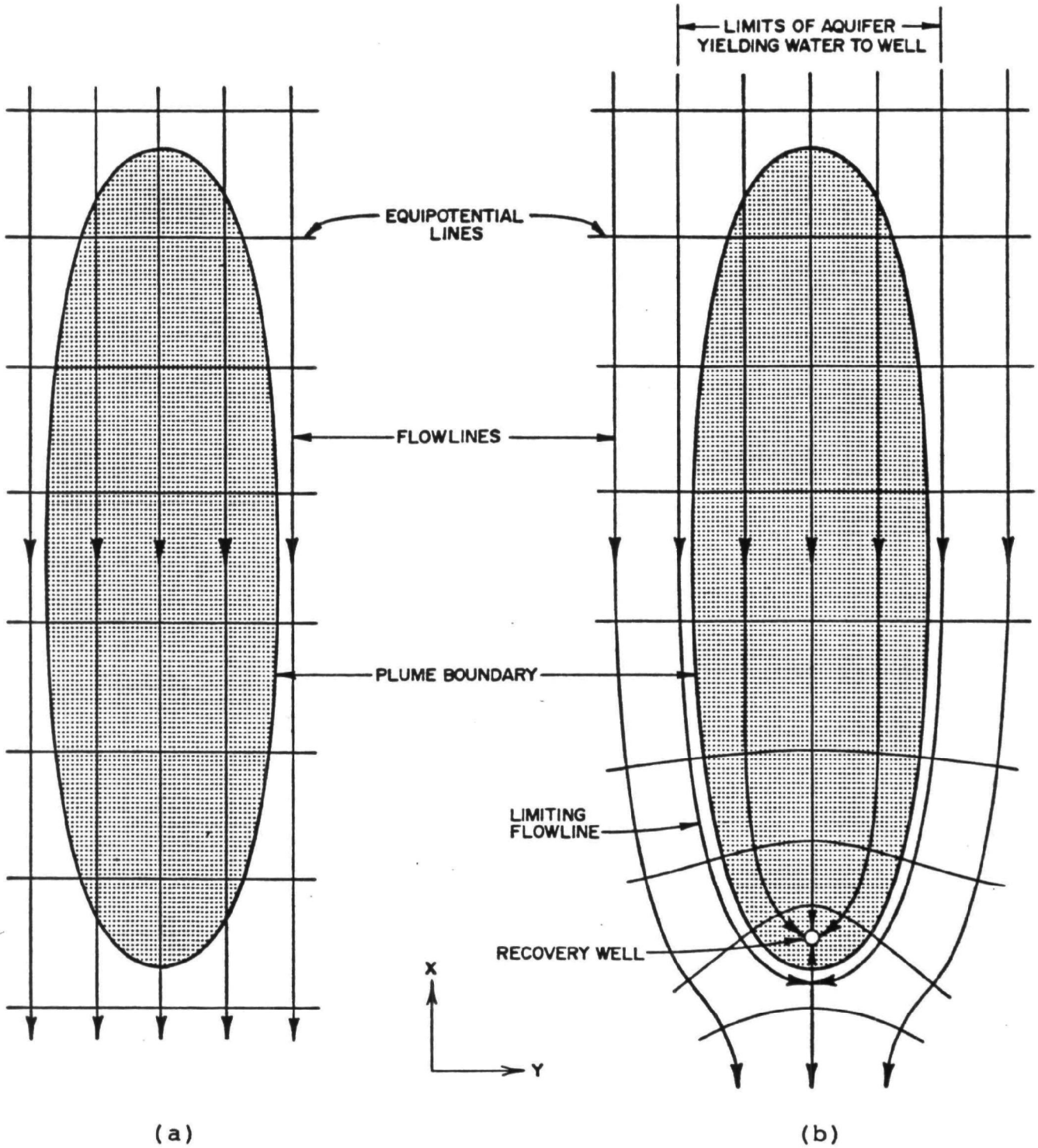


FIGURE 3 Ground-water Flow Conditions for Strategy 1.
(a) Plan View of Plume in a Undirectional Flow Field.
(b) Containment of Plume with One Discharging Recovery Well.

As shown in Figure 3, the limiting flowlines diverge from each other in an upgradient direction from the recovery well. If the well is located a large distance from the plume and is pumping the plume discharge, Q_p, the flowlines will encompass the plume. If the well is located near or inside the plume and produces Q_p, the flowlines may not encompass the plume at its widest point. In such a case, the well discharge must be somewhat greater than Q_p.

Strategy 2

Strategy 2 is a set of algorithms designed to deal with the least favorable plume migration condition. As shown in Figure 4, this strategy is used as a response to a plume that is spreading in a radial pattern. Radial flow may be caused by local mounding of the water table due to recharge of liquid wastes or discharge from off-site wells surrounding the plume. Under Strategy 2, the recovery wells or drains are located inside the plume, either along the major axis itself or in rows parallel to the major axis.

Like Strategy 1, total discharge from the wells or drains must at least be as large as the total discharge through the plume itself. The Darcy equation can be used to

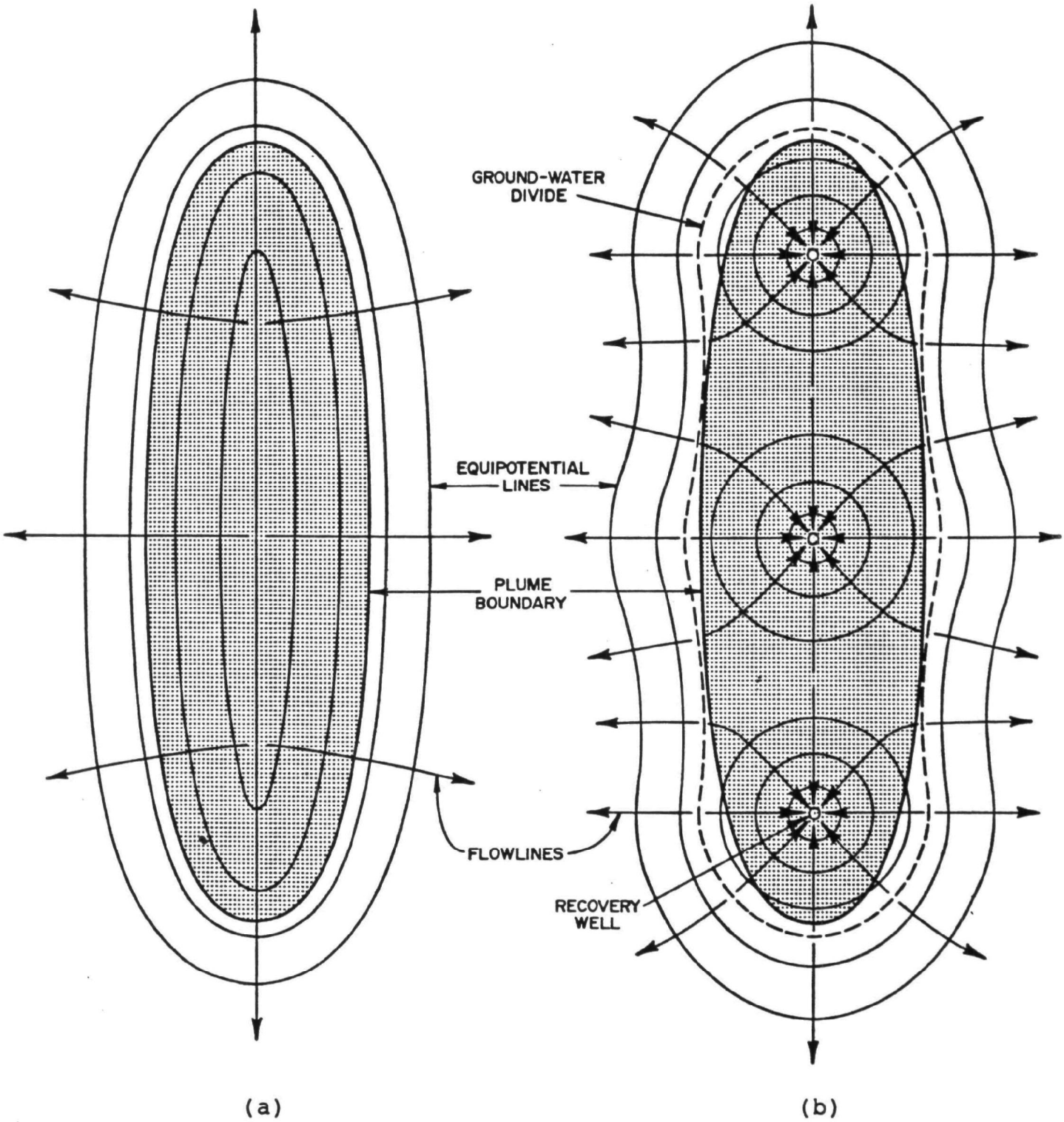


FIGURE 4. Ground-water Flow Conditions for Stragegy 2.
(a) Plan View of Plume in a Radial Flow Field;
(b) Containment of Plume with Three Discharging Recovery Wells.

determine the plume discharge. However, under radial flow conditions, the variable "W" is equal to the perimeter rather than the width of the plume. Under Strategy 2, the recovery system must reverse the direction of the hydraulic gradients around the plume boundaries so that ground-water flow is toward the wells or drains. As shown in Figure 2, a ground-water divide is created outside of the plume boundary.

Strategy 1 Algorithm

This section includes the specific algorithm and mathematical expressions used under Strategy 1 for determining containment requirements. In addition, the specific values of driving variables used as input data to the algorithm are presented.

Under Strategy 1, containment is achieved by a discharging well or drain that creates a limiting flowline around a plume. At the theoretical optimum discharge rate, the limiting flowline is tangent to the plume boundaries and encompasses the entire plume area in plan view.

The algorithm for finding the optimum discharge from one or several wells/drains is to use a graphical technique with the following expression for the limiting flowline

(Forchheimer, 1930):

$$\frac{-y}{x} = \tan\left(\frac{2\pi KbI}{Q} y\right)$$

where,

y, x = Rectangular coordinates, [L]

K = Aquifer hydraulic conductivity, [L/t]

b = Aquifer thickness, [L]

I = Hydraulic gradient, [dimensionless]

Q = Well discharge, [L^3/t]

The graphical technique involves mapping flowlines for various discharges from one recovery well. The well is located at the origin of a coordinate system inside the downgradient limit of each plume. Figure 3 shows the orientation of the x and y coordinates. The optimum discharge is selected by making the best fit between a limiting flowline and an elliptical plume. This technique also approximates the total discharge from several recovery wells or a single drain located near the toe of the plume.

Drawdown at a pumping well is calculated with the Cooper and Jacob (1946) equation, where the well radius is

set equal to one foot. Interference from other recovery wells is estimated with distance-drawdown graphs generated with the Cooper and Jacob equation.

Although it is possible to draw the water down to the bottom of the aquifer at a well or drain, maximum drawdown at a well for this study is arbitrarily limited to 70 percent of the original saturated thickness of the aquifer. This drawdown constraint is needed to allow for additional drawdown caused by well losses and to maintain the proper submergence head above the pump intake to prevent breaking suction (see Appendix A for definitions of technical terms).

Practical limits on pump capacity are primarily controlled by the optimum well discharge, the total vertical distance water must be lifted, and the pump efficiency. For this study, the lower and upper bounds on individual well discharge are arbitrarily set at 5 and 4000 gpm/well, respectively. Total lift and pump efficiency affect both design and O&M costs and are discussed later.

Strategy 2 Algorithm

The algorithm for determining the well/drain discharge for Strategy 2 assumes that the hydraulic gradient is equal in magnitude at all points along the plume boundary. Only the direction of the gradient varies under pre-response conditions. A mathematical expression is used to determine the optimum discharge needed to create a gradient that is equal to the pre-defined gradient along the plume boundary. The expression (Forchheimer, 1930) is written in consistent units as follows:

$$Q = 2\pi TIr,$$

where,

Q = Well discharge, $[L^3/t]$

T = Aquifer transmissivity, $[L^2/t]$

I = Hydraulic gradient, [dimensionless]

r = Radial distance, [L].

The radial distance from the well to the plume boundary is set equal to one half the plume width when several wells are used, or plume length when one well is used. As in Strategy 1, a drawdown constraint of 70 percent of maximum thickness of aquifer is imposed under Strategy 2.

Values of Driving Variables

The values assigned to the driving variables for generating containment design requirements are as follows:

- Hydraulic gradients: 0.5, 5, 50, and 500 ft/mi.
- Aquifer transmissivities: 1,000, 10,000, 100,000, and 1,000,000 gal/day/ft.
- Plume sizes (length x width): 100 x 200, 100 x 500, 500 x 1000, 500 x 2500, 1000 x 2000, 1000 x 5000, 2000 x 5000, and 2000 x 10000 ft.
- Plume depths: 25, 50, 75, 100, and 200 ft.

Under Strategy 1, the plume discharge is directly proportional to discharge through a unit width of aquifer. To insure that the ranges of gradients, transmissivities and plume discharges used in this study are reasonable, the 16 possible combinations of gradient, I, and transmissivity, T, were tested with the Darcy equation. Sixteen hypothetical calculations were made using all combinations of I and T with a standard aquifer width equal to one mile. Aquifer discharges ranged from 0.005 to 500 mgd/mi (million gallons per day flowing acoss a section of aquifer one mile wide). Ten of the 16 combinations of gradient and transmissivity

yielded aquifer discharges in the range of 0.05 to 5 mgd/mi. Because this range is considered representative of the majority of aquifers in the United States, only those combinations of I and T that create this range were used.

The elliptical shape and range of plume widths and lengths are considered representative on the basis of numerous transport model studies (Freeze and Cherry, 1979) and actual case histories where plumes have been mapped. The range of depths to the bottoms of plumes is also representative of plumes in water-table aquifers in the United States. There are an increasing number of case histories that document contamination of the water-table aquifer and several underlying confined aquifers to greater than 200-foot depths. However, these are considered special cases and are not considered for the purposes of this study.

Output Design Requirements

Output from the application of Strategy 1 and 2 algorithms are containment design requirements for 400 scenarios under Strategy 1, and 120 scenarios under Strategy 2. In Appendix B, the design data are shown in Tables B-1 through B-10 for Strategy 1, and Tables B-11 through B-13 for Strategy 2. These tables show the minimum number of wells and per-well discharges needed to produce the

optimum discharge for plumes of various sizes in a range of hydrogeologic settings.

Strategy 1

Table 3 shows the format of data in Appendix B and contains design requirements for 40 Strategy 1 scenarios. The hydrogeologic setting defined by the aquifer discharge, transmissivity, and gradient represents median values within the ranges used for these variables. For each of 20 plume width-depth combinations, Table 3 shows two numbers that respectively represent the number of wells and the optimum discharge per well. Because plume length has no bearing on the number of wells or discharge under Strategy 1, the 20 pairs of data can be used for 40 scenarios representing 8 plume width-length sizes and 5 plume depths.

Table 3 shows that only one recovery well is needed to control the specific plume discharges for each of 4 plume widths. The discharge from a single recovery well is approximately 120 percent of its respective plume discharge. This relationship holds for all plume and well discharges under Strategy 1 and is the result of locating the well inside the plume rather than an arbitrarily large distance downgradient of the plume.

TABLE 3

CONTAINMENT DESIGN REQUIREMENTS FOR FLUID REMOVAL SYSTEMS UNDER STRATEGY 1 FOR MEDIAN AQUIFER CHARACTERISTICS[a]

Plume Width (ft):	100	500	1000	2000
Plume Discharge (gpm):	(6.6)	(33)	(66)	(132)
Plume Depth (ft)	Number of Wells and Discharge (gpm)			
25	1(8)[b]	1(40)	1(80)	1(160)
50	↓	↓	↓	↓
75	↓	↓	↓	↓
100	↓	↓	↓	↓
200	↓	↓	↓	↓

[a]Hydraulic Gradient = 5 ft/mi; Transmissivity = 100,000 gal/day/ft

[b]Number of wells and per-well discharge, in gallons per minute (gpm), e.g., 1(8): one well with a discharge of 8 gpm

The data in Appendix B show that under Strategy 1 conditions the number of recovery wells increases as:

- Hydraulic gradient and plume discharge increase
- Plume width increases
- Plume depth decreases
- Aquifer transmissivity decreases

These four variables begin to influence the number of wells when the limit on drawdown occurs at a pumping well or when drawdown near plume boundaries is too small to overcome local hydraulic gradients which prevents in-flow to the well. The above changes in plume discharge, depth, and transmissivity can cause excessive drawdown at the well. Changes in plume width and transmissivity can cause insufficient drawdown near plume boundaries.

All four factors can operate independently or together. As all factors approach their extreme valves, there is no reasonable number of wells in a line along the x-axis that can produce the optimum discharge and satisfy the drawdown constraints. Under these conditions the design options available are:

- Install a recovery drain near the toe of the plume.
- Locate some wells upgradient, inside the plume.

For the purposes of this study, the first option was used when the plume depth was 25 feet, and the second option was used when the depth was greater than 25 feet. Table B-9 and B-10 in Appendix B are examples of how the number of wells is affected by application of this rule.

Strategy 2

Table 4 is an example of design requirements for 40 scenarios under Strategy 2. The hydrogeologic settings for these data are the same as that for the Strategy 1 example in Table 3. One of the major differences shown between the two strategies is that under Strategy 2 the plume length is an important factor in determining design requirements.

Table 4 shows that under Strategy 2, the total discharge from the fluid recovery system is consistently (for one or more wells) about 130 percent of the plume discharge for 1:2 plumes and about 150 percent for 1:5 plumes. This is primarily the result of the plume shape. As plumes become less elongated, the percentage decreases and is equal to 100 percent of plume discharge when the plume is circular.

TABLE 4

CONTAINMENT DESIGN REQUIREMENTS FOR FLUID REMOVAL SYSTEMS UNDER STRATEGY 2 FOR MEDIAN AQUIFER CHARACTERISTICS[a]

Plume Dimensions (ft) (width x length):	100x200	100x500	500x1000	500x2500	1000x2000	1000x5000	2000x4000	2000x10000
Plume Discharge (gpm):	(32)	(72)	(158)	(349)	(316)	(723)	(638)	(1380)
Plume Depth (ft)	Number of Wells and Per-Well Discharge (gpm)							
25	1(41)[b]	1(103)	1(206)	1(515)	1(413)	3(343)	2(413)	5(413)
50	↓	↓	↓	↓	↓	1(1030)	1(825)	3(680)
75	↓	↓	↓	↓	↓	↓	↓	2(1032)
100	↓	↓	↓	↓	↓	↓	↓	1(2065)
200	↓	↓	↓	↓	↓	↓	↓	↓

[a]Hydraulic Gradient = 5 ft/mi; Transmissivity = 100,000 gal/day/ft

[b]Minimum number of wells needed to control gradients with a 70 percent limit on well drawdown; discharge units are gpm

In general, the number of recovery wells needed under Strategy 2 increases as:

- Hydraulic gradient and plume discharge increase
- Plume perimeter (width and length) increases
- Plume depth decreases
- Aquifer transmissivity decreases

Like Strategy 1, these factors take effect when either excessive drawdown occurs at a well or insufficient drawdown occurs near plume boundaries. Under exteme conditions, the rule of installing a drain or locating additional wells inside the plume is applied.

When all driving variables are set equal and drawdown constraints are met, a predictable relationship develops between the design requirements of Strategies 1 and 2. The optimum discharge for a specific Strategy 2 scenario can be predicted if the discharge is known for the corresponding Strategy 1 scenario. This can be seen by comparing data for specific scenarios from Tables 3 and 4. The Strategy 1 total optimum discharge can be multiplied by a factor that is a function of plume width to length ratio to obtain the Strategy 2 discharge. For 1:2 plumes the factor is approximately 5.2, whereas for 1:5 plumes, the factor is about 12.9.

It was assumed that a similar relationship would exist between the two strategies when recovery wells or a drain must be located off the major plume axis to meet the drawdown constraints. Fewer scenarios were developed for Strategy 2 because of this assumption and because of the predictable relationship between the optimum discharge of each scenario for both strategies.

Containment Costs

This section presents costs for the installation and operation of fluid removal/treatment systems. Included are discussions pertaining to the conceptual design of engineered structures, unit costs, and development of algorithms for fluid recovery, transmission, and treatment. Cost curves for infrastructure and treatment were developed in conjunction with SCS Engineers of Reston, Virginia, and are presented in Appendices D and E. Tables with total containment costs for selected scenarios are presented in Appendix F.

General Approach

A conceptual design is needed for each structure to derive unit costs for labor and materials used in construction. Figures 5a and 5b show the conceptual design of

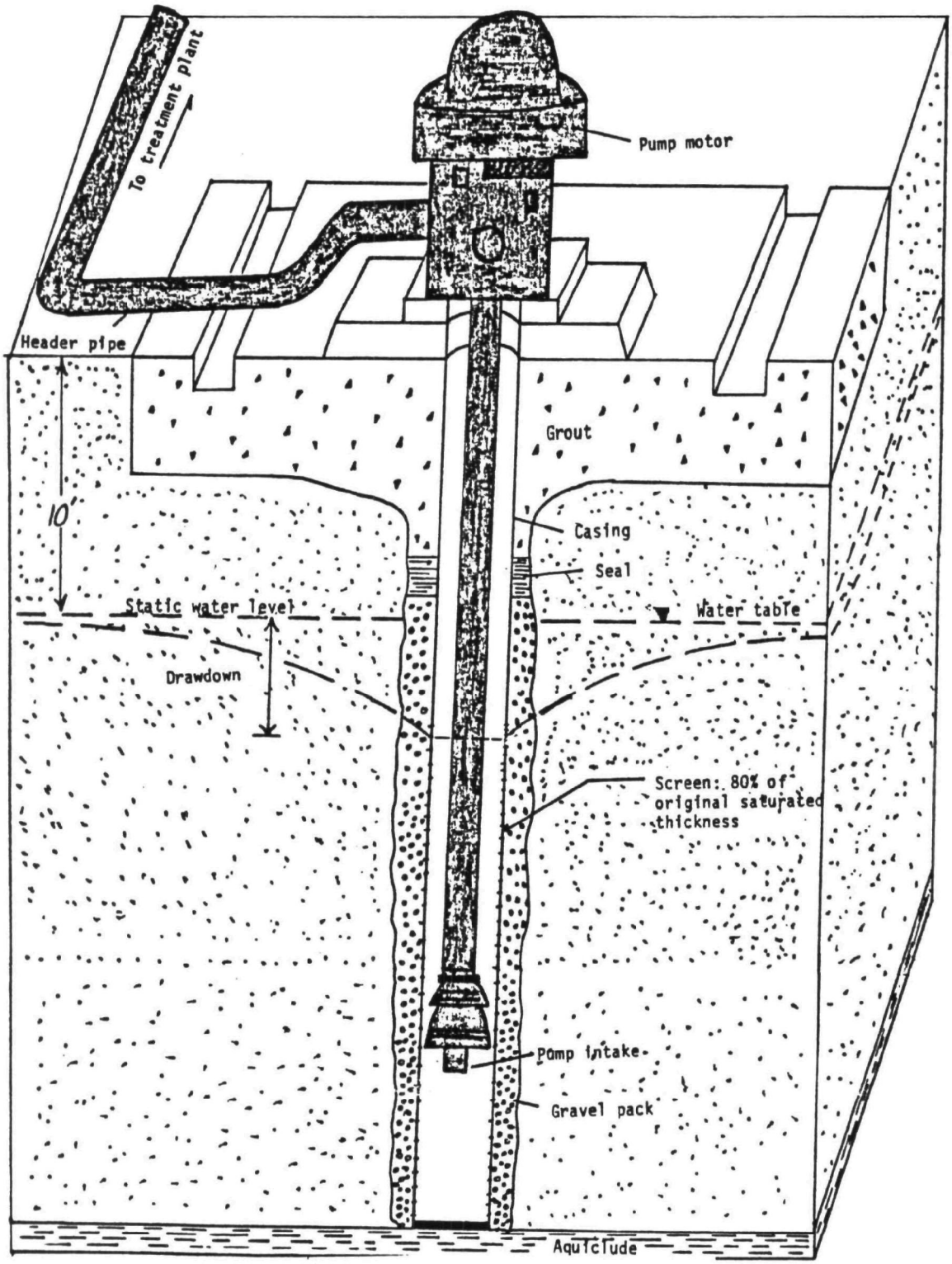


Figure 5a. Conceptual Design of Fluid Removal Structures
(a) Design of Recovery Well
(b) Design of Recovery Drain

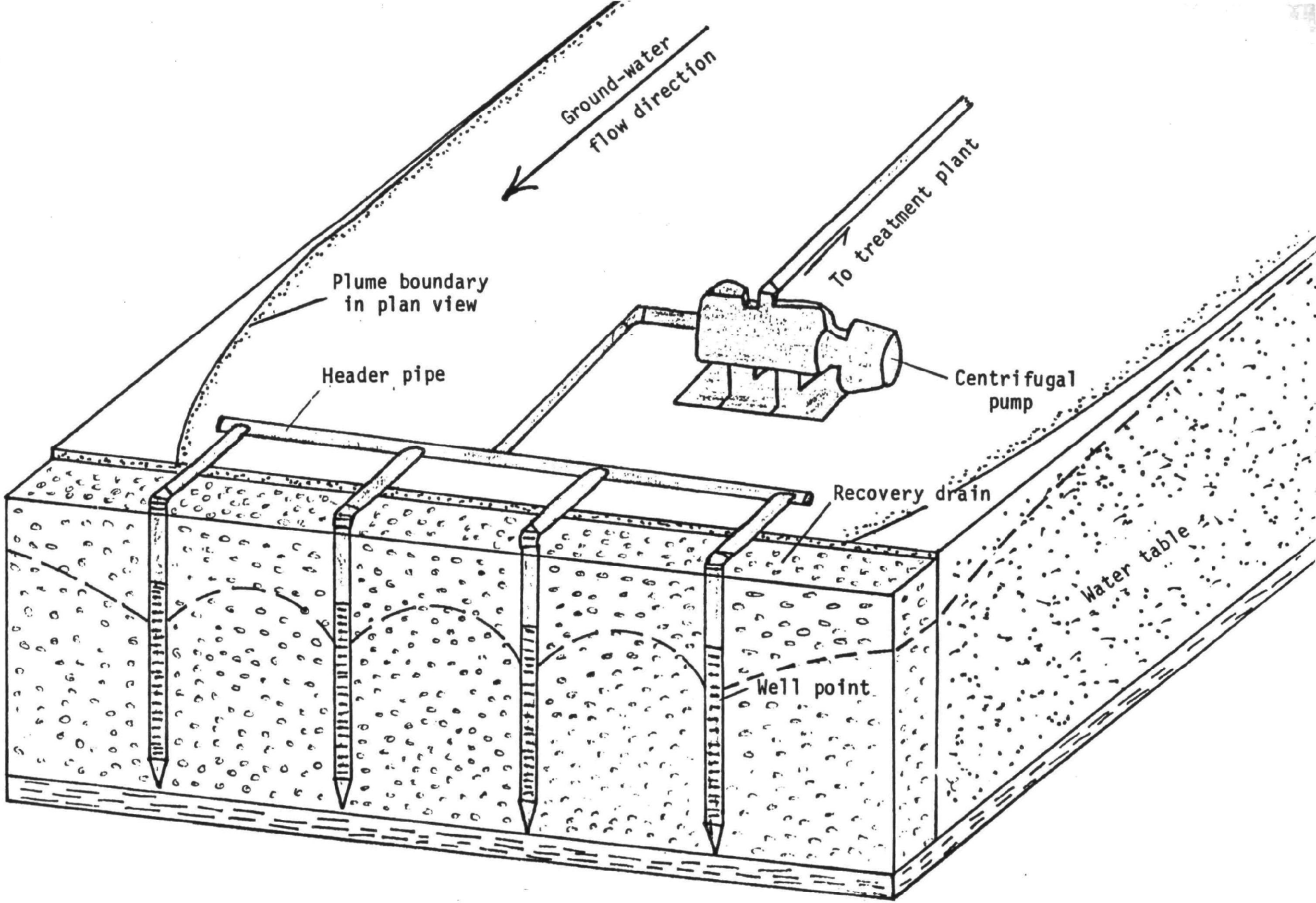


FIGURE 5b. Conceptual Design of Recovery Drain

the two fluid removal systems used in this study--recovery wells and drains.

All recovery wells were assumed to have a screen and gravel-pack design. The lengths of well screens were set equal to 80 percent of the saturated thickness of the aquifer. Other elements of each well shown on Figure 5a include a gravel pack around each well screen, a bentonite plug above the gravel pack, and cement grouting to the surface. Well casing sizes were selected as a function of the anticipated aquifer yield and are shown in Table 5. Two types of pumps were selected for the recovery well system due to the anticipated variation in well yield. Submersible pumps were selected for small yields in the range of 5 to 100 gpm, while turbine pumps were used for larger yields in the range of 100 to 4000 gpm.

The conceptual design of a recovery drain, shown on Figure 5b, is a gravel-filled trench with wellpoints (small diameter wells) completed in the gravel backfill. The length of the drain is equal to the maximum plume width and is located just inside the downgradient limit of the plume in Strategy 1, or along the axis of the plume in Strategy 2. Drains were limited to scenarios involving plume depths equal to 25 feet.

TABLE 5

WELL CASING DIAMETERS[1]

Anticipated Well Yield (gpm)	Well Casing Diameter (inches)
≤50	4 ID
50 - 85	6 ID
75 - 175	8 ID
150 - 400	10 ID
350 - 650	12 ID
600 - 900	14 OD
850 -1300	16 OD
1300 -1800	20 OD
>1800	24 OD

[1]Source of data: Johnson Division, UOP, Inc., Ground Water and Wells, 1980

As mentioned, containment design requirements were generated for numerous scenarios under each of the two containment strategies. From these scenarios, a total of 128 scenarios under Strategy 1, and 24 under Strategy 2 were selected for developing cost scenarios. For each "no treatment" cost scenario, three possible treatment options were also costed in order to allow estimation of a range of total costs, development of a relationship between Strategy 1 and 2 costs, and performance of a qualitative sensitivity analysis of variables that affect costs.

Cost Algorithms and Input Data

This section presents the development of unit costs and associated cost algorithms for fluid removal, infrastructure, and treatment systems.

Fluid Removal Systems

The supportive capital cost elements involved in the installation and operation of a fluid removal system include:

- Delineation of plume boundaries
- Design engineering
- Well/drain system installation/operation
- Construction engineering

The cost for each element is determined with a separate algorithm described below. The algorithm may be in the form of a cost curve or a simple mathematical equation. After each element is determined, they are summed to yield the total capital cost for the well or drain fluid removal system.

Plume Delineation

A model approach was used to determine the cost of delineating a plume of a given size in an aquifer. In this approach, the cost for a subsurface field investigation, including drilling and installation of monitor wells, is required. Pairs of test borings are placed along the perimeter of the plume to establish its areal extent. Approximately one-third of all borings are converted to monitor wells. All wells are completed to the lower impermeable boundary of the aquifer. The investigation does not involve a search for the maximum plume depth which is assumed to coincide with the bottom of the aquifer.

To perform this approach, the following assumptions were made in addition to those identified in the introductory chapter of this report:

- Local aquifer parameters are known or can be estimated.

- Local hydraulic gradients and ground-water flow directions are known.
- The age and location of the facility, its waste characteristics, and operational procedures are known and indicate the approximate waste loading rates.
- The boundaries of the plume can be approximately determined with the above information.

The delineation cost is the sum of seven cost elements: (1) a ground-water quality assessment plan; (2) test borings; (3) conversion of test borings to monitor wells; (4) test boring abandonment; (5) ground-water sampling; (6) ground-water sample analysis; and (7) consultant fee. These cost elements were combined to provide a unit cost per vertical foot of plume depth.

Total delineation costs were derived using the unit cost per vertical foot for the 5 depths selected for this study and are shown on Figure 6. The number of borings required for the selected plume sizes was determined on the basis of Geraghty & Miller, Inc.'s field experience. As shown on Figure 6, the number of borings is related only to plume area and ranges from 10 to 50 borings. The number of monitor wells installed for each plume ranges from 4 to 17. As an example, a plume occupying 200 acres with a depth of 100 feet would be delineated with 40 borings at a cost of $135,000.

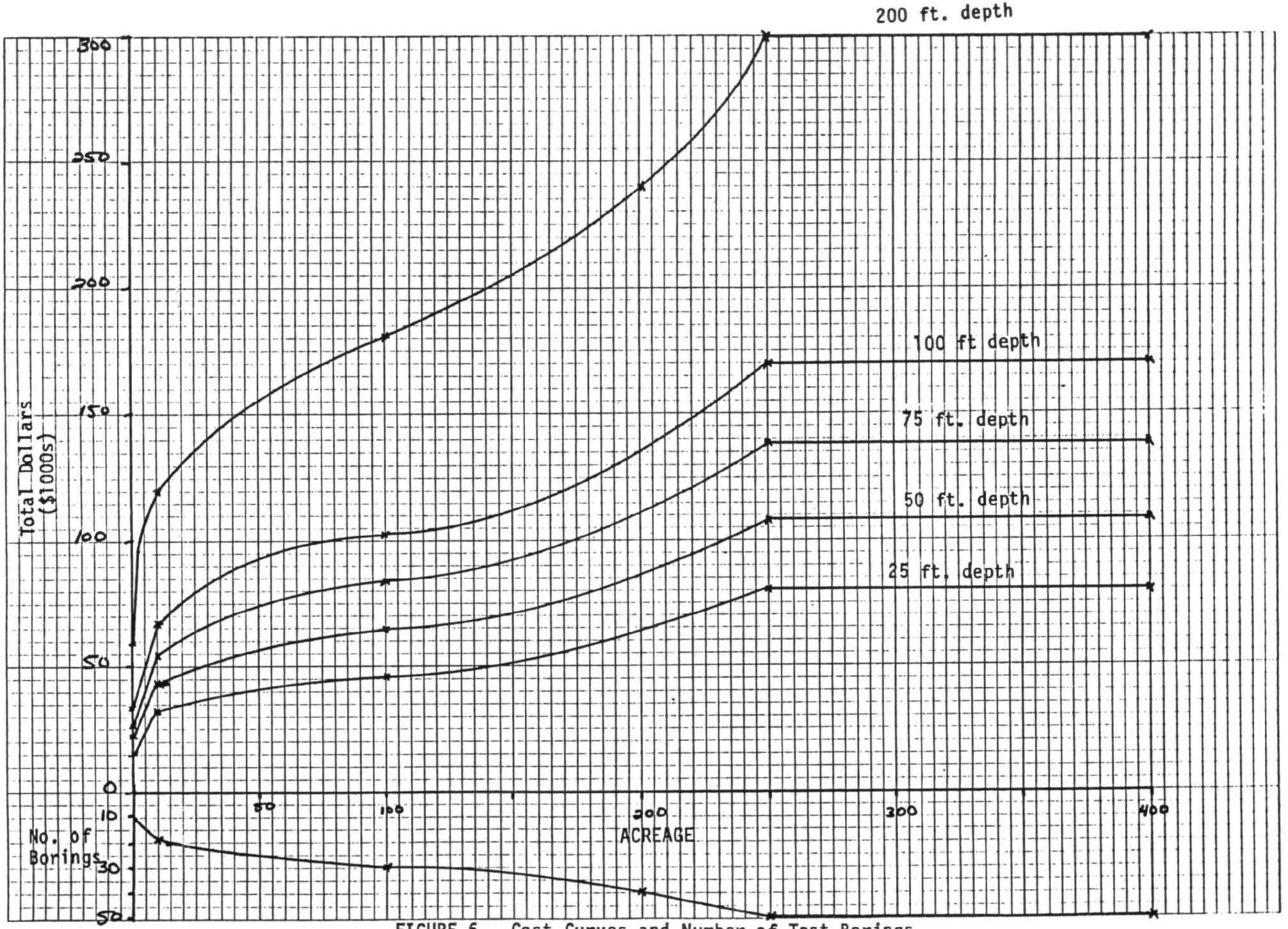


FIGURE 6. Cost Curves and Number of Test Borings for Plume Delineation

Design Engineering

A design engineering fee is needed in assessing the hydrogeologic parameters and designing a fluid removal system capable of containing the downgradient migration of the plume. This element includes only a conceptual design of the well/drain system and not detailed plans and specifications. Figure 7 is a cost curve showing the cost of design engineering as a function of plume area.

Well/Drain System

Unit costs for the well/drain structures are primarily functions of the optimum discharge per well or drain. Well casing diameters are determined by anticipated discharge based on these data and are shown on Table 5. For recovery wells, the unit cost per foot for well drilling, and construction, is a function of well diameter and the per-well discharge rate. The unit costs include preparation of plans and specs for the wells/drains. Unit costs also represent a drilling contractor's cost for labor and materials for mobilization, drilling, construction, development, and pump-testing. Unit costs are based on data in the Robert S. Means cost guide (Means, 1980), manufacturer's catalogues, a survey of well costs performed by the National Water Well

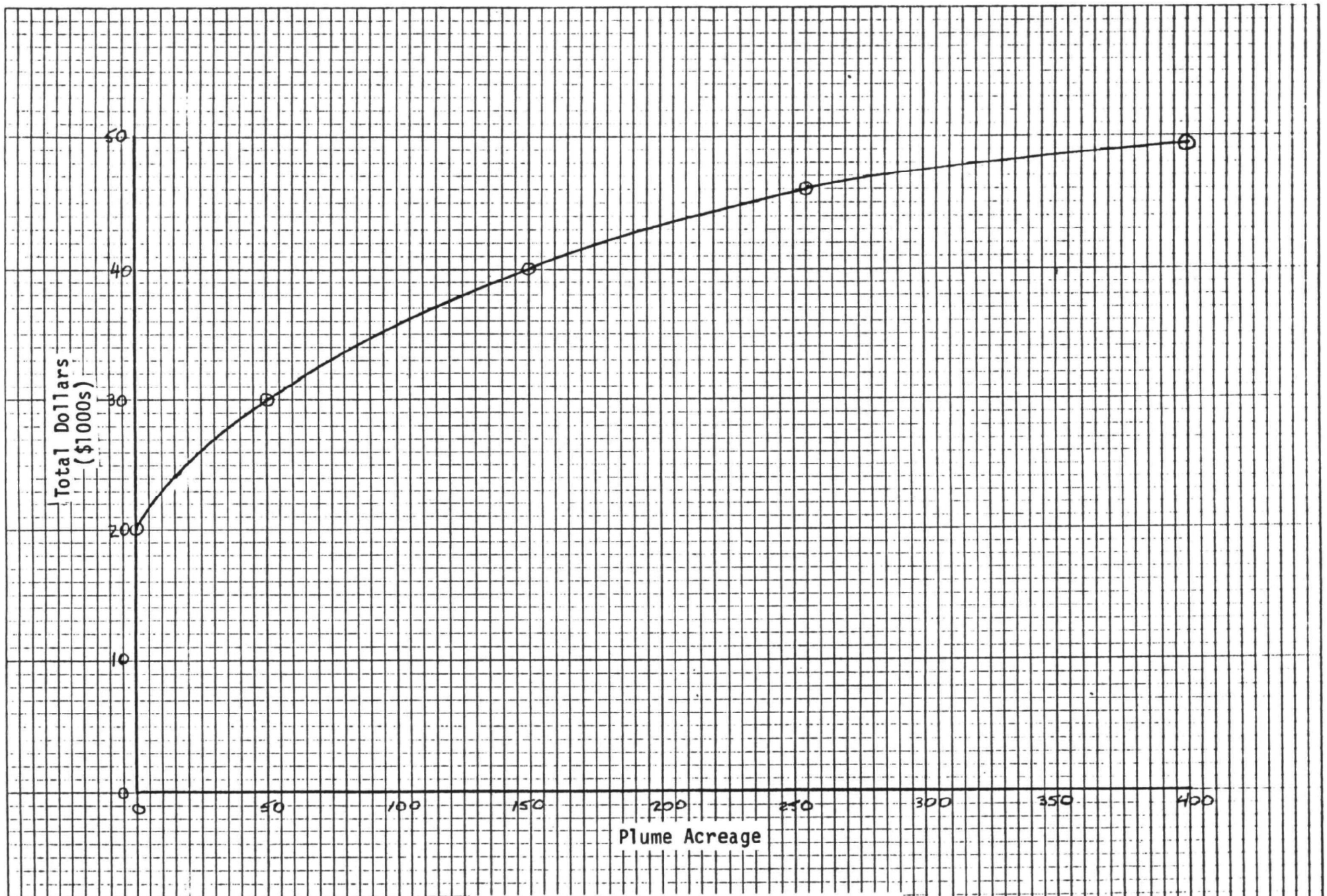


FIGURE 7. Cost Curve for System Design Engineering

Association (Water Well Journal, 1981) and Geraghty & Miller, Inc.'s experience.

Capital cost curves for recovery wells are shown on Figure 8. As an example, if the anticipated well yield is 300 gallons per minute to contain plume migration, a 10-inch diameter recovery well could be installed. The unit cost for the well is $385 per vertical foot. For a 100-foot deep plume, the well would cost $38,500.

The total cost for a recovery drain is determined with the following algorithm:

Drain Cost = $16/lineal ft + $240/well point
+ pump cost + $15,200

The lineal foot charge represents union labor, operation of a trenching machine, and backfill or gravel material placed in the trench. The cost per well represents a contractor's costs for labor and materials involved in wellpoint installation. Figure 9 presents the cost curve for centrifugal pumps with cost shown as a function of total discharge from the system of wellpoints. The final cost element in the algorithm represents an average mobilization/ demobilization charge incurred in using track-mounted equipment for trenching and a drilling rig for well-point installation.

