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TRANSPORT OF SEWAGE SLUDGE

Municipal Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

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TRANSPORT OF SEWAGE SLUDGE

by

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Contract No. 68-03-2186

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This report presents data from which costs may be estimated for transport of liquid and dewatered sewage sludge and for construction costs and operating and maintenance requirements for associated handling facilities.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

The overall objective of this project was to develop organized information on the costs of various sewage sludge transport systems. The method used to prepare the cost data is presented, and the data are organized to facilitate manual calculation of total transport costs for a variety of conditions. Included are transport of liquid and dewatered sludge by truck and rail, and transport of liquid sludge by barge and pipeline.

The data include the installed cost for each system, sludge processing requirements, fuel consumption, manpower, and other operation and maintenance requirements. The construction costs and operation and maintenance requirements for the loading, unloading, and sludge handling facilities are tabulated separately from the requirements for direct transport so that the data can be applied to a variety of specific applications.

Results of the study are related in tabular and graphical presentations to appropriate parameters -- cubic yards for dewatered sludge and gallons for liquid sludge.

This report was submitted in partial fulfillment of Contract 68-03-2186 by Culp/Wesner/Culp - Clean Water Consultants under the sponsorship of the U.S. Environmental Protection Agency. The report covers the period from June 1975 to August 1976, and work was completed as of April 1977.

CONTENTS

NOTE: The List of Errata are on the last Page.

FIGURES

FIGURES (continued)

FIGURES (continued)

TABLES

TABLES (continued)

ABBREVIATIONS

cu yd	--	cubic yard
fps	--	feet per second
ft	--	feet
gal	--	gallon
gph	--	gallon per hour
hp	--	horsepower
in	--	inch
kwh	--	kilowatt-hour
lb	--	pound
lb/cu ft	--	pound per cubic foot
mg	--	million gallons
mgd	--	million gallons per day
mpg	--	miles per gallon
mph	--	miles per hour
rpm	--	revolutions per minute

ACKNOWLEDGMENTS

Culp/Wesner/Culp - Clean Water Consultants are grateful to the owners and operators of municipal treatment plants, equipment manufacturers, consulting engineers, and the U.S. Environmental Protection Agency for data and information necessary for the preparation of this report.

The substantial and beneficial assistance of Robert A. Olexsey and others within the Ultimate Disposal Section, U.S. Environmental Protection Agency was invaluable to completion of this study.

SECTION 1

INTRODUCTION

Traditionally, land disposal of municipal sewage sludge has been the least costly method for ultimate disposal of these sludges. Unlike competing, on-site disposal alternatives such as incineration, heat treatment, and digestion, land disposal has not been a capital intensive technique, the major capital investment being the cost for the land itself. The greatest costs associated with land disposal are the operational costs for application of the waste at the disposal site, and the cost of transporting the sludge from the collection site to the disposal site.

Urban pressures have forced authorities charged with sludge disposal to seek disposal sites that are located great distances, often hundreds of miles, from the large population centers that produce the sludge. The costs of transporting the sludge to disposal sites have taken on increasing importance.

Transport to disposal sites has been accomplished by truck or rail haul transport of liquid or dewatered sludge, and barge or pipeline transport of liquid sludge. The cost effectiveness of each method varies with the locale, transport distance, and volume of sludge.

Even if land disposal is not the ultimate fate of the sludge, some form of transport may be required. For instance, sludge produced by a number of treatment plants may be collected at a single facility for combined disposal. In all cases, the transport mechanism chosen will be that method judged to be the most cost effective alternative.

Among the considerations in the design of a sludge handling and disposal system are:

1. Determining whether sludge should be transported to distant disposal sites or disposed of at the point of production.

2. Determining the optimum moisture content of the sludge (liquid, dewatered cake, dried) as a function of the disposal process selected and transport distance required.

3. Selecting the transport mode: truck, rail, barge or pipeline.

This report presents estimated capital costs and operating and maintenance requirements for various sludge transport modes as they apply to municipal facilities. These data are applicable to preliminary estimates for general planning, studies of alternatives, or to long-range financial or facilities planning. Careful review of the methodology, features, and components included in the data is encouraged if these data are used for specific project planning purposes. Comparison of alternative schemes may be made, however, if costs are within 15 percent, the cost difference may not be real, and more intensive analysis may be needed to discern real differences between the alternatives under study.