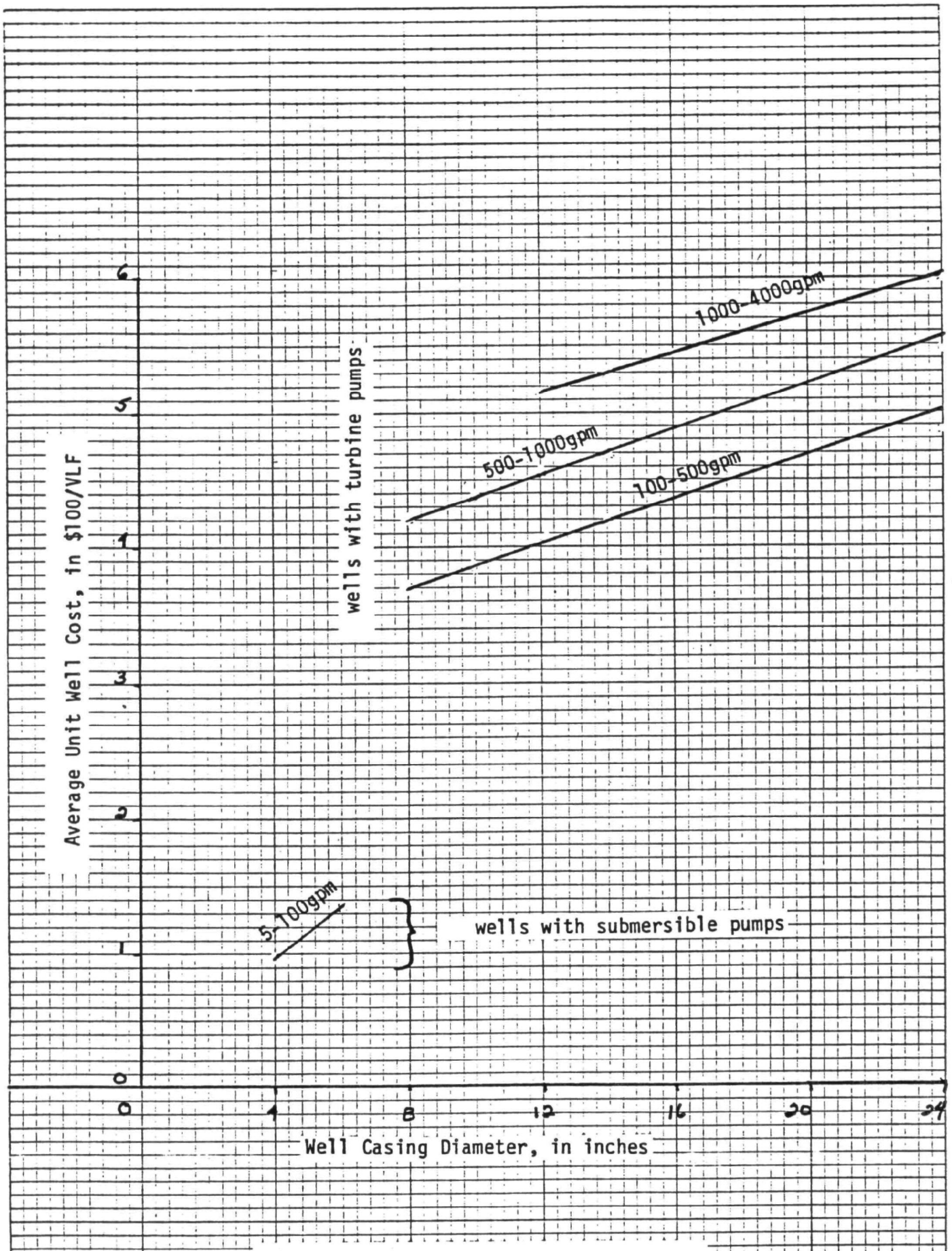


FIGURE 8. Recovery Well K-Cost Curves

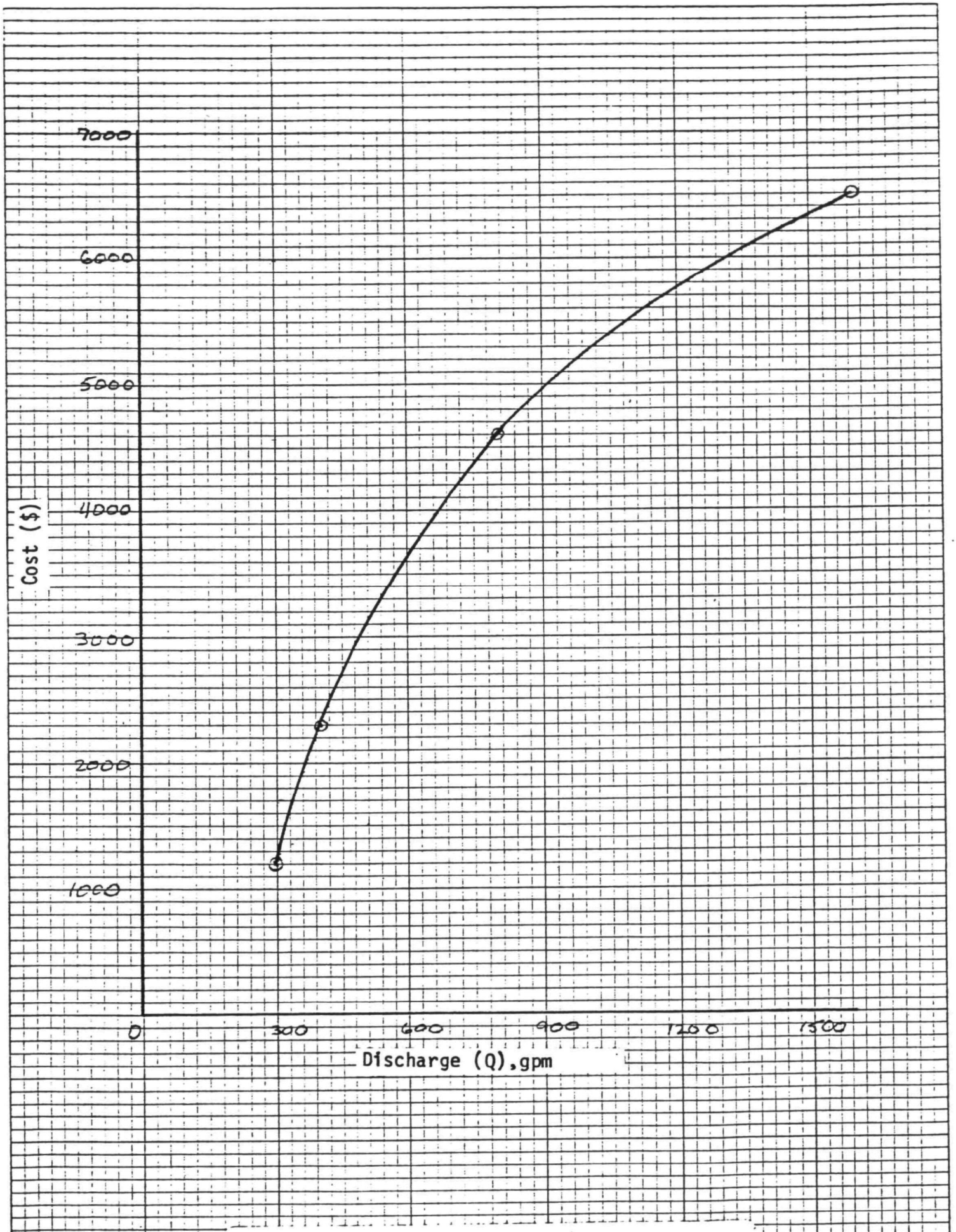


FIGURE 9. Cost Curve for Centrifugal Pumps

In addition to the capital costs for the installation of a fluid removal system, operation and maintenance costs (O&M) were calculated. The algorithm used for both wells and drains is as follows:

$$\text{O\&M Cost} = \$11{,}000 + N(0.11)QL + 0.1\ C$$

where,

N = number of recovery wells or well points

Q = discharge rate, in gpm per well

L = total lift, in feet

C = capital cost of wells or drain, in dollars

The $11,000 fee covers annual field sampling and laboratory analysis of water samples from monitor wells. The 0.11 constant is a power consumption factor taking into account a pump efficiency of 75 percent, a power cost of $0.05 per kilowatt hour, and a unit conversion factor. The total pumping lift is set equal to the calculated drawdown in a pumping well, plus the 10 feet depth to the water table, plus an arbitrary 100 feet of above-ground lift at the wellhead.

Construction Engineering

The final capital cost element for construction engineering is expressed as one of the following two algorithms:

Engineering Cost for Wells = $10,000 + $25.00/lineal foot drilled

Engineering Cost for Drains = $10,000 + $1/lineal foot trenched + $100/well point

The $10,000 figure covers the documentation of installing the fluid removal system including a record of pump and aquifer testing, and laboratory water sample analyses. For well systems, the graduated cost ($25/LF) covers the cost of field inspecting and supervising the installation. For drain systems, the graduated cost ($1/LF + $100/well point) covers similar construction management services.

Infrastructure

The infrastructure is a system of engineered structures needed for maintenance of the well/drain system and for transport of pumped fluids. The fluids would be transported in buried pipelines to either an acceptable point of discharge or to an on-site water treatment plant.

The capital and O&M costs for the infrastructure were determined with a conceptual model of a hypothetical system involving roads, powerlines, and a manifold and service piping system. Details of the conceptual design and assumptions associated with the development of unit costs were prepared by SCS Engineers of Reston, Virginia. These are presented with tables of cost data and cost curves in Appendix D.

Infrastructure capital costs for both containment strategies are controlled by plume and removal system characteristics. Strategy 1 capital costs are a function of plume length, the ratio of plume width to length, the total number of wells or wellpoints, and the discharge from each individual well. Strategy 2 capital costs are a function of plume length, the number of wells, and the per-well discharge. The width to length ratio does not affect costs under Strategy 2 because the locations of roads, powerlines, and pipelines coincide with the long axis of the plume under Strategy 2 (see Appendix A).

Figure D-1 in Appendix D and Table 6 were used to determine mean capital costs for Strategy 1. For example, the infrastructure capital costs read from Figure D-1 for a 1:2 plume with total length of 2,000 feet would be $67,000. If the fluid removal system involves one well with a discharge rate of less than 66 gpm, this capital cost would be adjusted by a 0.84 multiplier from Table 6. The adjusted cost would equal $56,280. For Strategy 2, Figures D-2, D-3, and D-4 were used to calculate the capital infrastructure costs.

Infrastructure O&M costs are relatively small compared to capital costs and are treated as a function of two variables: plume length and the number of wells for both

TABLE 6

RECOVERY WELL INFRASTRUCTURE
CAPITAL COST FACTORS
FOR STRATEGY 1

Total Number of Wells (N)	Discharge Per-Well (Q), in gpm	Multiplier W:L 1:2	W:L 1:5
N=1	$Q \leq 66$	0.84	0.90
N=1	$66 < Q \leq 660$	0.92	0.95
N=1	$Q > 660$	1.00	1.00
$1 < N \leq 4$	$Q \leq 66$	0.98	0.99
$1 < N \leq 4$	$66 < Q \leq 660$	1.08	1.05
$1 < N \leq 4$	$Q > 660$	1.16	1.10
$4 < N \leq 8$	$Q \leq 66$	1.14	1.08
$4 < N \leq 8$	$66 < Q \leq 660$	1.16	1.10
$4 < N \leq 8$	$Q > 660$	1.18	1.12
$N > 8$	$Q \leq 66$	1.18	1.14

TABLE 7

INFRASTRUCTURE O&M COSTS FOR STRATEGIES 1 AND 2

Plume length (ft)	No. of Wells	O&M(1,000's Dollars)
200 to 2500	1 to 3	3
4000 to 5000	1	3
	>1	4
10,000	1	4
	>1	5

strategies. Three O&M cost curves developed by SCS Engineers are shown on Figure D-5 in Appendix D. Table 7 is the schedule of O&M costs, rounded to the nearest thousand dollars, for scenarios selected for costing in this study.

Treatment

Capital and O&M costs for four treatment options were costed for this study by SCS Engineers. These included the following:

- Activated Carbon Filtration
- Reverse Osmosis
- Coagulation/Floculation/Sedimentation/Filtration
- Ultrafiltration

The assumptions associated with development of these costs are presented with tables and cost curves in Appendix E.

Capital and O&M costs were treated only as functions of total discharge (gpm) from the fluid removal system. Cost curves for all four water treatment options are presented in Figures E-1 and E-2. Ultrafiltration was not used in developing the cost scenarios because its cost was very similar to that for reverse osmosis and costs for larger flows could not be determined.

Output Cost Data

The containment design requirements were used as input to a costing model comprised of the above cost algorithms to yield output in the form of capital and annual O&M costs for containment structures. Costs representing 512 Strategy 1 scenarios and 94 Strategy 2 scenarios are presented in a series of tables in Appendices C and F.

Tables in Appendix C contain capital costs only for fluid removal systems composed of one or more recovery wells or drains. The cost elements which are summed to yield these capital costs are also shown and include plume delineation, design engineering, well/drain construction, and construction engineering. Capital costs shown in tables of Appendix C are support data for the costs in tables in Appendix F.

Tables in Appendix F contain the capital and annual O&M costs for fluid removal, infrastructure, and treatment systems. The sum of these three elements represents the total cost of containment for a particular scenario. Each table in Appendix F represents 32 scenarios.

Sensitivity Analysis

Figure 2 showed the major factors affecting containment costs: plume characteristics, aquifer characteristics,

and engineering constraints. This figure also showed the driving variables that were allowed to take on a range of values for costing selected scenarios in this study. A qualitative sensitivity analysis was performed to evaluate the relative importance of these variables on total containment costs.

General Approach

The general approach was to graph the total containment costs against each driving variable while holding all other variables constant whenever possible. The graphs were used to test for linearity between costs and driving variables and to show the direction in which costs increase or decrease with changes in the variables. In addition to the graphing exercise, calculations of total change in cost for a given change in a driving variable were used as a general quantitative indicator of sensitivity. Graphs and calculations were prepared with cost data representing the total cost scenarios for Strategies 1 and 2 tabulated in Appendix F. Additional sensitivity graphs not presented in the main body of this report, are compiled in Appendix G.

Sensitivity to Driving Variables

Total containment costs are generally most sensitive to plume size and plume discharge. Under special plume

and aquifer conditions, however, costs also become sensitive to limits on drawdown and pumpage in wells or drains. Sensitivity to driving variables under these cost-influencing factors are discussed below.

Plume Size

The driving variables for plume size are depth, width, length, and perimeter. Increases in these variables have the greatest impact on the no-treatment cost scenarios (those that exclude treatment of pumped fluids). This is due to the fact that the capital costs associated with fluid removal and infrastructures are directly affected by plume size, whereas treatment is totally independent of size.

This relationship is illustrated in Figures 10 and 11, which are graphs of capital costs versus plume depths for selected treatment and no-treatment options. These figures show that, when plume discharge is held constant, costs increase linearly with depth. The graphed parallel lines for different treatment options indicate that treatment costs are independent of depth. The percent change in cost over the depth range is virtually the same for both no-treatment and treatment options. For the no-treatment option, increases in plume depth have a greater effect on small plumes, of limited areal extent, than on large plumes.

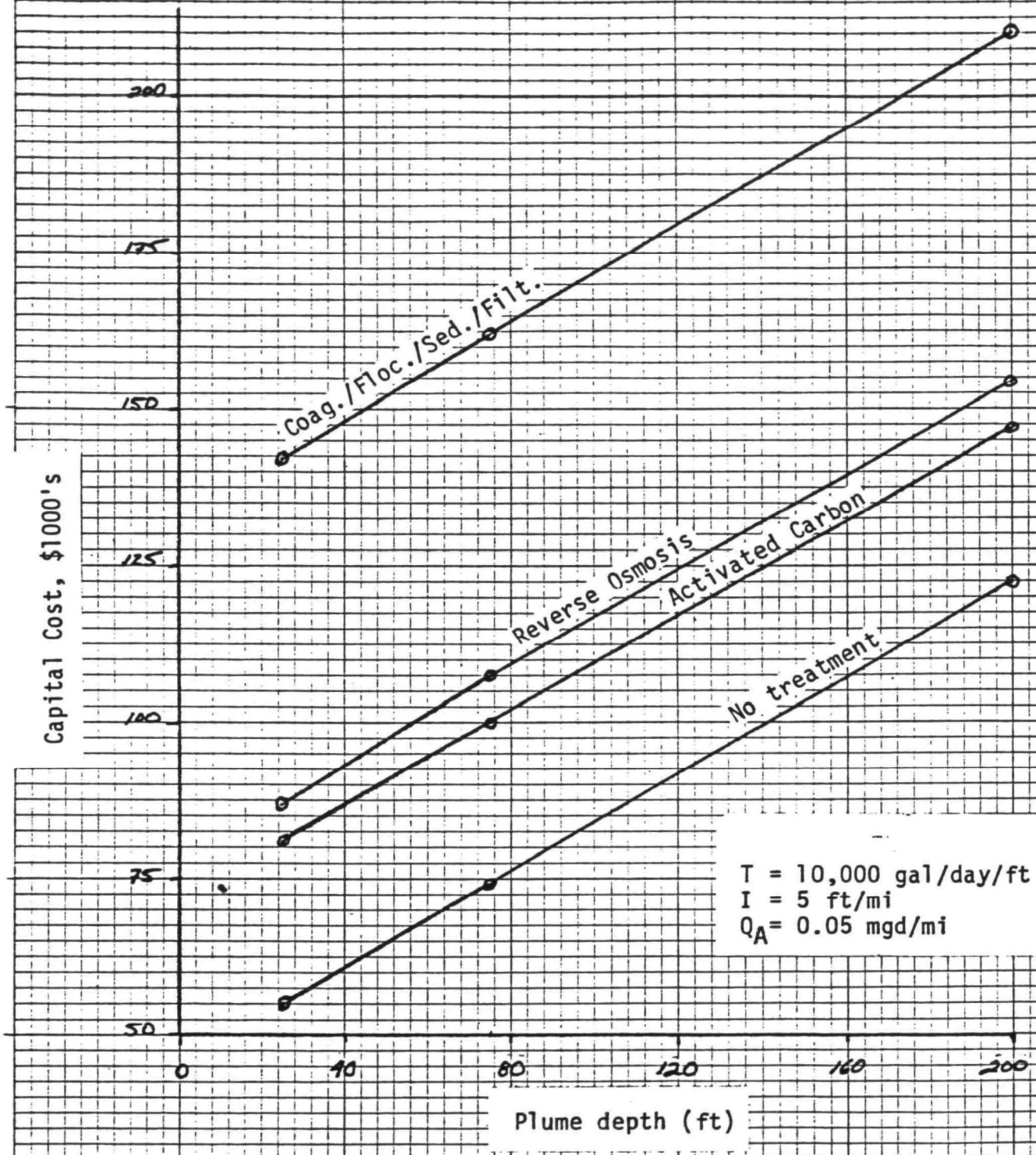


FIGURE 10. Plume depth vs capital costs for a 100 x 200 foot plume under Strategy 1

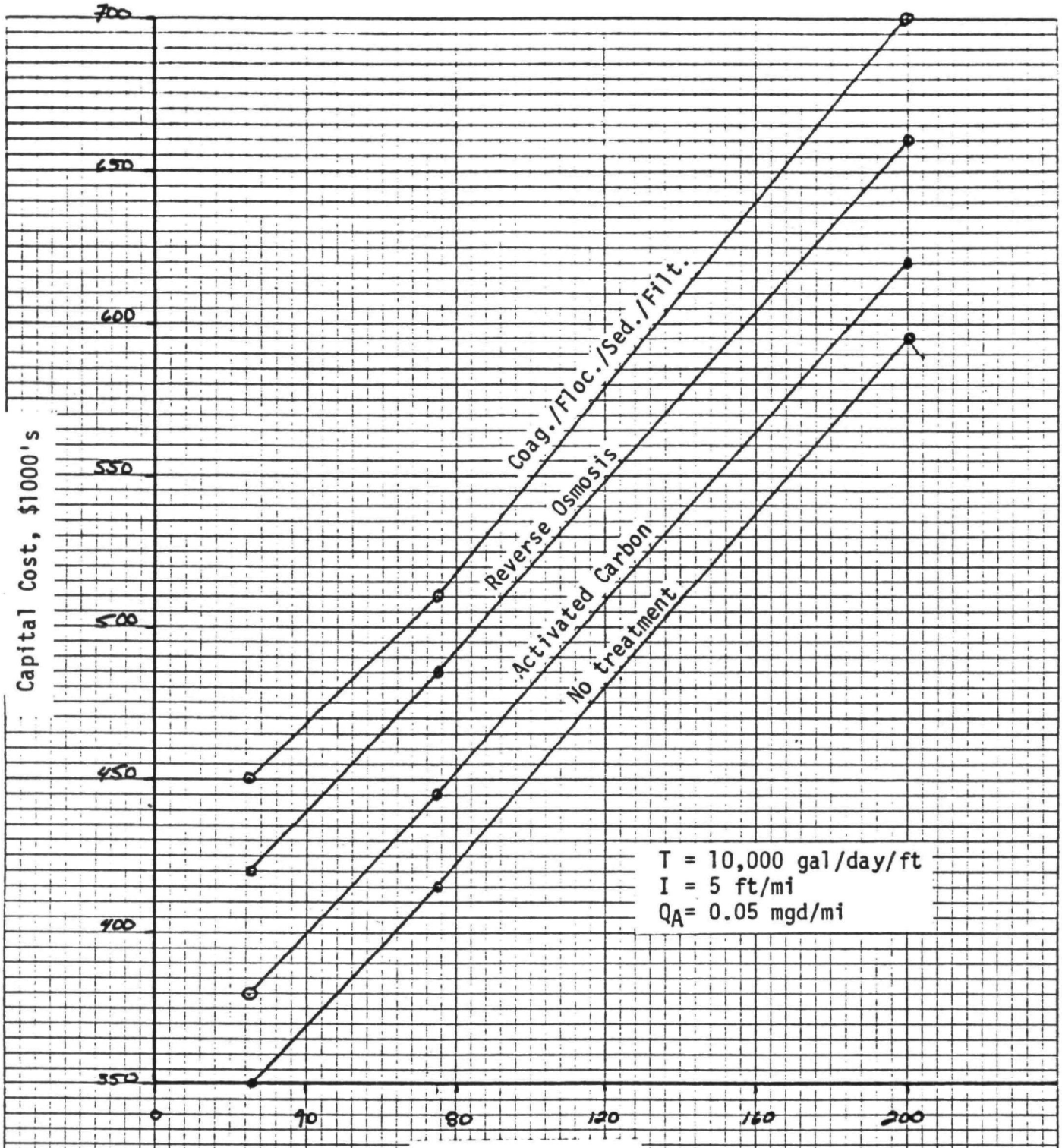


FIGURE 11. Plume depth vs capital costs for a 2000 x 10000 foot plume under Strategy 1

Figure 12 illustrates the sensitivity of costs to plume area, a function of width and length. The cost curves shown represent an average of the three treatment options for Stragety 1 and 2 scenarios. The curves represent 1:2 plumes with the same plume depth and aquifer characteristics. Values selected for the driving variables represent the middle of the range of values used in this study. As shown on the figure, these are:

- Plume depth equal to 75 feet
- Aquifer thickness equal to 65 feet
- Aquifer transmissivity equal to 100,000 gal/day/ft
- Hydraulic gradient equal to 5 ft/mi

Figure 12 shows that costs under Strategy 2 conditions are more sensitive to plume area than are costs under Strategy 1 conditions. This is primarily because Strategy 2 costs are more sensitive to plume length and perimeter than are analogous Strategy 1 costs. Increasing length will increase the plume perimeter which results in larger plume discharge, other things being equal. Larger discharge must be controlled by larger wells, pumps, etc., which require higher O&M costs.

Plume Discharge

As shown in Figure 2, plume discharge is a function of both plume and aquifer characteristics. This can most

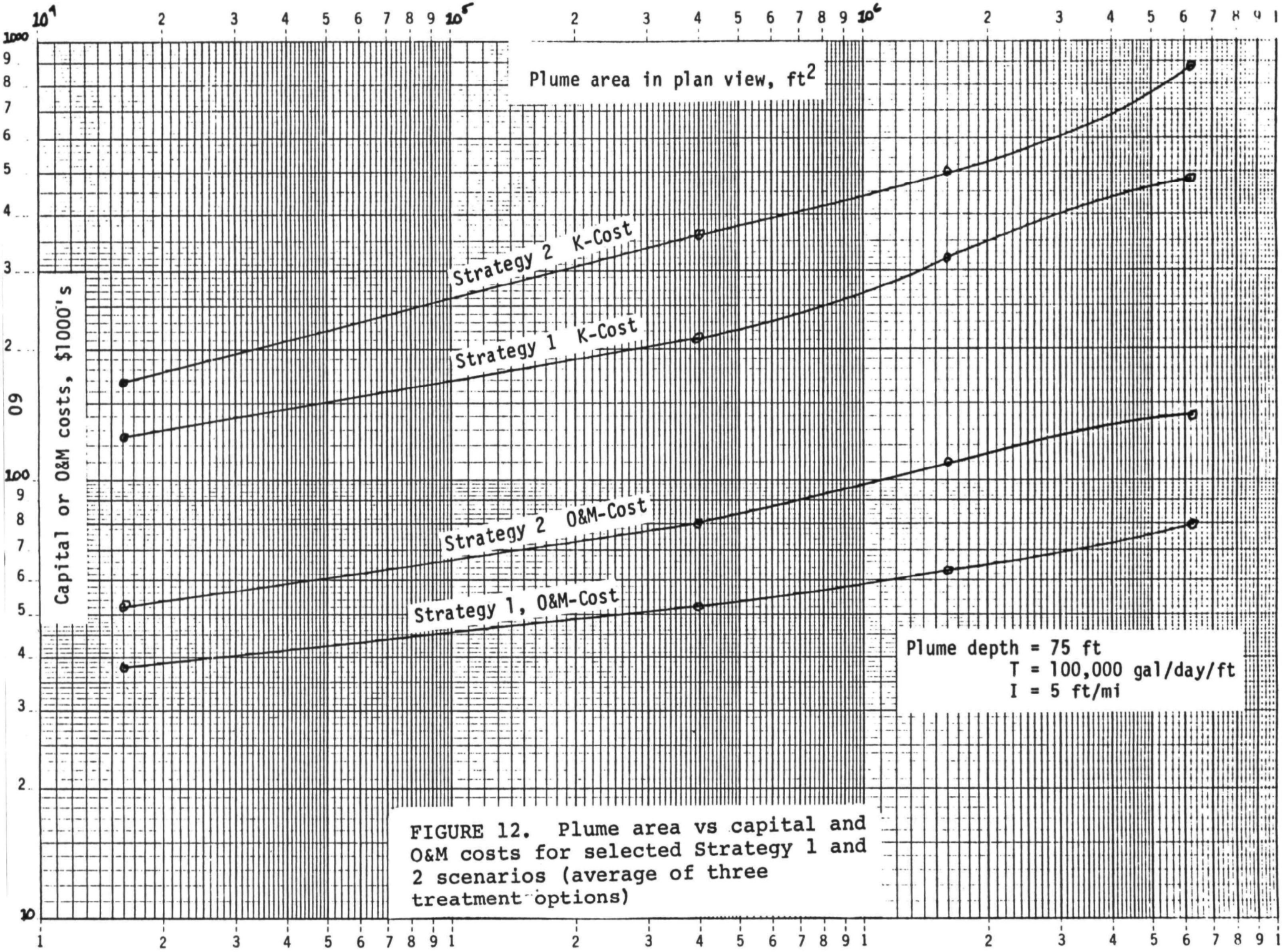


FIGURE 12. Plume area vs capital and O&M costs for selected Strategy 1 and 2 scenarios (average of three treatment options)

easily be shown with the Darcy equation used earlier and repeated here in three different forms:

$$Q_p = TIW = KbIW = K(d-10)IW$$

where,

Q_p = Plume discharge, $[L^3/t]$

T = Aquifer transmissivity, $[L^2/t]$

I = Hydraulic gradient, [dimensionless]

W = Plume width (Strategy 1) or plume perimeter (Strategy 2), [L]

K = Hydraulic conductivity, [L/t]

b = Aquifer thickness, [L]

d = Plume depth, [L]

From the above, the following relationships should be clear:

$T = Kb$, and $b = d-10$.

A series of cost scenarios involving increases in discharge due to transmissivity and gradient alone are fairly reliable for studying the effect of plume discharge on costs. The increase in discharge essentially requires only an increase in discharge capacities of the fluid removal, infrastructure, and treatment systems.

Figures 13, 14, 15, and 16 are examples of these types of cost scenarios for Strategies 1 and 2. These figures show that, when plume size is held constant, increases in plume discharge have the greatest influence on scenarios involving expensive treatment and relatively large plumes.

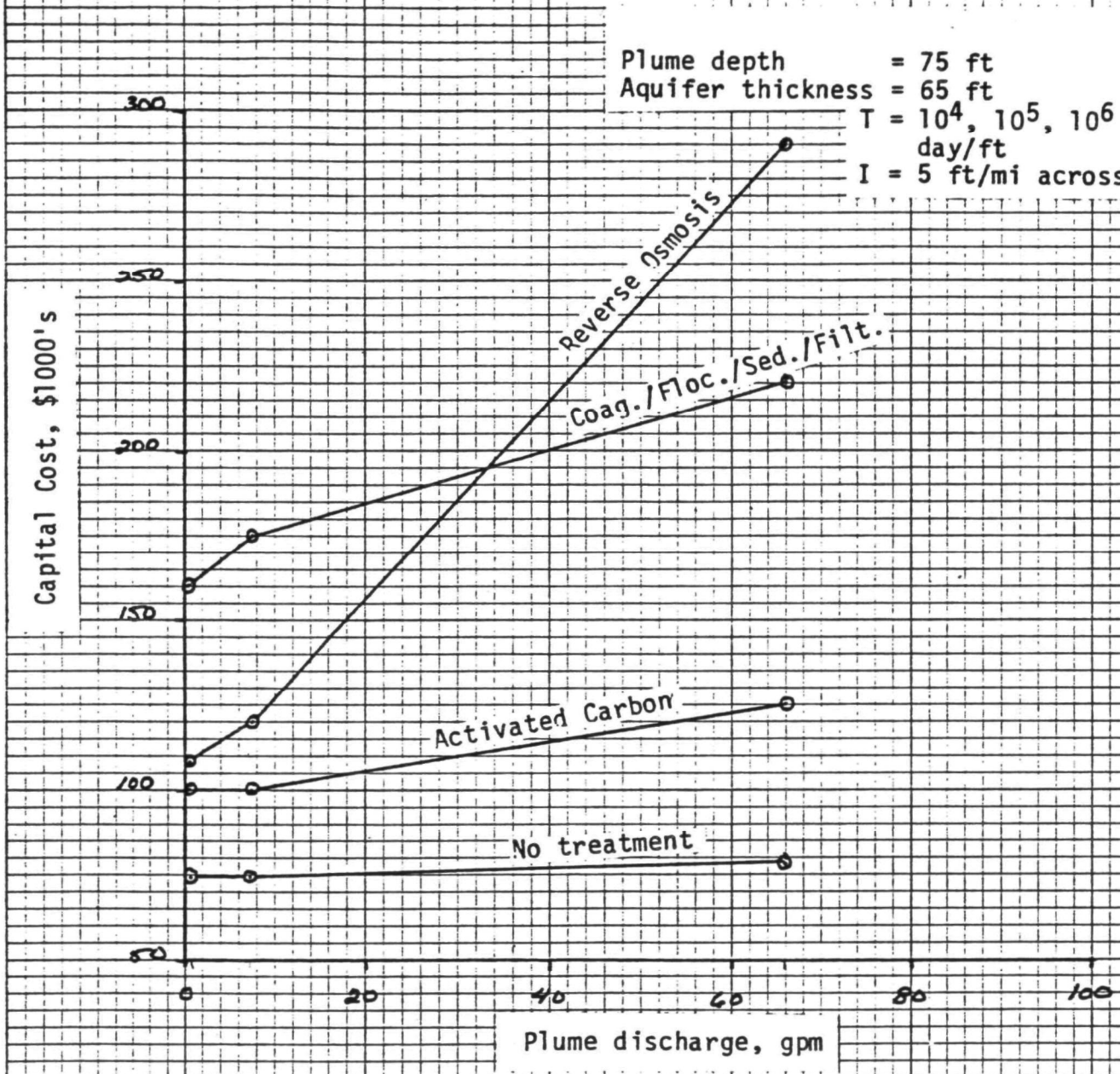


FIGURE 13. Plume discharge vs capital costs for a 100 x 200 foot plume under Strategy 1

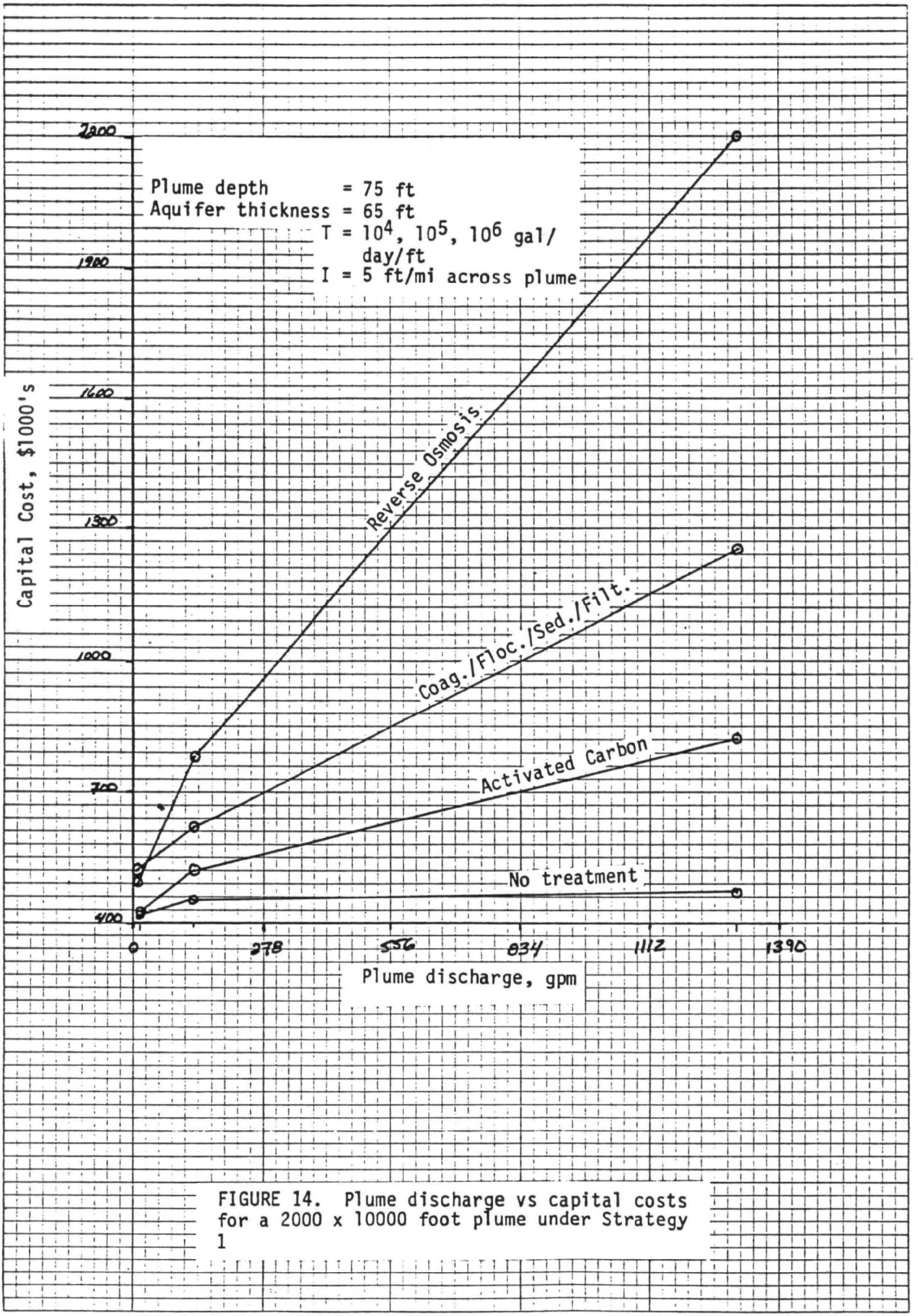


FIGURE 14. Plume discharge vs capital costs for a 2000 x 10000 foot plume under Strategy 1

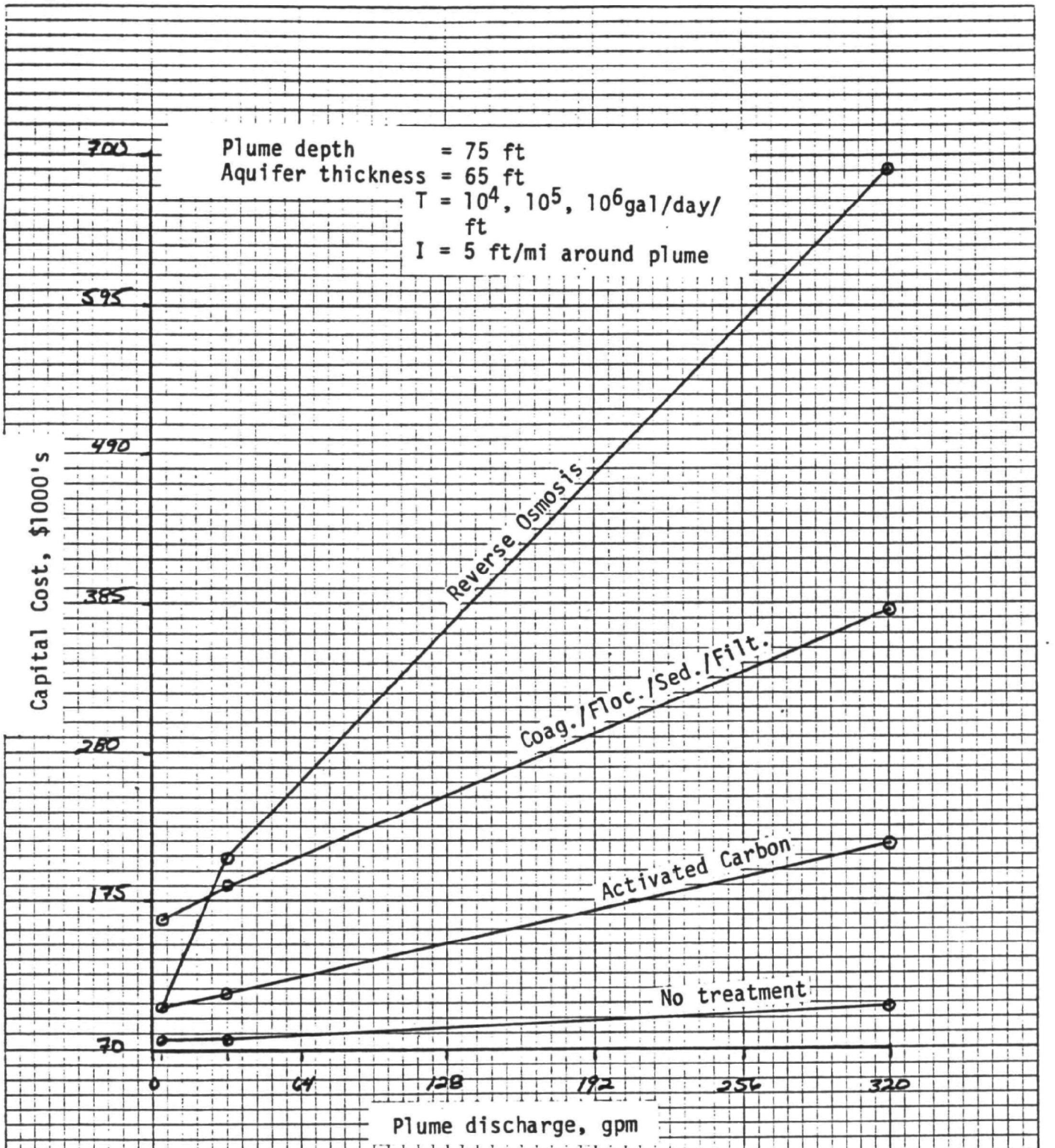


FIGURE 15. Plume discharge vs capital costs for a 100 x 200 foot plume under Strategy 2

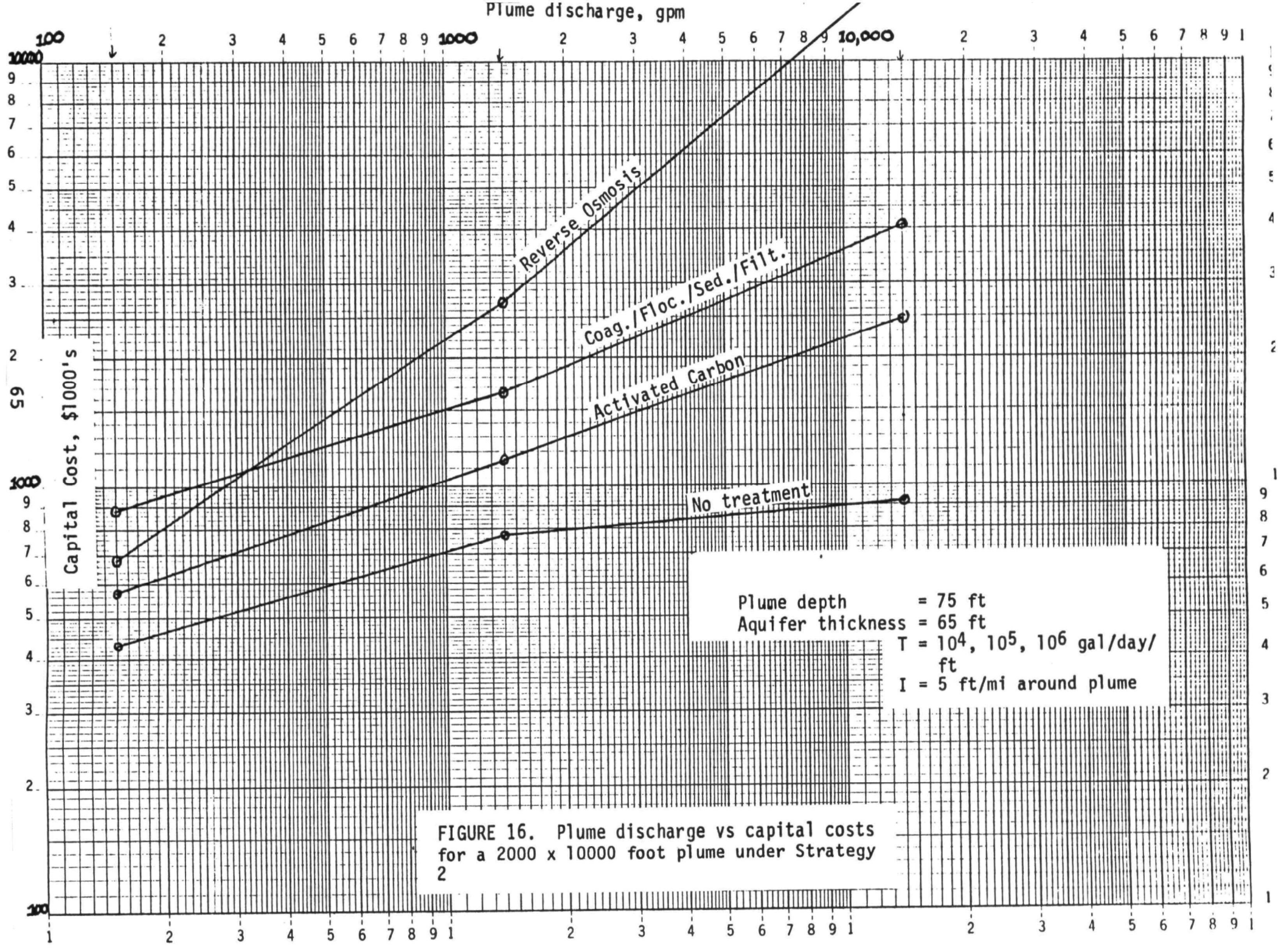


FIGURE 16. Plume discharge vs capital costs for a 2000 x 10000 foot plume under Strategy 2

plume discharge have the greatest influence on scenarios involving expensive treatment and relatively large plumes. Strategy 2 costs are more sensitive to plume discharge than Strategy 1 costs. This is because the total discharge from a well/drain system must be greater under Strategy 2 (other factors being equal) which leads to larger unit costs for treatment (see Appendix E).