Manual calculation methods are included that allow transport systems costs to be calculated at any point in time by using current or estimated future unit costs or cost escalation factors. Suggested, published indices are included in this report.

SECTION 2

SUMMARY OF RESULTS

The results of this study are summarized in the various figures and tables.

The information in this report is usable in making manual calculations of transport system costs and is intended to be developed into a computer program to facilitate cost calculations.

Three methods of manual cost calculation are possible using the information in this report. The first method involves calculation of each component of cost such as fuel, electric energy, and man hours. This method allows flexibility in making total cost determinations because current unit costs can be used, and the impact of the various component costs can be adjusted for particular situations. Some time is required to calculate the cost of each alternative by this method.

As an aid in making manual calculations, outlines and example calculations are provided for each transport mode as follows:

Mode	Outline
Truck	Appendix A
Barge	Appendix B
Railroad	Appendix C
Pipeline	Appendix D

The applicable figures and tables are referenced in each appendix. When the total cost calculation is completed, it can be converted to any desired units.

The second manual method is simplified to the point of determining the total costs graphically without calculating each component individually. This method is limited because unit costs cannot be escalated. With current rates of inflation, the unit cost assumptions used in preparing graphs will soon be out of date. For truck, barge, and railroad, the terminal facilities and associated operation and maintenance costs are separated from the actual point to point transport costs to make the information more useful. The total annual costs with and without facilities are shown in Figures 1 through 21 as indexed in Table 1.

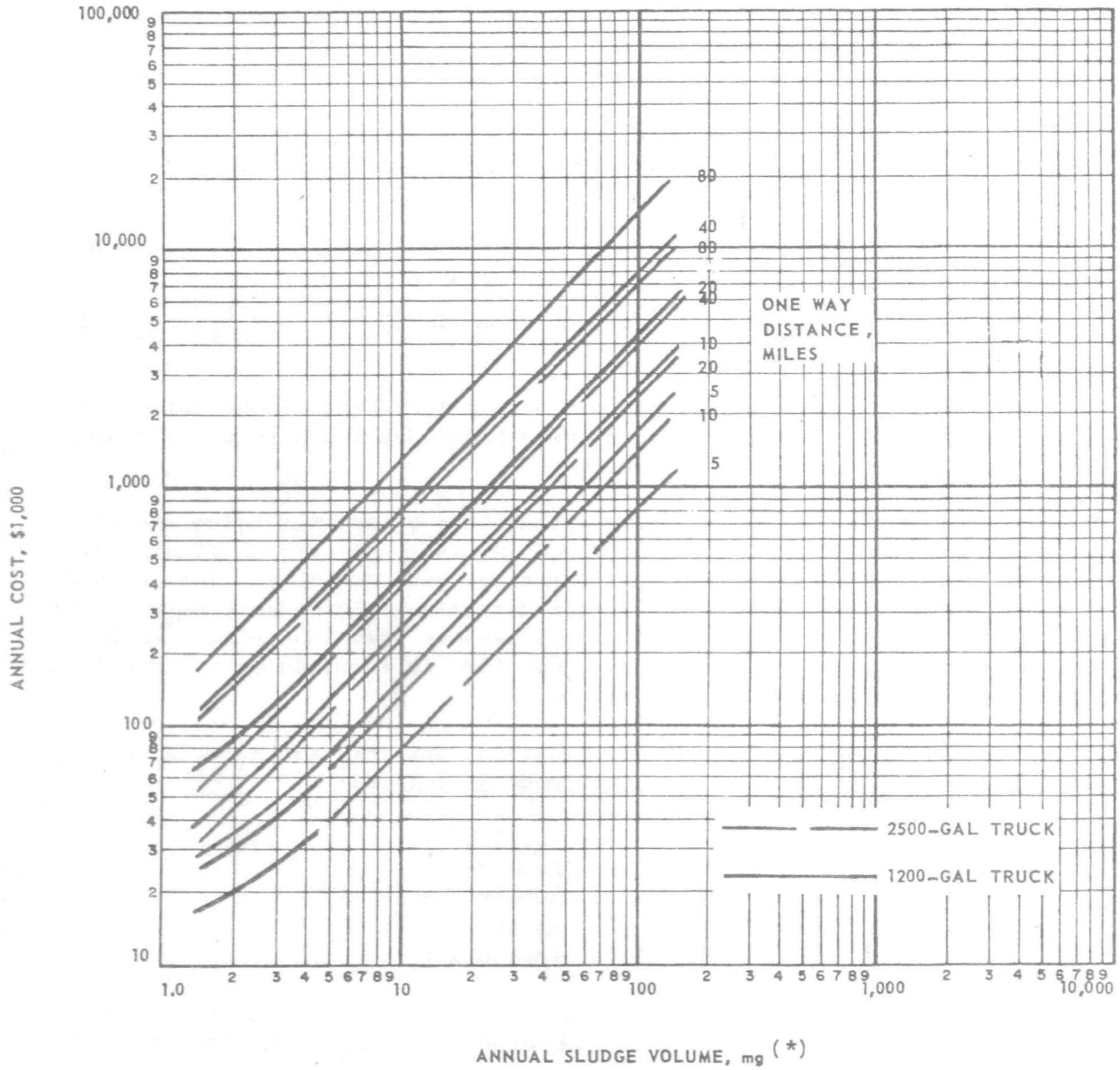

Figure 1. Truck transport total annual cost without facilities, liquid sludge, 1975.

(*) English units are used uniformly in this report because many of the English measures are common in the sanitary field. Conversion factors are contained in the List of Metric Conversions.