When plume discharge is increased by increasing plume width (Strategy 1) or perimeter (Strategy 2), the following "hidden costs" are increased in addition to increases in discharge capacity:

- More borings and wells for plume delineation
- Longer roads, pipelines, and powerlines for infrastructures
- More recovery wells with more manifold piping

Increases in plume depth may have a similar set of hidden costs if transmissivity increases with depth. This variable was held constant for creating Figures 10 and 11 by allowing hydraulic conductivity to decrease as depth and aquifer thickness increased (see Darcy equations above). At many sites, the vertical spreading of contaminants with time will cause a thicker plume and contamination of more than one aquifer. This type of scenario was costed

as a special case where both transmissivity and plume discharge are allowed to increase in direct proportion to depth. Figures 17 and 18 show capital costs becoming increasingly sensitive to depth/plume discharge as plume depth increases. Figures 19 and 20 show that O&M costs are essentially linear with depth for the no-treatment option and decelerate with depth for all treatment options.

Drawdown and Pumping Limits

Figure 2 showed that drawdown limits and pump capacity are engineering constraints that are related to both plume and aquifer characteristics. Both factors are also related to, and may restrict, well discharge which is calculated from plume discharge.

To test sensitivity of costs to these constraints in a rigorous way, it would be necessary to generate costs for a range of drawdown and pumping limits. As discussed earlier, the limits were arbitrarily held constant with the following values:

- Drawdown was limited to 70 percent of saturated thickness

- Lower and upper bounds on pump capacity were set equal to 5 and 4000 gpm per well, respectively

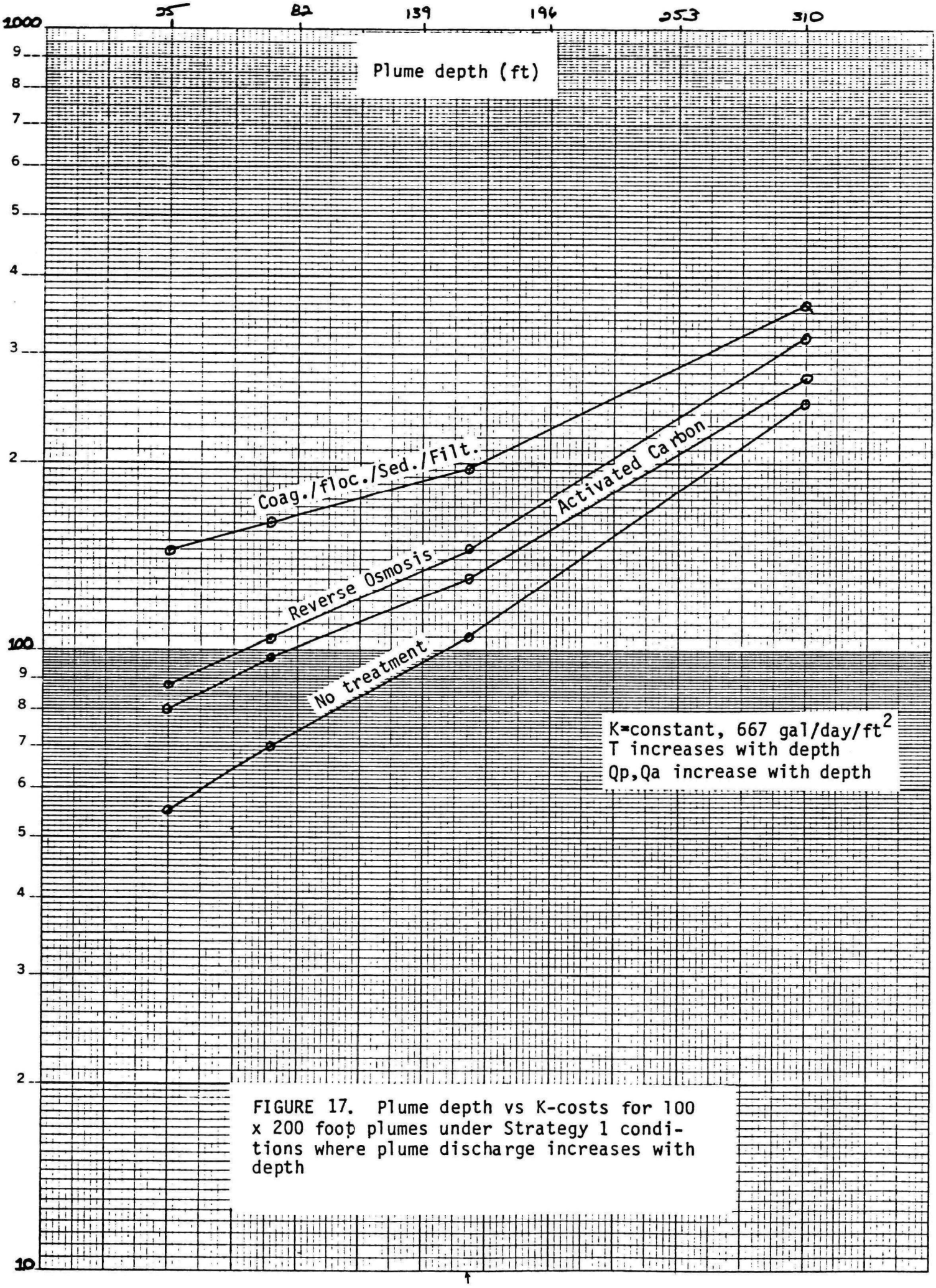


FIGURE 17. Plume depth vs K-costs for 100 x 200 foot plumes under Strategy 1 conditions where plume discharge increases with depth

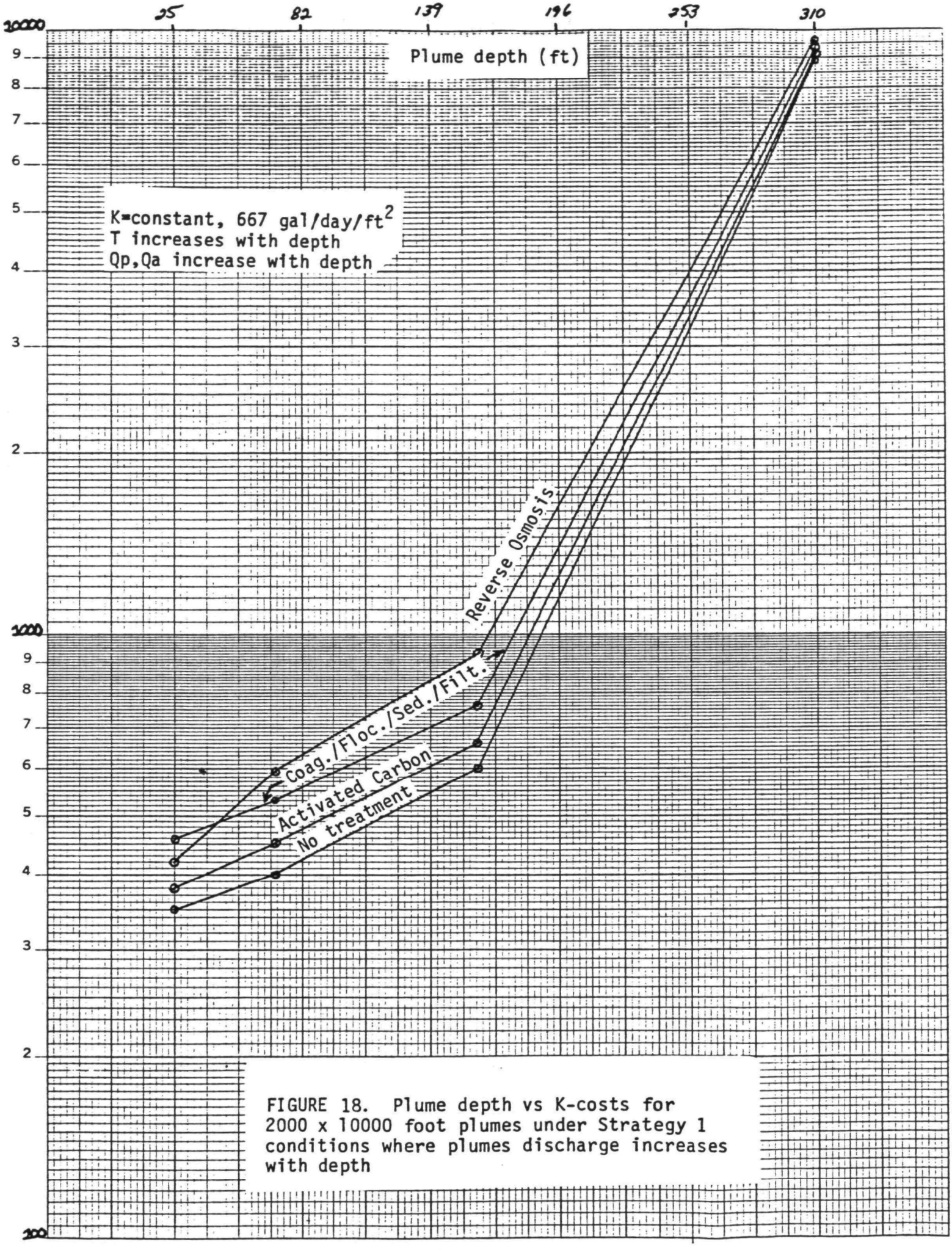


FIGURE 18. Plume depth vs K-costs for 2000 x 10000 foot plumes under Strategy 1 conditions where plumes discharge increases with depth

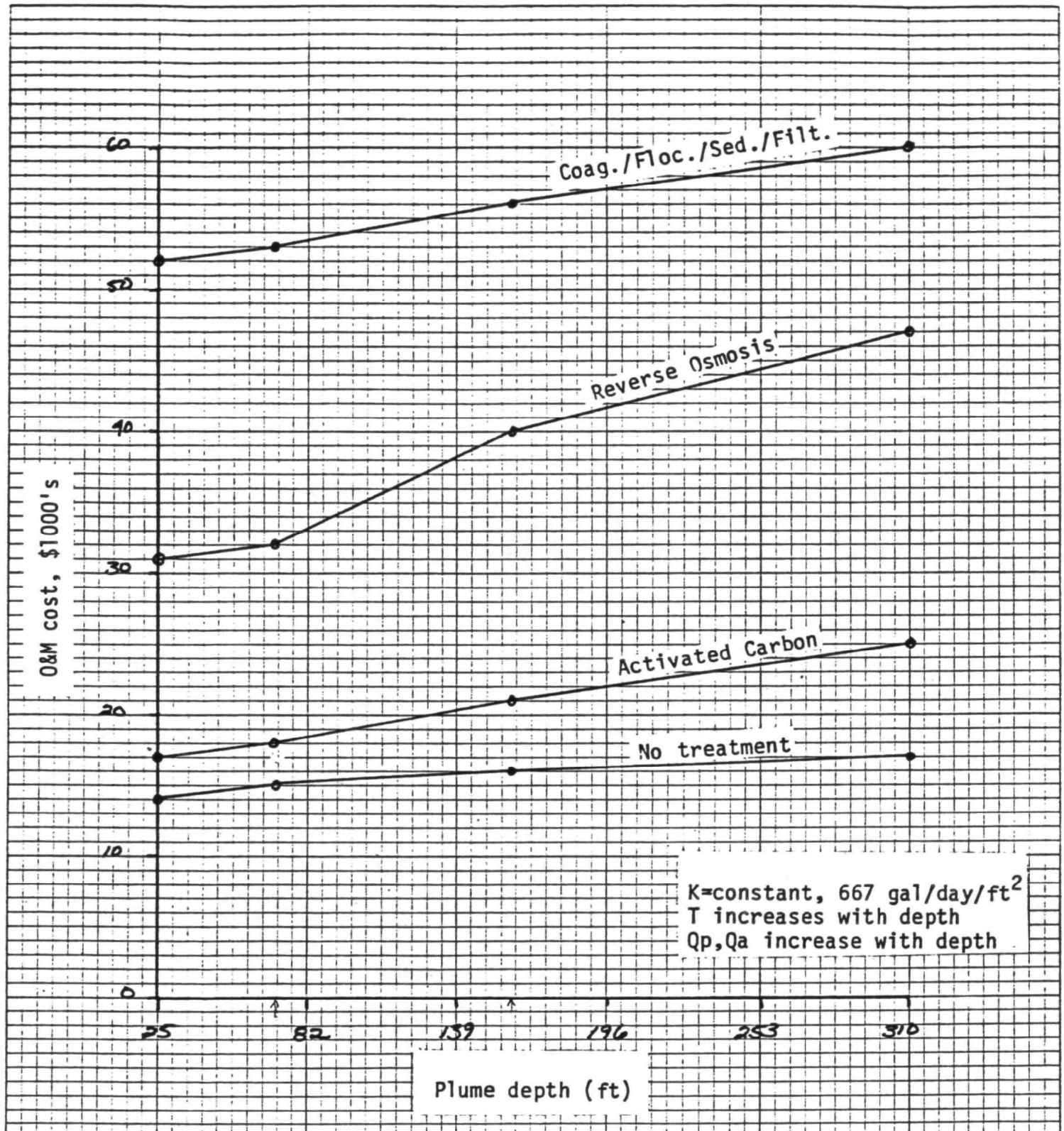


FIGURE 19. Plume depth vs O&M-costs for 100x200 ft plumes under Strategy 1 conditions where plume discharge increases with depth

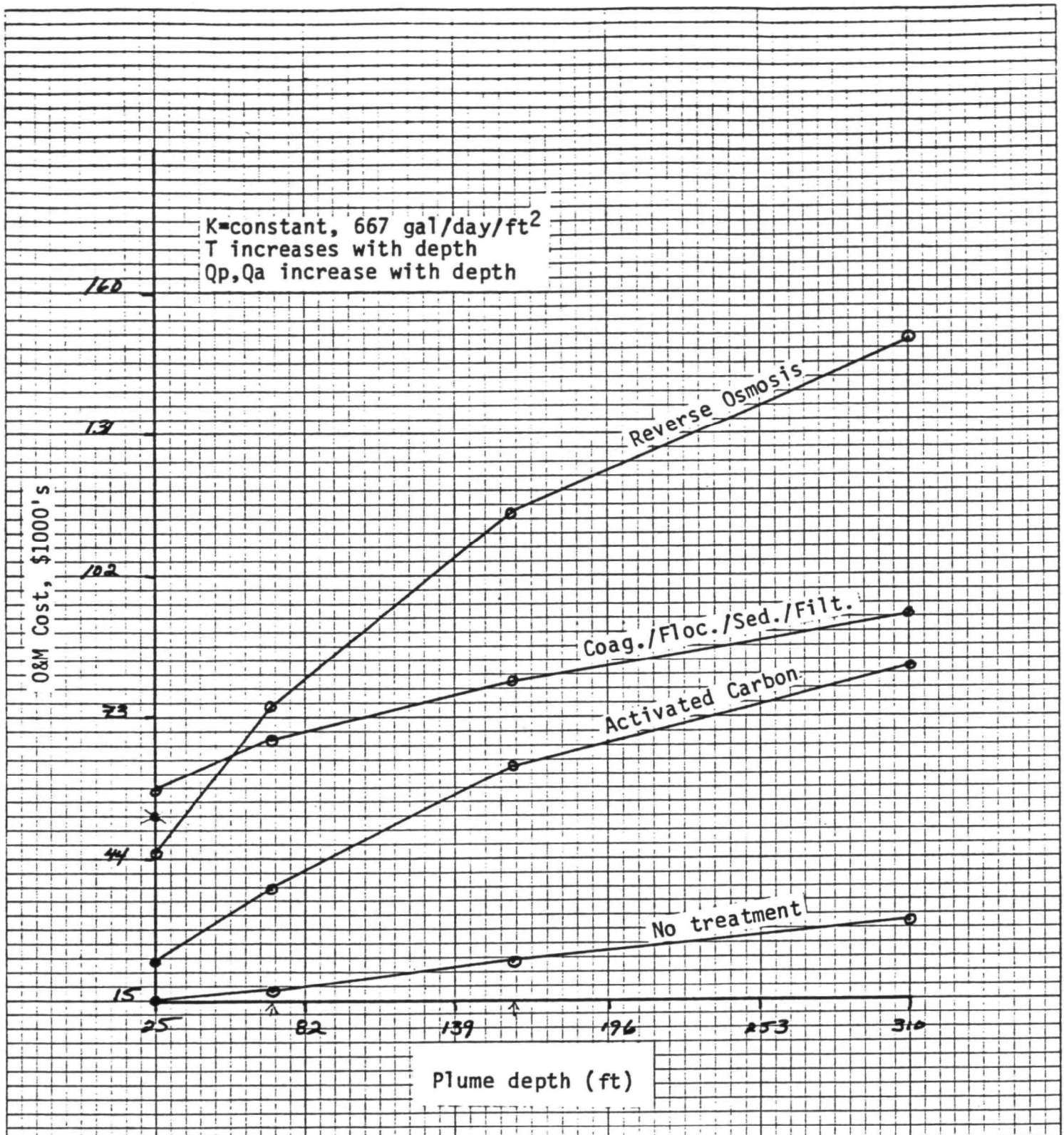


FIGURE 20. Plume depth vs O&M-costs for 2000x10,000 ft plumes under Strategy 1 conditions where plume discharge increases with depth

The drawdown constraint serves to increase the number of wells and decrease the per-well discharge up to a point where drains must be used to meet the constraint. In our costing model, this occurs when plume depth is small (lower end of its range) and plume discharge is large (upper end of its range). A rough measure of maximum sensitivity can be obtained by comparing scenarios involving drains to those involving wells. For example, by comparing total containment costs for scenarios where plume size and discharge are held constant (see Tables F-10 and F-13), the use of drains rather than wells can increase capital costs as much as 22 percent but has virtually no effect on total O&M costs.

The lower limit on pump capacity results in slightly larger well discharges and associated costs for scenarios involving small plume discharges. The upper limit causes the number of recovery wells to be increased when plume discharge exceeds 4000 gpm. In our study, this only occurs with relatively large plumes and plume discharges under Strategy 2, but can cause a significant increase in capital costs, especially for the no-treatment option.

In general, costs are more sensitive to the drawdown constraint than the pumping constraint. The drawdown constraint has a moderate effect on fluid removal system

costs which are generally more sensitive to plume size and discharge.

Sensitivity to Basic Assumptions

The containment costs presented in this report are considered to be at the low end of the possible range of costs that may be encountered in implementing the EPA regulations. These costs are minimal because they are based on simplified, idealized assumptions that are required for cost modeling. The following section will discuss how the basic assumptions affect costs in a qualitative way. Actual numerical factors for adjusting the costs must rely on a later validation phase where model-generated costs would be compared to actual case history costs.

Plume Characteristics

Under the major cost factor of plume characteristics, several important assumptions were made regarding the mobility, solubility, and treatability of contaminants in the plume. The contaminants were assumed to be soluble in ground water and to form a homogeneous aqueous solution. Contaminants that are partially soluble in ground water will form a second phase in the subsurface. Containment of this second phase will require special engineering considerations for collection, handling, and disposal.

For example, if a separate waste oil phase is present in addition to contaminated ground water, it will be necessary to remove both the ground water and oil and provide structures for separating oil from water. A special facility might be required for drumming the waste oil, along with arrangements for off-site transport and incineration of the oil. The existence of a separate insoluble phase in the ground-water system therefore requires a separate set of costs in addition to the removal and treatment of the contaminated ground water.

It was assumed that the contaminants in the plume are in fact mobile and are not strongly adsorbed onto the solid soil particles in the subsurface. In cases where contaminants are significantly less mobile, different remedial actions may be taken. The most common type of remedial response may be excavation of the soils and buried wastes with some collection of fluids during the excavation process. Excavation with fluid removal is much more expensive than fluid removal alone. Therefore, if a site is found to contain both immobile and mobile species, the costs estimated in this report would only cover fluid removal activities, not excavation of soils and wastes.

A third important assumption made under plume characteristics is that the contaminants can be treated, i.e., removed, from the contaminated plume of ground water. This assumption was extended in the sense that only three treatment options were costed. However, on many sites it is possible that more than one type of treatment system may be necessary to handle a variety of contaminants. In such cases, our estimate would be significantly less than the actual cost. For example, it is common to use the activated carbon system to remove organics from the waste stream in conjunction with an air stripping system to remove the more volatile organic species. Besides the consideration of additional treatment facilities, the costs ignored disposal of residue from a treatment facility. Additional costs for treatment systems not included in the estimates are listed in Appendix E.

Aquifer Characteristics

The basic assumptions under aquifer characteristics that have the greatest effect on costs are as follows:

- A single layer system, i.e., only one aquifer
- Aquifer is homogeneous and isotropic
- Water table is everywhere 10 feet deep
- Simple aquifer boundary conditions.

The assumption of only one aquifer may be violated on sites where strong vertical gradients have transported contaminants into deeper aquifers or have increased the depth of a plume within an arbitrarily thick aquifer. The costs for plume delineation and recovery of fluids would be greatly impacted under these circumstances. When more than one aquifer is contaminated, the delineation model can be applied separately to each aquifer. Delineation efforts would involve additional wells drilled to greater depths with additional sampling and laboratory analysis.

The cost of fluid removal would also be roughly proportional to the number of aquifers contaminated. Containment by pumpage from wells completed in deeper aquifers involves higher drilling costs and, in many cases, larger capacity wells. At many sites a deeper confined aquifer may be the water-supply aquifer in the region and may therefore be subject to steeper hydraulic gradients affecting plume movement and discharge rates.

Under the assumption of homogeneity and isotropy, relatively simple hydraulic models are justified for estimating the optimum discharge from recovery wells or drains.

If this assumption is not valid, there will be more uncertainty regarding the directions and rates of transport of contaminants through the aquifer. To deal with this uncertainty, recovery drains may be selected over wells for shallow plumes, and additional recovery wells will be required for deeper plumes. In addition, the total discharge from the well/drain system may also be increased to handle the uncertainty of plume movement. This will impact O&M costs for both fluid removal and treatment.

The assumption regarding a constant 10-foot depth to the water table will be representative of most industrial facilities; however, some selected sites (especially in the arid west) will have significantly deeper water tables. At these sites, the costs that will be most impacted will be those involving drilling, well construction, and O&M for pumping fluids from the wells.

Aquifer boundary assumptions influence costs for plume delineation, well/drain discharge, and associated infrastructure and treatment costs. For our costing model the lower boundary of the aquifer was assumed to be impermeable. This type of idealized boundary is very favorable for delineating a plume because it eliminates the need to

search for the bottom of the plume. Only a search for the lateral extent of the plume is required under this assumption. Relaxing this assumption would probably result in at least a doubling of the delineation costs predicted by our model. Delineation costs are also influenced by lateral boundaries on the aquifer. The plume's proximity to either barrier boundaries or recharge boundaries can significantly influence delineation. Just as the impermeable boundary limits the search for the bottom of the plume, these lateral boundaries would also limit the lateral extent of a plume. Therefore, a relaxation of the infinite lateral boundary condition could reduce the cost for delineation.

The assumption of a lower impermeable boundary on the aquifer will create a lower bound estimate on the discharge from recovery wells and drains. The phenomena of leakage through or from underlying poorly-permeable materials is well known and well documented in the literature. Significant leakage across this boundary to wells in the aquifer can increase capital and O&M costs.

When barrier or recharge boundaries are imposed in lateral directions, the discharge from the well/drain system may be significantly smaller or greater, respectively, than that predicted by the hydraulic model. Costs will

be correspondingly influenced in a manner that is analogous to increases in plume discharge shown in Figures 13, 14, 15 and 16.

Engineering Constraints

The arbitrary constraints set in our cost model for engineering activities were governed primarily by aquifer characteristics. There are additional aquifer and plume characteristics that may affect engineering constraints on selected sites. In addition to these, the inclusion of safety factors, which may be influenced by legal constraints, can serve to increase containment costs.

The assumption that earth materials must be drillable or excavatable for engineering activities is the basis for estimating costs for well and drain installations. As aquifer materials become more indurated, the costs for drilling and excavation will increase. Cost increases result from more expensive machinery, methods (such as blasting), and labor.

Under plume characteristics, the degree of hazard of a contaminant can affect costs adversely. Although a safety factor was included in our well/drain unit costs for on-site protection of personnel, it is possible that this was underestimated in certain special cases. Higher costs

may also be incurred with the disposal of excavated material, contaminated drilling fluids, and contaminated equipment and clothing. These are poorly defined costs and difficult to predict.

Most engineered structures have safety factors built into the design criteria. While our costing model relied upon an optimum discharge calculated from a hydraulic model, safety factors could be applied to increase significantly the number of wells/drains and the total discharge from the fluid removal system. In cases where contaminated fluids are highly corrosive or cause incrustation on well screens and piping, recovery wells/drains may be out of service more frequently for maintenance and repairs. At many sites, therefore, it will be wise to include several backup wells or drains in order to maintain a constant pumping rate.

Some safety factors may be related to legal constraints beyond the control of those in charge of remedial actions. These may include compliance with orders from regulatory agencies, compliance with agreements made with concerned citizen groups, or concern over pending lawsuits.

A final cause of safety factors in the well/drain discharge may result from a lack of legal control over other pumpage from the same aquifer. Without aid from a government agency to control other pumpers, the facility operator may have to increase discharge from the well/drain system to counteract increased pumpage off-site. Additional capital and O&M costs could be realized over time as new structures are added to cope with increasing discharge by other groundwater users.

COST OF CONTAINMENT BY FLUID ISOLATION

Isolation of contaminant plumes using slurry wall systems is possible within a variety of geohydrological conditions. In addition to wall installation, proper land surface treatment such as sealing may be necessary in order to limit recharge into the contaminated area. The degree of leakage and longevity of the slurry wall system is not specifically addressed in this study. However, it is assumed that wall materials will be appropriately matched to containment requirements. Further, since empirical data on wall longevity are not available, structural integrity cannot be assured in the long run. A risk factor must eventually be derived and included in comparative cost analyses.

Wall leakage can occur without structural failure if differences in ground-water elevations across the wall are allowed. The addition of a small capacity fluid removal system inside the plume can provide the necessary management of water levels to prevent outward leakage of plume fluids. For the purposes of this study, it was assumed that fluid removal/treatment would be added for gradient control without significantly affecting total costs based only on installation and maintenance of the encapsulating materials.

The implication of any leakage in the slurry wall containment strategy is dependent upon site specific conditions including proximity to discharge points, transport rates, and resultant concentration/toxicity of the contaminant outside the wall.

Various factors affect the feasibility of slurry wall containment systems. In particular, the media in which the wall is to be installed must be compatible with rapid excavation and be underlain by an adequate confining layer less than about 125 feet deep. In general, containment requirements/costs are functionally related to slurry wall area, land surface treatment requirements, ease of excavation, and contaminant characteristics as they impact the quantity and characteristics of wall materials and the cost of placement.

General Approach

The cost estimation approach used for slurry wall systems is similar to the preceeding discussion of fluid removal systems. Containment scenarios were first developed, then, through the use of unit costs, total cost of containment was derived. The same range of plume sizes were used as in the preceeding section; however, the diversity in hydrogeological variables is not maintained as

they do not directly impact system cost. Background cost matrices for slurry wall systems are presented in Appendix H.

Cost estimates were developed for two principal components: wall materials/installation and the treatment of the land surface above a plume (e.g., modification of slope, integrity, vegetation, etc.). Included in these estimates are the costs of engineering, site investigations, monitoring and field work. Other ancillary costs such as legal fees and land acquisition are not readily quantified and are specifically excluded. For each of the model plumes, the perimeter, land surface area and vertical wall area were calculated (Table 8) and represent the principal driving variables.

Wall area is based on a slurry wall completely surrounding the plume as indicated by the estimates of plume perimeter presented in Table 8. The maximum depth of wall installation was set at 100 feet, although installation depths as great as 125 feet have been achieved.

Total capital costs were calculated using slurry wall and land surface treatment unit costs. These unit costs were selected for establishing reasonable cost ranges, and

TABLE 8

PLUME AND SLURRY WALL DIMENSIONS

Plume Dimensions WidthxLength (ft)	Plume Perimeter (1000's ft)	Land Surface Area (1000's ft^2)	Vertical Area of Slurry Walls (1000's ft^2) at Various Depths (ft)			
			25	50	75	100
100 x 200	.48	16	12	24	36	48
100 x 500	1.1	39	26	53	83	110
500 x 1000	2.4	390	61	120	180	240
500 x 2500	5.3	980	130	260	400	530
1000 x 2000	4.8	1600	120	240	360	480
1000 x 5000	11.0	3900	260	530	830	1100
2000 x 4000	9.7	6300	240	480	730	970
2000 x 10000	21.0	16000	530	1100	1600	2100

do not represent specific wall designs. Examples of specific slurry wall/surface treatment design are offered in the next section in order to demonstrate the basis for the selected range. In addition to installation costs, the costs for plume delineation and perimeter soil borings were developed specifically for fluid isolation systems. Costs for delineation, soil borings, and engineering are presented in Appendix H, Table H-10.

The primary element in annual O&M costs is $10,000 for ground-water monitoring around and inside the encapsulated plume. No maintenance cost are anticipated for the slurry wall system, although maintenance costs are incurred in the low-cost land treatment scenario.

Numerous assumptions and limiting conditions were needed for developing slurry wall cost estimates. Although these are mentioned throughout the text, they are summarized in Table 9. Limitations of slurry wall containment systems that are not inherent in fluid removal systems are listed in Table 10.

Development of Unit Costs

The cost estimation algorithm for fluid isolation systems combines a series of supportive unit costs into

TABLE 9

DESIGN CONSIDERATIONS/ASSUMPTIONS
OF SLURRY WALL INSTALLATIONS

- Walls extend from the land surface to the bottom of the aquifer and are keyed into existing, underlying "impermeable" materials.

- Walls are elliptical in plan view, coincide with plume boundaries, and have constant thickness and height.

- A geotechnical investigation must be performed in order to generate design criteria for the wall.

- Monitoring of ground-water quality around the plume is required during the life of the wall; no other maintenance of the wall is anticipated.

- Wall composition is designed to be chemically compatible with the contaminant plume, e.g., materials may include bentonite/soil mix, cold asphalt emulsion, and special chemical additives.

- Mobilization/demobilization costs are considered to be included in the costs per vertical square foot.

- Site conditions are assumed to be amenable to slurry wall construction. The perimeter of the plume is accessible, with no excessive vegetation or grades. Also, accessway construction is not required.

- Site ownership and management is assumed and is the responsibility of the owner. No costs will be incurred for legal access, fencing, or control.

- Land surface treatment costs assume minimal clearing requirements before grading and recontouring.

- Costs of disposal of any excavated material is not included. This may be required if contaminated material is encountered and where conventional excavation methods are used.

TABLE 10

LIMITATIONS OF SLURRY WALL SYSTEMS

- Wall installation is limited to unconsolidated or soft consolidated materials (no hard rock).
- Emplacement is limited to maximum depths of 125 feet, using the vibrating beam method and less than 100 feet with more conventional excavation equipment.
- Wall systems maintenance is not technically feasible.
- Full control of surface rights may be required to limit recharge.

	K Costs	O&M Costs
Slurry Wall	A	B
Land Surface Treatment	C	D
Total		

FIGURE 21. Format of Cost Components for Fluid Isolation Systems.

major capital and O&M component costs. Figure 21 shows the major cost components in the format used for presenting data in Appendix H. Each component of the matrix is identified by letter to facilitate the following discussion.

Slurry wall capital costs presented as Block A of Figure 21 include unit costs for:

- slurry wall materials and installation
- plume delineation
- perimeter borings
- engineering

Unit costs of slurry walls used in this analysis are $2.50, $5.00, and $10.00 per vertical square foot and include materials, installation and mobilization/demobilization.

This range was derived from prices estimated by various U. S. contractors* and does not correspond to a particular wall type. In specific applications, unit wall costs will be related to economies of scale, permeability requirement, depth, slurry material, accessibility of the site, and other factors such as union labor rates. Due to these

* Unit Costs for slurry wall systems were generally reported for the "vibrating beam" method of installation. Details of wall installation using this method are available. See reference under Slurry Systems, 1981.

complexities and a general lack of consistency in the reported cost estimates, a well defined cost curve could not be developed.

In general, a number of conditions can be combined to result in the unit costs used herein. For example, installation of a relatively deep wall around a small plume using Aspemix*, an asphalt based slurry, could be in the range of $10.00 per vertical square foot, whereas, installation of a relatively shallow bentonite slurry wall around a large plume may be in the range of $2.50 per vertical square foot. Most slurry wall applications range in cost between $4.00 and $7.50 per vertical square foot as represented in the mid-wall case where $5.00 per vertical square foot was used. Specific placement methods and isolation characteristics of various slurry material options are presented in Tables 11 and 12, respectively.

Plume delineation costs were determined by the same algorithm as described in the chapter on fluid removal systems and were derived from Figure 6. Delineation costs range between $20,000 and $175,000 for slurry walls as specified in Table H-10 of Appendix H.

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*Aspemix: Trade name of slurry material developed by Slurry Systems, 1981.

TABLE 11

SLURRY WALL SYSTEMS: INSTALLATION OPTIONS

- Backhoe and Crawler Tractor
  - Up to 30 feet deep and several feet wide
  - Soil/bentonite or bentonite/cement slurry
  - Poor quality control over slurry mixture
  - No control over sluffing
- Trencher
  - Up to 25 feet deep by 1 foot wide
  - Bentonite and asphalt slurries
  - Good quality control over mixture
- Vibrating Beam
  - Up to 125 feet deep by minimum width of 1/2 feet
  - Bentonite and asphalt slurries
  - Good quality control over mixture

TABLE 12

SLURRY WALL SYSTEMS: WALL MATERIALS, PERMEABILITIES

- Bentonite-Based Slurries
  - Cement as additive
  - Other chemical additives
  - Permeabilities on order of 10^{-7} cm/sec
- Asphalt-Based Slurries
  - "Aspemix" is brand name
  - Cold asphalt emulsion
  - Permeabilities on order of 10^{-11} cm/sec

Once the contaminant plume is delineated and the slurry wall containment option is selected, additional soil borings are required to further define wall placement and to design the slurry composition. Borings are placed along the perimeter of the plume to the approximate depth of the confining unit. Actual boring spacing will be a function of the complexity or homogeneity of the media and can vary from 50 to 250-foot spacing. For the purposes of this study, 100-foot spacing was assumed. This results in a range of boring costs between $2,000 and $25,000 over the range of plume sizes (perimeters) used in this study. Specific boring costs are presented in Table H-10.

The unit costs for plume delineation, perimeter soil borings, and slurry wall installation represent basic contracting costs exclusive of engineering fees. Block A of Figure 21 includes engineering fees calculated as a percentage of these costs. Figure 22 is a standard curve (developed by ASCE) which was used to determine this percentage. As shown, the percentage can range from 5.7 to 11.7. Costs not included in Block A include capital financing and protection of the facility if necessary (e.g., fencing or guards).

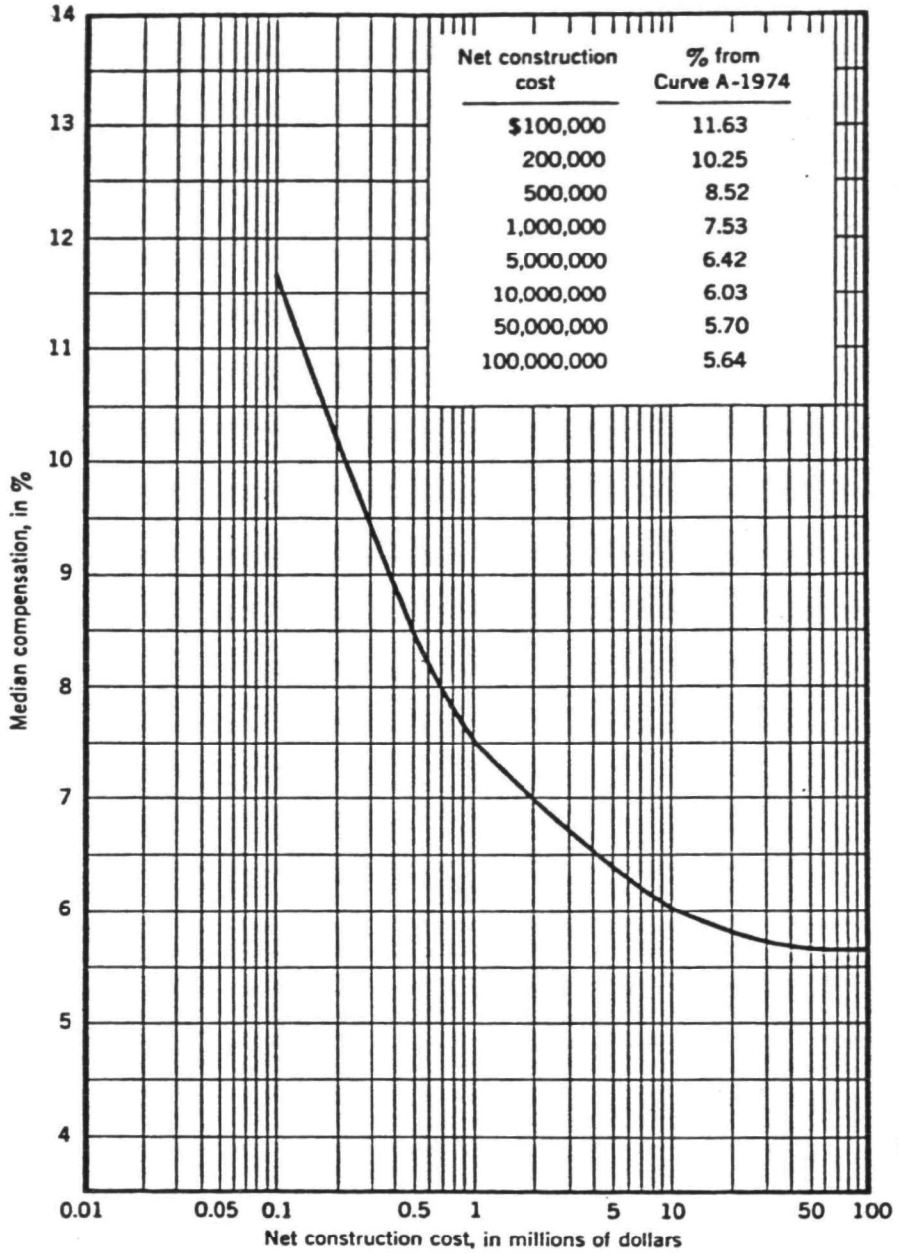

FIGURE 22. Median Compensation for Engineering Services Expressed as a Percentage of Construction Cost

Slurry wall operation and maintenance (O&M) costs are included in Block B of Figure 21. These are assumed to be negligible for this analysis. Any notion of "design life" of slurry walls must be accomodated externally to this study because little empirical data regarding wall longevity in a hazardous waste environment are available.

An average monitoring cost of $10,000/year was imposed as an O&M cost for each slurry wall. This cost, held constant for plumes of all sizes, includes monitor well sampling and analysis only for selected indicator parameters. It is assumed that a partial chemical analysis is adequate because all ground-water contaminants are assumed to be identified during the delineation phase. In cases where leakage is detected, the cost of troubleshooting can be substantially higher than $10,000/year. Also included in the monitoring cost is the cost of reporting laboratory analytical results and maintaining the monitor wells.

Block C of Figure 21 includes capital costs for land surface treatment. As indicated in Table 13, three surface treatment options were considered in this study. Land surface treatment is performed in order to limit recharge of surface water into the encapsulated plume. It is judged necessary because without a surface treatment option, the

TABLE 13

SURFACE TREATMENT OPTIONS AND ASSIGNED COSTS

	Land Surface Treatment	Cost
1.	None	None
2.	Grading, recontouring, and re-vegetation	Low Cost: $.15/ $foot^2$
3.	Grading, recontouring, and surface sealing	High cost: $.75/ $foot^2$

walled area can accumulate fluids faster than they can be lost by leakage across the wall boundaries.

Several treatment options were discussed in a recent report by SCS Engineers (1981) which is based on the Means 1980 cost guide. The low cost option includes initial grading and recontouring the area. About 1.5 feet of soil is applied to the surface area which is then mulched and seeded (soil is assumed to be available at the site). In the high cost option, the grading and recontouring process is followed by the application of a 3-inch bituminous concrete cap. Actual selection of a land surface treatment option for a given site will be based on local conditions such as existing recharge potential, contours and the existence of surface structures. In addition, other more costly sealing options such as plastics are available but are not considered in this analysis. It is assumed for this analysis that the surface is accessible and free of major obstructions.

In addition to basic land treatment costs, an engineering cost is incurred based on percentage determined with Figure 22.

Operation and maintenance costs for land surface treatment are included in Block D. These costs are minimal

and are incurred only in the grading and revegetation option (the low capital cost option). Costs in this area correspond primarily to fertilizing and mowing of vegetation.

SUMMARY OF COST ESTIMATES/SENSITIVITIES

Slurry wall containment costs vary with plume perimeter, surface area, and depth. Containment costs are presented in Appendix H for eight different plume sizes and four different depths. Graphs indicating sensitivity to perimeter size, depth, and land surface treatment requirement are also included in the Appendix.