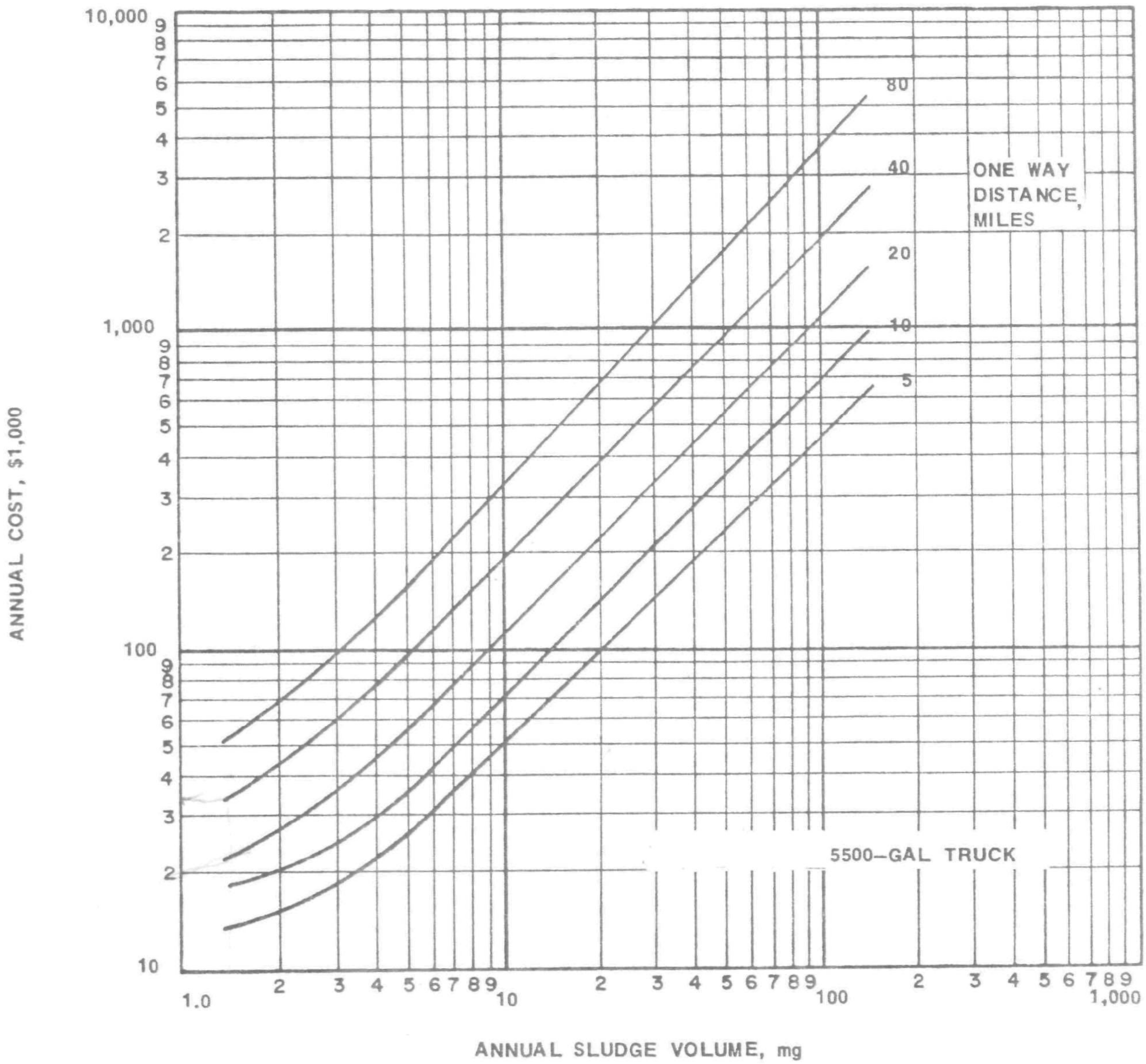

Figure 2. Truck transport total annual cost without facilities, liquid sludge, 1975.