The cost summary presented in Table 14 indicates total containment costs for four plume sizes and several containment options. It is clear from the table that land surface treatment, and in particular, surface sealing becomes a dominant cost as plume area increases.

TABLE 14

SUMMARY OF SLURRY WALL
CONTAINMENT COSTS ($1000's)

Slurry wall dimensions (feet):	100 x 200	500 x 2500	2000 x 4000	2000 x 10,000
Containment perimeter (feet):	480	5,300	9,700	21,000
Design area (feet^2):	16,000	980,000	6,300,000	16,000,000
CONTAINMENT DESIGN				
Mid-cost 25 foot slurry wall with no land surface treatment	90	770	1,382	2,928
Mid-cost 75 foot slurry wall with no land surface treatment	240	2,255	3,963	8,845
Mid-cost 25 foot slurry wall with surface sealing	103	1,568	6,382	15,648
Mid-cost 75 foot slurry wall with surface sealing	253	3,053	8,963	21,565

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APPENDIX A: GLOSSARY OF TECHNICAL TERMS

APPENDIX A

GLOSSARY OF TECHNICAL TERMS

Aquifer	Rock or sediment which is saturated and sufficiently permeable to transmit economic quantities of water to wells and springs.
Aquifer, confined	An aquifer that is overlain by confining strata. The confining strata have a significantly lower hydraulic conductivity than the aquifer.
Aquifer, unconfined	An aquifer in which there are no confining strata between the zone of saturation and the surface. There will be a water table in an unconfined aquifer. Water-table aquifer is a synonym.
Barrier boundary	An aquifer-system boundary represented by a rock mass that is not a source of water.
Drawdown	A lowering of the water table of an unconfined aquifer or the potentiometric surface of a confined aquifer caused by pumping of ground water from wells.
Equipotential line	A line in a two-dimensional groundwater flow field such that the total hydraulic head is the same for all points along the line.
Flow field	The set of intersecting equipotential lines and flowlines representing two-dimensional steady flow through porous media.
Ground water	The water contained in interconnected pores located below the water table in an unconfined aquifer or located in a confined aquifer.
Ground water flow	The movement of water through openings in sediment and rock which occurs in the zone of saturation.

GLOSSARY (continued)

Head, total	The sum of the elevation head, the pressure head, and the velocity head at a given point in an aquifer.
Hydraulic gradient	The change in total head with a change in distance in a given direction. The direction is that which yields a maximum rate of decrease in head.
Isotropy	The condition in which hydraulic properties of the aquifer are equal in all directions.
Recharge boundary	An aquifer system boundary that adds water to the aquifer. Streams and lakes are typical recharge boundaries.
Submergence head	The minimum pressure head required at a submerged pump intake to permit operation of the pump. Measured in feet of water above the intake structure.
Transmissivity	The rate at which water of a prevailing density and viscosity is transmitted through a unit width of an aquifer or confining bed under a unit hydraulic gradient. It is a function of properties of the liquid, the porous media, and the thickness of the porous media.
Water table	The surface in an unconfined aquifer or confining bed at which the pore water pressure is atmospheric. It can be measured by installing shallow wells extending a few feet into the zone of saturation and then measuring the water level in those wells.
Well interference	The result of two or more pumping wells, the drawdown cones of which intercept. At a given location, the total well interference is the sum of the drawdowns due to each individual well.
Well losses	Head losses, or drawdown, in a pumping well that result from turbulent flow inside the well and across the well screen.

APPENDIX B: CONTAINMENT DESIGN REQUIREMENTS FOR WELL/DRAIN FLUID REMOVAL SYSTEMS

TABLE B-1

CONTAINMENT DESIGN REQUIREMENTS FOR FLUID REMOVAL SYSTEMS UNDER STRATEGY 1

Hydraulic Gradient = 0.5 ft/mi Transmissivity = 100,000 gal/day/ft

Plume Width (ft)		100	500	1000	2000
Plume Discharge (gpm)		(0.66)	(3.3)	(6.6)	(13)
Plume Depth (ft)	25	1(5)[a]	1(5)	1(8)	1(16)
	50	↓	↓	↓	↓
	75	↓	↓	↓	↓
	100	↓	↓	↓	↓
	200	↓	↓	↓	↓

[a] Number of wells and per-well discharge, in gal/min, e.g. 1(8): one well with a discharge of 8 gpm

TABLE B-2

CONTAINMENT DESIGN REQUIREMENTS FOR FLUID REMOVAL SYSTEMS UNDER STRATEGY 1

Hydraulic Gradient = 0.5 ft/mi Transmissivity = 1,000,000 gal/day/ft

Plume Width (ft)		100	500	1000	2000
Plume Discharge (gpm)		(6.6)	(33)	(66)	(132)
Plume Depth (ft)	25	1(8)[a]	1(40)	1(80)	1(160)
	50	↓	↓	↓	↓
	75	↓	↓	↓	↓
	100	↓	↓	↓	↓
	200	↓	↓	↓	↓

[a] Number of wells and per-well discharge, in gal/min, e.g. 1(8): one well with a discharge of 8 gpm

TABLE B-3

CONTAINMENT DESIGN REQUIREMENTS FOR FLUID REMOVAL SYSTEMS UNDER STRATEGY 1

Hydraulic Gradient = 5 ft/mi Transmissivity = 10,000 gal/day/ft

Plume Width (ft)		100	500	1000	2000
Plume Discharge (gpm)		(0.66)	(3.3)	(6.6)	(13)
Plume Depth (ft)	25	1(5)[a]	1(5)	1(8)	1(16)
	50	↓	↓	↓	↓
	75	↓	↓	↓	↓
	100	↓	↓	↓	↓
	200	↓	↓	↓	↓

[a] Number of wells and per-well discharge, in gal/min, e.g. 1(8): one well with a discharge of 8 gpm

TABLE B-4

CONTAINMENT DESIGN REQUIREMENTS FOR FLUID REMOVAL SYSTEMS UNDER STRATEGY 1

Hydraulic Gradient = 5 ft/mi Transmissivity = 100,000 gal/day/ft

Plume Width (ft)		100	500	1000	2000
Plume Discharge (gpm)		(6.6)	(33)	(66)	(132)
Plume Depth (ft)	25	1(8)[a]	1(40)	1(80)	1(160)
	50	↓	↓	↓	↓
	75	↓	↓	↓	↓
	100	↓	↓	↓	↓
	200	↓	↓	↓	↓

[a] Number of wells and per-well discharge, in gal/min, e.g. 1(8): one well with a discharge of 8 gpm

TABLE B-5

CONTAINMENT DESIGN REQUIREMENTS FOR FLUID REMOVAL SYSTEMS UNDER STRATEGY 1

Hydraulic Gradient = 5 ft/mi Transmissivity = 1,000,000 gal/day/ft

Plume Width (ft)		100	500	1000	2000
Plume Discharge (gpm)		(66)	(330)	(660)	(1320)
Plume Depth (ft)	25	1(80)[a]	1(400)	1(800)	1(1600)
	50	↓	↓	↓	↓
	75	↓	↓	↓	↓
	100	↓	↓	↓	↓
	200	↓	↓	↓	↓

[a] Number of wells and per-well discharge, in gal/min, e.g. 1(8): one well with a discharge of 8 gpm

TABLE B-6

CONTAINMENT DESIGN REQUIREMENTS FOR FLUID REMOVAL SYSTEMS UNDER STRATEGY 1

Hydraulic Gradient = 50 ft/mi Transmissivity = 1,000 gal/day/ft

Plume Width (ft)		100	500	1000	2000
Plume Discharge (gpm)		(0.66)	(3.3)	(6.6)	(13)
Plume Depth (ft)	25	1(5)[a]	1(5)	1(8)	2(8)
	50	↓	↓	↓	↓
	75	↓	↓	↓	↓
	100	↓	↓	↓	↓
	200	↓	↓	↓	↓

[a] Number of wells and per-well discharge, in gal/min, e.g. 1(8): one well with a discharge of 8 gpm

TABLE B-7

CONTAINMENT DESIGN REQUIREMENTS FOR FLUID REMOVAL SYSTEMS UNDER STRATEGY 1

Hydraulic Gradient = 50 ft/mi Transmissivity = 10,000 gal/day/ft

Plume Width (ft)		100	500	1000	2000
Plume Discharge (gpm)		(6.6)	(33)	(66)	(132)
Plume Depth (ft)	25	1(8)[a]	1(40)	8(10)[b]	16(10)[b]
	50			2(40)	1(160)
	75			1(80)	
	100				
	200				

[a] Number of wells and per-well discharge, in gal/min, e.g. 1(8): one well with a discharge of 8 gpm

[b] Wells installed in gravel-filled drain

TABLE B-8

CONTAINMENT DESIGN REQUIREMENTS FOR FLUID REMOVAL SYSTEMS UNDER STRATEGY 1

Hydraulic Gradient = 50 ft/mi Transmissivity = 100,000 gal/day/ft

Plume Width (ft)		100	500	1000	2000
Plume Discharge (gpm)		(66)	(330)	(660)	(1320)
Plume Depth (ft)	25	1(80)[a]	1(400)	2(400)	160(10)[b]
	50			1(800)	1(1600)
	75				
	100				
	200				

[a] Number of wells and per-well discharge, in gal/min, e.g. 1(8): one well with a discharge of 8 gpm

[b] Wells installed in gravel-filled drain

TABLE B-9

CONTAINMENT DESIGN REQUIREMENTS FOR FLUID REMOVAL SYSTEMS UNDER STRATEGY 1

Hydraulic Gradient = 500 ft/mi		Transmissivity = 1,000 gal/day/ft			
Plume Width (ft)		100	500	1000	2000
Plume Discharge (gpm)		(6.6)	(33)	(66)	(132)
Plume Depth (ft)	25	2(4.0)[a]	4(10)[b]	8(10)[b]	16(10)[b]
	50	1(8.0)	3(13.2)	5(16)[c]	9(18)[c]
	75	↓	2(20)	3(26.4)	6(26.4)
	100		1(40)	2(40)	4(40)
	200			1(80)	2(80)

[a] Number of wells and per-well discharge, in gal/min, e.g. 1(8): one well with a discharge of 8 gpm

[b] Wells installed in gravel-filled drain

[c] Some wells located upgradient inside plume

TABLE B-10

CONTAINMENT DESIGN REQUIREMENTS FOR FLUID REMOVAL SYSTEMS UNDER STRATEGY 1

Hydraulic Gradient = 500 ft/mi		Transmissivity = 10,000 gal/day/ft			
Plume Width (ft)		100	500	1000	2000
Plume Discharge (gpm)		(66)	(330)	(660)	(1320)
Plume Depth (ft)	25	2(40)[a]	40(10)[b]	80(10)[b]	160(10)[b]
	50	1(80)	10(40)	15(53)[c]	18(89)[c]
	75	↓	4(100)	10(80)	12(133)[c]
	100		2(200)	4(200)	8(200)
	200		1(400)	1(800)	2(800)

[a] Number of wells and per-well discharge, in gal/min, e.g. 1(8): one well with a discharge of 8 gpm

[b] Wells installed in gravel-filled drain

[c] Some wells located upgradient inside plume

TABLE B-11

CONTAINMENT DESIGN REQUIREMENTS FOR FLUID REMOVAL SYSTEMS UNDER STRATEGY 2

Hydraulic Gradient = 5 ft/mi Transmissivity = 10,000 gal/day/ft

Plume Dimensions (ft) (width x length)		100x200	100x500	500x1000	500x2500	1000x2000	1000x5000	2000x4000	2000x10000
Plume Discharge (gpm)		(3.3)	(7.3)	(16)	(35)	(33)	(73)	(65)	(138)
Plume Depth (ft)	25	1(4.1)[a]	1(10)	1(21)	1(52)	1(41)	3(34)	2(41)	5(41)
	50						1(103)	1(83)	3(68)
	75								1(206)
	100								
	200								

[a] Minimum number of wells needed to control gradients with a 70% limit on well drawdown; discharge units are gpm

TABLE B-12

CONTAINMENT DESIGN REQUIREMENTS FOR FLUID REMOVAL SYSTEMS UNDER STRATEGY 2

Hydraulic Gradient = 5 ft/mi Transmissivity = 100,000 gal/day/ft

Plume Dimensions (ft) (width x length)		100x200	100x500	500x1000	500x2500	1000x2000	1000x5000	2000x4000	2000x10000
Plume Discharge (gpm)		(32)	(72)	(158)	(349)	(316)	(723)	(638)	(1380)
Plume Depth (ft)	25	1(41)[a]	1(103)	1(206)	1(515)	1(413)	3(343)	2(413)	5(413)
	50	↓	↓	↓	↓	↓	1(1030)	1(825)	3(680)
	75	↓	↓	↓	↓	↓	↓	↓	2(1032)
	100	↓	↓	↓	↓	↓	↓	↓	1(2065)
	200	↓	↓	↓	↓	↓	↓	↓	↓

[a] Minimum number of wells needed to control gradients with a 70% limit on well drawdown; discharge units are gpm

TABLE B-13

CONTAINMENT DESIGN REQUIREMENTS FOR FLUID REMOVAL SYSTEMS UNDER STRATEGY 2

Hydraulic Gradient = 5 ft/mi Transmissivity = 1,000,000 gal/day/ft

Plume Dimensions (ft) (width x length)		100x200	100x500	500x1000	500x2500	1000x2000	1000x5000	2000x4000	2000x10000
Plume Discharge (gpm)		(316)	(723)	(1580)	(3490)	(3160)	(7230)	(6380)	(13,800)
Plume Depth (ft)	25	1(410)[a]	1(1030)	1(2060)	2(2575)	1(4000)	3(3433)	2(4000)	5(4000)
	50	↓	↓	↓	↓	↓	↓	↓	↓
	75	↓	↓	↓	↓	↓	↓	↓	↓
	100	↓	↓	↓	↓	↓	↓	↓	↓
	200	↓	↓	↓	↓	↓	↓	↓	↓

[a] Minimum number of wells needed to control gradients with a 70% limit on well drawdown; discharge units are gpm

APPENDIX C: CAPITAL COSTS FOR WELL/DRAIN FLUID REMOVAL SYSTEMS

Table C-1. Supportive Capital Costs for Fluid Removal Systems

Total Containment Cost Table	Support Cost Element	Width x Length (ft) and Associated Capital Costs (1000's dollar)			
		100 x 200	100 x 500	500 x 1000	500 x 2500
F-1	Delineation	28.0	28.0	50.0	62.0
	Design Eng.	20.0	20.0	22.0	25.0
	Well/Drain	7.4	7.4	7.4	7.4
	Const. Eng.	11.9	11.9	11.9	11.9
	Totals	67.3	67.3	91.3	106.3
F-2	Delineation	15.0	15.0	30.0	38.0
	Design Eng.	20.0	20.0	22.0	25.0
	Well/Drain	2.4	2.4	2.4	2.4
	Const. Eng.	10.6	10.6	10.6	10.6
	Totals	48.0	48.0	65.0	76.0
F-3	Delineation	28.0	28.0	50.0	62.0
	Design Eng.	20.0	20.0	22.0	25.0
	Well/Drain	7.4	7.4	7.4	7.4
	Const. Eng.	11.9	11.9	11.9	11.9
	Totals	67.3	67.3	91.3	106.3
F-4	Delineation	60.0	60.0	110.0	138.0
	Design Eng.	20.0	20.0	22.0	25.0
	Well/Drain	19.6	19.6	19.6	19.6
	Const. Eng.	15.0	15.0	15.0	15.0
	Totals	114.6	114.6	166.6	197.6

Table C-1. (Continued)

Total Containment Cost Table	Support Cost Element	Width x Length (ft) and Associated Capital Costs (1000's dollar)			
		1000 x 2000	1000 x 5000	2000 x 4000	2000 x 10000
F-1	Delineation	70.0	80.0	90.0	140.0
	Design Eng.	28.0	35.0	39.5	50.0
	Well/Drain	7.4	7.4	7.4	7.4
	Const. Eng.	11.9	11.9	11.9	11.9
	Totals	117.3	134.3	148.8	209.3
F-2	Delineation	41.0	48.0	50.0	80.0
	Design Eng.	28.0	34.5	39.5	50.0
	Well/Drain	2.4	2.4	2.4	2.4
	Const. Eng.	10.6	10.6	10.6	10.6
	Totals	82.0	95.5	102.5	143.0
F-3	Delineation	70.0	80.0	90.0	140.0
	Design Eng.	28.0	35.0	39.5	50.0
	Well/Drain	7.4	7.4	7.4	7.4
	Const. Eng.	11.9	11.9	11.9	11.9
	Totals	117.3	134.3	148.8	209.3
F-4	Delineation	150.0	178.0	198.0	300.0
	Design Eng.	28.0	35.0	39.5	50.0
	Well/Drain	19.6	19.6	19.6	19.6
	Const. Eng.	15.0	15.0	15.0	15.0
	Totals	212.6	247.6	272.1	384.6

Table C-2. Supportive Capital Costs for Fluid Removal Systems

Total Containment Cost Table	Support Cost Element	Width x Length (ft) and Associated Capital Costs (1000's dollar)			
		100 x 200	100 x 500	500 x 1000	500 x 2500
F-5	Delineation	25.2	25.2	48.0	59.6
	Design Eng.	20.0	20.0	22.0	25.0
	Well/Drain	6.9	6.9	6.9	6.9
	Const. Eng.	11.8	11.8	11.8	11.8
	Totals	63.9	63.9	88.7	103.3
F-6	Delineation	28.0	28.0	50.0	62.0
	Design Eng.	20.0	20.0	22.0	25.0
	Well/Drain	7.4	7.4	7.4	7.4
	Const. Eng.	11.9	11.9	11.9	11.9
	Totals	67.3	67.3	91.3	106.3
F-7	Delineation	48.0	48.0	95.0	116.0
	Design Eng.	20.0	20.0	22.0	25.0
	Well/Drain	15.7	15.7	15.7	15.7
	Const. Eng.	14.0	14.0	14.0	14.0
	Totals	97.7	97.7	146.7	170.7
F-8	Delineation	176.1	271.6	640.7	1174.8
	Design Eng.	20.0	20.0	22.0	25.0
	Well/Drain	30.4	30.4	41.5	41.5
	Const. Eng.	17.8	17.8	17.8	17.8
	Totals	244.3	339.8	722.0	1259.1

Table C-2. (Continued)

Total Containment Cost Table	Support Cost Element	Width x Length (ft) and Associated Capital Costs (1000's dollar)			
		1000 x 2000	1000 x 5000	2000 x 4000	2000 x 10000
F-5	Delineation	67.0	76.8	86.8	134.0
	Design Eng.	28.0	35.0	39.5	50.0
	Well/Drain	6.9	6.9	9.4	9.4
	Const. Eng.	11.8	11.8	11.8	11.8
	Totals	113.7	130.5	147.5	205.2
F-6	Delineation	70.0	80.0	90.0	140.0
	Design Eng.	28.0	35.0	39.5	50.0
	Well/Drain	10.0	10.0	28.9	28.9
	Const. Eng.	11.9	11.9	11.9	11.9
	Totals	119.9	136.9	170.3	230.8
F-7	Delineation	126.0	145.6	164.8	248.0
	Design Eng.	28.0	35.0	39.5	50.0
	Well/Drain	21.4	21.4	61.6	61.6
	Const. Eng.	14.0	14.0	14.0	14.0
	Totals	189.4	216.0	279.9	373.6
F-8	Delineation	1333.2	3403.9	3403.9	8499.6
	Design Eng.	28.0	35.0	39.5	50.0
	Well/Drain	119.4	119.4	119.4	119.4
	Const. Eng.	17.8	17.8	17.8	17.8
	Totals	1498.4	3576.1	3580.6	8686.8

Table C-3. Supportive Capital Costs for Fluid Removal Systems

Total Containment Cost Table	Support Cost Element	Width x Length (ft) and Associated Capital Costs (1000's dollar)			
		100 x 200	100 x 500	500 x 1000	500 x 2500
F-9	Delineation	28.0	28.0	50.0	62.0
	Design Eng.	20.0	20.0	22.0	25.0
	Well/Drain	10.0	10.0	30.4	30.4
	Const. Eng.	11.9	11.9	11.9	11.9
	Totals	69.9	69.9	114.3	129.3
F-10	Delineation	15.0	15.0	30.0	38.0
	Design Eng.	20.0	20.0	22.0	25.0
	Well/Drain	2.4	2.4	2.4	2.4
	Const. Eng.	10.6	10.6	10.6	10.6
	Totals	48.0	48.0	65.0	76.0
F-11	Delineation	15.0	15.0	30.0	38.0
	Design Eng.	20.0	20.0	22.0	25.0
	Well/Drain	3.4	3.4	10.1	10.1
	Const. Eng.	10.6	10.6	10.6	10.6
	Totals	49.0	49.0	72.7	83.7
F-12	Delineation	28.0	28.0	50.0	62.0
	Design Eng.	20.0	20.0	22.0	25.0
	Well/Drain	10.0	10.0	30.4	30.4
	Const. Eng.	11.9	11.9	11.9	11.9
	Totals	69.9	69.9	114.3	129.3

Table C-3. (Continued)

Total Containment Cost Table	Support Cost Element	Width x Length (ft) and Associated Capital Costs (1000's dollar)			
		1000 x 2000	1000 x 5000	2000 x 4000	2000 x 10000
F-9	Delineation	70.0	80.0	90.0	140.0
	Design Eng.	28.0	35.0	39.5	50.0
	Well/Drain	35.2	35.2	45.0	45.0
	Const. Eng.	11.9	11.9	11.9	11.9
	Totals	145.1	162.1	186.4	246.9
F-10	Delineation	41.0	48.0	50.0	80.0
	Design Eng.	28.0	34.5	39.5	50.0
	Well/Drain	34.4*	34.4*	52.4*	52.4*
	Const. Eng.	11.8	11.8	13.6	13.6
	Totals	115.2*	128.7*	155.5*	196.0*
F-11	Delineation	41.0	48.0	50.0	80.0
	Design Eng.	28.0	34.5	39.5	50.0
	Well/Drain	20.0	20.0	92.2*	92.2*
	Const. Eng.	11.3	11.3	28.0	28.0
	Totals	100.3*	113.8*	209.7*	250.2*
F-12	Delineation	70.0	80.0	90.0	140.0
	Design Eng.	28.0	35.0	39.5	50.0
	Well/Drain	35.2	35.2	45.0	45.0
	Const. Eng.	11.9	11.9	11.9	11.9
	Totals	145.1	162.1	186.4	246.9

*Gravel-filled trench with small diameter wells

Table C-4. Supportive Capital Costs for Fluid Removal Systems

Total Containment Cost Table	Support Cost Element	Width x Length (ft) and Associated Capital Costs (1000's dollar)			
		100 x 200	100 x 500	500 x 1000	500 x 2500
F-13	Delineation	15.0	15.0	30.0	38.0
	Design Eng.	20.0	20.0	22.0	25.0
	Well/Drain	4.9	4.9	25.4*	25.4*
	Const. Eng.	11.2	11.2	10.9	10.9
	Totals	51.1	51.1	88.3*	99.3*
F-14	Delineation	15.0	15.0	30.0	38.0
	Design Eng.	20.0	20.0	22.0	25.0
	Well/Drain	4.9	4.9	35.0*	35.0*
	Const. Eng.	11.2	11.2	14.5	14.5
	Totals	51.1	51.1	101.5*	112.5*
F-15	Delineation	28.0	28.0	50.0	62.0
	Design Eng.	20.0	20.0	22.0	25.0
	Well/Drain	10.0	10.0	111.0	111.0
	Const. Eng.	11.9	11.9	17.5	17.5
	Totals	69.9	69.9	200.5	215.5
F-16	Delineation	60.0	60.0	110.0	138.0
	Design Eng.	20.0	20.0	22.0	25.0
	Well/Drain	26.8	26.8	81.0	81.0
	Const. Eng.	15.0	15.0	15.0	15.0
	Totals	121.8	121.8	228.0	259.0

* Gravel-filled trench with small diameter wells

Table C-4. (Continued)

Total Containment Cost Table	Support Cost Element	Width x Length (ft) and Associated Capital Costs (1000's dollar)			
		1000 x 2000	1000 x 5000	2000 x 4000	2000 x 10000
F-13	Delineation	41.0	48.0	50.0	80.0
	Design Eng.	28.0	34.5	39.5	50.0
	Well/Drain	34.4*	34.4*	52.4*	52.4*
	Const. Eng.	11.8	11.8	13.6	13.6
	Totals	106.2*	128.7*	155.5*	196.0*
F-14	Delineation	41.0	48.0	50.0	80.0
	Design Eng.	28.0	34.5	39.5	50.0
	Well/Drain	55.0*	55.0*	92.2*	92.2*
	Const. Eng.	19.0	19.0	28.0	28.0
	Totals	143.0*	156.5*	209.7*	250.2*
F-15	Delineation	70.0	80.0	90.0	140.0
	Design Eng.	28.0	35.0	39.5	50.0
	Well/Drain	100.5	100.5	333.0	333.0
	Const. Eng.	28.8	28.8	32.5	32.5
	Totals	227.3	244.3	495.0	555.5
F-16	Delineation	150.0	178.0	198.0	300.0
	Design Eng.	28.0	35.0	39.5	50.0
	Well/Drain	94.0	94.0	188.0	188.0
	Const. Eng.	15.0	15.0	20.0	20.0
	Totals	287.0	322.0	445.5	558.0

* Gravel-filled trench with small diameter wells

Table C-5. Supportive Capital Costs for Fluid Removal Systems

Total Containment Cost Table	Support Cost Element	Width x Length (ft) and Associated Capital Costs (1000's dollar)			
		100 x 200	100 x 500	500 x 1000	500 x 2500
F-17	Delineation	28.0	28.0	50.0	62.0
	Design Eng.	20.0	20.0	22.0	26.0
	Wells/Pumps	7.4	7.4	7.4	10.0
	Const. Eng.	11.9	11.9	11.9	11.9
	Totals	67.3	67.3	91.3	109.3
F-18	Delineation	28.0	28.0	50.0	62.0
	Design Eng.	20.0	20.0	22.0	26.0
	Wells/Pumps	7.4	27.8	28.9	34.1
	Const. Eng.	11.9	11.9	10.9	11.9
	Totals	67.3	87.7	112.8	134.0
F-19	Delineation	28.0	28.0	50.0	62.0
	Design Eng.	20.0	20.0	22.0	26.0
	Wells/Pumps	30.4	41.2	45.0	90.0
	Const. Eng.	11.9	11.9	11.9	13.6
	Totals	90.3	101.1	128.9	191.6

Table C-5. (Continued)

Total Containment Cost Table	Support Cost Element	Width x Length (ft) and Associated Capital Costs (1000's dollar)			
		1000 x 2000	1000 x 5000	2000 x 4000	2000 x 10000
F-17	Delineation	70.0	80.0	92.0	140.0
	Design Eng.	28.0	34.0	39.5	50.0
	Wells/Pumps	7.4	27.8	10.0	28.9
	Const. Eng.	11.9	11.9	11.9	11.9
	Totals	117.3	154.2	153.4	230.8
F-18	Delineation	70.0	80.0	92.0	140.0
	Design Eng.	28.0	34.5	39.5	50.0
	Wells/Pumps	30.4	41.2	35.2	82.5
	Const. Eng.	11.9	11.9	11.9	13.6
	Totals	140.3	167.6	178.6	286.1
F-19	Delineation	70.0	80.0	92.0	140.0
	Design Eng.	28.0	34.5	39.5	50.0
	Wells/Pumps	45.0	135.0*	90.0*	225.0*
	Const. Eng.	11.9	15.6	13.6	19.4
	Totals	154.9	265.1	235.1	434.4

* Costs affected by maximum limit on per-well pumpage.

APPENDIX D: INFRASTRUCTURE COSTS

APPENDIX D

INFRASTRUCTURE COSTS

APPROACH

Infrastructure costs (IFC) are those associated with constructing supporting roadways, bringing in electric power, and installing the manifold and service piping from the wells to the treatment plant. IFC were developed for two strategies:

- Strategy 1: Wells placed along the toe of the plume in the traverse direction.
- Strategy 2: Wells placed along the length of the plume.

Strategy 1 encompasses approximately 40 scenarios while Strategy 2 covers approximately 30. Cost estimates were developed for each scenario.

To estimate IFC, hypothetical facility layouts were developed for both strategies. The two layouts chosen for Strategy 1 and Strategy 2 are shown in Tables D-1 and D-2, respectively. These tables demonstrate the approach used to estimate the IFC. The IFC results for each scenario were then analyzed to determine the controlling variables.

ASSUMPTIONS

The assumptions made in developing the IFC are presented below:

- Flat topography
- Extensive earthwork for road subgrade not included
- Access roads to wells and treatment plant begin at the plume source
- Roadways are 12 feet wide and constructed of gravel or crushed stone
- Overhead electric lines brought in along roadway and poles placed every 200 feet
- Treatment plant located at toe of plume for both strategies

- Each well equipped with a check valve, gate valve and flow meter.
- All underground piping provided with a minimum 3 feet of cover. Unit price for pipe includes excavation.
- Pipes sized to minimize head loss to 100 feet or less (not practical in all cases).
- Engineering (costs not included).
- Contingency of 30 percent on cost estimate assumed to arrive at total IFC.
- Means Cost Estimating Guide and Richardson's Cost Estimating Guide used for unit price information.

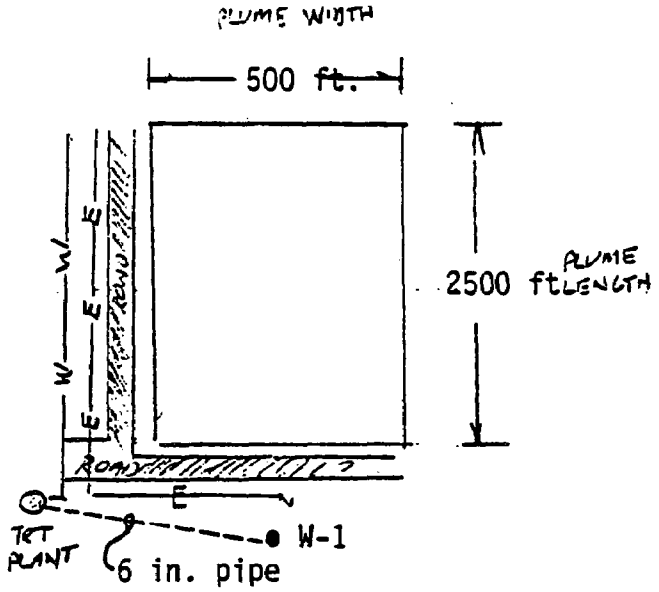
RESULTS

The results of the cost analysis are summarized in the following Tables and Figures:

- Table D-3 STRATEGY 1 - INFRASTRUCTURE CONSTRUCTION COSTS
- Table D-4 STRATEGY 2 - INFRASTRUCTURE CONSTRUCTION COSTS (with O&M)
- Figure D-1 STRATEGY 1 - INFRASTRUCTURE CONSTRUCTION COSTS VERSUS PLUME LENGTH
- Figure D-2 STRATEGY 2 - INFRASTRUCTURE CONSTRUCTION COSTS VERSUS PLUME LENGTH (1 Well)
- Figure D-3 STRATEGY 2 - INFRASTRUCTURE CONSTRUCTION COSTS VERSUS PLUME LENGTH (3 Wells)
- Figure D-4 STRATEGY 2 - INFRASTRUCTURE CONSTRUCTION COSTS VERSUS PLUME LENGTH (5 Wells)
- Figure D-5 O&M COSTS FOR INFRASTRUCTURE

The analysis of the cost estimate results show that for Strategy 1, plume length and the plume length to width ratio appear to be the controlling variables affecting construction costs, while plume length, total well output, and the number of wells appear to be the controlling variables for Strategy 2. Operation and maintenance costs are primarily a function of the length of the plume and the number of wells. The larger plumes will require longer access roads. Road maintenance will be a large percentage of the O&M costs; however, the number of wells also will add to the O&M costs, since periodic maintenance and repair of pumps is to be expected.

TABLE D.1- Example Infrastructure Cost Calculation for Strategy 1



ORIENTATION Strategy 1

NO. OF WELLS 1 at 330 gpm and 660 gpm per well

Description		Quantity	Unit Cost	Total Cost ($)
Gate Valve Size	6"	1	$ 530/ea	530
Check Valve	6"	1	570/ea	570
Tees	6" x 6"	1	270/ea	270
Meters	6"	1 ea	3,430/ea	3,430
Pipe	6"	350 lf	12.60/lf	4,410
6 inch Potable Water Main				
Fire Hydrant				
Gravel Road (12 ft)		2900	7/lf	20,300
Overhead Electricity		2900	4/lf	11,600
No. of Poles		15	300/ea	4,500
Transformer Type	50 kva		2,300/ea	2,300
Switchgear and Controls		1 ea	1,000/ea	1,000
			Sub-total	48,910
			Contingency (30%)	14,673
			TOTAL	$63,583

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Jan. 1982
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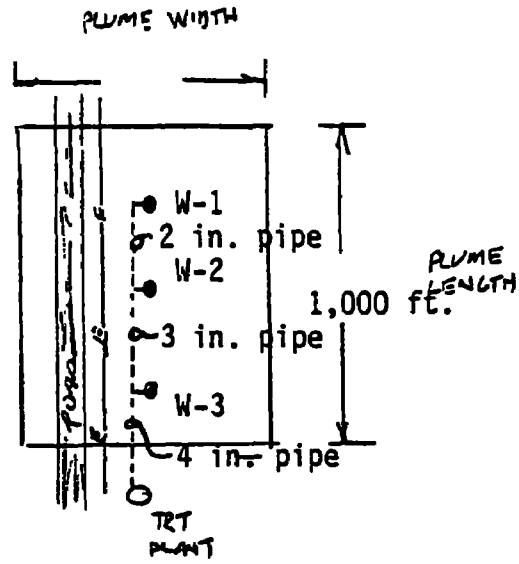
TABLE D.2- Example Infrastructure Cost Calculation for Strategy 2



ORIENTATION Strategy II

NO. OF WELLS 3 wells at 33 gpm=100 gpm

Description		Quantity	Unit Cost	Total Cost ($)
Gate Valve Size	2"	3 ea	$ 70	210
	4"	1 ea	420	420
Check Valve	2"	3 ea	80	240
Tees	2 x 2	1 ea	170	170
	2 x 3	1 ea	180	180
	2 x 4	1 ea	200	200
Meters	2"	3 ea	330	990
	4"	1 ea	1,800	1,800
Pipe	2"	250 lf	6.60	1,650
	3"	250 lf	7.60	1,900
	4"	300 lf	11.60	3,480
6 inch Potable Water Main				
Fire Hydrant				
Gravel Road (12 ft)		1050 lf	7	7,350
Overhead Electricity		1050 lf	4	4,200
No. of Poles		5 ea	300	1,500
Transformer Type		1	1,000	1,000
Switchgear and Controls		3 ea	500	1,500

Subtotal	26,790
Contingency (30%)	8,040
TOTAL	34,830

TABLE D-3. CONSTRUCTION COST FOR STRATEGY I INFRASTRUCTURE

Plume Length (ft)	Average Cost ± Standard Deviation $	Plume Length to Width Radio
1,000	33,700 ± 6,700	2:1
2,000	73,600 ± 15,600	2:1
4,000	144,600 ± 23,700	2:1
500	13,600 ± 0	5:1
2,500	59,900 ± 8,500	5:1
5,000	126,200 ± 11,700	5:1
10,000	242,200 ± 24,200	5:1

TABLE D-4. CONSTRUCTION COST FOR STRATEGY 2

Plume Length (Ft.)	No. of Wells	Flow (gpm)	Capital Cost ($)	O & M ($)
200	1	5	8,400	2,500
	1	50	8,400	2,500
	1	500	14,700	2,500
	3	5	11,700	2,700
	3	50	12,400	2,700
	3	500	21,700	2,700
1,000	1	10	24,400	2,500
	1	100	26,400	2,500
	1	1,000	43,900	2,500
	3	10	31,000	2,700
	3	100	34,800	2,700
	3	1,000	60,700	2,700
5,000	1	20	106,700	3,000
	1	200	131,800	3,000
	1	2,000	182,800	3,000
	3	20	122,200	3,500
	3	200	150,300	3,500
	3	2,000	212,600	3,500
	5	20	127,400	4,000
	5	200	163,900	4,000
	5	2,000	216,400	4,000
10,000	1	40	217,400	4,000
	1	400	255,400	4,000
	1	4,000	401,000	4,000
	3	40	239,700	4,500
	3	400	319,300	4,500
	3	4,000	481,156	4,500
	5	40	252,400	5,000
	5	400	322,200	5,000
	5	4,000	476,400	5,000

FIGURE D-1

STRATEGY 1 - INFRASTRUCTURE CONSTRUCTION

COST VERSUS PLUME LENGTH

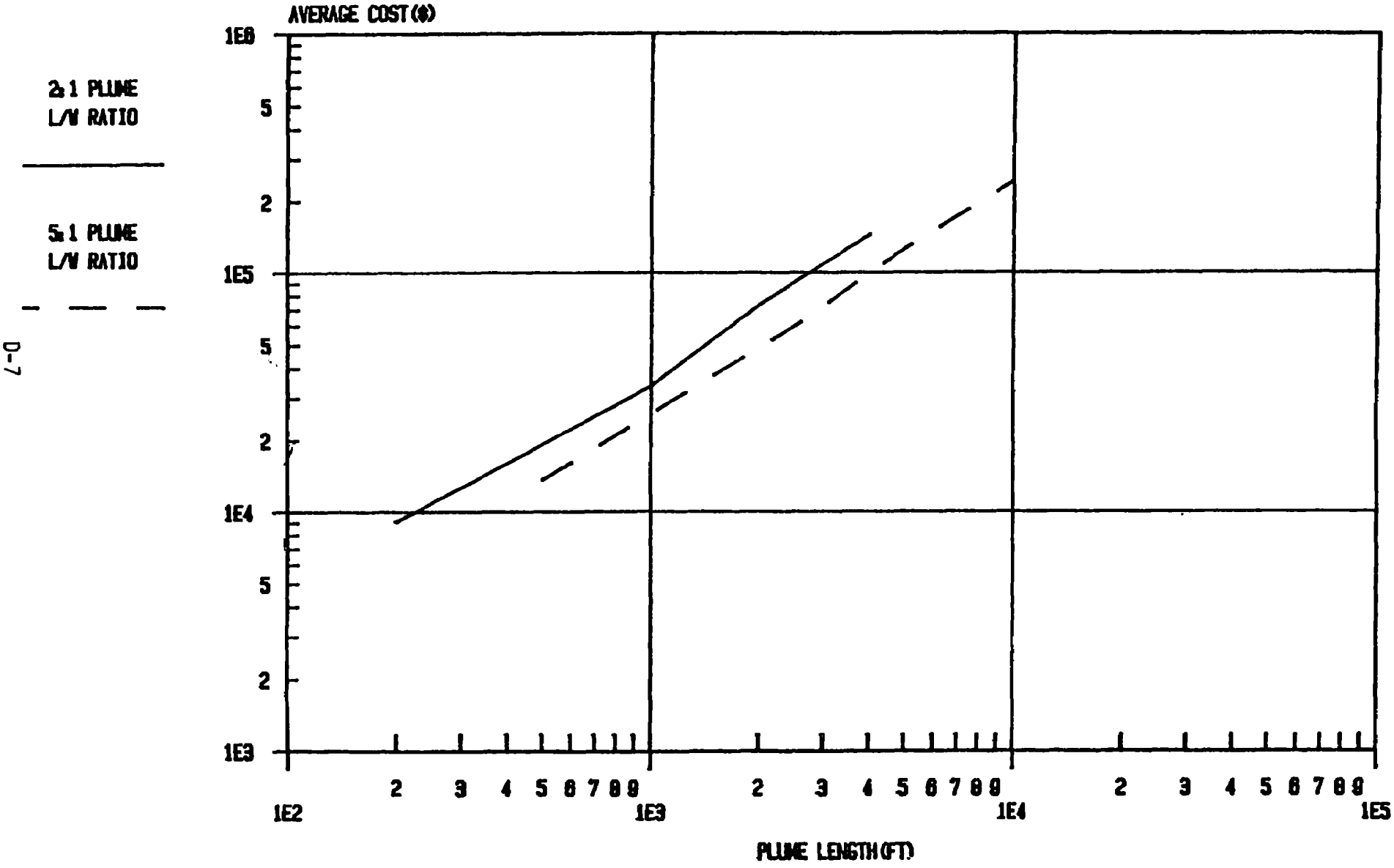


FIGURE D-2.