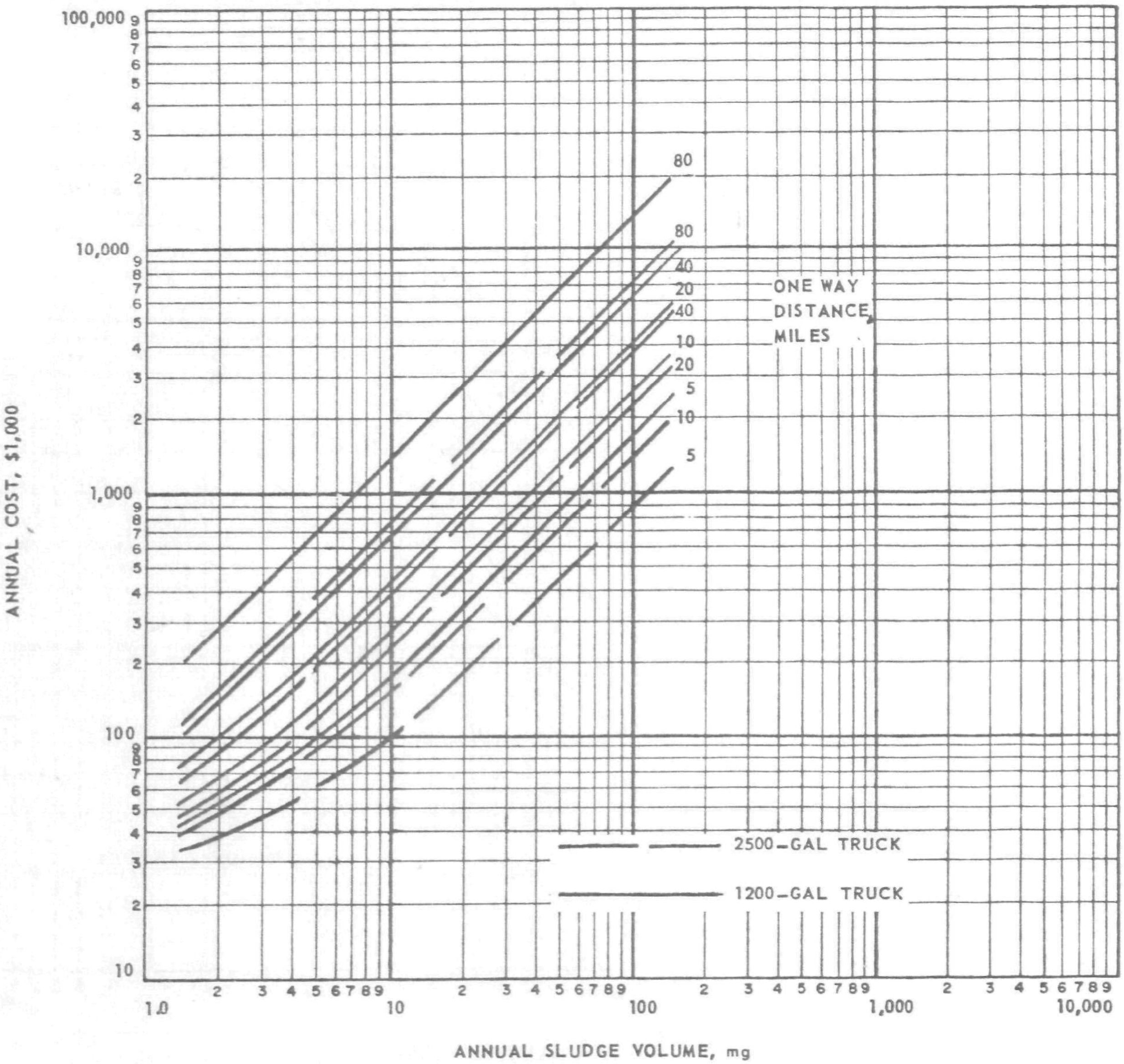

Figure 3. Truck transport total annual cost with loading and unloading facilities, liquid sludge, 1975.