STRATEGY 2 - INFRASTRUCTURE CONSTRUCTION

COST VERSUS PLUME LENGTH (1 WELL)

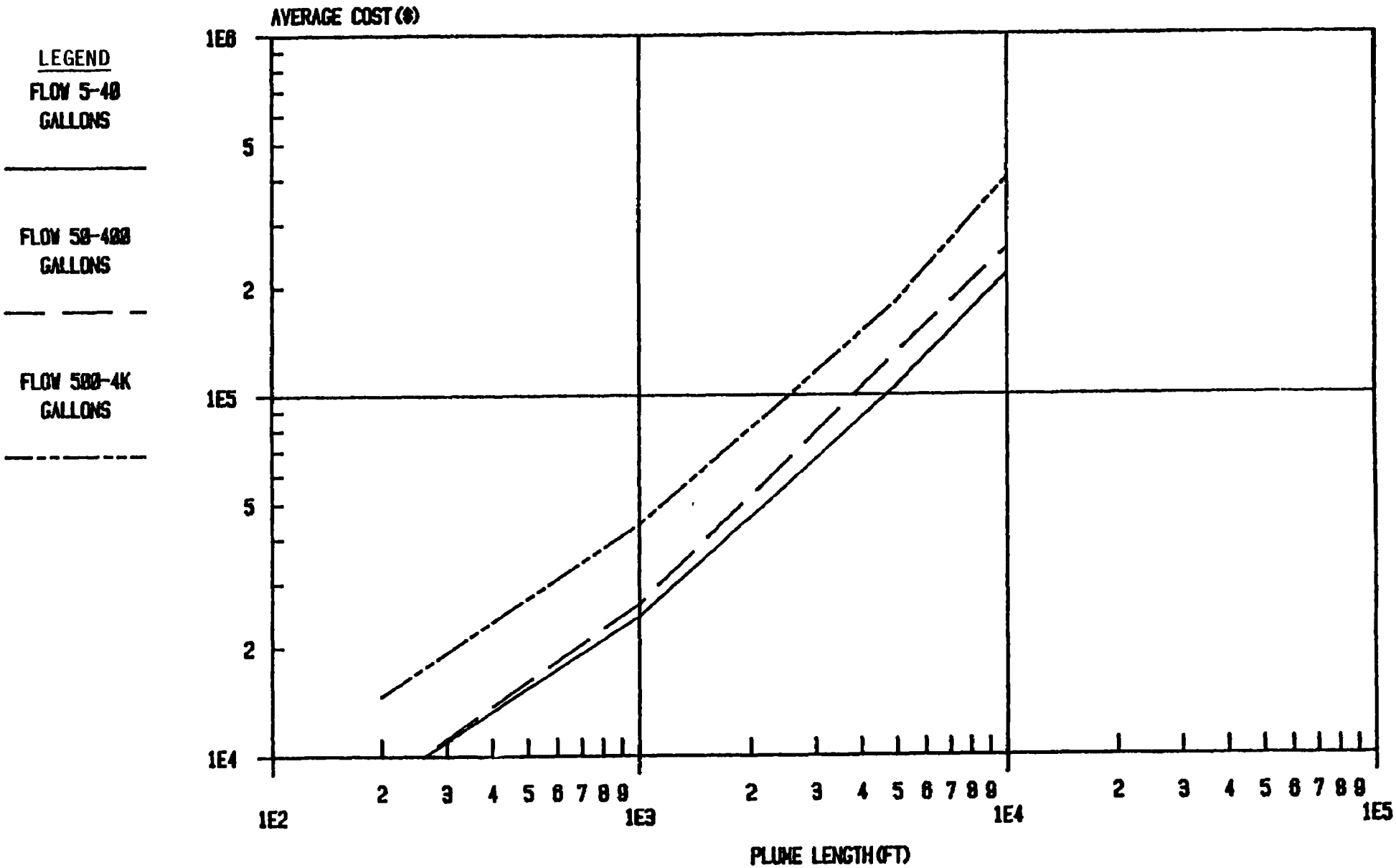


FIGURE D-3.

STRATEGY 2 - INFRASTRUCTURE CONSTRUCTION

COST VERSUS PLUME LENGTH (3 WELLS)

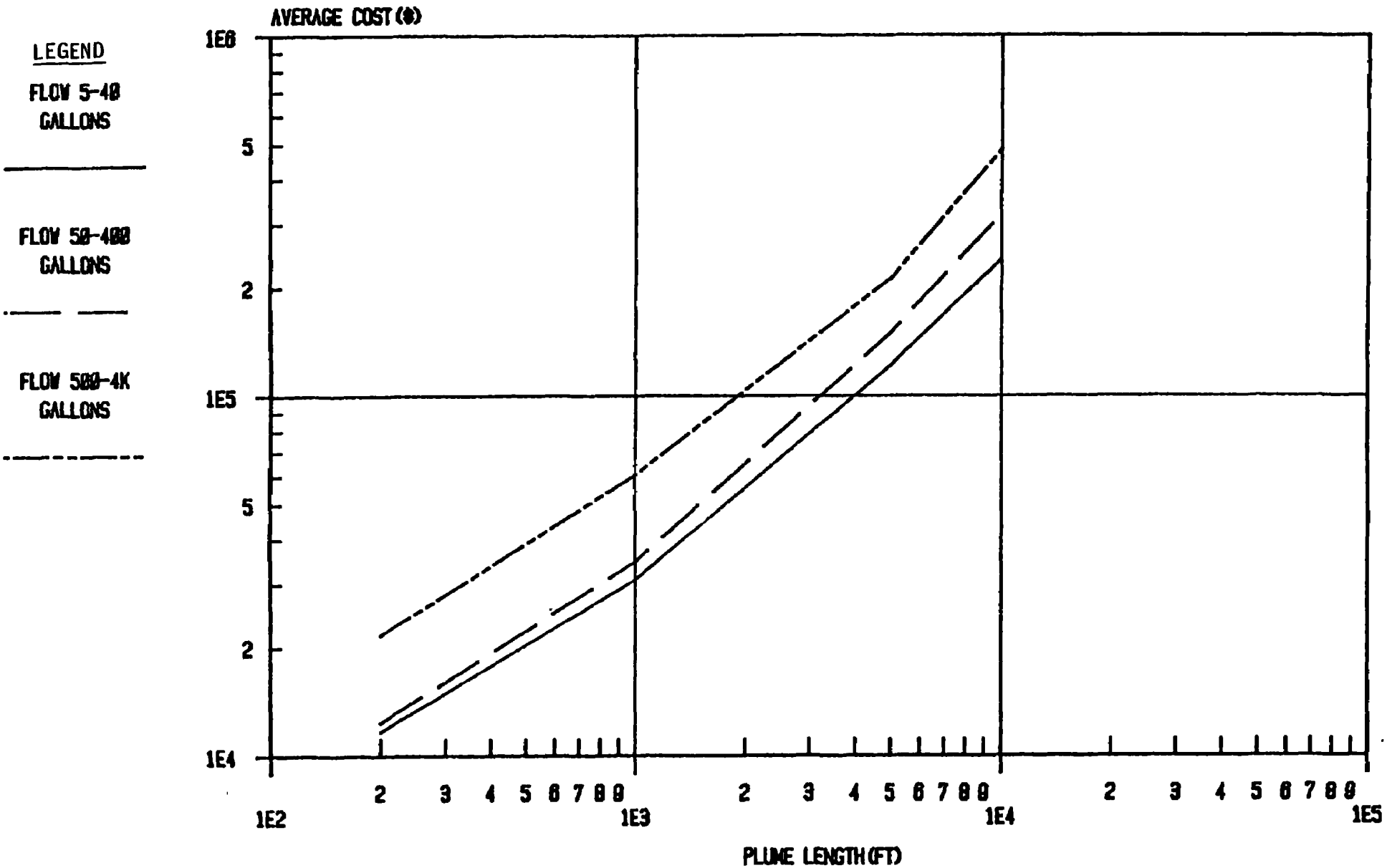


FIGURE D-4.

STRATEGY 2 - INFRASTRUCTURE CONSTRUCTION

COST VERSUS PLUME LENGTH (5 WELLS)

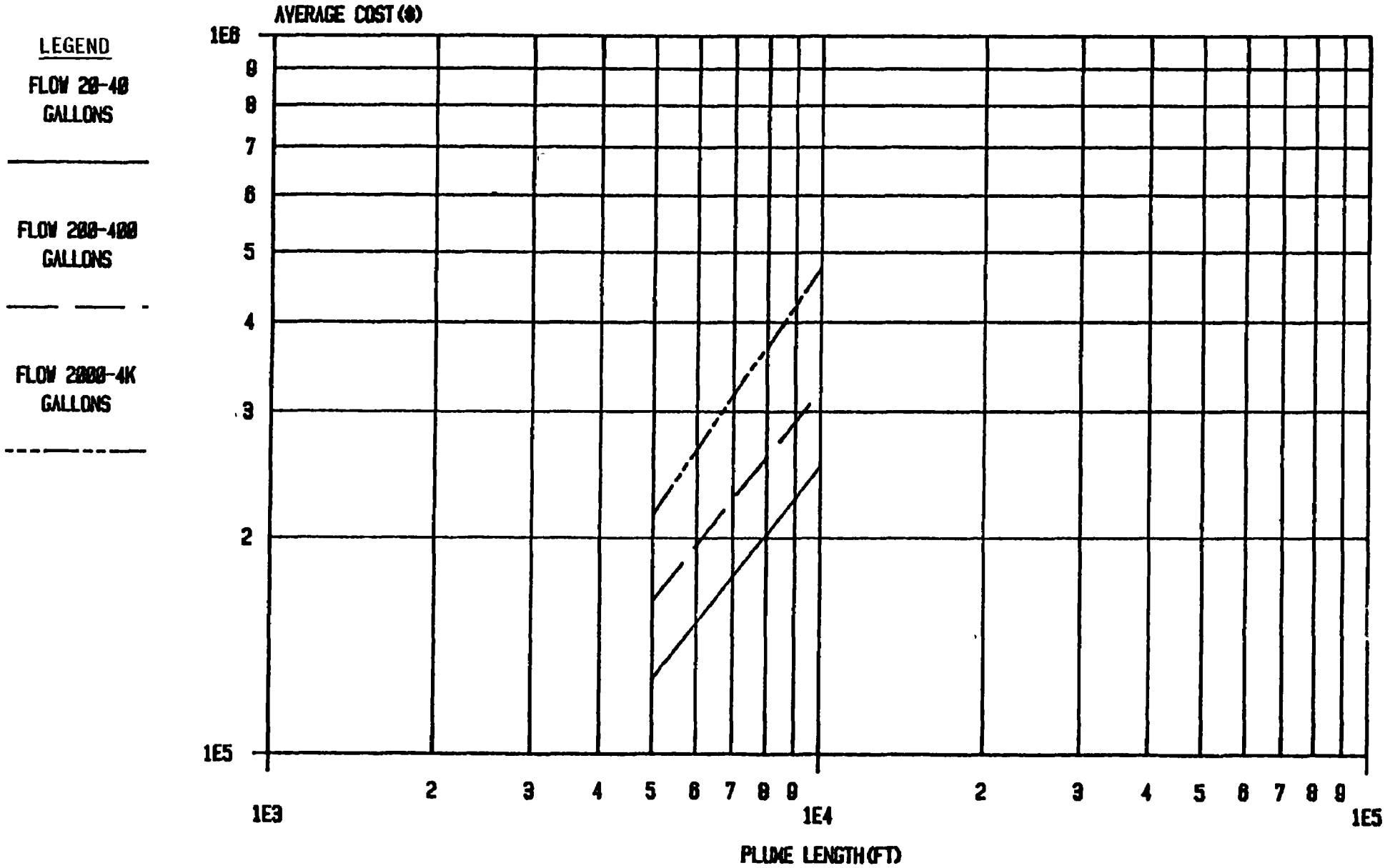
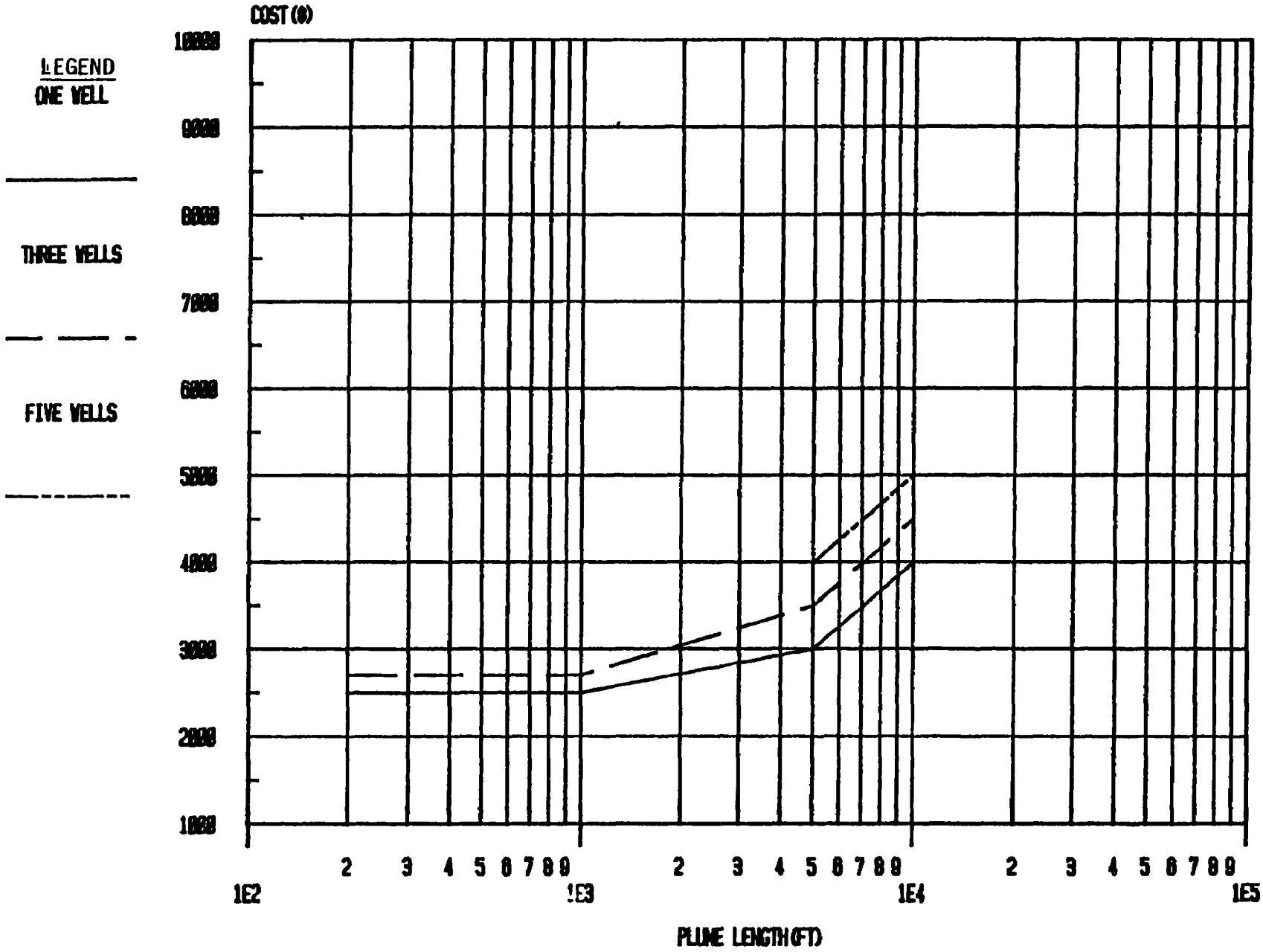


FIGURE D-5.

O & M COSTS FOR INFRASTRUCTURE

VERSUS PLUME LENGTH



APPENDIX E: TREATMENT COSTS

APPENDIX E

TREATMENT COSTS

APPROACH

Four treatment processes were selected for cost evaluation: 1) Activated Carbon, 2) Coagulation/Floculation/Sedimentation/Filtration, 3) Ultrafiltration and 4) Reverse Osmosis. These processes were chosen to demonstrate the range of treatment costs that may be encountered in treating contaminated ground water, and cover a broad range of treatment capabilities.

Construction, engineering, and operational and maintenance costs were developed for each treatment process as a function of plant capacity (in gallons per minute (GPM)). Six treatment plant capacities were investigated: 6 gpm, 250 gpm, 2,600 gpm, 4,000 gpm, 8,000 gpm, and 20,000 gpm. These capacities relate to the well pumping scenarios developed in this report. Cost data was taken from Reference E.1 and engineering fees were estimated using Reference E.2.

ASSUMPTIONS

Along with the assumptions outlined in Reference E.1, the following assumptions were made in developing the treatment costs:

- Treatment plants placed at toe of plume
- Discharge piping (if lengthy) not included
- Site work and contractor overhead not included
- ENR Construction Cost Index (CCI) used = 391 (Date: Jan., 1981) ENR-CCI of reference = 219
- Sludge treatment and disposal not included.
- Activated carbon replaced 3 times per year at $0.60/lb
- Minimum labor requirements of activated carbon plant above 2,600 gpm equals 2,000 hours (1 man year).
- Chemical costs not included
- No contingency included in cost estimates

RESULTS

The results of the treatment cost analysis are summarized in the following Tables and Figures:

- Table E.1 Capital, Engineering and O&M Costs for Activated Carbon
- Table E.2 Capital, Engineering, and O&M Costs for Coag/Floc/Sed/Filt
- Table E.3 Capital, Engineering and O&M Costs for Ultrafiltration
- Table E.4 Capital, Engineering and O&M Costs for Reverse Osmosis
- Figure E.1 Capital, Plus Engineering Costs for Treatment versus Flow Rate
- Figure E.2 O&M Costs for Treatment versus Flow Rate

It should be noted that the cost data for ultrafiltration only extends through 250 gpm. Reference E.1 does not cover the ultrafiltration treatment costs above one million gallons per day (MGD) capacity. The purpose of the estimates is to show the order of magnitude that can be expected in constructing and operating a treatment system. The estimates are not exact and careful attention should be given to the stated assumptions when interpreting the results.

TABLE E-1. CAPITAL, ENGINEERING AND O&M COSTS FOR ACTIVATED CARBON

low, gpm	5	250	2,600	4,000	8,000	20,000
apital ($)	15,700	76,200	441,800	626,000	710,200	1,059,000
ngr. ($)	10,000	10,000	40,100	56,300	60,400	79,400
ubtotal ($)	25,700	86,200	481,900	682,300	770,600	1,138,400
)&M ($/yr)	3,400	49,940	169,000	438,000	600,000	1,085,800

TABLE E-2. CAPITAL, ENGINEERING AND O&M COSTS FOR COAG/FLOC/SED/FILT

'low, gpm	5	250	2,600	4,000	8,000	20,000
'apital (4)	78,200	180,900	940,000	1,522,800	2,166,800	3,030,000
:ngr. ($)	10,000	20,000	72,000	112,700	149,500	197,000
ubtotal ($)	88,200	200,900	1,012,000	1,635,500	2,316,300	3,227,000
ı&M ($/yr)	38,500	60,500	100,000	121,280	137,800	177,900

TABLE E-3. CAPITAL, ENGINEERING AND O&M COSTS FOR ULTRAFILTRATION

Flow, gpm	5	250
Capital ($)	21,900	301,000
Engr. ($)	10,000	28,800
Subtotal ($)	31,900	329,800
O&M ($/yr)	5,900	42,500

TABLE E-4. CAPITAL, ENGINEERING AND O&M COSTS FOR REVERSE OSMOSIS

Flow, gpm	5	250	2,600	4,000	8,000	20,000
Capital ($)	21,900	421,200	2,407,400	3,600,000	5,500,000	15,000,000
Engr. ($)	10,000	38,200	163,300	234,000	346,500	900,000
Subtotal ($)	31,900	459,400	2,570,700	3,834,000	5,846,500	15,900,000
O&M ($/yr)	17,800	100,800	333,800	1,158,000	1,996,000	5,573,000

FIGURE E.1

CAPITAL PLUS ENGINEERING COSTS

FOR TREATMENT VERSUS FLOW RATE

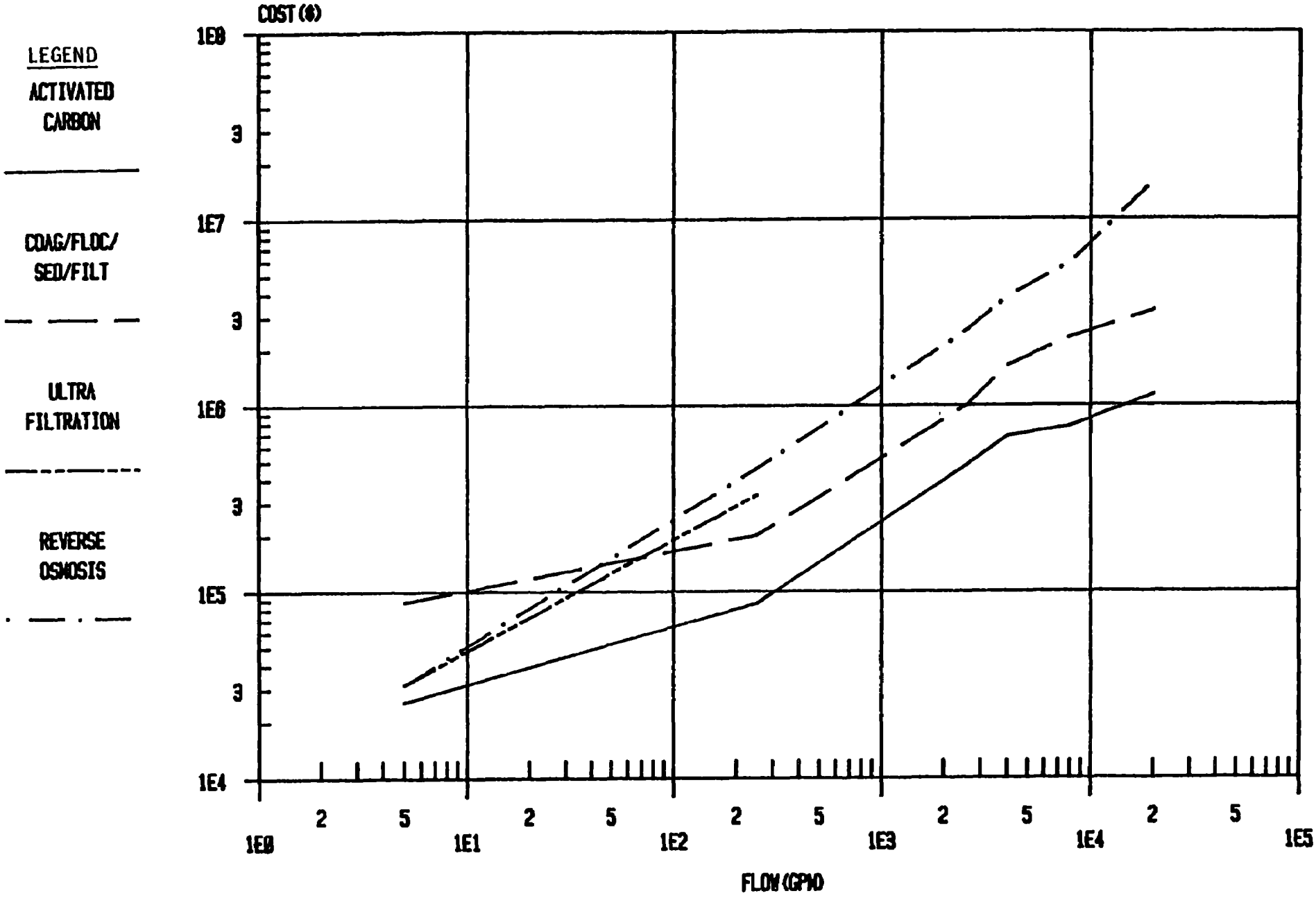
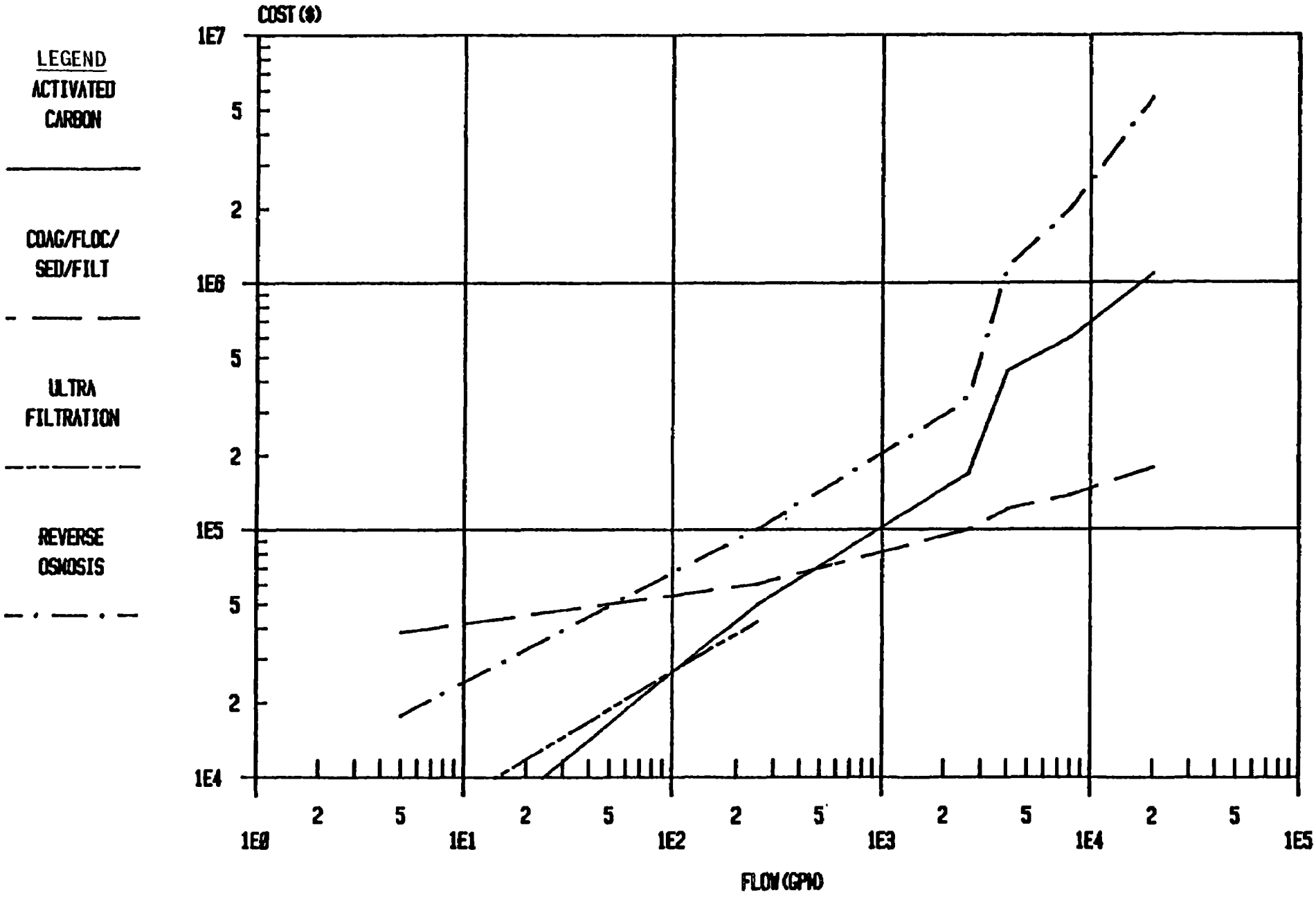


FIGURE E.2

O & M COST FOR TREATMENT

VERSUS FLOW RATE



REFERENCES

E.1 R.C. Gumerman, R.C. Culp, and S.P. Hansen. Estimating Water Treatment Costs. Volumes 2 and 3. U.S. Environmental Protection Agency, Cincinnati, OH. EPA-600/2-79-162 b and c, August 1979.

E.2 ASCE. Consulting Engineering, A Guide for the Engagement of Engineering Services, No. 45. American Socity of Civil Engineers. 1981.

APPENDIX F: TOTAL COSTS FOR FLUID REMOVAL/ TREATMENT SYSTEMS

Table F-1. Total Containment Costs for Fluid Removal/Treatment Systems:

Strategy[a] = 1
Depth of Plume = 75 ft.

Hydraulic Gradient = 0.5 ft/mile
Transmissivity = 100,000 gpd/ft
Aquifer Discharge = 0.05 mgd/mile

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		100 x 200		100 x 500		500 x 1000		500 x 2500	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	67	12	67	12	91	12	106	12
	Infrastructure[c]	7	3	13	3	29	3	54	3
	Treatment	-	-	-	-	-	-	-	-
	Totals	74	15	80	15	120	15	160	15
Activated Carbon	Fluid Removal	67	12	67	12	91	12	106	12
	Infrastructure	7	3	13	3	29	3	54	3
	Treatment	26	3	26	3	26	3	26	3
	Totals	100	18	105	18	146	18	186	18
Reverse Osmosis	Fluid Removal	67	12	67	12	91	12	106	12
	Infrastructure	7	3	13	3	29	3	54	3
	Treatment	32	18	32	18	32	18	32	18
	Totals	106	33	112	33	152	33	192	33
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	67	12	67	12	91	12	106	12
	Infrastructure	7	3	13	3	29	3	54	3
	Treatment	86	38	86	38	86	38	86	38
	Totals	160	53	166	53	206	53	246	53

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-1. (Continued)

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	117	12	134	12	149	12	209	12
	Infrastructure[c]	57	3	108	3	116	3	207	4
	Treatment	-	-	-	-	-	-	-	-
	Totals	174	15	242	15	265	15	416	16
Activated Carbon	Fluid Removal	117	12	134	12	149	12	209	12
	Infrastructure	57	3	108	3	116	3	207	4
	Treatment	27	5	27	5	28	8	28	8
	Totals	201	20	269	20	293	23	444	24
Reverse Osmosis	Fluid Removal	117	12	134	12	149	12	209	12
	Infrastructure	57	3	108	3	116	3	207	4
	Treatment	44	22	44	22	70	30	70	30
	Totals	218	37	286	37	335	45	486	46
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	117	12	134	12	149	12	209	12
	Infrastructure	57	3	108	3	116	3	207	4
	Treatment	90	40	90	40	100	44	100	44
	Totals	264	55	332	55	365	59	516	60

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-2. Total Containment Costs for Fluid Removal/Treatment Systems

Strategy[a] = 1
Depth of Plume = 25 ft.

Hydraulic Gradient = 5 ft/mile
Transmissivity = 10,000 gpd/ft
Aquifer Discharge = 0.05 mgd/mile

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		100 x 200		100 x 500		500 x 1000		500 x 2500	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	48	11	48	11	65	11	76	11
	Infrastructure[c]	7	3	13	3	29	3	54	3
	Treatment	-	-	-	-	-	-	-	-
	Totals	55	14	61	14	94	14	130	14
Activated Carbon	Fluid Removal	48	11	48	11	65	11	76	11
	Infrastructure	7	3	13	3	29	3	54	3
	Treatment	26	3	26	3	26	3	26	3
	Totals	81	17	87	17	120	17	156	17
Reverse Osmosis	Fluid Removal	48	11	48	11	65	11	76	11
	Infrastructure	7	3	13	3	29	3	54	3
	Treatment	32	17	32	17	32	17	32	17
	Totals	87	31	93	31	126	31	162	31
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	48	11	48	11	65	11	76	11
	Infrastructure	7	3	13	3	29	3	54	3
	Treatment	88	38	88	38	88	38	88	38
	Totals	143	52	149	52	182	52	218	52

a Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

b Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

c Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

d Well System includes gravel-filled drain with small diameter wells

Table F-2. (Continued)

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	82	11	96	11	102	11	143	11
	Infrastructure[c]	57	3	108	3	116	3	207	4
	Treatment	–	–	–	–	–	–	–	–
	Totals	139	14	204	14	218	14	350	15
Activated Carbon	Fluid Removal	82	11	96	11	102	11	143	11
	Infrastructure	57	3	106	3	116	3	207	4
	Treatment	26	5	26	5	27	8	27	8
	Totals	165	19	230	19	245	22	377	23
Reverse Osmosis	Fluid Removal	82	11	96	11	102	11	143	11
	Infrastructure	57	3	108	3	116	3	207	4
	Treatment	44	24	44	24	70	30	70	30
	Totals	183	38	248	38	288	44	420	45
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	82	11	96	11	102	11	143	11
	Infrastructure	57	3	108	3	116	3	207	4
	Treatment	90	40	90	40	100	43	100	43
	Totals	229	54	294	54	318	57	450	58

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-3. Total Containment Costs for Fluid Removal/Treatment Systems:

Strategy[a] = 1
Depth of Plume = 75 ft.

Hydraulic Gradient = 5 ft/mile
Transmissivity = 10,000 gpd/ft
Aquifer Discharge = 0.05 mgd/mile

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		100 x 200		100 x 500		500 x 1000		500 x 2500	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	67	12	67	12	91	12	106	12
	Infrastructure[c]	7	3	13	3	29	3	54	3
	Treatment	-	-	-	-	-	-	-	-
	Totals	74	15	80	15	120	15	160	15
Activated Carbon	Fluid Removal	67	12	67	12	91	12	106	12
	Infrastructure	7	3	13	3	29	3	54	3
	Treatment	26	3	26	3	26	3	26	3
	Totals	100	18	106	18	146	18	186	18
Reverse Osmosis	Fluid Removal	67	12	67	12	91	12	106	12
	Infrastructure	7	3	13	3	29	3	54	3
	Treatment	32	17	32	17	32	17	32	17
	Totals	106	32	112	32	152	32	192	32
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	67	12	67	12	91	12	106	12
	Infrastructure	7	3	13	3	29	3	54	3
	Treatment	88	38	88	38	88	38	88	38
	Totals	162	53	168	53	208	53	248	53

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-3. (Continued)

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	117	12	134	12	149	12	209	12
	Infrastructure[c]	57	3	108	3	116	3	207	4
	Treatment	-	-	-	-	-	-	-	-
	Totals	174	15	242	15	265	15	416	16
Activated Carbon	Fluid Removal	117	12	134	12	149	12	209	12
	Infrastructure	57	3	108	3	116	3	207	4
	Treatment	26	5	26	5	27	5	27	8
	Totals	200	20	268	20	292	23	443	24
Reverse Osmosis	Fluid Removal	117	12	134	12	149	12	209	12
	Infrastructure	57	3	108	3	116	3	207	4
	Treatment	44	24	44	24	70	30	70	30
	Totals	218	39	286	39	335	45	486	46
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	117	12	134	12	149	12	209	12
	Infrastructure	57	3	108	3	116	3	207	4
	Treatment	90	40	90	40	100	43	100	43
	Totals	264	55	332	55	365	58	516	59

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-4. Total Containment Costs for Fluid Removal/Treatment Systems:

Strategy[a] = 1
Depth of Plume = 200 ft.

Hydraulic Gradient = 5 ft/mile
Transmissivity = 10,000 gpd/ft
Aquifer Discharge = 0.05 mgd/mile

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		100 x 200		100 x 500		500 x 1000		500 x 2500	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	115	13	115	13	167	13	198	13
	Infrastructure[c]	7	3	13	3	29	3	54	3
	Treatment	-	-	-	-	-	-	-	-
	Totals	122	16	128	16	196	16	252	16
Activated Carbon	Fluid Removal	115	13	115	13	167	13	198	13
	Infrastructure	7	3	13	3	29	3	54	3
	Treatment	26	3	26	3	26	3	26	3
	Totals	148	19	154	19	222	19	278	19
Reverse Osmosis	Fluid Removal	115	13	115	13	167	13	198	13
	Infrastructure	7	3	13	3	29	3	54	3
	Treatment	32	17	32	17	32	17	32	17
	Totals	154	33	160	33	228	33	284	33
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	115	13	115	13	167	13	198	13
	Infrastructure	7	3	13	3	29	3	54	3
	Treatment	88	38	88	38	88	38	88	38
	Totals	210	54	216	54	284	54	340	54

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-4. (Continued)

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	213	13	248	13	272	13	272	13
	Infrastructure[c]	57	3	108	3	118	3	207	4
	Treatment	–	–	–	–	–	–	–	–
	Totals	270	16	356	16	390	16	592	17
Activated Carbon	Fluid Removal	213	13	248	13	272	13	385	13
	Infrastructure	57	3	108	3	118	3	207	4
	Treatment	26	5	26	5	27	8	27	8
	Totals	296	21	382	21	417	24	619	25
Reverse Osmosis	Fluid Removal	213	13	248	13	272	13	385	13
	Infrastructure	57	3	108	3	118	3	207	4
	Treatment	44	24	44	24	70	30	70	30
	Totals	314	40	400	40	460	46	662	47
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	213	13	248	13	272	13	385	13
	Infrastructure	57	3	108	3	118	3	207	4
	Treatment	90	40	90	40	100	43	100	43
	Totals	360	56	446	56	490	59	692	60

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-5. Total Containment Costs for Fluid Removal/Treatment Systems:

Strategy[a] = 1
Depth of Plume = 70 ft.

Hydraulic Gradient = 5 ft/mile
Transmissivity = 40,000 gpd/ft
Aquifer Discharge = 0.2 mgd/mile

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		100 x 200		100 x 500		500 x 1000		500 x 2500	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	64	12	64	12	89	12	103	12
	Infrastructure[c]	7	3	13	3	29	3	54	3
	Treatment	-	-	-	-	-	-	-	-
	Totals	71	15	77	15	118	15	157	15
Activated Carbon	Fluid Removal	64	12	64	12	89	12	103	12
	Infrastructure	7	3	13	3	29	3	54	3
	Treatment	26	3	26	3	27	8	27	8
	Totals	97	18	103	18	145	23	184	23
Reverse Osmosis	Fluid Removal	64	12	64	12	89	12	103	12
	Infrastructure	7	3	13	3	29	3	54	3
	Treatment	32	17	32	17	70	30	70	30
	Totals	103	32	109	32	188	45	227	45
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	64	12	64	12	89	12	103	12
	Infrastructure	7	3	13	3	29	3	54	3
	Treatment	88	38	88	38	100	43	100	43
	Totals	159	53	165	53	218	58	257	58

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-5. (Continued)

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	114	12	130	12	148	13	205	13
	Infrastructure[c]	57	3	108	3	118	3	207	4
	Treatment	-	-	-	-	-	-	-	-
	Totals	171	15	238	15	266	16	412	17
Activated Carbon	Fluid Removal	114	12	130	12	148	13	205	13
	Infrastructure	57	3	108	3	118	3	207	4
	Treatment	33	13	33	13	44	21	44	21
	Totals	204	28	271	28	310	37	456	38
Reverse Osmosis	Fluid Removal	114	12	130	12	148	13	295	13
	Infrastructure	57	3	108	3	118	3	207	4
	Treatment	110	42	110	42	180	58	180	58
	Totals	281	57	348	57	446	74	592	75
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	114	12	130	12	148	13	205	13
	Infrastructure	57	3	108	3	118	3	207	4
	Treatment	110	47	110	47	130	51	130	51
	Totals	281	62	348	62	396	67	542	68

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-6. Total Containment Costs for Fluid Removal/Treatment Systems:

Strategy[a] = 1
Depth of Plume = 75 ft.

Hydraulic Gradient = 5 ft/mile
Transmissivity = 100,000 gpd/ft
Aquifer Discharge = 0.5 mgd/mile

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		100 x 200		100 x 500		500 x 1000		500 x 2500	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	67	12	67	12	91	12	106	12
	Infrastructure[c]	7	3	13	3	29	3	54	3
	Treatment	-	-	-	-	-	-	-	-
	Totals	74	15	80	15	120	15	160	15
Activated Carbon	Fluid Removal	67	12	67	12	91	12	106	12
	Infrastructure	7	3	13	3	29	3	54	3
	Treatment	26	5	26	5	36	15	36	15
	Totals	100	20	106	20	156	30	196	30
Reverse Osmosis	Fluid Removal	67	12	67	12	91	12	106	12
	Infrastructure	7	3	13	3	29	3	54	3
	Treatment	44	24	44	24	130	48	130	48
	Totals	118	39	124	39	250	63	290	63
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	67	12	67	12	91	12	106	12
	Infrastructure	7	3	13	3	29	3	54	3
	Treatment	90	40	90	40	115	48	115	48
	Totals	164	55	170	55	235	63	275	63

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-6. (Continued)

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	120	13	137	13	170	16	231	16
	Infrastructure[c]	63	3	114	3	127	3	218	4
	Treatment	-	-	-	-	-	-	-	-
	Totals	183	16	251	16	297	19	449	20
Activated Carbon	Fluid Removal	120	13	137	13	170	16	231	16
	Infrastructure	63	3	114	3	127	3	218	4
	Treatment	49	25	49	25	70	40	70	40
	Totals	232	41	300	41	367	59	519	60
Reverse Osmosis	Fluid Removal	120	13	137	13	170	16	231	16
	Infrastructure	63	3	114	3	127	3	218	4
	Treatment	215	65	215	65	340	90	340	90
	Totals	398	81	466	81	637	109	789	110
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	120	13	137	13	170	16	231	16
	Infrastructure	63	3	114	3	127	3	218	4
	Treatment	145	53	145	53	170	57	170	57
	Totals	328	69	396	69	467	76	619	77

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-7. Total Containment Costs for Fluid Removal/Treatment Systems:

Strategy[a] = 1
Depth of Plume = 160 ft.

Hydraulic Gradient = 5 ft/mile
Transmissivity = 100,000 gpd/ft
Aquifer Discharge = 0.5 mgd/mile

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		100 x 200		100 x 500		500 x 1000		500 x 2500	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	98	13	98	13	147	13	171	13
	Infrastructure[c]	7	3	13	3	29	3	54	3
	Treatment	-	-	-	-	-	-	-	-
	Totals	105	16	111	16	176	16	225	16
Activated Carbon	Fluid Removal	98	13	98	13	147	13	171	13
	Infrastructure	7	3	13	3	29	3	54	3
	Treatment	26	5	26	5	36	15	36	15
	Totals	131	21	137	21	212	31	261	31
Reverse Osmosis	Fluid Removal	98	13	98	13	147	13	171	13
	Infrastructure	7	3	13	3	29	3	54	3
	Treatment	44	24	44	24	130	48	130	48
	Totals	149	40	155	40	306	64	355	64
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	98	13	98	13	147	13	171	13
	Infrastructure	7	3	13	3	29	3	54	3
	Treatment	90	40	90	40	115	48	115	48
	Totals	195	56	201	56	291	64	340	64

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-7. (Continued)

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	189	14	216	14	280	19	374	19
	Infrastructure[c]	63	3	114	3	140	3	230	4
	Treatment	-	-	-	-	-	-	-	-
	Totals	252	17	330	17	420	22	604	23
Activated Carbon	Fluid Removal	189	14	216	14	280	19	374	19
	Infrastructure	63	3	114	3	140	3	230	4
	Treatment	49	25	49	25	70	40	70	40
	Totals	301	42	379	42	490	62	674	63
Reverse Osmosis	Fluid Removal	189	14	216	14	280	19	374	19
	Infrastructure	63	3	114	3	140	3	230	4
	Treatment	215	65	215	65	340	90	340	90
	Totals	467	82	545	82	760	112	944	113
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	189	14	216	14	280	19	374	19
	Infrastructure	63	3	114	3	140	3	230	4
	Treatment	145	53	145	53	170	57	170	57
	Totals	397	70	475	70	590	79	774	80

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-8. Total Containment Costs for Fluid Removal/Treatment Systems:

Strategy[a] = 1
Depth of Plume = 310 ft.

Hydraulic Gradient = 5 ft/mile
Transmissivity = 200,000 gpd/ft
Aquifer Discharge = 1 mgd/mile

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		100 x 200		100 x 500		500 x 1000		500 x 2500	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	244	14	340	14	722	16	1259	16
	Infrastructure[c]	7	3	13	3	31	3	32	3
	Treatment	-	-	-	-	-	-	-	-
	Totals	251	17	353	17	753	19	1291	19
Activated Carbon	Fluid Removal	244	14	340	14	722	16	1259	16
	Infrastructure	7	3	13	3	31	3	32	3
	Treatment	27	8	27	8	49	25	49	25
	Totals	278	25	380	25	802	44	1340	44
Reverse Osmosis	Fluid Removal	244	14	340	14	722	16	1259	16
	Infrastructure	7	3	13	3	31	3	32	3
	Treatment	70	30	70	30	215	65	215	65
	Totals	321	47	423	47	968	84	1506	84
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	244	14	340	14	722	16	1259	16
	Infrastructure	7	3	13	3	31	3	32	3
	Treatment	100	43	100	43	145	53	145	53
	Totals	351	60	453	60	898	72	1436	72

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-8. (Continued)

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	1498	25	3576	25	3581	27	8687	27
	Infrastructure[c]	63	3	114	3	129	3	218	4
	Treatment	-	-	-	-	-	-	-	-
	Totals	1561	28	3690	28	3710	30	8905	31
Activated Carbon	Fluid Removal	1498	25	3576	25	3581	27	8687	27
	Infrastructure	63	3	114	3	129	3	218	4
	Treatment	70	40	70	40	205	52	105	52
	Totals	1631	68	3760	68	3815	82	9010	83
Reverse Osmosis	Fluid Removal	1498	25	3576	25	3581	27	8687	27
	Infrastructure	63	3	114	3	129	3	218	4
	Treatment	340	90	340	90	540	122	540	122
	Totals	1901	118	4030	118	4250	152	9445	153
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	1498	25	3576	25	3581	27	8687	27
	Infrastructure	63	3	114	3	129	3	218	4
	Treatment	170	57	170	57	240	63	240	63
	Totals	1731	85	3860	85	3950	93	9145	94

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-9. Total Containment Costs for Fluid Removal/Treatment Systems:

Strategy[a] = 1
Depth of Plume = 75 ft.

Hydraulic Gradient = 5 ft/mile
Transmissivity = 1,000,000 gpd/ft
Aquifer Discharge = 5 mgd/mile

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		100 x 200		100 x 500		500 x 1000		500 x 2500	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	70	13	70	13	114	19	129	19
	Infrastructure[c]	7	3	13	3	30	3	57	3
	Treatment	-	-	-	-	-	-	-	-
	Totals	77	16	83	16	144	22	186	22
Activated Carbon	Fluid Removal	70	13	70	13	114	19	129	19
	Infrastructure	7	3	13	3	30	3	57	3
	Treatment	49	25	49	25	120	54	120	54
	Totals	126	41	132	41	264	76	306	76
Reverse Osmosis	Fluid Removal	70	13	70	13	114	19	129	19
	Infrastructure	7	3	13	3	30	3	57	3
	Treatment	215	65	215	65	625	140	625	140
	Totals	292	81	298	81	769	162	811	162
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	70	13	70	13	114	19	129	19
	Infrastructure	7	3	13	3	30	3	57	3
	Treatment	145	53	145	53	275	65	275	65
	Totals	222	69	228	69	419	87	461	87

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-9. (Continued)

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	145	24	162	24	186	35	247	35
	Infrastructure[b]	68	3	120	3	140	3	230	4
	Treatment	-	-	-	-	-	-	-	-
	Totals	213	27	282	27	326	38	477	39
Activated Carbon	Fluid Removal	145	24	162	24	186	35	247	35
	Infrastructure	68	3	120	3	140	3	230	4
	Treatment	200	62	200	62	330	88	330	88
	Totals	413	89	482	89	656	126	807	127
Reverse Osmosis	Fluid Removal	145	24	162	24	186	35	247	35
	Infrastructure	68	3	120	3	140	3	230	4
	Treatment	1050	190	1050	190	1800	250	1800	250
	Totals	1263	117	1332	117	2126	288	2277	289
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	145	24	162	24	186	35	247	35
	Infrastructure	68	3	120	3	140	3	230	4
	Treatment	403	73	403	73	750	88	750	88
	Totals	616	100	685	100	1076	126	1227	127

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-10. Total Containment Costs for Fluid Removal/Treatment Systems:

Strategy[a] = 1
Depth of Plume = 25 ft.

Hydraulic Gradient = 50 ft/mile
Transmissivity = 10,000 gpd/ft
Aquifer Discharge = 0.5 mgd/mile

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		100 x 200		100 x 500		500 x 1000		500 x 2500	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	48	11	48	11	65	12	76	12
	Infrastructure[c]	7	3	13	3	29	3	54	3
	Treatment	-	-	-	-	-	-	-	-
	Totals	55	14	61	14	94	15	130	15
Activated Carbon	Fluid Removal	48	11	48	11	65	12	76	12
	Infrastructure	7	3	13	3	29	3	54	3
	Treatment	26	5	26	5	36	15	36	15
	Totals	81	19	87	19	130	30	166	30
Reverse Osmosis	Fluid Removal	48	11	48	11	65	12	76	12
	Infrastructure	7	3	13	3	29	3	54	3
	Treatment	44	24	44	24	130	48	130	48
	Totals	99	38	105	38	224	63	260	63
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	48	11	48	11	65	12	76	12
	Infrastructure	7	3	13	3	29	3	54	3
	Treatment	90	40	90	40	115	48	115	48
	Totals	145	54	151	54	209	63	245	63

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-10. (Continued)

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	115[d]	16	129[d]	16	156[d]	16	196[d]	16
	Infrastructure[c]	7	3	13	3	29	3	54	3
	Treatment	-	-	-	-	-	-	-	-
	Totals	422	19	142	19	185	19	250	19
Activated Carbon	Fluid Removal	115	16	129	16	156	16	196	16
	Infrastructure	7	3	13	3	29	3	54	3
	Treatment	26	5	26	5	36	15	36	15
	Totals	148	24	168	24	221	34	286	34
Reverse Osmosis	Fluid Removal	115	16	129	16	156	16	196	16
	Infrastructure	7	3	13	3	29	3	54	3
	Treatment	44	24	44	24	130	48	130	48
	Totals	166	43	186	43	315	109	380	109
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	115	16	129	16	156	16	196	16
	Infrastructure	7	3	13	3	29	3	54	3
	Treatment	90	40	90	40	115	56	115	56
	Totals	212	59	232	59	300	75	365	75

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-11. Total Containment Costs for Fluid Removal/Treatment Systems:

Strategy[a] = 1
Depth of Plume = 25 ft.

Hydraulic Gradient = 50 ft/mile
Transmissivity = 100,000 gpd/ft
Aquifer Discharge = 5 mgd/mile

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		100 x 200		100 x 500		500 x 1000		500 x 2500	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	49	11	49	11	73	17	84	17
	Infrastructure[c]	7	3	13	3	31	3	57	3
	Treatment	-	-	-	-	-	-	-	-
	Totals	56	14	62	14	104	20	141	20
Activated Carbon	Fluid Removal	49	11	49	11	73	17	84	17
	Infrastructure	7	3	13	3	31	3	57	3
	Treatment	49	25	49	25	120	54	120	54
	Totals	105	39	111	39	224	74	261	74
Reverse Osmosis	Fluid Removal	49	11	49	11	73	17	84	17
	Infrastructure	7	3	13	3	31	3	57	3
	Treatment	215	65	215	65	625	140	625	140
	Totals	271	79	277	79	729	160	766	160
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	49	11	49	11	73	17	84	17
	Infrastructure	7	3	13	3	31	3	57	3
	Treatment	145	53	145	53	275	65	275	65
	Totals	201	67	207	67	379	85	416	85

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-11. (Continued)

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	100[d]	23	114[d]	23	210[d]	41	250[d]	41
	Infrastructure[c]	73	3	126	3	165	4	262	5
	Treatment	-	-	-	-	-	-	-	-
	Totals	173	26	240	26	375	45	712	46
Activated Carbon	Fluid Removal	100	23	114	23	210[d]	41	250[d]	41
	Infrastructure	73	3	126	3	165	4	262	5
	Treatment	200	62	200	62	330	88	330	88
	Totals	373	88	440	88	705	133	842	134
Reverse Osmosis	Fluid Removal	100	23	114	23	210[d]	41	250[d]	41
	Infrastructure	73	3	126	3	165	4	262	5
	Treatment	1050	190	1050	190	1800	250	1800	250
	Totals	1223	216	1290	216	2175	295	2312	296
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	100	23	114	23	210	41	250	41
	Infrastructure	73	3	126	3	165	4	262	5
	Treatment	403	73	403	73	750	88	750	88
	Totals	576	99	643	99	1125	133	1262	134

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-12. Total Containment Costs for Fluid Removal/Treatment Systems:

Strategy[a] = 1
Depth of Plume = 75 ft.

Hydraulic Gradient = 50 ft/mile
Transmissivity = 100,000 gpd/ft
Aquifer Discharge = 5.0 mgd/mile

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		100 x 200		100 x 500		500 x 1000		500 x 2500	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	70	13	70	13	114	19	129	19
	Infrastructure[c]	7	3	13	3	31	3	57	3
	Treatment	-	-	-	-	-	-	-	-
	Totals	77	16	83	16	145	22	186	22
Activated Carbon	Fluid Removal	70	13	70	13	114	19	129	19
	Infrastructure	7	3	13	3	31	3	57	3
	Treatment	49	25	49	25	120	54	120	54
	Totals	126	41	132	41	265	76	306	76
Reverse Osmosis	Fluid Removal	70	13	70	13	114	19	129	19
	Infrastructure	7	3	13	3	31	3	57	3
	Treatment	215	65	215	65	625	140	625	140
	Totals	292	81	298	81	770	162	811	162
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	70	13	70	13	114	19	129	19
	Infrastructure	7	3	13	3	31	3	57	3
	Treatment	145	53	145	53	275	65	275	65
	Totals	222	69	228	69	420	87	461	87

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-12 (Continued)

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	145	26	162	26	186	40	247	40
	Infrastructure[c]	68	3	120	4	140	3	230	4
	Treatment	-	-	-	-	-	-	-	-
	Totals	213	29	282	30	326	43	477	44
Activated Carbon	Fluid Removal	145	26	162	26	186	40	247	40
	Infrastructure	68	3	120	4	140	3	230	4
	Treatment	200	62	200	62	330	88	330	88
	Totals	413	91	482	92	656	131	807	132
Reverse Osmosis	Fluid Removal	145	26	162	26	186	40	247	40
	Infrastructure	68	3	120	4	140	3	230	4
	Treatment	1050	190	1050	190	1800	250	1800	250
	Totals	1263	219	1332	220	2126	293	2277	294
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	145	26	162	26	186	40	247	40
	Infrastructure	68	3	120	4	140	3	230	4
	Treatment	403	73	403	73	750	88	750	88
	Totals	616	102	685	103	1076	131	1227	132

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-13. Total Containment Costs for Fluid Removal/Treatment Systems:

Strategy[a] = 1
Depth of Plume = 25 ft.

Hydraulic Gradient = 500 ft/mile
Transmissivity = 1,000 gpd/ft
Aquifer Discharge = 0.5 mgd/mile

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		100 x 200		100 x 500		500 x 1000		500 x 2500	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	51	12	51	12	88[d]	12	99[d]	12
	Infrastructure[c]	9	3	14	3	33	3	59	3
	Treatment	-	-	-	-	-	-	-	-
	Totals	60	15	65	15	121	15	158	15
Activated Carbon	Fluid Removal	51	12	51	12	88	12	99	12
	Infrastructure	9	3	14	3	33	3	59	3
	Treatment	26	5	26	5	36	15	36	15
	Totals	86	20	91	20	157	30	194	30
Reverse Osmosis	Fluid Removal	51	12	51	12	88	12	99	12
	Infrastructure	9	3	14	3	33	3	59	3
	Treatment	44	24	44	24	130	48	130	48
	Totals	104	39	109	39	251	63	288	63
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	51	12	51	12	88	12	99	12
	Infrastructure	9	3	14	3	33	3	59	3
	Treatment	90	40	90	40	115	48	115	48
	Totals	150	55	155	55	236	63	273	63

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d]

Table F-13. Continued

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	106[d]	12	128[d]	12	156[d]	13	196[d]	13
	Infrastructure[c]	78	3	130	4	163	4	262	5
	Treatment	-	-	-	-	-	-	-	-
	Totals	184	15	258	16	319	17	458	18
Activated Carbon	Fluid Removal	106	12	128	12	156	13	196	13
	Infrastructure	78	3	130	4	163	4	262	5
	Treatment	49	25	49	25	70	40	70	40
	Totals	233	40	307	41	389	57	528	58
Reverse Osmosis	Fluid Removal	106	12	128	12	156	13	196	13
	Infrastructure	78	3	130	4	163	4	262	5
	Treatment	215	65	215	65	340	90	340	90
	Totals	399	80	464	81	659	107	798	108
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	106	12	128	12	156	13	196	13
	Infrastructure	78	3	130	4	163	4	262	5
	Treatment	145	53	145	53	170	57	170	57
	Totals	329	68	394	69	489	74	628	75

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-14. Total Containment Costs for Fluid Removal/Treatment Systems:

Strategy[a] = 1
Depth of Plume = 25 ft.

Hydraulic Gradient = 500 ft/mile
Transmissivity = 10,000 gpd/ft
Aquifer Discharge = 5 mgd/mile

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		100 x 200		100 x 500		500 x 1000		500 x 2500	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	51	13	51	13	102[d]	17	113[d]	17
	Infrastructure[c]	9	3	14	3	40	3	68	3
	Treatment	-	-	-	-	-	-	-	-
	Totals	60	16	65	16	142	20	181	20
Activated Carbon	Fluid Removal	51	13	51	13	102	17	113	17
	Infrastructure	9	3	14	3	40	3	68	3
	Treatment	49	25	49	25	120	54	120	54
	Totals	109	41	114	41	262	74	301	74
Reverse Osmosis	Fluid Removal	51	13	51	13	102	17	113	17
	Infrastructure	9	3	14	3	40	3	68	3
	Treatment	215	65	215	65	625	140	625	140
	Totals	275	81	280	81	767	160	806	160
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	51	13	51	13	102	17	113	17
	Infrastructure	9	3	14	3	40	3	68	3
	Treatment	145	53	145	53	275	65	275	65
	Totals	205	69	210	69	417	85	456	85

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-14. (Continued)

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	143[d]	23	157[d]	23	210[d]	34	250[d]	34
	Infrastructure[c]	80	3	137	4	163	4	262	5
	Treatment	-	-	-	-	-	-	-	-
	Totals	223	26	294	27	373	38	512	39
Activated Carbon	Well System	143	23	157	23	210	34	250	34
	Infrastructure	80	3	137	4	163	4	262	5
	Treatment	200	62	200	62	330	88	330	88
	Totals	423	88	494	89	703	126	842	127
Reverse Osmosis	Well System	143	23	157	23	210	34	250	34
	Infrastructure	80	3	137	4	163	4	262	5
	Treatment	1050	190	1050	190	1800	250	1800	250
	Totals	1273	216	1344	217	2173	288	2312	289
Coagulation, Flocculation, Sed., and Filtration	Well System	143	23	157	23	210	34	250	34
	Infrastructure	80	3	137	4	163	4	262	5
	Treatment	403	73	403	73	750	88	750	88
	Totals	626	99	697	100	123	126	1262	127

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Well System cost includes delineation of plume boundaries with drilling program, recovery well system design, well installation, and engineering for testing and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-15. Total Containment Costs for Fluid Removal/Treatment Systems:

Strategy[a] = 1
Depth of Plume = 75 ft.

Hydraulic Gradient = 500 ft/mile
Transmissivity = 10,000 gpd/ft
Aquifer Discharge = 5 mgd/mile

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		100 x 200		100 x 500		500 x 1000		500 x 2500	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	70	13	70	13	200	28	216	28
	Infrastructure[c]	7	3	13	3	37	3	63	3
	Treatment	-	-	-	-	-	-	-	-
	Totals	77	16	83	16	237	31	279	31
Activated Carbon	Fluid Removal	70	13	70	13	200	28	216	28
	Infrastructure	7	3	13	3	37	3	63	3
	Treatment	49	25	49	25	120	54	120	54
	Totals	126	41	132	41	357	85	399	85
Reverse Osmosis	Fluid Removal	70	13	70	13	200	28	216	28
	Infrastructure	7	3	13	3	37	3	63	3
	Treatment	215	65	215	65	625	140	625	140
	Totals	292	81	298	81	862	171	904	171
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	70	13	70	13	200	28	216	28
	Infrastructure	7	3	13	3	37	3	63	3
	Treatment	145	53	145	53	275	65	275	65
	Totals	222	69	228	69	512	96	554	96

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-15. (Continued)

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	227	34	244	34	495	73	556	73
	Infrastructure[c]	80	3	137	4	165	4	262	5
	Treatment	-	-	-	-	-	-	-	-
	Totals	307	37	381	38	660	77	818	78
Activated Carbon	Fluid Removal	227	34	244	34	495	73	556	73
	Infrastructure	80	3	137	4	165	4	262	5
	Treatment	200	62	200	62	330	88	330	88
	Totals	507	99	581	100	990	165	1148	166
Reverse Osmosis	Fluid Removal	227	34	244	34	495	73	556	73
	Infrastructure	80	3	137	4	165	4	262	5
	Treatment	1050	190	1050	190	1800	250	1800	250
	Totals	1357	227	1431	228	2460	327	2618	328
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	227	34	244	34	495	73	556	73
	Infrastructure	80	3	137	4	165	4	262	5
	Treatment	403	73	403	73	750	88	750	88
	Totals	710	110	784	111	1410	165	1568	166

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-16. Total Containment Costs for Fluid Removal/Treatment Systems:

Strategy[a] = 1
Depth of Plume = 200 ft.

Hydraulic Gradient = 500 ft/mile
Transmissivity = 10,000 gpd/ft
Aquifer Discharge = 5 mgd/mile

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		100 x 200		100 x 500		500 x 1000		500 x 2500	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	122	15	122	15	228	27	259	27
	Infrastructure[c]	7	3	13	3	34	3	60	3
	Treatment	-	-	-	-	-	-	-	-
	Totals	129	18	135	18	262	30	319	30
Activated Carbon	Fluid Removal	122	15	122	15	228	27	259	27
	Infrastructure	7	3	13	3	34	3	60	3
	Treatment	49	25	49	25	120	54	120	54
	Totals	178	43	184	43	382	84	439	84
Reverse Osmosis	Fluid Removal	122	15	122	15	228	27	259	27
	Infrastructure	7	3	13	3	34	3	60	3
	Treatment	215	65	215	65	625	140	625	140
	Totals	344	83	350	83	887	170	944	170
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	122	15	122	15	228	27	259	27
	Infrastructure	7	3	13	3	34	3	60	3
	Treatment	145	53	145	53	275	65	275	65
	Totals	274	71	280	71	537	95	594	95

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-16. Continued

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	287	42	322	42	446	76	558	76
	Infrastructure[c]	68	3	120	3	162	4	253	5
	Treatment	-	-	-	-	-	-	-	-
	Totals	355	45	442	45	608	80	811	81
Activated Carbon	Fluid Removal	287	42	322	42	446	76	558	76
	Infrastructure	68	3	120	3	162	4	253	5
	Treatment	200	62	200	62	330	88	330	88
	Totals	555	107	642	107	938	168	1141	169
Reverse Osmosis	Fluid Removal	287	42	322	42	446	76	558	76
	Infrastructure	68	3	120	3	162	4	253	5
	Treatment	1050	190	1050	190	1800	250	1800	250
	Totals	1405	235	1492	235	2408	330	2611	331
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	287	42	322	42	446	76	558	76
	Infrastructure	68	3	120	3	162	4	253	5
	Treatment	403	73	403	73	750	88	750	88
	Totals	758	118	845	118	1358	168	1561	169

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Fluid Removal System cost includes delineation of plume boundaries with drilling program, recovery well/drain system design, well/drain construction, and engineering for construction and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-17. Containment Costs for Recovery Well/Treatment Systems:

Strategy[a] = 2
Depth of Plume = 75 ft.

Hydraulic Gradient = 5 ft/mile
Transmissivity = 10,000 gpd/ft
Aquifer Flux = Varies

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		100 x 200		100 x 500		500 x 1000		500 x 2500	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	67	12	67	12	91	12	110	13
	Infrastructure[c]	8	3	15	3	25	3	65	3
	Treatment	-	-	-	-	-	-	-	-
	Totals	75	15	82	15	116	15	175	16
Activated Carbon	Fluid Removal	67	12	67	12	91	12	110	13
	Infrastructure	8	3	15	3	25	3	65	3
	Treatment	26	3	28	6	29	13	40	19
	Totals	101	18	110	21	145	28	215	35
Reverse Osmosis	Fluid Removal	67	12	67	12	91	12	110	13
	Infrastructure	8	3	15	3	25	3	65	3
	Treatment	26	16	50	24	80	34	150	52
	Totals	101	31	132	39	196	49	325	68
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	67	12	67	12	91	12	110	13
	Infrastructure	8	3	15	3	25	3	65	3
	Treatment	85	36	95	41	100	47	120	50
	Totals	160	51	177	56	216	62	295	66

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Well System cost includes delineation of plume boundaries with drilling program, recovery well system design, well installation, and engineering for testing and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-17. (Continued)

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	117	12	154	15	153	13	231	17
	Infrastructure[c]	44	3	130	3	105	3	260	4
	Treatment	-	-	-	-	-	-	-	-
	Totals	161	15	284	18	258	16	491	21
Activated Carbon	Fluid Removal	117	12	154	15	153	13	231	17
	Infrastructure	44	3	130	3	105	3	260	4
	Treatment	36	16	55	30	50	26	80	45
	Totals	197	31	339	48	308	42	571	66
Reverse Osmosis	Fluid Removal	117	12	154	15	153	13	231	17
	Infrastructure	44	3	130	3	105	3	260	4
	Treatment	130	48	250	74	200	67	400	100
	Totals	291	63	534	92	458	73	891	121
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	117	12	154	15	153	13	231	17
	Infrastructure	44	3	130	3	105	3	260	4
	Treatment	110	49	145	56	135	55	190	59
	Totals	271	64	429	74	393	71	681	80

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Well System cost includes delineation of plume boundaries with drilling program, recovery well system design, well installation, and engineering for testing and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-18. Containment Costs for Recovery Well/Treatment Systems:

Strategy[a] = 2
Depth of Plume = 75 ft.

Hydraulic Gradient = 5 ft/mile
Transmissivity = 100,000 gpd/ft
Aquifer Flux = Varies

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		100 x 200		100 x 500		500 x 1000		500 x 2500	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	67	12	88	15	113	16	134	21
	Infrastructure[c]	8	3	15	3	27	3	95	3
	Treatment	–	–	–	–	–	–	–	–
	Totals	75	15	103	18	140	19	229	24
Activated Carbon	Fluid Removal	67	12	88	15	113	16	134	21
	Infrastructure	8	3	15	3	27	3	95	3
	Treatment	36	16	55	30	80	45	150	57
	Totals	111	31	158	48	220	64	379	81
Reverse Osmosis	Fluid Removal	67	12	88	15	113	16	134	21
	Infrastructure	8	3	15	3	27	3	95	3
	Treatment	130	48	250	74	400	100	750	160
	Totals	205	63	353	92	540	119	979	184
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	67	12	88	15	113	16	134	21
	Infrastructure	8	3	15	3	27	3	95	3
	Treatment	110	49	145	56	190	59	300	69
	Totals	185	64	248	74	330	78	529	93

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Well System cost includes delineation of plume boundaries with drilling program, recovery well system design, well installation, and engineering for testing and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-18. Continued

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	140	19	168	30	179	26	286	49
	Infrastructure[c]	52	3	185	3	150	3	480	5
	Treatment	-	-	-	-	-	-	-	-
	Totals	192	22	353	33	329	29	766	54
Activated Carbon	Fluid Removal	140	19	168	30	179	26	286	49
	Infrastructure	52	3	185	3	150	3	480	5
	Treatment	120	54	230	67	200	63	380	118
	Totals	312	76	583	100	529	92	1146	172
Reverse Osmosis	Fluid Removal	140	19	168	30	179	26	286	49
	Infrastructure	52	3	185	3	150	3	480	5
	Treatment	600	143	1200	220	1000	195	2000	300
	Totals	792	165	1553	253	1329	224	2766	354
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	140	19	168	30	179	26	286	49
	Infrastructure	52	3	185	3	150	3	480	5
	Treatment	280	66	500	78	420	75	900	95
	Totals	372	88	853	111	749	104	1666	149

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Well System cost includes delineation of plume boundaries with drilling program, recovery well system design, well installation, and engineering for testing and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-19. Containment Costs for Recovery Well/Treatment Systems:

Strategy[a] = 2
Depth of Plume = 75 ft.

Hydraulic Gradient = 5 ft/mile
Transmissivity = 1,000,000 gpd/ft
Aquifer Flux = Varies

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		100 x 200		100 x 500		500 x 1000		500 x 2500	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	90	19	101	28	129	41	192	87
	Infrastructure[c]	9	3	25	3	43	3	128	3
	Treatment	-	-	-	-	-	-	-	-
	Totals	99	22	126	31	172	44	320	90
Activated Carbon	Fluid Removal	90	19	101	28	120	41	192	87
	Infrastructure	9	3	25	3	43	3	128	3
	Treatment	120	54	230	67	380	118	800	520
	Totals	219	76	356	98	552	162	1120	610
Reverse Osmosis	Fluid Removal	90	19	101	28	129	41	192	87
	Infrastructure	9	3	25	3	43	3	128	3
	Treatment	600	143	1200	220	2000	300	5000	1450
	Totals	699	165	1326	251	2172	344	5320	1540
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	90	19	101	28	129	41	192	87
	Infrastructure	9	3	25	3	43	3	128	3
	Treatment	280	66	500	78	900	95	2000	130
	Totals	379	88	626	109	1072	139	2320	220

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

[b] Well System cost includes delineation of plume boundaries with drilling program, recovery well system design, well installation, and engineering for testing and start-up

[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

[d] Well System includes gravel-filled drain with small diameter wells

Table F-19. Continued

Type of Treatment	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
		K	O&M	K	O&M	K	O&M	K	O&M
None	Fluid Removal[b]	155	70	265	162	235	131	434	318
	Infrastructure[c]	78	3	230	4	190	4	470	5
	Treatment	-	-	-	-	-	-	-	-
	Totals	233	73	495	166	425	135	904	323
Activated Carbon	Fluid Removal	155	70	265	162	235	131	434	318
	Infrastructure	78	3	230	4	190	4	470	5
	Treatment	600	500	810	610	775	600	1140	1100
	Totals	833	573	1305	776	1200	735	2044	1423
Reverse Osmosis	Fluid Removal	155	70	265	162	235	131	434	318
	Infrastructure	78	3	230	4	190	4	470	5
	Treatment	4000	1350	7000	2400	6000	2000	15000	5500
	Totals	4233	1423	7495	2566	6425	2135	15904	5823
Coagulation, Flocculation, Sed., and Filtration	Fluid Removal	155	70	265	162	235	131	434	318
	Infrastructure	78	3	230	4	190	4	470	5
	Treatment	1700	130	2500	140	2400	137	3100	180
	Totals	1933	203	2995	306	2825	272	4004	503

[a] Strategy 1 controls unidirectional gradient across plume with wells located at downgradient toe of plume, transverse to major axis of plume
Strategy 2 controls radial gradients around plume boundary with wells located inside plume along major axis of plume

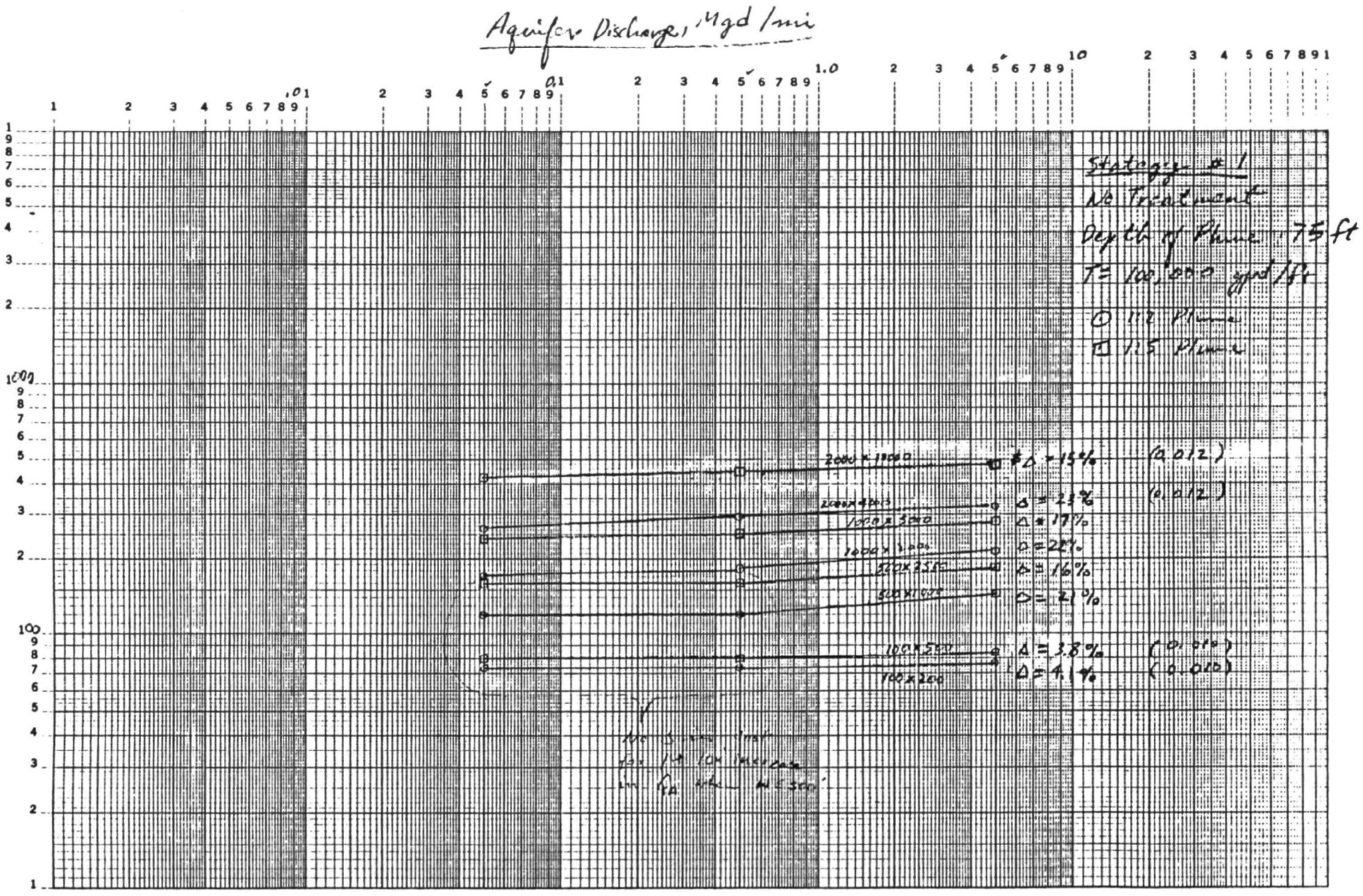
[b] Well System cost includes delineation of plume boundaries with drilling program, recovery well system design, well installation, and engineering for testing and start-up

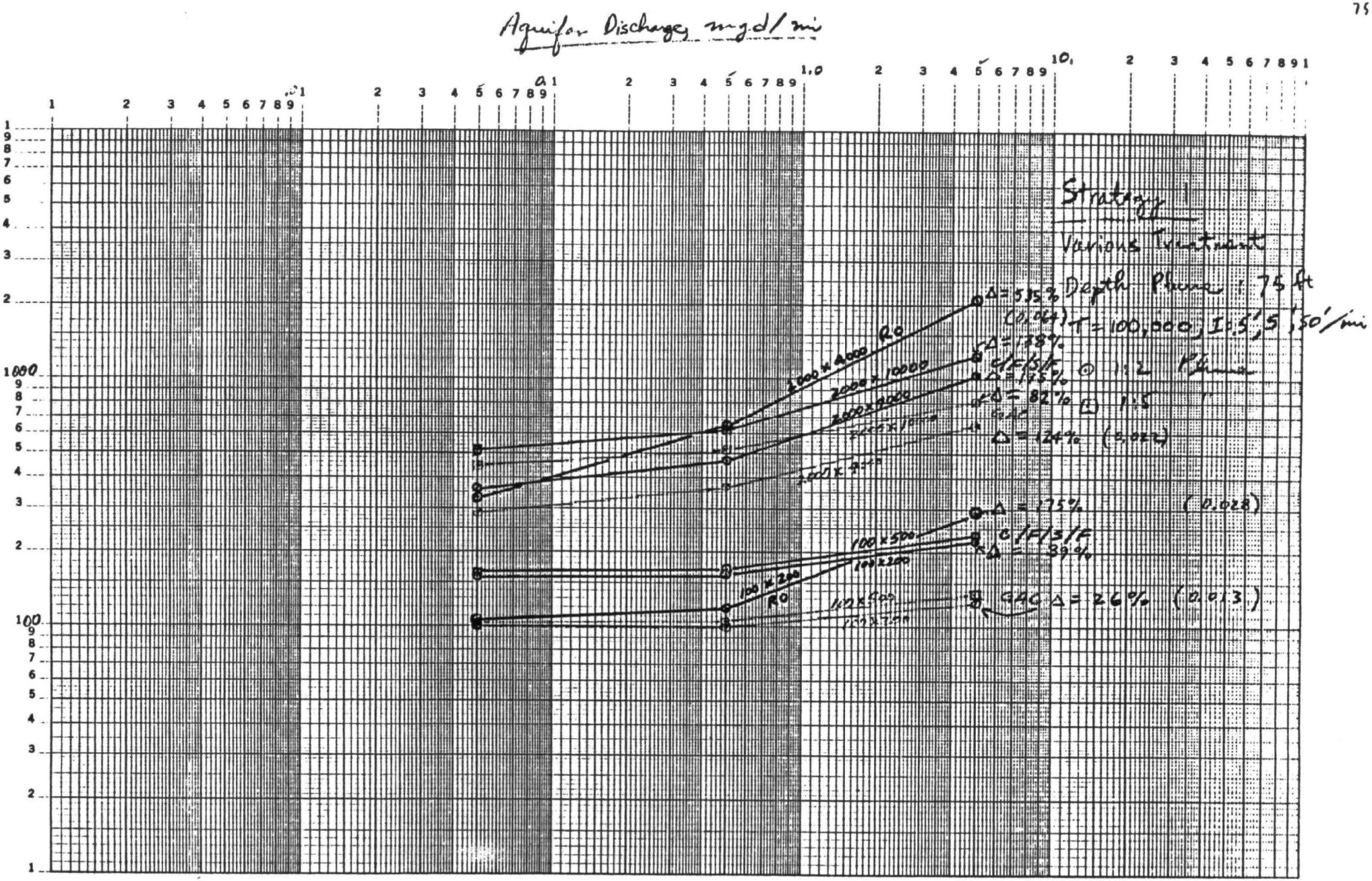
[c] Infrastructure includes manifold piping, meters and valves, influent piping, roads, and powerlines

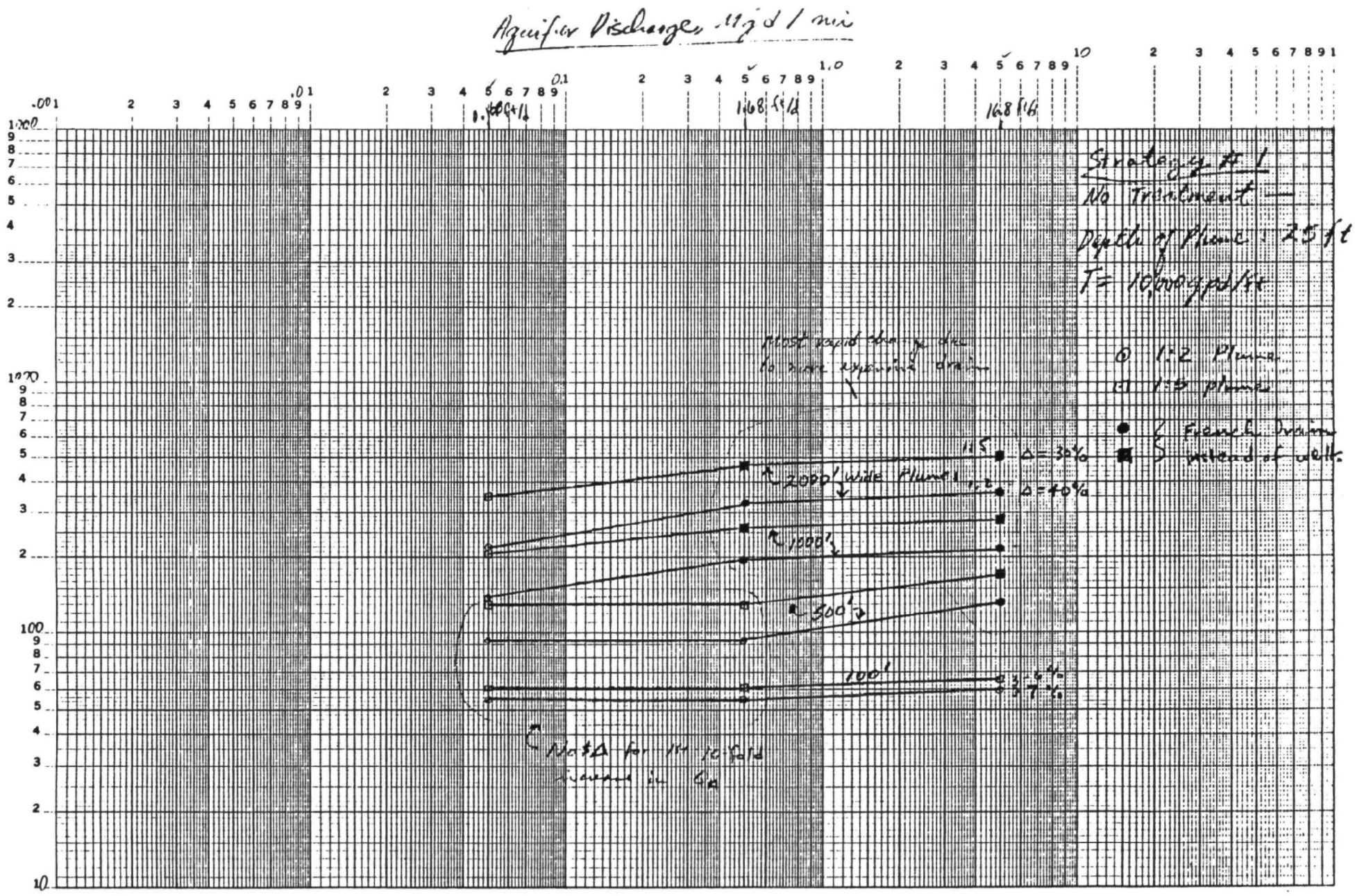
[d] Well System includes gravel-filled drain with small diameter wells