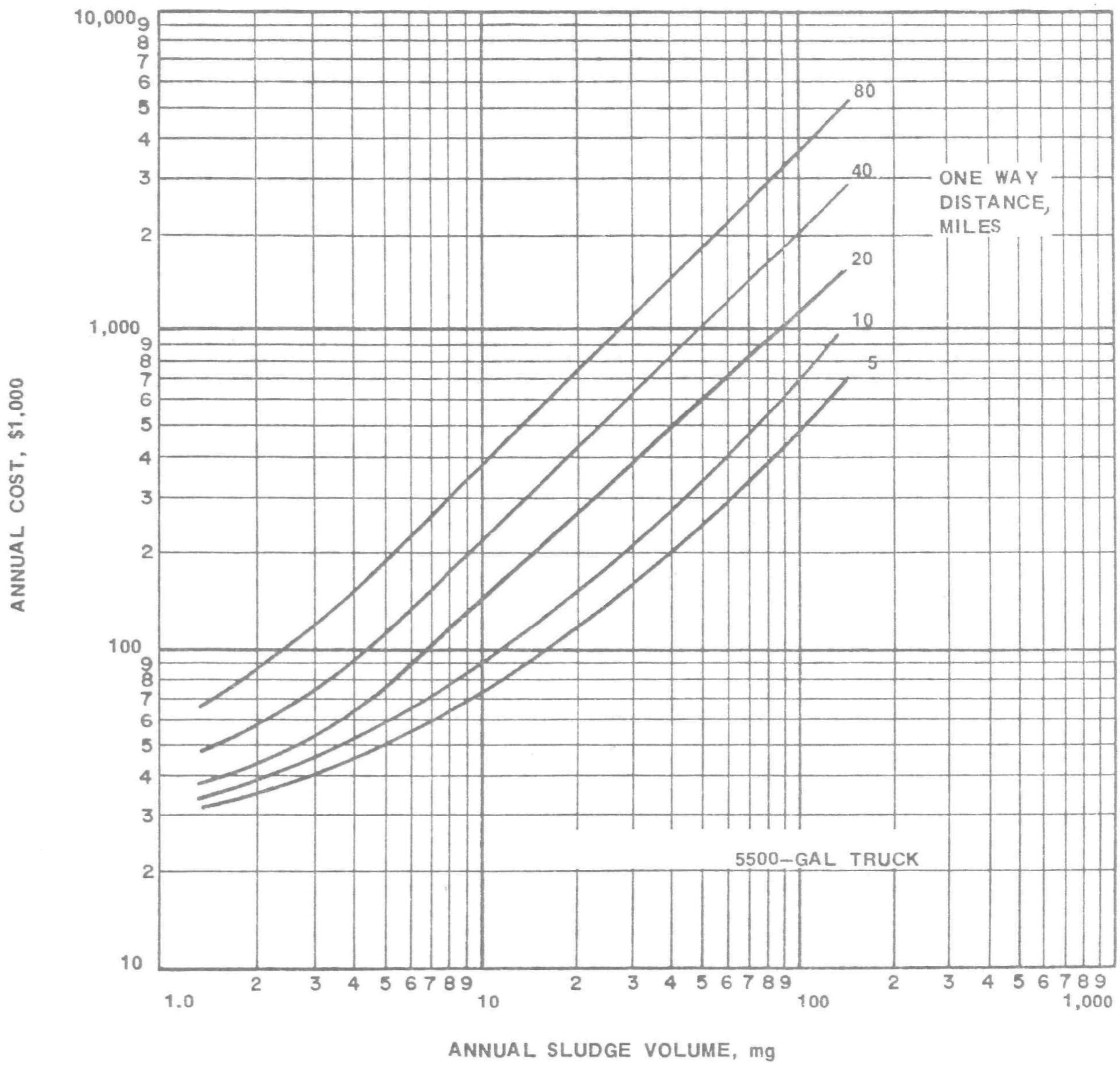

Figure 4. Truck transport total annual cost with loading and unloading facilities, liquid sludge, 1975.

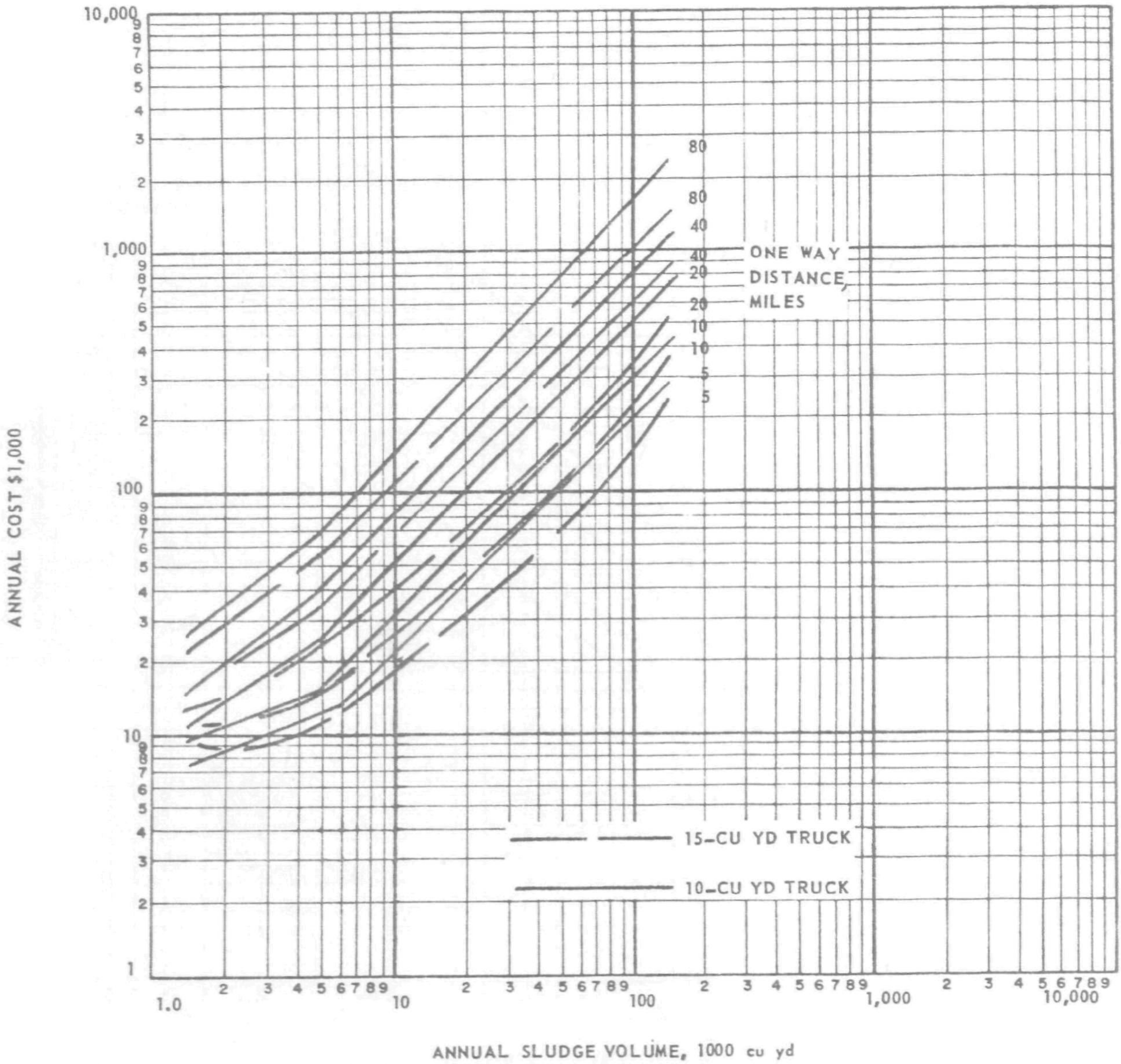

Figure 5. Truck transport total annual cost without facilities, dewatered sludge, 1975.