APPENDIX G: GRAPHS USED IN SENSITIVITY ANALYSIS FOR FLUID REMOVAL/TREATMENT COSTS

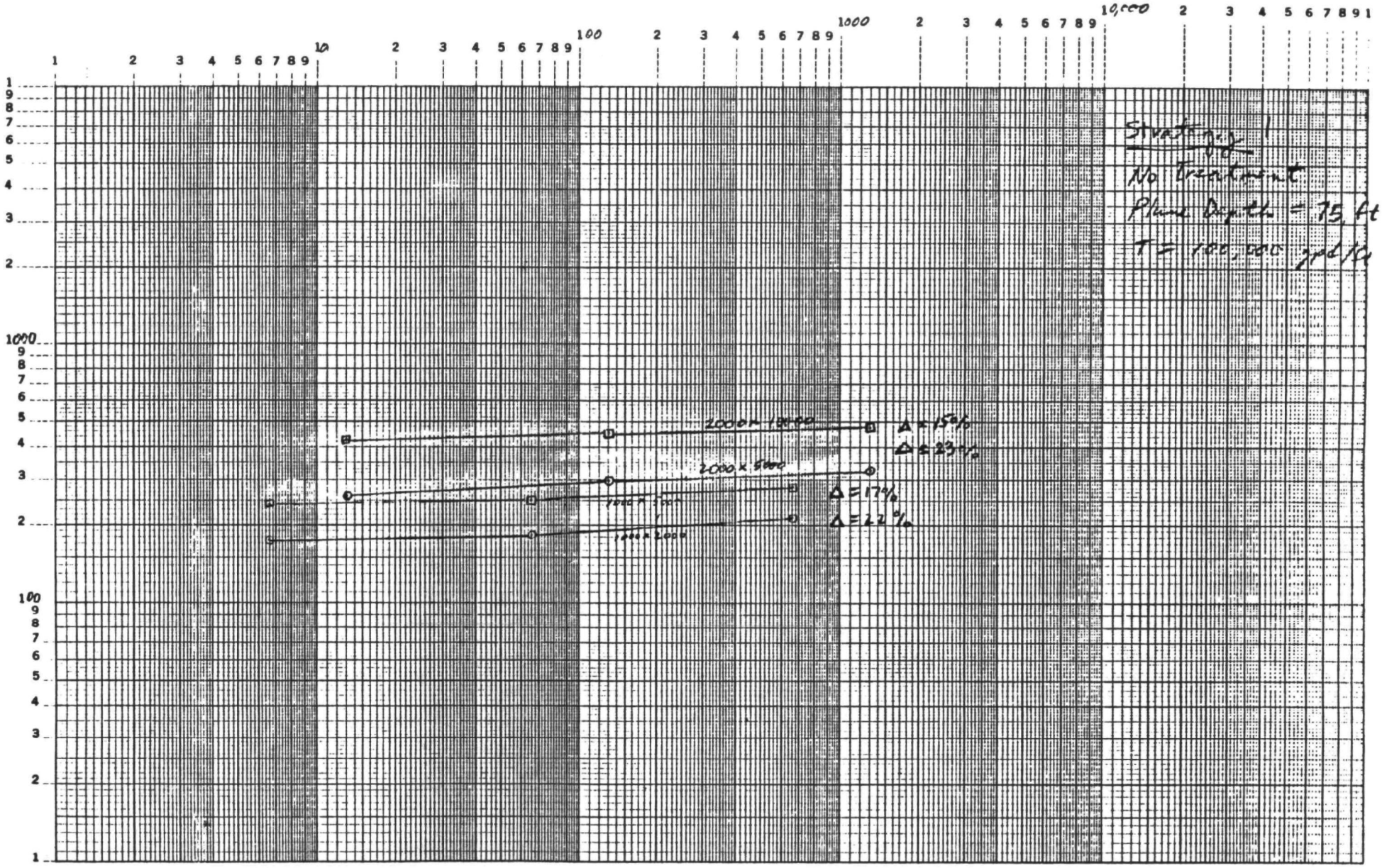
K+E LOGARITHMIC 3 x 5 CYCLES
EL & CO. I

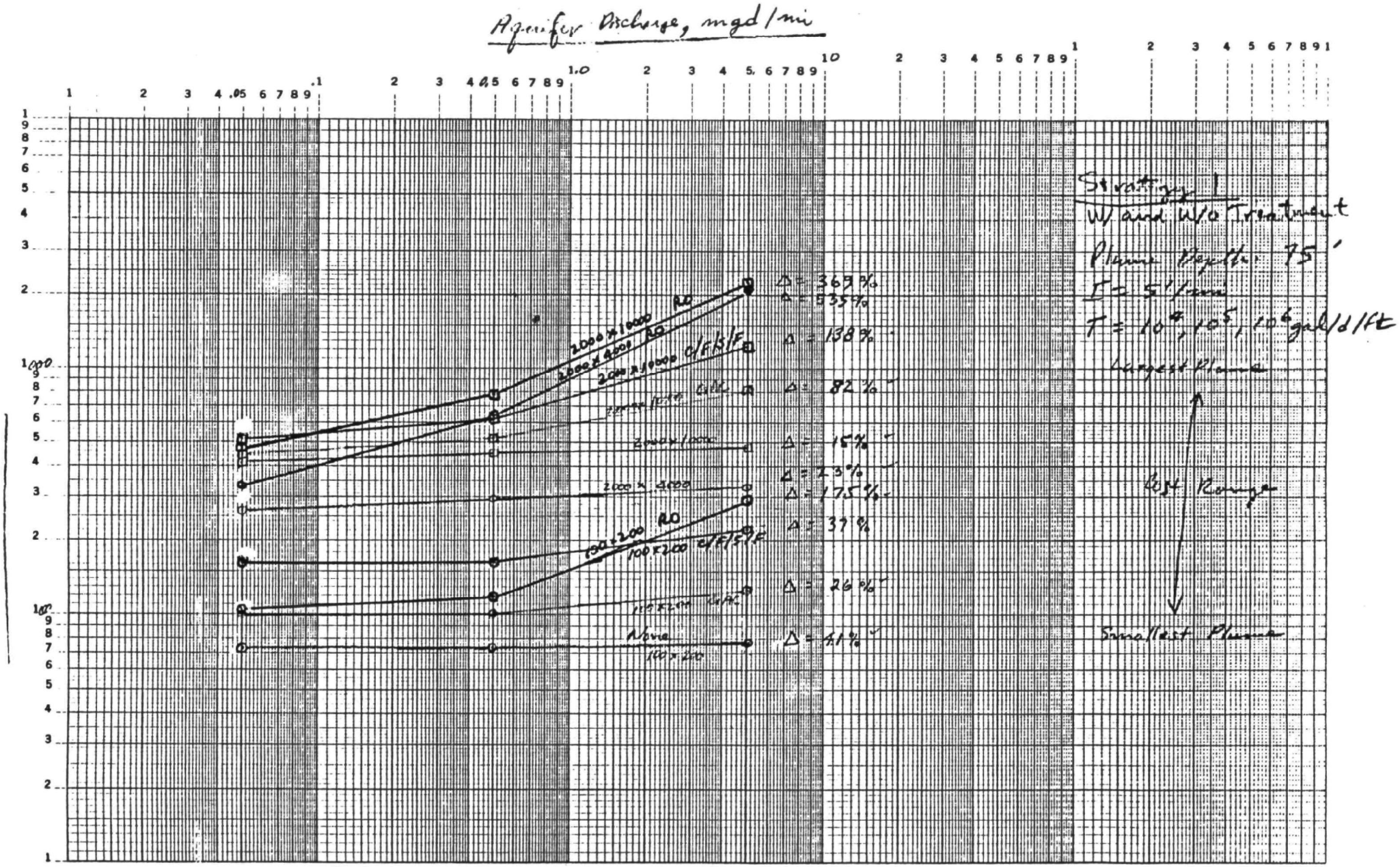


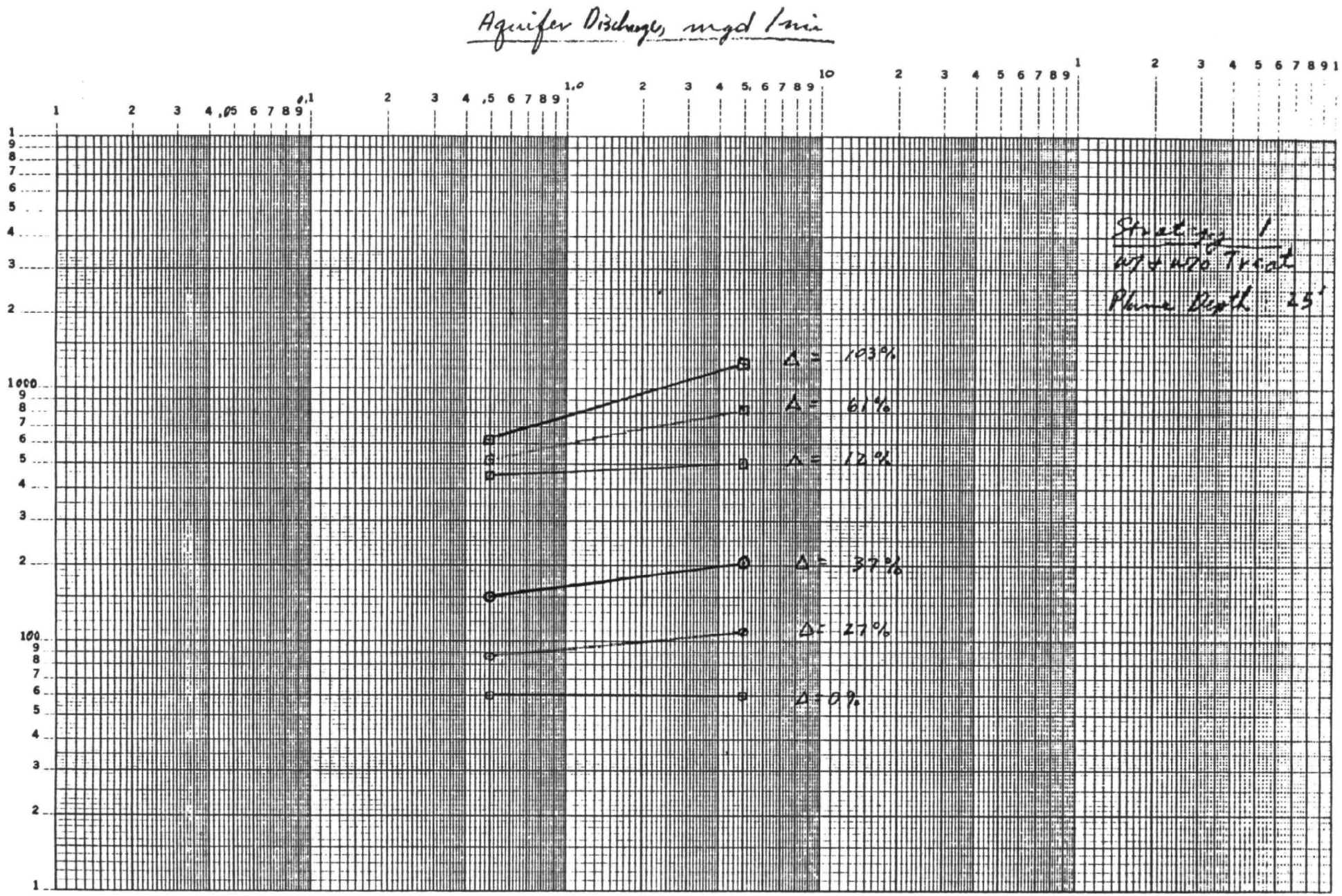

Aquifer Discharge mgd/mi
Strategy
Various Treatment
Depth Plume : 75 ft
(0.064) T = 100,000 ; I = .5, 5, 50'/mi
Δ = 55%
Δ = 78%
C/F/S/F
Δ = 145%
Δ = 82%
Δ = 24%
(0.022)
Δ = 175%
(0.028)
C/F/S/F
Δ = 39%
CAC Δ = 26%
(0.013)
2000 x 4000
2000 x 10000
2000 x 8000
100 x 500
100 x 200
RO

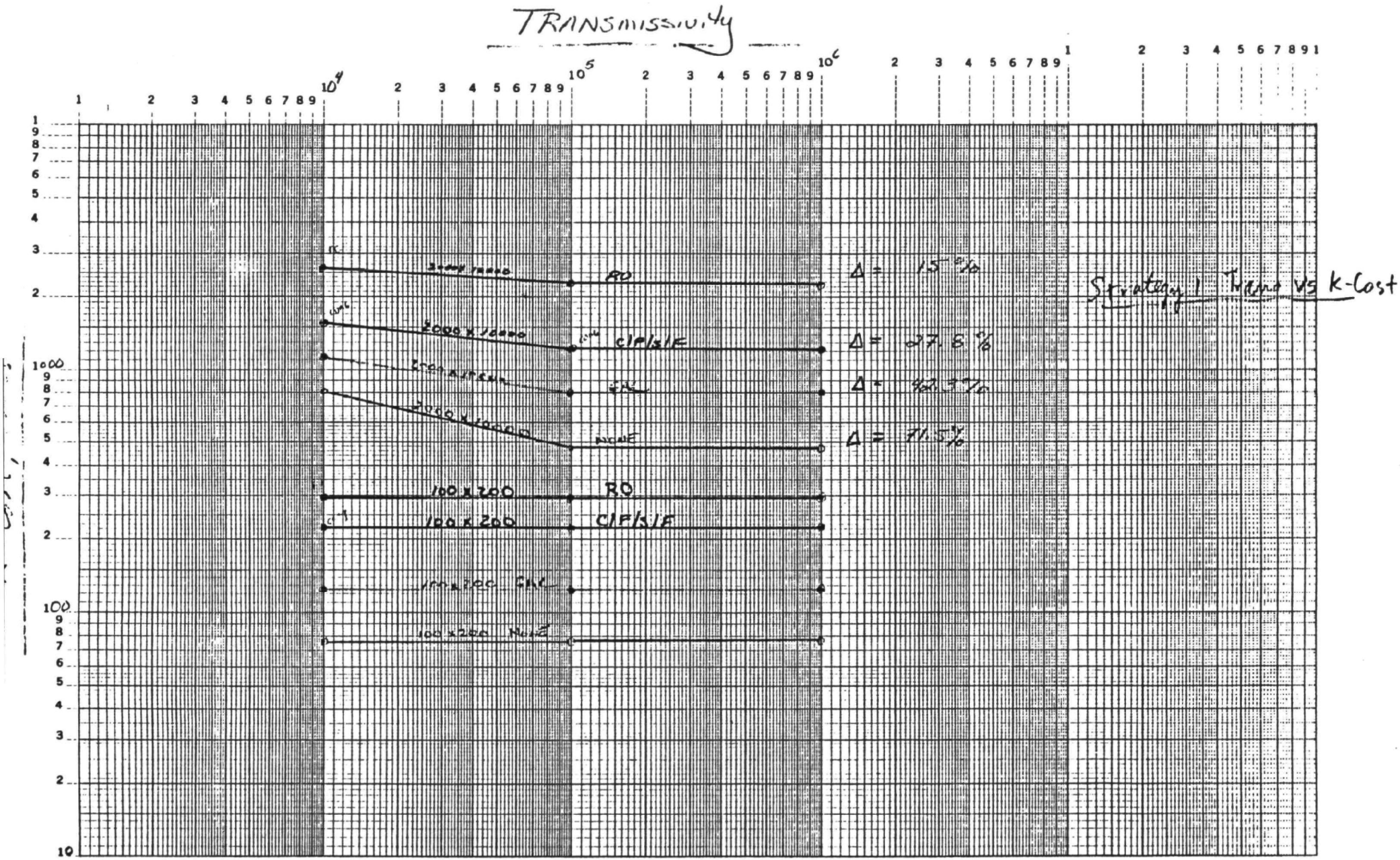

Aquifer Discharge, Mgd / mi
Strategy # 1
No Treatment
Depth of Plume: 25 ft
T = 10,000 gpd/ft
Most rapid change due to more expansive drain
1:2 Plume
1:5 plume
French Drains
Extend of well
2000' wide Plume
1000'
500'
100'
Δ=30%
Δ=40%
37%
Note Δ for the 10-fold decrease in Q

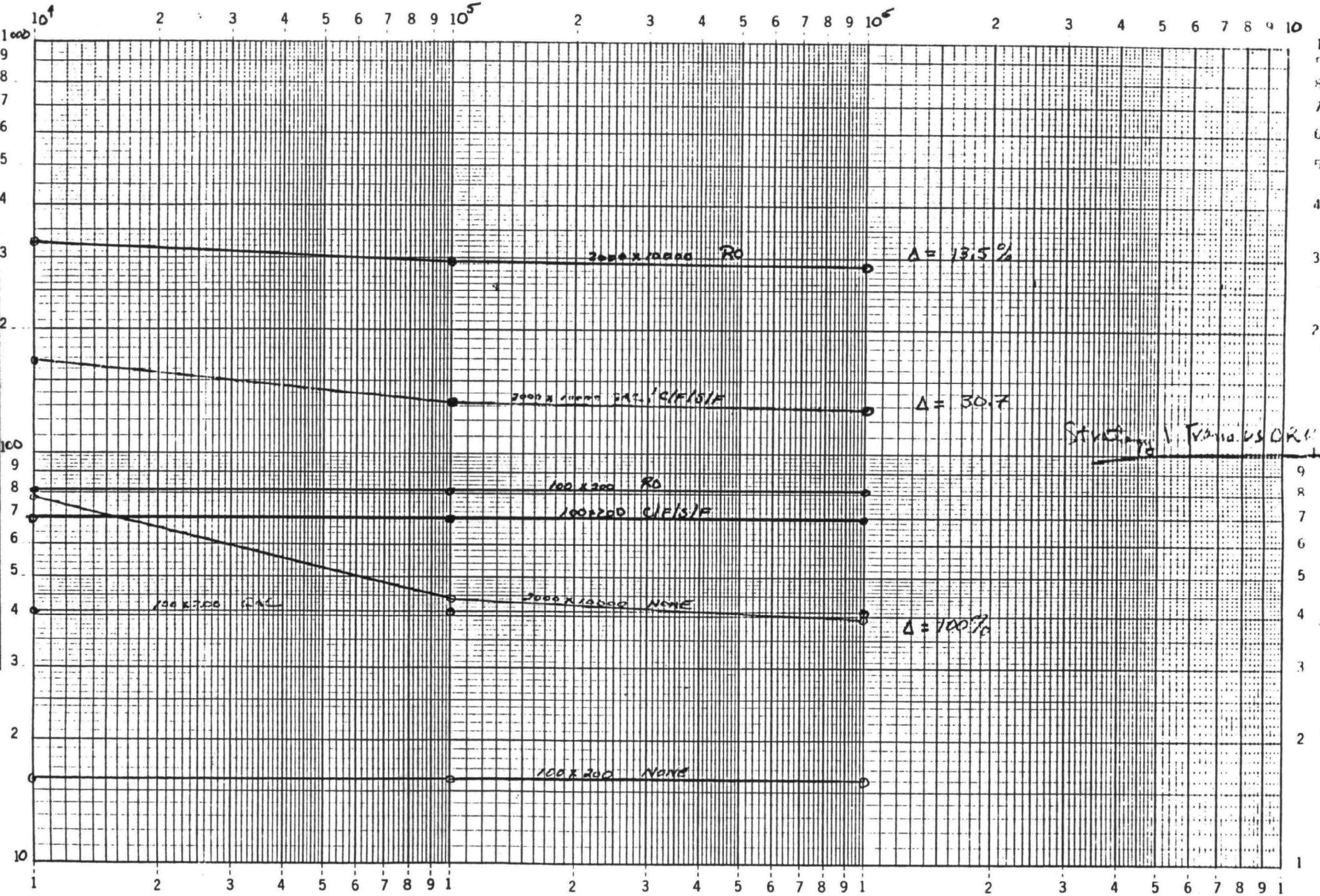
Plume Discharge, gpm

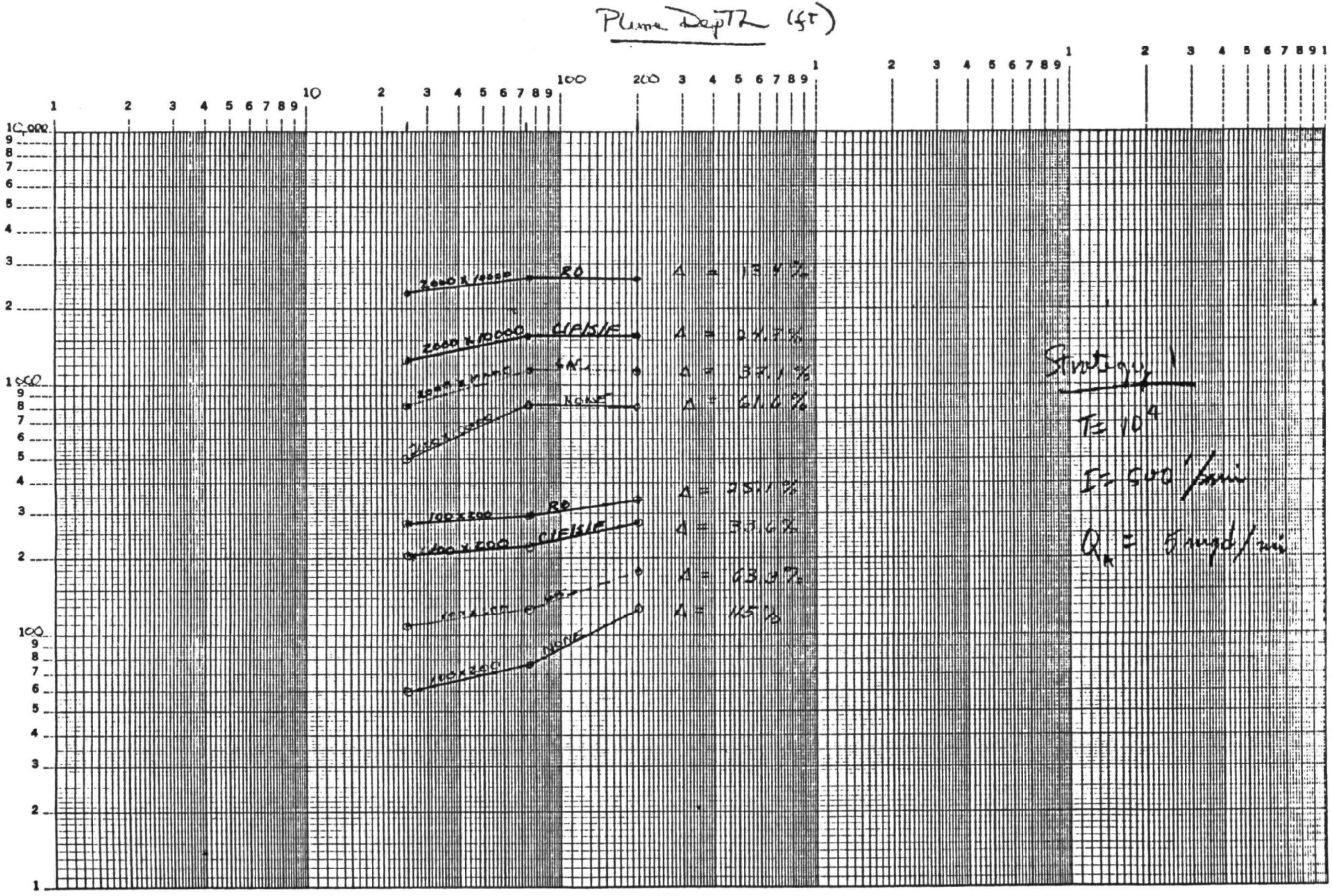



Aquifer Discharge, mgd/mi
Strategy 1
W/ and W/o Treatment
Plume Depth: 75'
I = 5'/mile
T = 10^4, 10^5, 10^6 gal/d/ft
Largest Plume
Cost Range
Smallest Plume
2000 x 10000 RO
2000 x 4000 RO
2000 x 10000 C/F&S/F
2000 x 1000 C/F
2000 x 4000
100 x 200 RO
100 x 200 C/F&S/F
100 x 200 C/F
None 100 x 200
Δ = 369 %
Δ = 335 %
Δ = 138 %
Δ = 82 %
Δ = 15 %
Δ = 23 %
Δ = 175 %
Δ = 37 %
Δ = 26 %
Δ = 41 %

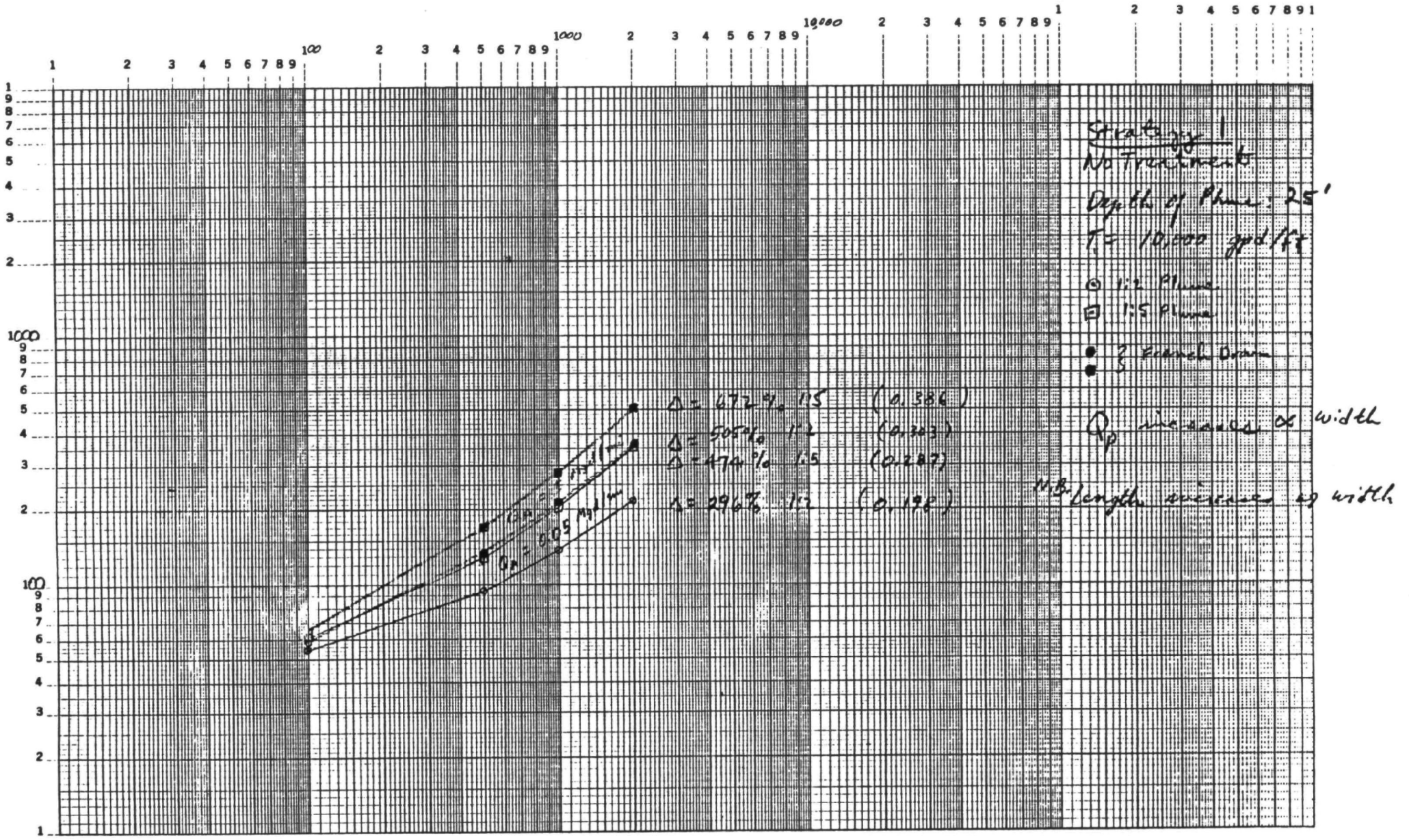

Aquifer Discharge, mgd 1/min
K - Cost, 1000$ N
Δ = 103%
Δ = 61%
Δ = 12%
Δ = 37%
Δ = 27%
Δ = 0%
Strategy 1
WT & WO Treat
Plume Depth 25'


TRANSMISSIVITY
2000 x 10000
RO
Δ = 15 %
2000 x 10000
CIF/SIF
Δ = 27.8 %
2000 x 10000
NONE
Δ = 71.5 %
100 x 200
RO
100 x 200
CIF/SIF
100 x 200
NONE
Sensitivity! Trans vs K-Cost


3000 x 10000 RO
Δ = 13.5%
3000 x 10000 C/F/S/F
Δ = 30.7
100 x 200 RO
100 x 200 C/F/S/F
3000 x 10000 NONE
Δ = 100%
100 x 200 NONE

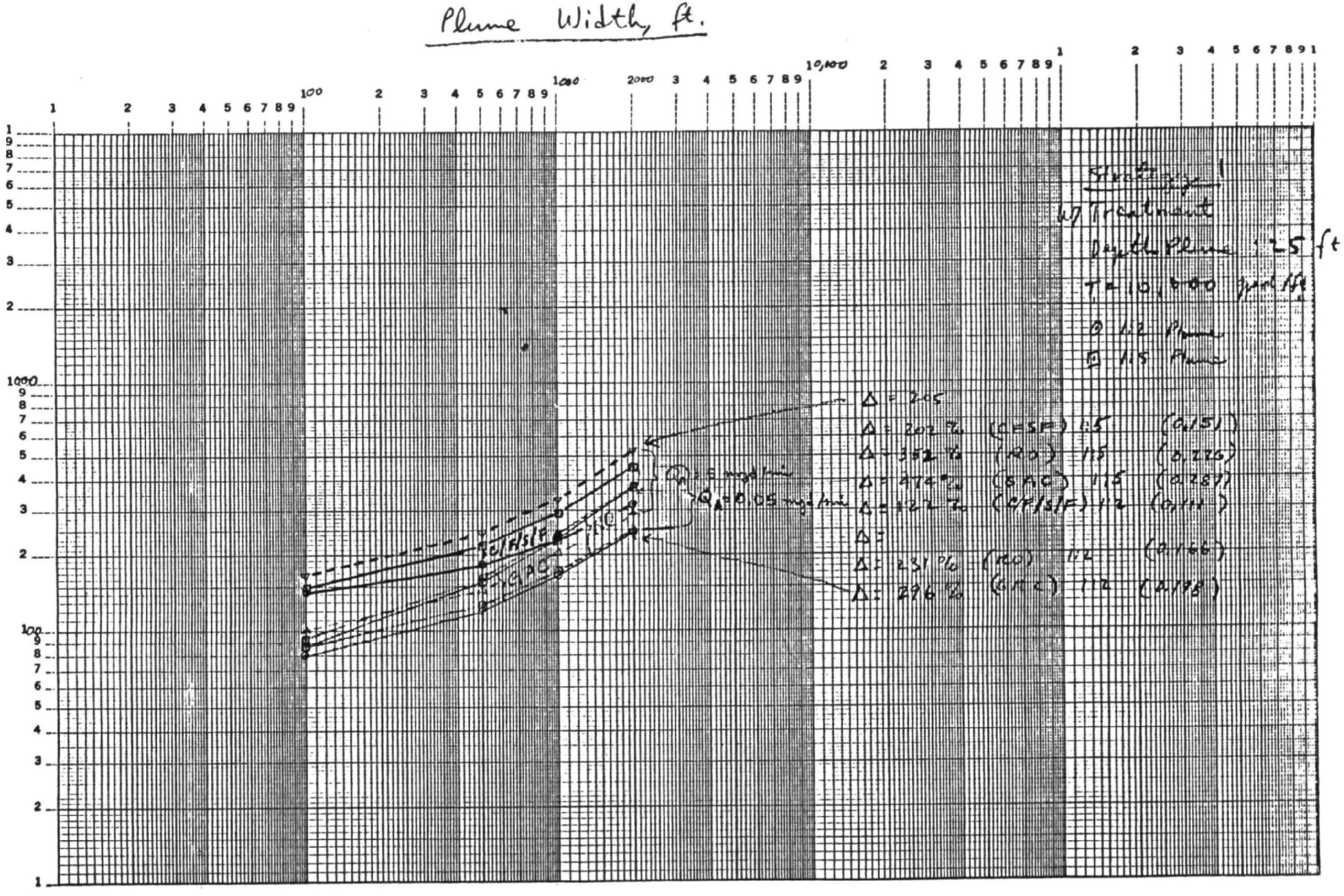

LOGARITHMIC 3 x 5 CYCLES
Plume Depth (ft)
2000 x 10000 RO Δ = 13.4%
2000 x 10000 CIFISIF Δ = 24.5%
2000 x 10000 SAN Δ = 37.1%
2000 x 10000 NONE Δ = 61.6%
100 x 500 RO Δ = 25.1%
100 x 500 CIFISIF Δ = 33.6%
100 x 500 SAN Δ = 63.9%
100 x 500 NONE Δ = 115%
Strategy 1
T = 10^4
I = 500 l/min
Q_R = 5 mgd/min

Plume Width, ft

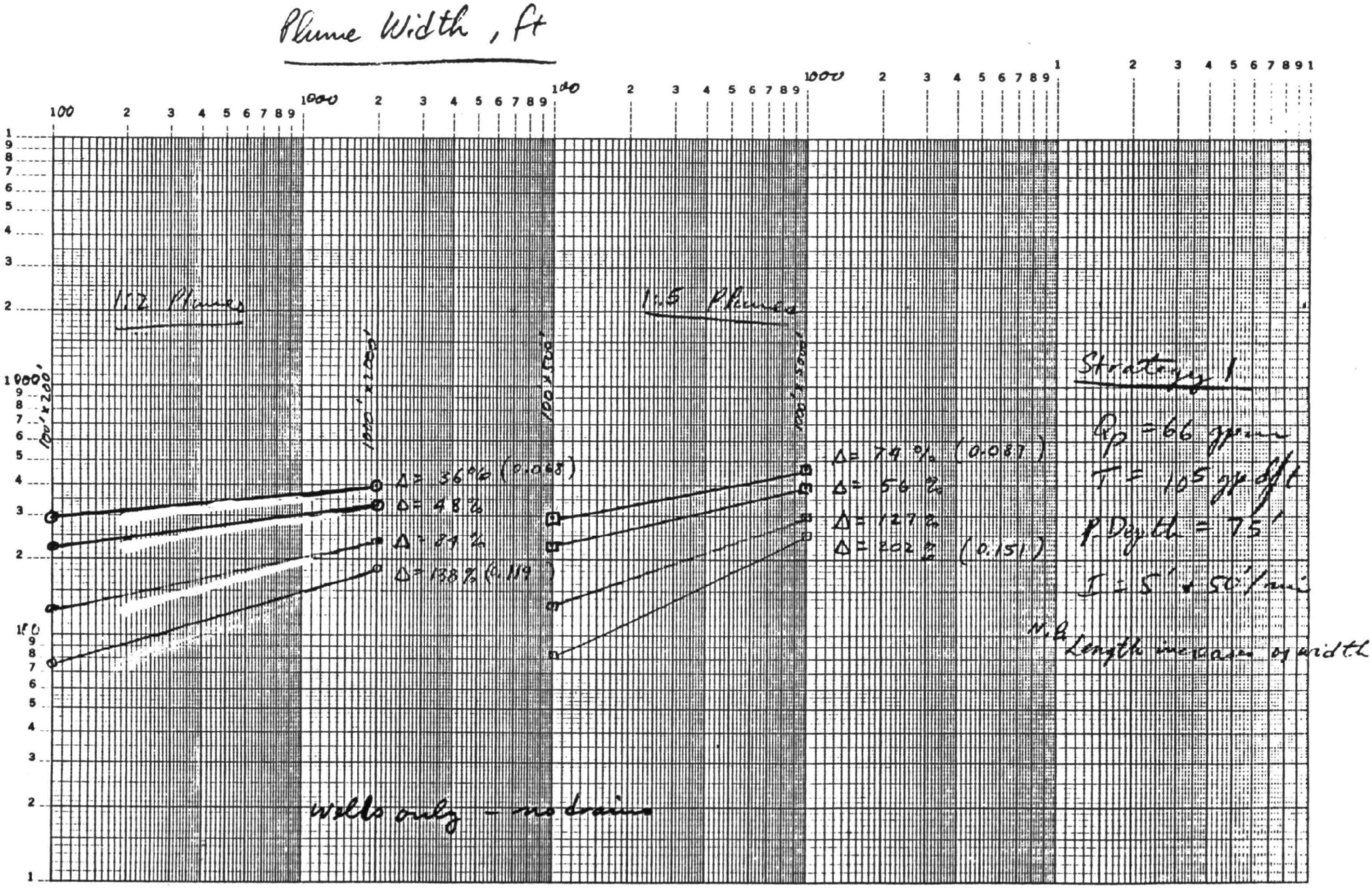


Data from Tables C-2, C-

K+E LOGARITHMIC 3 X 3 CYCLES
KEUFFEL & ESSER CO.
46 7522



Data from Tables C-2, C-14



Data from Tables C-6, C-12

APPENDIX H: TOTAL COSTS FOR FLUID ISOLATION SYSTEMS

Plume Depth (feet)	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		100 x 200		100 x 500		500 x 1000		500 x 2500	
		K	O&M	K	O&M	K	O&M	K	O&M
25	Slurry Wall	60	10	93	10	210	10	413	10
	Surface Treatment	-	-	-	-	-	-	-	-
	Totals	60	10	93	10	210	10	413	10
50	Slurry Wall	97	10	185	10	380	10	793	10
	Surface Treatment	-	-	-	-	-	-	-	-
	Totals	97	10	185	10	380	10	793	10
75	Slurry Wall	140	10	274	10	561	10	1196	10
	Surface Treatment	-	-	-	-	-	-	-	-
	Totals	140	10	274	10	561	10	1196	10
100	Slurry Wall	180	10	359	10	750	10	1560	10
	Surface Treatment	-	-	-	-	-	-	-	-
	Totals	180	10	359	10	750	10	1560	10

[a] Low Cost Wall: \$2.5/Vertical Foot^2
Mid Cost Wall: \$5.00/Vertical Foot^2
High Cost Wall: \$10.00/Vertical Foot^2
Low Cost Surface Treatment: \$.15/Foot^2 (e.g. grading, recontouring, and revegetation)
High Cost Surface Treatment: \$.75/Foot^2 (e.g. grading, recontouring, and surface seal)

[b] Cost Includes: Engineering, installation, materials, plume delineation

[c] Cost Includes: Engineering, installation, materials

Table H-1. (Continued)

Plume Depth (feet)	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
		K	O&M	K	O&M	K	O&M	K	O&M
25	Slurry Wall[b]	387	10	789	10	733	10	1575	10
	Surface Treatment[c]	-	-	-	-	-	-	-	-
	Totals	387	10	789	10	733	10	1575	10
50	Slurry Wall	733	10	1559	10	1426	10	3186	10
	Surface Treatment	-	-	-	-	-	-	-	-
	Totals	733	10	1559	10	1426	10	3186	10
75	Slurry Wall	1083	10	2383	10	2116	10	4610	10
	Surface Treatment	-	-	-	-	-	-	-	-
	Totals	1083	10	2383	10	2116	10	4610	10
100	Slurry Wall	1427	10	3162	10	2845	10	6029	10
	Surface Treatment	-	-	-	-	-	-	-	-
	Totals	1427	10	3162	10	2845	10	6029	10

[a] Low Cost Wall: $2.5/Vertical Foot^2
Mid Cost Wall: $5.00/Vertical Foot^2
High Cost Wall: $10.00/Vertical Foot^2
Low Cost Surface Treatment: $.15/Foot^2 (e.g. grading, recontouring, and revegetation)
High Cost Surface Treatment: $.75/Foot^2 (e.g. grading, recontouring, and surface seal)

[b] Cost Includes: Engineering, installation, materials, plume delineation

[c] Cost Includes: Engineering, installation, materials

Table H-2. Containment Costs for Slurry Wall Systems: Low Cost Wall, Low Cost Land Surface Treatment[a]

Plume Depth (feet)	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		100 x 200		100 x 500		500 x 1000		500 x 25000	
		K	O&M	K	O&M	K	O&M	K	O&M
25	Slurry Wall[b]	60	10	93	10	210	10	413	10
	Surface Treatment[c]	2	<1	7	<1	66	<1	164	1
	Totals	62	10	100	10	276	10	577	11
50	Slurry Wall	97	10	185	10	380	10	793	10
	Surface Treatment	2	<1	7	<1	66	<1	164	1
	Totals	99	10	192	10	446	10	957	11
75	Slurry Wall	140	10	274	10	561	10	1196	10
	Surface Treatment	2	<1	7	<1	66	<1	164	1
	Totals	142	10	281	10	627	10	1360	11
100	Slurry Wall	180	10	359	10	750	10	1560	10
	Surface Treatment	2	<1	7	<1	66	<1	164	1
	Totals	182	10	366	10	816	10	1724	11

[a] Low Cost Wall: $2.5/Vertical Foot^2
Mid Cost Wall: $5.00/Vertical Foot^2
High Cost Wall: $10.00/Vertical Foot^2
Low Cost Surface Treatment: $.15/Foot^2 (e.g. grading, recontouring, and revegetation)
High Cost Surface Treatment: $.75/Foot^2 (e.g. grading, recontouring, and surface seal)

[b] Cost Includes: Engineering, installation, materials, plume delineation

[c] Cost Includes: Engineering, installation, materials

Table H-2. (Continued)

Plume Depth (feet)	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
		K	O&M	K	O&M	K	O&M	K	O&M
25	Slurry Wall[b]	387	10	789	10	733	10	1575	10
	Surface Treatment[c]	264	2	630	5	1015	9	2550	21
	Totals	651	12	1419	15	1748	19	4125	31
50	Slurry Wall	733	10	1559	10	1426	10	3186	10
	Surface Treatment	264	2	630	5	1015	9	2550	21
	Totals	977	12	2189	15	2441	19	5736	31
75	Slurry Wall	1083	10	2383	10	2116	10	4610	10
	Surface Treatment	264	2	630	5	1015	1	2550	21
	Totals	1347	12	3013	15	3121	19	7160	31
100	Slurry Wall	1427	10	3126	10	2845	10	6029	10
	Surface Treatment	264	2	630	5	1015	9	2550	21
	Totals	1691	12	3792	15	3860	19	8579	31

[a] Low Cost Wall: \$2.5/Vertical Foot^2
Mid Cost Wall: \$5.00/Vertical Foot^2
High Cost Wall: \$10.00/Vertical Foot^2
Low Cost Surface Treatment: \$.15/Foot^2 (e.g. grading, recontouring, and revegetation)
High Cost Surface Treatment: \$.75/Foot^2 (e.g. grading, recontouring, and surface seal)

[b] Cost Includes: Engineering, installation, materials, plume delineation

[c] Cost Includes: Engineering, installation, materials

Plume Depth (feet)	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		100 x 200		100 x 500		500 x 1000		500 x 2500	
		K	O&M	K	O&M	K	O&M	K	O&M
25	Slurry Wall[b]	60	10	93	10	210	10	413	10
	Surface Treatment[c]	13	0	33	0	320	0	798	0
	Totals	73	10	126	10	530	10	1211	10
	Slurry Wall	97	10	185	10	380	10	793	10
	Surface Treatment	13	0	33	0	320	0	798	0
	Totals	110	10	218	10	700	10	1591	10
75	Slurry Wall	140	10	274	10	561	10	1196	10
	Surface Treatment	13	0	33	0	320	0	798	0
	Totals	153	10	307	10	881	10	1994	10
100	Slurry Wall	180	10	359	10	750	10	1560	10
	Surface Treatment	13	0	33	0	320	0	798	0
	Totals	193	10	392	10	1070	10	2358	10

[a] Low Cost Wall: $2.5/Vertical Foot^2
Mid Cost Wall: $5.00/Vertical Foot^2
High Cost Wall: $10.00/Vertical Foot^2
Low Cost Surface Treatment: $.15/Foot^2 (e.g. grading, recontouring, and revegetation)
High Cost Surface Treatment: $.75/Foot^2 (e.g. grading, recontouring, and surface seal)

[b] Cost Includes: Engineering, installation, materials, plume delineation

[c] Cost Includes: Engineering, installation, materials

Table B-3. (Continued)

Plume Depth (feet)	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
		K	O&M	K	O&M	K	O&M	K	O&M
25	Slurry Wall[b]	387	10	789	10	733	10	1575	10
	Surface Treatment[c]	1280	0	3115	0	5000	0	12720	0
	Totals	1667	10	3904	10	5733	10	14295	10
50	Slurry Wall	733	10	1559	10	1426	10	3186	10
	Surface Treatment	1280	0	3115	0	5000	0	12720	0
	Totals	2013	10	4674	10	6426	10	15906	10
75	Slurry Wall	1083	10	2383	10	2116	10	4610	10
	Surface Treatment	1280	0	3115	0	5000	0	12720	0
	Totals	2363	10	5498	10	7116	10	17330	10
100	Slurry Wall	1427	10	3162	10	2845	10	6029	10
	Surface Treatment	1280	0	3115	0	5000	0	12720	0
	Totals	2707	10	6277	10	7845	10	18749	10

[a] Low Cost Wall: $2.5/Vertical Foot^2
Mid Cost Wall: $5.00/Vertical Foot^2
High Cost Wall: $10.00/Vertical Foot^2
Low Cost Surface Treatment: $.15/Foot^2 (e.g. grading, recontouring, and revegetation)
High Cost Surface Treatment: $.75/Foot^2 (e.g. grading, recontouring, and surface seal)

[b] Cost Includes: Engineering, installation, materials, plume delineation

[c] Cost Includes: Engineering, installation, materials

Table H-4. Containment Costs for Slurry Wall Systems: Mid Cost Wall, No Land Surface Treatment