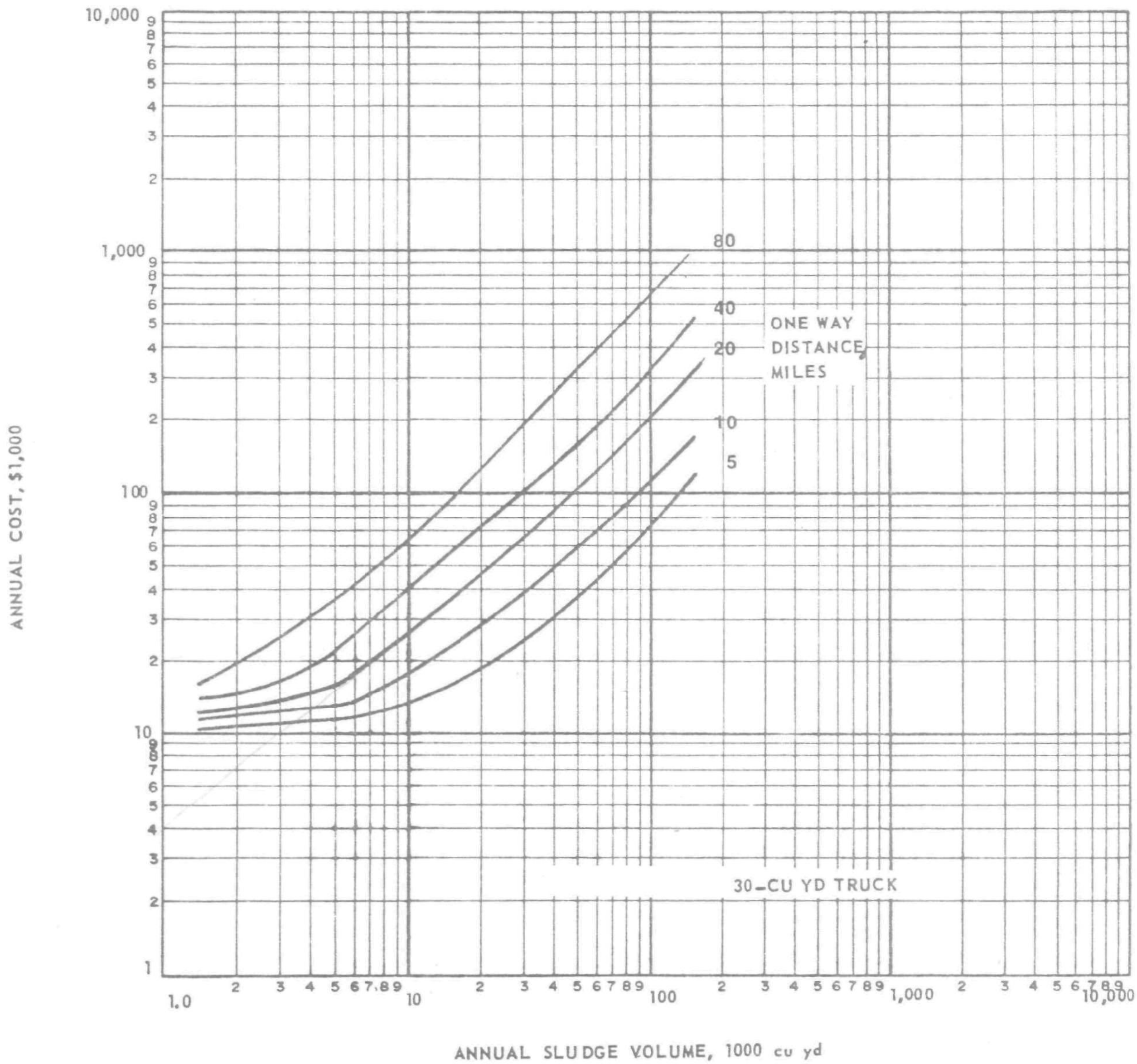

Figure 6. Truck transport total annual cost without facilities, dewatered sludge, 1975.