Plume Depth (feet)	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		100 x 200		100 x 500		500 x 1000		500 x 2500	
		K	O&M	K	O&M	K	O&M	K	O&M
25	Slurry Wall	90	10	165	10	374	10	770	10
	Surface Treatment	-	-	-	-	-	-	-	-
	Totals	90	10	165	10	374	10	770	10
50	Slurry Wall	161	10	333	10	700	10	1500	10
	Surface Treatment	-	-	-	-	-	-	-	-
	Totals	161	10	333	10	700	10	1500	10
75	Slurry Wall	240	10	495	10	1041	10	2255	10
	Surface Treatment	-	-	-	-	-	-	-	-
	Totals	240	10	495	10	1041	10	2255	10
100	Slurry Wall	310	10	652	10	1385	10	2969	10
	Surface Treatment	-	-	-	-	-	-	-	-
	Totals	310	10	652	10	1385	10	2969	10

[a] Low Cost Wall: \$2.5/Vertical Foot^2
Mid Cost Wall: \$5.00/Vertical Foot^2
High Cost Wall: \$10.00/Vertical Foot^2
Low Cost Surface Treatment: \$.15/Foot^2 (e.g. grading, recontouring, and revegetation)
High Cost Surface Treatment: \$.75/Foot^2 (e.g. grading, recontouring, and surface seal)

[b] Cost Includes: Engineering, installation, materials, plume delineation

[c] Cost Includes: Engineering, installation, materials

Table H-4. (Continued)

Plume Depth (feet)	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
		K	O&M	K	O&M	K	O&M	K	O&M
25	Slurry Wall[b]	705	10	1550	10	1382	10	2928	10
	Surface Treatment[c]	-	-	-	-	-	-	-	-
	Totals	705	10	1550	10	1382	10	2928	10
50	Slurry Wall	1365	10	3110	10	2623	10	6103	10
	Surface Treatment	-	-	-	-	-	-	-	-
	Totals	1365	10	3110	10	2623	10	6103	10
75	Slurry Wall	2045	10	4567	10	3963	10	8845	10
	Surface Treatment	-	-	-	-	-	-	-	-
	Totals	2045	10	4567	10	3963	10	8845	10
100	Slurry Wall	2705	10	6080	10	5405	10	11557	10
	Surface Treatment	-	-	-	-	-	-	-	-
	Totals	2705	10	6080	10	5405	10	11557	10

[a] Low Cost Wall: \$2.5/Vertical Foot^2
Mid Cost Wall: \$5.00/Vertical Foot^2
High Cost Wall: \$10.00/Vertical Foot^2
Low Cost Surface Treatment: \$.15/Foot^2 (e.g. grading, recontouring, and revegetation)
High Cost Surface Treatment: \$.75/Foot^2 (e.g. grading, recontouring, and surface seal)

[b] Cost Includes: Engineering, installation, materials, plume delineation

[c] Cost Includes: Engineering, installation, materials

Table H-5. Containment Costs for Slurry Wall Systems: Mid Cost Wall, Low Cost Surface Treatment[a]

Plume Depth (feet)	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		100 x 200		100 x 500		500 x 1000		500 x 2500	
		K	O&M	K	O&M	K	O&M	K	O&M
25	Slurry Wall[b]	90	10	165	10	374	10	770	10
	Surface Treatment[c]	2	<1	7	<1	66	<1	164	1
	Totals	92	10	172	10	440	10	934	11
50	Slurry Wall	161	10	333	10	700	10	1500	10
	Surface Treatment	2	<1	7	<1	66	<1	164	1
	Totals	163	10	340	10	766	10	1664	11
75	Slurry Wall	240	10	495	10	1041	10	2255	10
	Surface Treatment	2	<1	7	<1	66	<1	164	1
	Totals	242	10	502	10	1107	10	2419	11
100	Slurry Wall	310	10	652	10	1385	10	2969	10
	Surface Treatment	2	<1	7	<1	66	<1	164	1
	Totals	312	10	659	10	1451	10	3133	11

[a] Low Cost Wall: \$2.5/Vertical Foot^2
Mid Cost Wall: \$5.00/Vertical Foot^2
High Cost Wall: \$10.00/Vertical Foot^2
Low Cost Surface Treatment: \$.15/Foot^2 (e.g. grading, recontouring, and revegetation)
High Cost Surface Treatment: \$.75/Foot^2 (e.g. grading, recontouring, and surface seal)

[b] Cost Includes: Engineering, installation, materials, plume delineation

[c] Cost Includes: Engineering, installation, materials

Table H-5. (Continued)

Plume Depth (feet)	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
		K	O&M	K	O&M	K	O&M	K	O&M
25	Slurry Wall[b]	705	10	1550	10	1382	10	2928	10
	Surface Treatment[c]	264	2	630	5	1015	9	2550	21
	Totals	969	12	2180	15	2397	19	5478	31
50	Slurry Wall	1365	10	3110	10	2623	10	6103	10
	Surface Treatment	264	2	630	5	1015	9	2550	21
	Totals	1629	12	3740	15	3638	19	8653	31
75	Slurry Wall	2045	10	4567	10	3963	10	8845	10
	Surface Treatment	264	2	630	5	1015	9	2550	21
	Totals	2309	12	5197	15	4978	19	11395	31
100	Slurry Wall	2705	10	6080	10	5405	10	11557	10
	Surface Treatment	264	2	630	5	1015	9	2550	21
	Totals	2969	12	6710	15	6420	19	14107	31

[a] Low Cost Wall: $2.5/Vertical Foot^2
Mid Cost Wall: $5.00/Vertical Foot^2
High Cost Wall: $10.00/Vertical Foot^2
Low Cost Surface Treatment: $.15/Foot^2 (e.g. grading, recontouring, and revegetation)
High Cost Surface Treatment: $.75/Foot^2 (e.g. grading, recontouring, and surface seal)

[b] Cost Includes: Engineering, installation, materials, plume delineation

[c] Cost Includes: Engineering, installation, materials

Table H-6. Containment Costs for Slurry Wall Systems: Mid Cost Wall, High Cost Land Surface Treatment[a]

Plume Depth (feet)	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		100 x 200		100 x 500		500 x 1000		500 x 2500	
		K	O&M	K	O&M	K	O&M	K	O&M
25	Slurry Wall[b]	90	10	165	10	374	10	770	10
	Surface Treatment[c]	13	0	33	0	320	0	798	0
	Totals	103	10	198	10	694	10	1568	10
50	Slurry Wall	161	10	333	10	700	10	1500	10
	Surface Treatment	13	0	33	0	320	0	798	0
	Totals	174	10	366	10	1020	10	2298	10
75	Slurry Wall	240	10	495	10	1041	10	2255	10
	Surface Treatment	13	0	33	0	320	0	798	0
	Totals	253	10	528	10	1361	10	3053	10
100	Slurry Wall	310	10	652	10	1385	10	2969	10
	Surface Treatment	13	0	33	0	320	0	798	0
	Totals	323	10	685	10	1705	10	3767	10

[a] Low Cost Wall: $2.5/Vertical Foot^2
Mid Cost Wall: $5.00/Vertical Foot^2
High Cost Wall: $10.00/Vertical Foot^2
Low Cost Surface Treatment: $.15/Foot^2 (e.g. grading, recontouring, and revegetation)
High Cost Surface Treatment: $.75/Foot^2 (e.g. grading, recontouring, and surface seal)

[b] Cost Includes: Engineering, installation, materials, plume delineation

[c] Cost Includes: Engineering, installation, materials

Table H-6. (Continued)

Plume Depth (feet)	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
		K	O&M	K	O&M	K	O&M	K	O&M
25	Slurry Wall[b]	705	10	1550	10	1382	10	2928	10
	Surface Treatment[c]	1280	0	3115	0	5000	0	12720	0
	Totals	1985	10	4665	10	6382	10	15648	10
50	Slurry Wall	1365	10	3110	10	2623	10	6103	10
	Surface Treatment	1280	0	3115	0	5000	0	12720	0
	Totals	2645	10	6225	10	7623	10	18823	10
75	Slurry Wall	2045	10	4567	10	3963	10	8845	10
	Surface Treatment	1280	0	3115	0	5000	0	12720	0
	Totals	3325	10	7682	10	8963	10	21565	10
100	Slurry Wall	2705	10	6080	10	5405	10	11557	10
	Surface Treatment	1280	0	3115	0	5000	0	12720	0
	Totals	3985	10	9195	10	10405	10	24277	10

[a] Low Cost Wall: $2.5/Vertical Foot^2
Mid Cost Wall: $5.00/Vertical Foot^2
High Cost Wall: $10.00/Vertical Foot^2
Low Cost Surface Treatment: $.15/Foot^2 (e.g. grading, recontouring, and revegetation)
High Cost Surface Treatment: $.75/Foot^2 (e.g. grading, recontouring, and surface seal)

[b] Cost Includes: Engineering, installation, materials, plume delineation

[c] Cost Includes: Engineering, installation, materials

Table H-7. Containment Costs for Slurry Wall Systems: High Cost Wall, No Land Surface Treatment[a]

Plume Depth (feet)	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		100 x 200		100 x 500		500 x 1000		500 x 2500	
		K	O&M	K	O&M	K	O&M	K	O&M
25	Slurry Wall[b]	153	10	305	10	680	10	1471	10
	Surface Treatment[c]	-	-	-	-	-	-	-	-
	Totals	153	10	305	10	680	10	1471	10
50	Slurry Wall	290	10	626	10	1341	10	2907	10
	Surface Treatment	-	-	-	-	-	-	-	-
	Totals	290	10	626	10	1341	10	2907	10
75	Slurry Wall	435	10	936	10	2000	10	4357	10
	Surface Treatment	-	-	-	-	-	-	-	-
	Totals	435	10	936	10	2000	10	4357	10
100	Slurry Wall	566	10	1183	10	2662	10	5767	10
	Surface Treatment	-	-	-	-	-	-	-	-
	Totals	566	10	1183	10	2662	10	5767	10

[a] Low Cost Wall: $2.5/Vertical Foot^2
Mid Cost Wall: $5.00/Vertical Foot^2
High Cost Wall: $10.00/Vertical Foot^2
Low Cost Surface Treatment: $.15/Foot^2 (e.g. grading, recontouring, and revegetation)
High Cost Surface Treatment: $.75/Foot^2 (e.g. grading, recontouring, and surface seal)

[b] Cost Includes: Engineering, installation, materials, plume delineation

[c] Cost Includes: Engineering, installation, materials

Table H-7. (Continued)

Plume Depth (feet)	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
		K	O&M	K	O&M	K	O&M	K	O&M
25	Slurry Wall[b]	1347	10	2863	10	2670	10	5791	10
	Surface Treatment[c]	-	-	-	-	-	-	-	-
	Totals	1347	10	2863	10	2670	10	5791	10
50	Slurry Wall	2642	10	5775	10	5280	10	11898	10
	Surface Treatment	-	-	-	-	-	-	-	-
	Totals	2642	10	5775	10	5280	10	11898	10
75	Slurry Wall	3879	10	8935	10	7896	10	17000	10
	Surface Treatment	-	-	-	-	-	-	-	-
	Totals	3879	10	8935	10	7896	10	17000	10
100	Slurry Wall	5156	10	11877	10	10512	10	22624	10
	Surface Treatment	-	-	-	-	-	-	-	-
	Totals	5156	10	11877	10	10512	10	22624	10

[a] Low Cost Wall: $2.5/Vertical Foot^2
Mid Cost Wall: $5.00/Vertical Foot^2
High Cost Wall: $10.00/Vertical Foot^2
Low Cost Surface Treatment: $.15/Foot^2 (e.g. grading, recontouring, and revegetation)
High Cost Surface Treatment: $.75/Foot^2 (e.g. grading, recontouring, and surface seal)

[b] Cost Includes: Engineering, installation, materials, plume delineation

[c] Cost Includes: Engineering, installation, materials

Table H-8. Containment Costs for Slurry Wall Systems: High Cost Wall, Low Cost Land Surface Treatment[a]

Plume Depth (feet)	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		100 x 200		100 x 500		500 x 1000		500 x 2500	
		K	O&M	K	O&M	K	O&M	K	O&M
25	Slurry Wall[b]	153	10	305	10	680	10	1471	10
	Surface Treatment[c]	2	0	7	0	66	0	164	1
	Totals	155	10	312	10	746	10	1407	11
50	Slurry Wall	290	10	626	10	1341	10	2907	10
	Surface Treatment	2	0	7	0	66	0	164	1
	Totals	292	10	633	10	1407	10	3071	11
75	Slurry Wall	435	10	936	10	2000	10	4357	10
	Surface Treatment	2	0	7	0	66	0	164	1
	Totals	437	10	943	10	2066	10	4521	11
100	Slurry Wall	566	10	1183	10	2662	10	5767	10
	Surface Treatment	2	0	7	0	66	0	164	1
	Totals	568	10	1190	10	2728	10	5931	11

[a] Low Cost Wall: $2.5/Vertical Foot^2
Mid Cost Wall: $5.00/Vertical Foot^2
High Cost Wall: $10.00/Vertical Foot^2
Low Cost Surface Treatment: $.15/Foot^2 (e.g. grading, recontouring, and revegetation)
High Cost Surface Treatment: $.75/Foot^2 (e.g. grading, recontouring, and surface seal)

[b] Cost Includes: Engineering, installation, materials, plume delineation

[c] Cost Includes: Engineering, installation, materials

Table H-8. (Continued)

Plume Depth (feet)	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
		K	O&M	K	O&M	K	O&M	K	O&M
25	Slurry Wall[b]	1347	10	2863	10	2670	10	5791	10
	Surface Treatment[c]	264	2	630	5	1015	9	2550	21
	Totals	1611	12	3493	15	3685	19	8341	31
50	Slurry Wall	2642	10	5775	10	5280	10	11898	10
	Surface Treatment	264	2	630	5	1015	9	2550	21
	Totals	2906	12	6405	15	6295	19	14448	31
75	Slurry Wall	3879	10	8935	10	7896	10	17000	10
	Surface Treatment	264	2	630	5	1015	9	2550	21
	Totals	4143	12	9565	15	8911	19	19550	31
100	Slurry Wall	5156	10	11877	10	10512	10	22624	10
	Surface Treatment	264	2	630	5	1015	9	2550	21
	Totals	5420	12	12507	15	11527	19	25174	31

[a] Low Cost Wall: $2.5/Vertical Foot^2
Mid Cost Wall: $5.00/Vertical Foot^2
High Cost Wall: $10.00/Vertical Foot^2
Low Cost Surface Treatment: $.15/Foot^2 (e.g. grading, recontouring, and revegetation)
High Cost Surface Treatment: $.75/Foot^2 (e.g. grading, recontouring, and surface seal)

[b] Cost Includes: Engineering, installation, materials, plume delineation

[c] Cost Includes: Engineering, installation, materials

Table H-9. Containment Costs for Slurry Wall Systems: High Cost Wall, High Cost Land Surface Treatment[a]

Plume Depth (feet)	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		100 x 200		100 x 500		500 x 1000		500 x 2500	
		K	O&M	K	O&M	K	O&M	K	O&M
25	Slurry Wall	153	10	305	10	680	10	1471	10
	Surface Treatment	13	0	33	0	320	0	798	0
	Totals	166	10	338	10	1000	10	2269	10
50	Slurry Wall	290	10	626	10	1341	10	2907	10
	Surface Treatment	13	0	33	0	320	0	798	0
	Totals	303	10	659	10	1661	10	3705	10
75	Slurry Wall	435	10	936	10	2000	10	4357	10
	Surface Treatment	13	0	33	0	320	0	798	0
	Totals	448	10	969	10	2320	10	5155	10
100	Slurry Wall	566	10	1183	10	2662	10	5767	10
	Surface Treatment	13	0	33	0	320	0	798	0
	Totals	579	10	1216	10	2982	10	6565	10

[a] Low Cost Wall: $2.5/Vertical Foot^2
Mid Cost Wall: $5.00/Vertical Foot^2
High Cost Wall: $10.00/Vertical Foot^2
Low Cost Surface Treatment: $.15/Foot^2 (e.g. grading, recontouring, and revegetation)
High Cost Surface Treatment: $.75/Foot^2 (e.g. grading, recontouring, and surface seal)

[b] Cost Includes: Engineering, installation, materials, plume delineation

[c] Cost Includes: Engineering, installation, materials

Table B-9. (Continued)

Plume Depth (feet)	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
		K	O&M	K	O&M	K	O&M	K	O&M
25	Slurry Wall[b]	1347	10	2863	10	2670	10	5791	10
	Surface Treatment[c]	1280	0	3115	0	5000	0	12720	0
	Totals	2627	10	5978	10	7670	10	18511	10
50	Slurry Wall	2642	10	5775	10	5280	10	11898	10
	Surface Treatment	1280	0	3115	0	5000	0	12720	0
	Totals	3922	10	8890	10	10280	10	24618	10
75	Slurry Wall	3879	10	8935	10	7896	10	17000	10
	Surface Treatment	1280	0	3115	0	5000	0	12720	0
	Totals	5159	10	12050	10	12896	10	29720	10
100	Slurry Wall	5156	10	11877	10	10512	10	22624	10
	Surface Treatment	1280	0	3115	0	5000	0	12720	0
	Totals	6436	10	14992	10	15512	10	35344	10

[a] Low Cost Wall: $2.5/Vertical Foot^2
Mid Cost Wall: $5.00/Vertical Foot^2
High Cost Wall: $10.00/Vertical Foot^2
Low Cost Surface Treatment: $.15/Foot^2 (e.g. grading, recontouring, and revegetation)
High Cost Surface Treatment: $.75/Foot^2 (e.g. grading, recontouring, and surface seal)

[b] Cost Includes: Engineering, installation, materials, plume delineation

[c] Cost Includes: Engineering, installation, materials

Table H- 10. Containment Costs for Slurry Wall Systems: Supportive Data

Plume Depth (feet)	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		100 x 200		100 x 500		500 x 1000		500 x 25000	
		K	O&M	K	O&M	K	O&M	K	O&M
25	Boring[a]	2		3		7		16	
	Delineation[b]	15		15		30		38	
	Totals	17		18		37		54	
50	Borings	3		7		14		32	
	Delineation	24		24		42		45	
	Totals	27		31		56		77	
75	Borings	5		10		22		48	
	Delineation	28		28		50		62	
	Totals	43		38		72		110	
100	Borings	6		13		28		64	
	Delineation	40		45		70		80	
	Totals	46		58		98		144	

[a] Assumes one boring every 100 feet of plume perimeter

[b] Includes boring, well completion, reporting and testing

Table H-10. (Continued)

Plume Depth (feet)	Cost Element	Width x Length Plume Dimensions (ft) and Associated Capital (K) and Operating and Maintenance (O&M)/Monitoring Costs (1000's Dollars)							
		1000 x 2000		1000 x 5000		2000 x 4000		2000 x 10000	
		K	O&M	K	O&M	K	O&M	K	O&M
25	Boring[a]	14		33		29		63	
	Delineation[b]	41		48		50		80	
	Totals	55		81		79		143	
50	Borings	29		66		60		126	
	Delineation	50		62		70		110	
	Totals	79		128		130		236	
75	Borings	45		99		90		189	
	Delineation	70		80		90		140	
	Totals	115		179		180		329	
100	Borings	56		132		120		252	
	Delineation	90		100		110		170	
	Totals	146		232		230		422	

[a] Assumes one boring every 100 feet of plume perimeter

[b] Includes boring, well completion, reporting and testing

APPENDIX I: GRAPHS USED IN SENSITIVITY ANALYSIS FOR FLUID ISOLATION SYSTEM COSTS

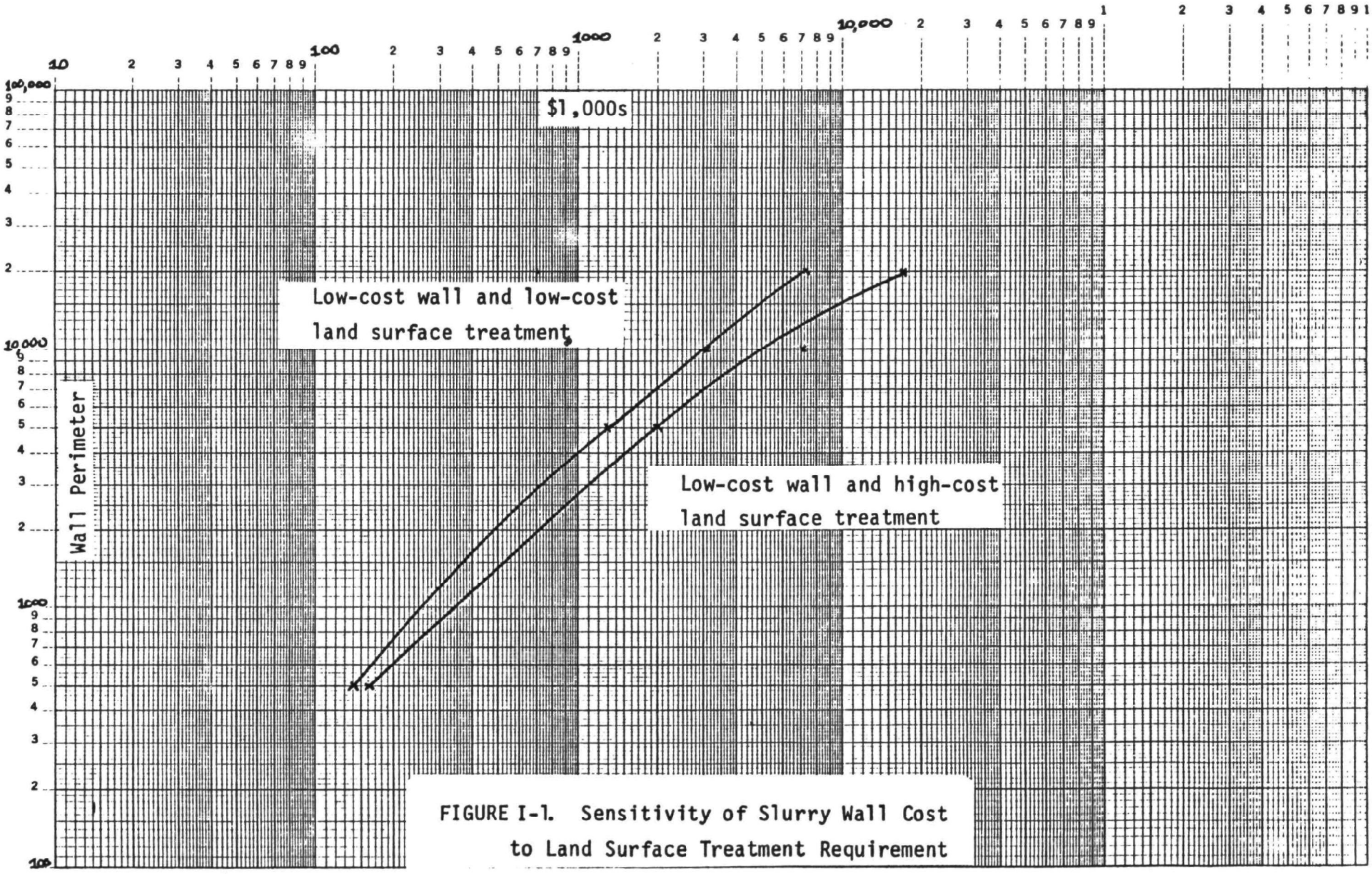


FIGURE I-1. Sensitivity of Slurry Wall Cost to Land Surface Treatment Requirement

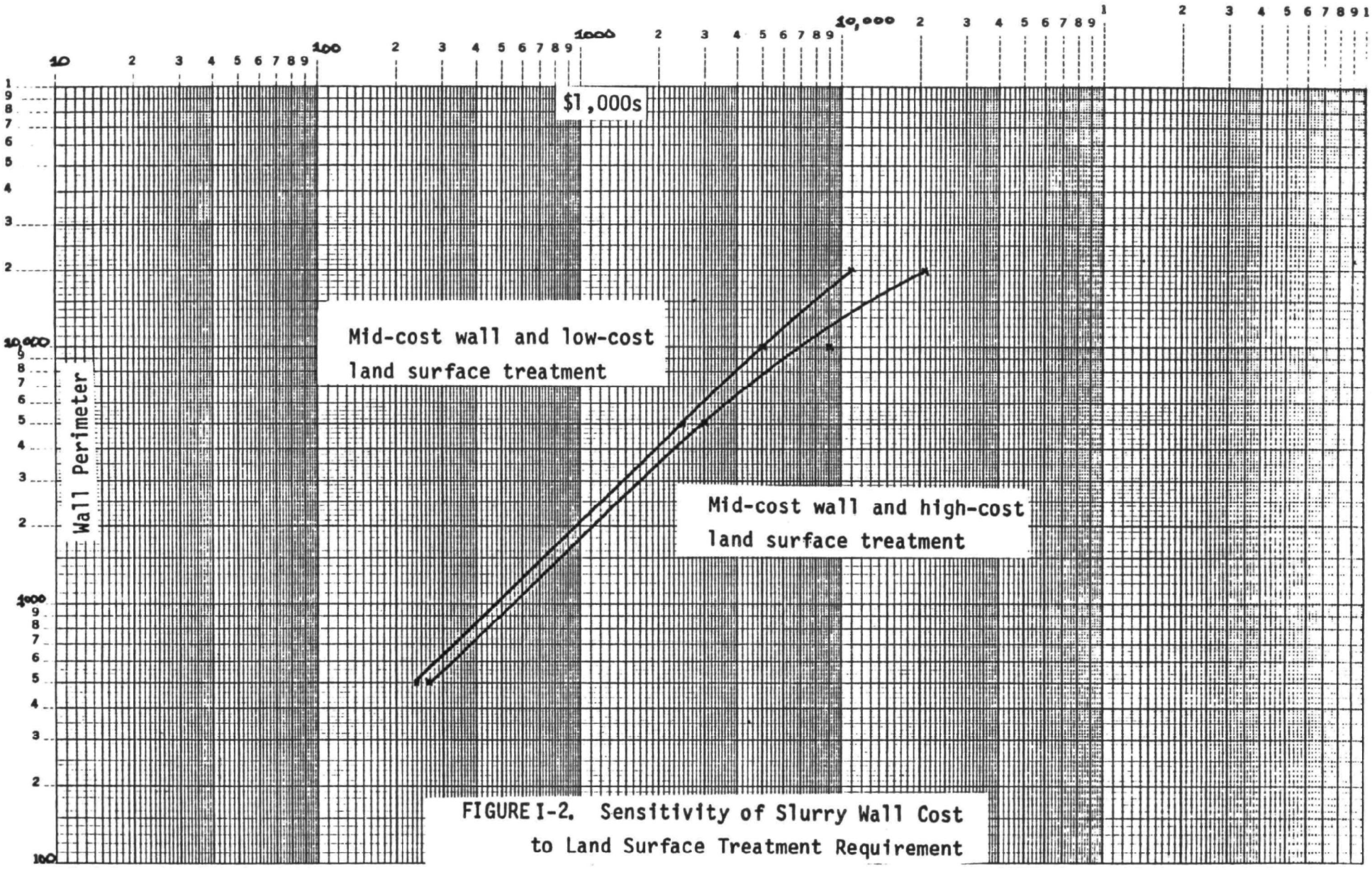


FIGURE I-2. Sensitivity of Slurry Wall Cost to Land Surface Treatment Requirement

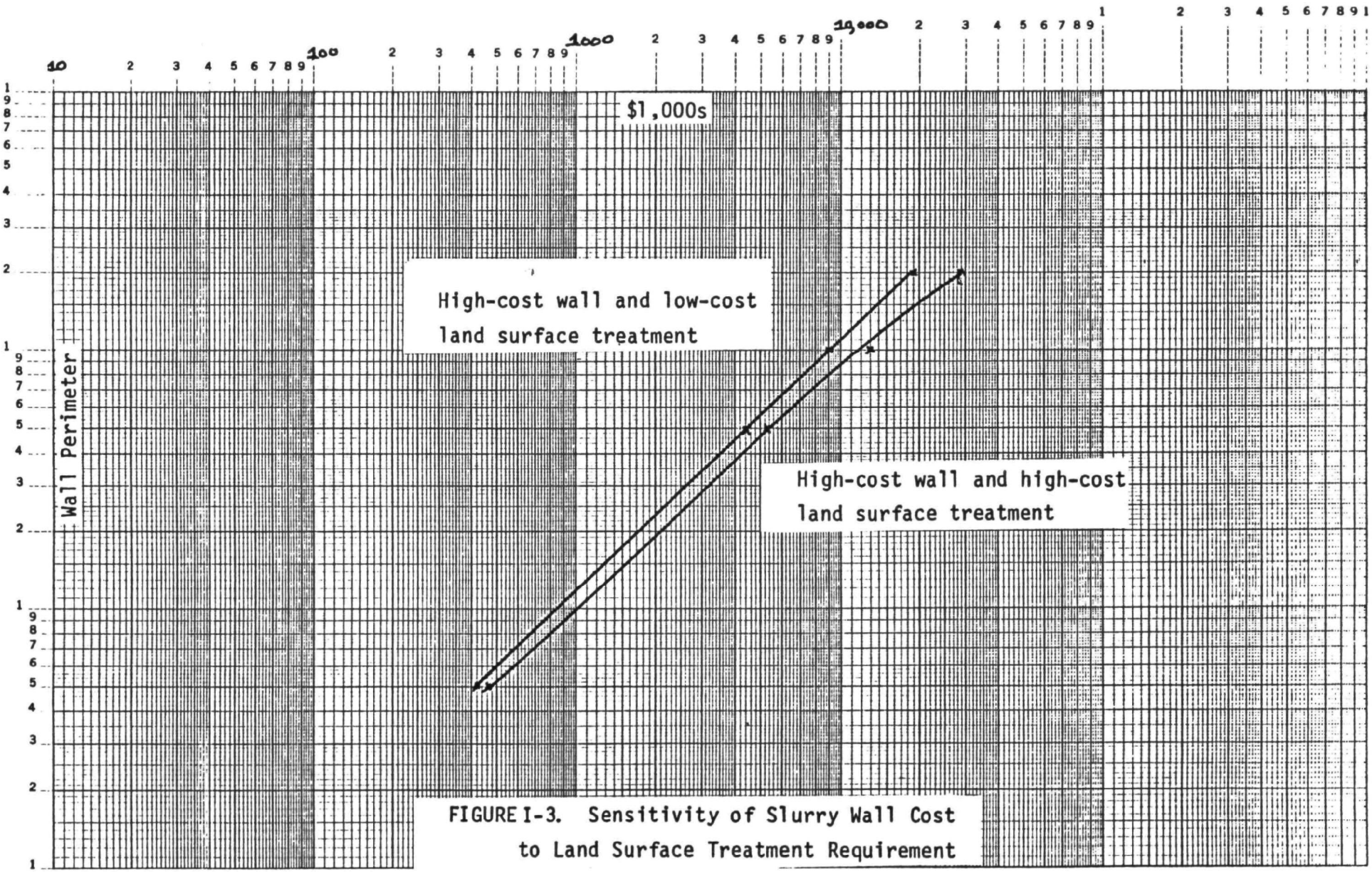


FIGURE I-3. Sensitivity of Slurry Wall Cost to Land Surface Treatment Requirement

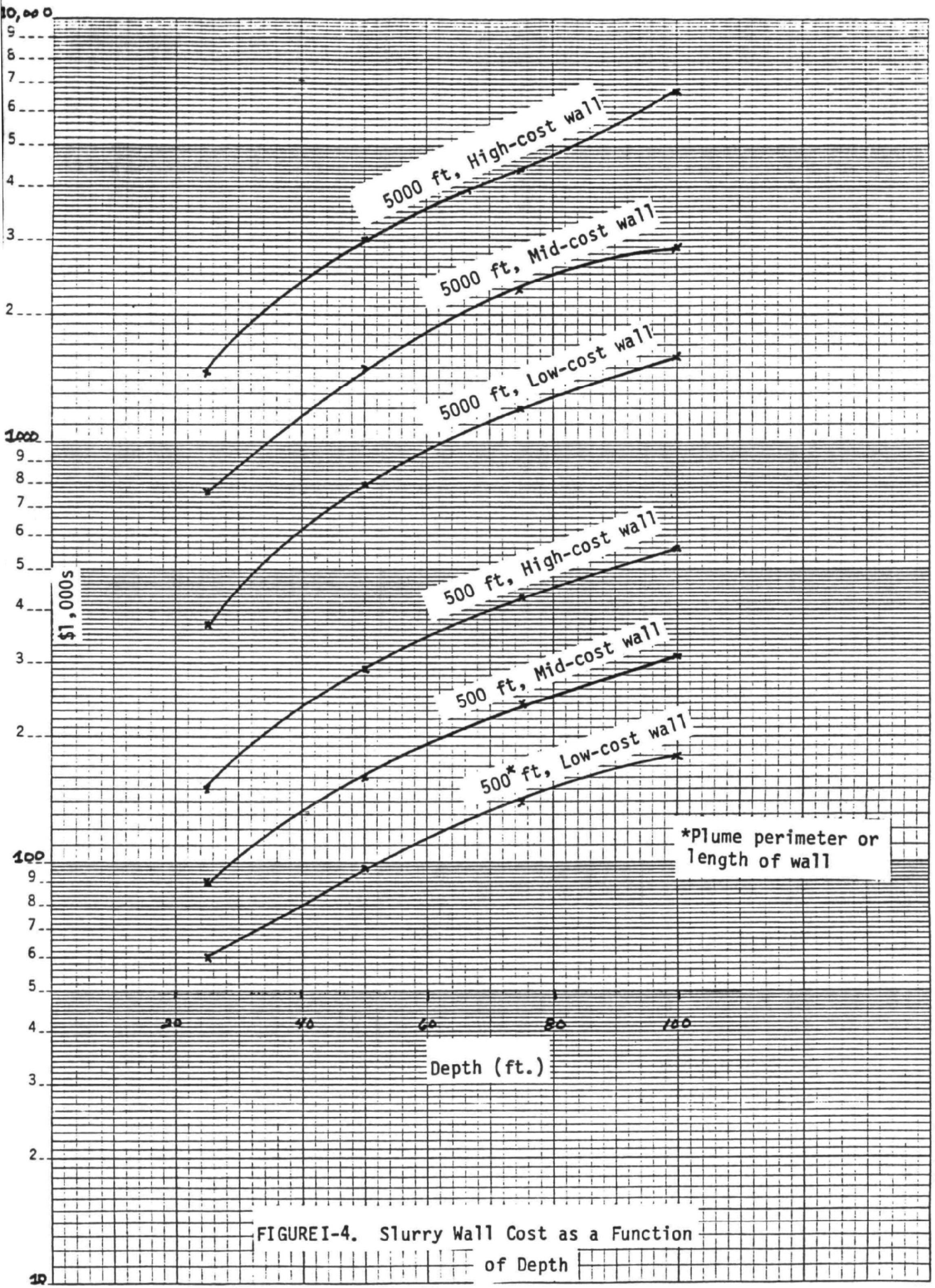


FIGURE I-4. Slurry Wall Cost as a Function of Depth

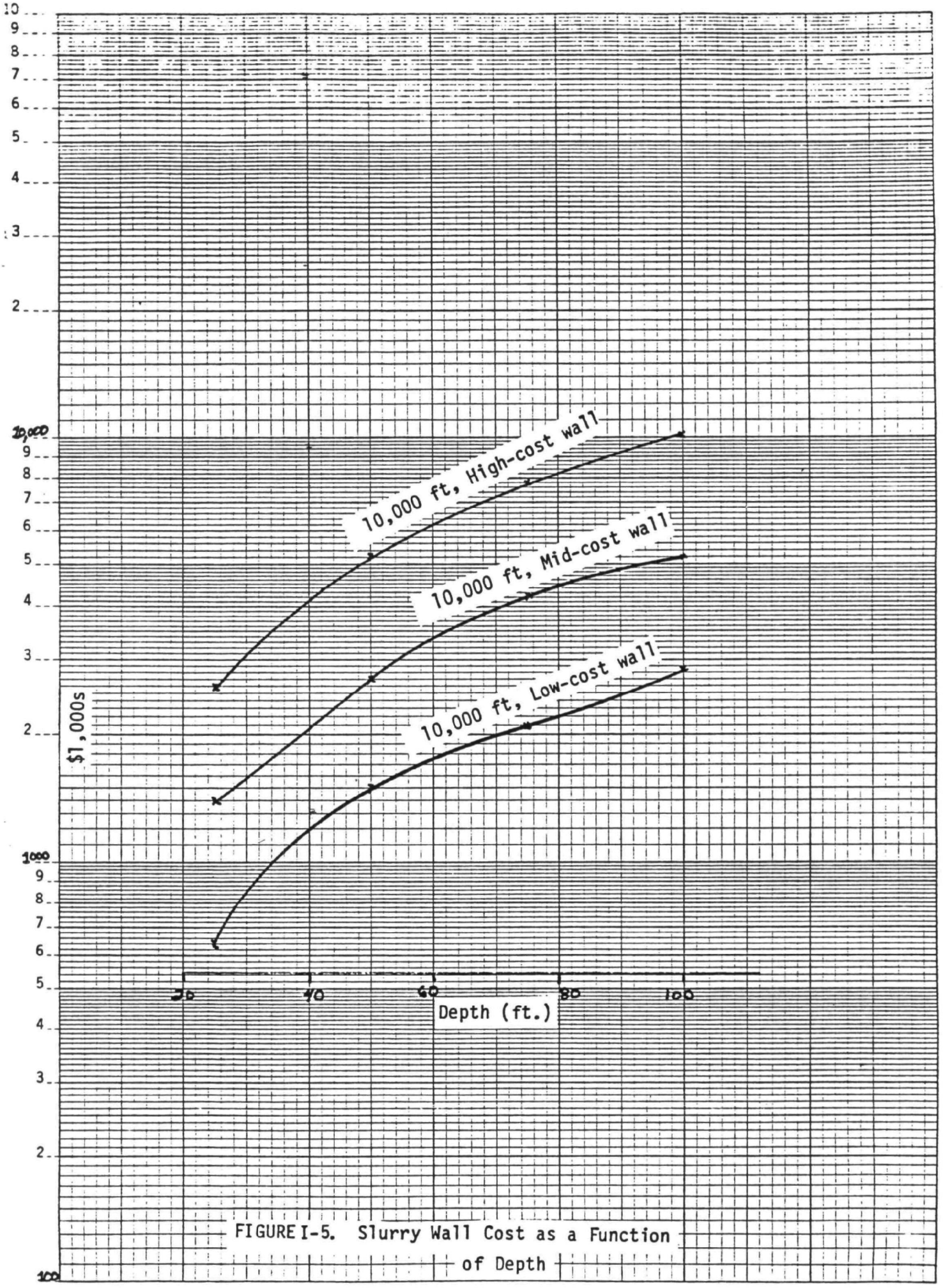


FIGURE I-5. Slurry Wall Cost as a Function of Depth

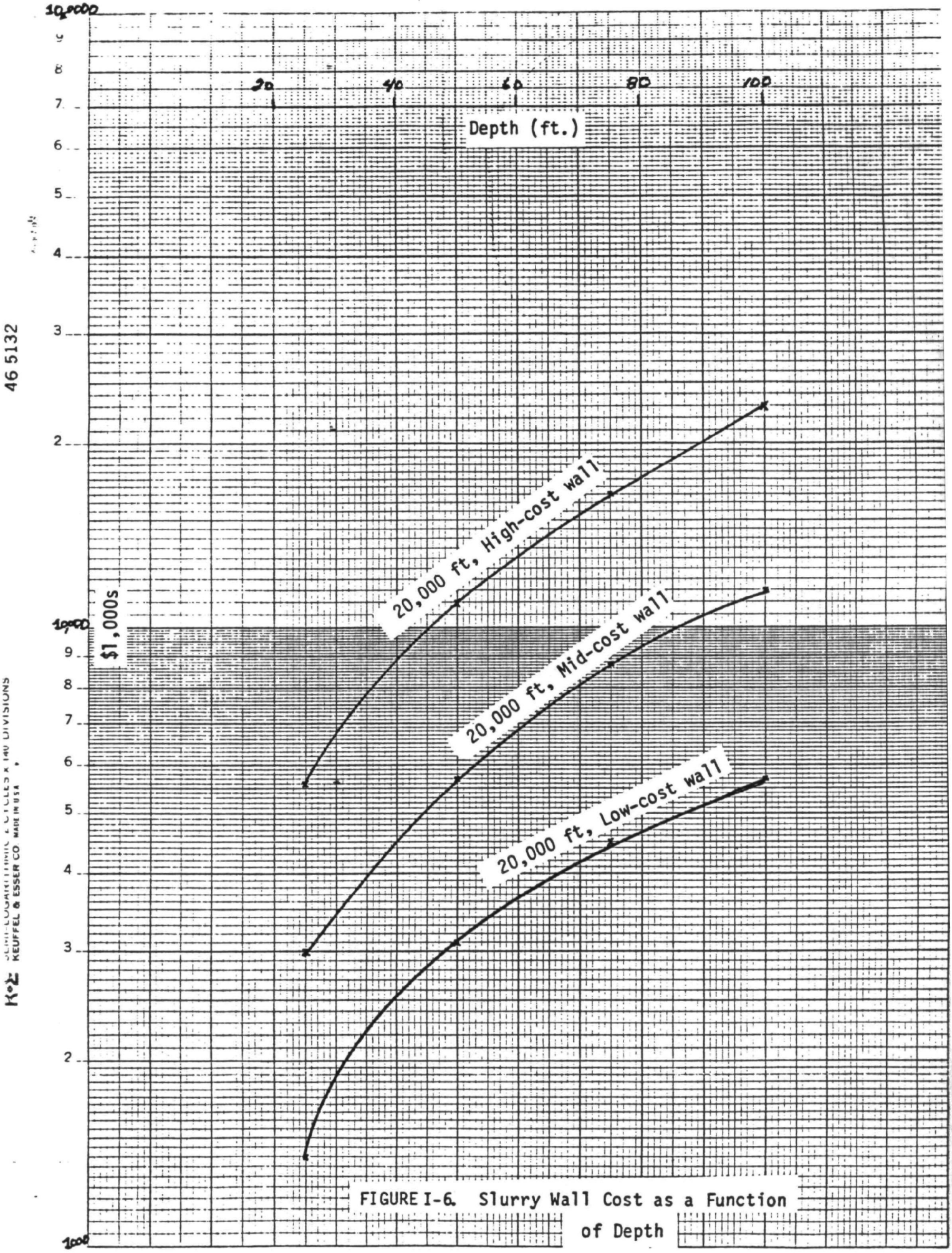


FIGURE I-6. Slurry Wall Cost as a Function of Depth