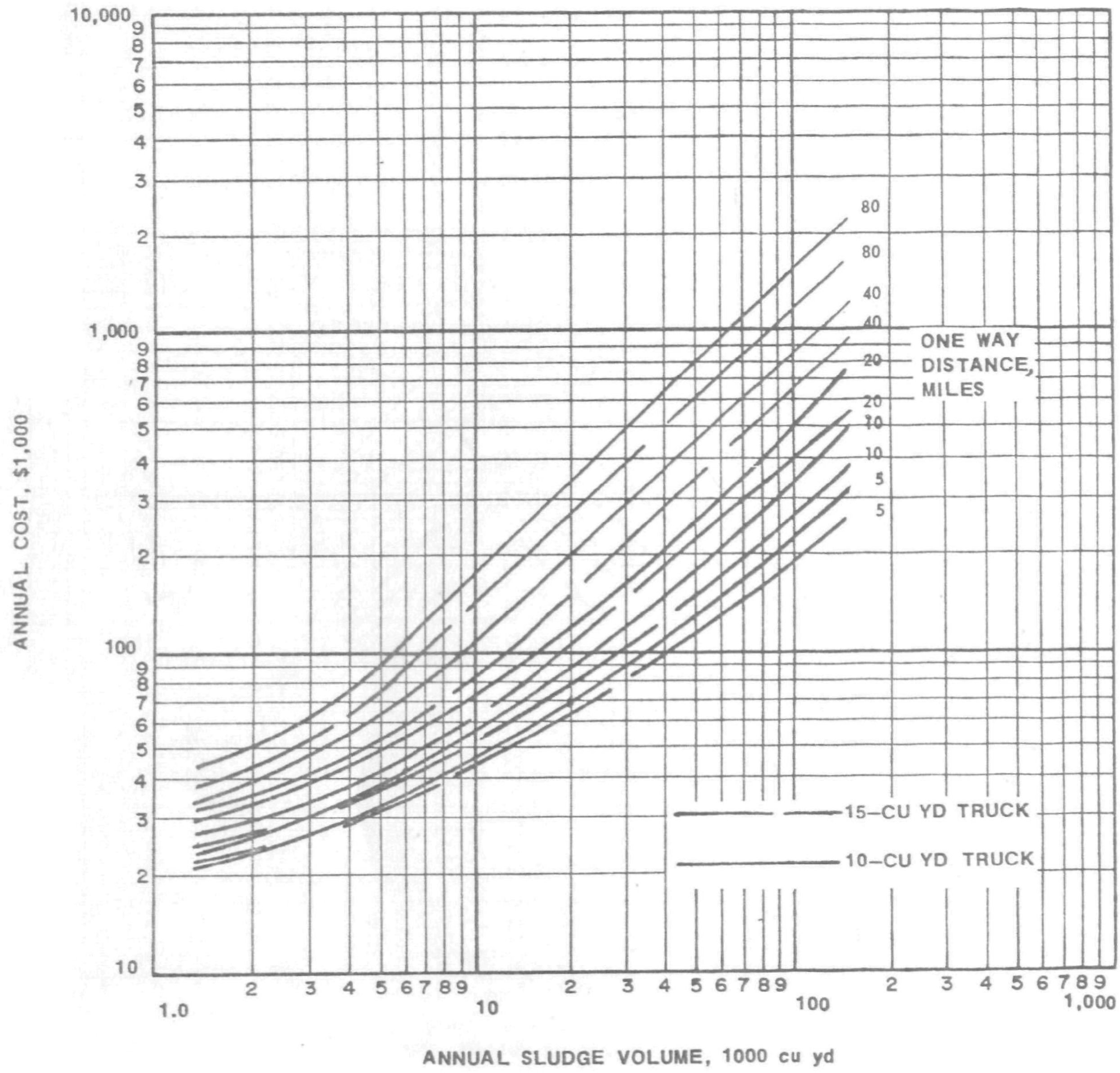

Figure 7. Truck transport total annual cost with loading and unloading facilities, dewatered sludge, 1975.

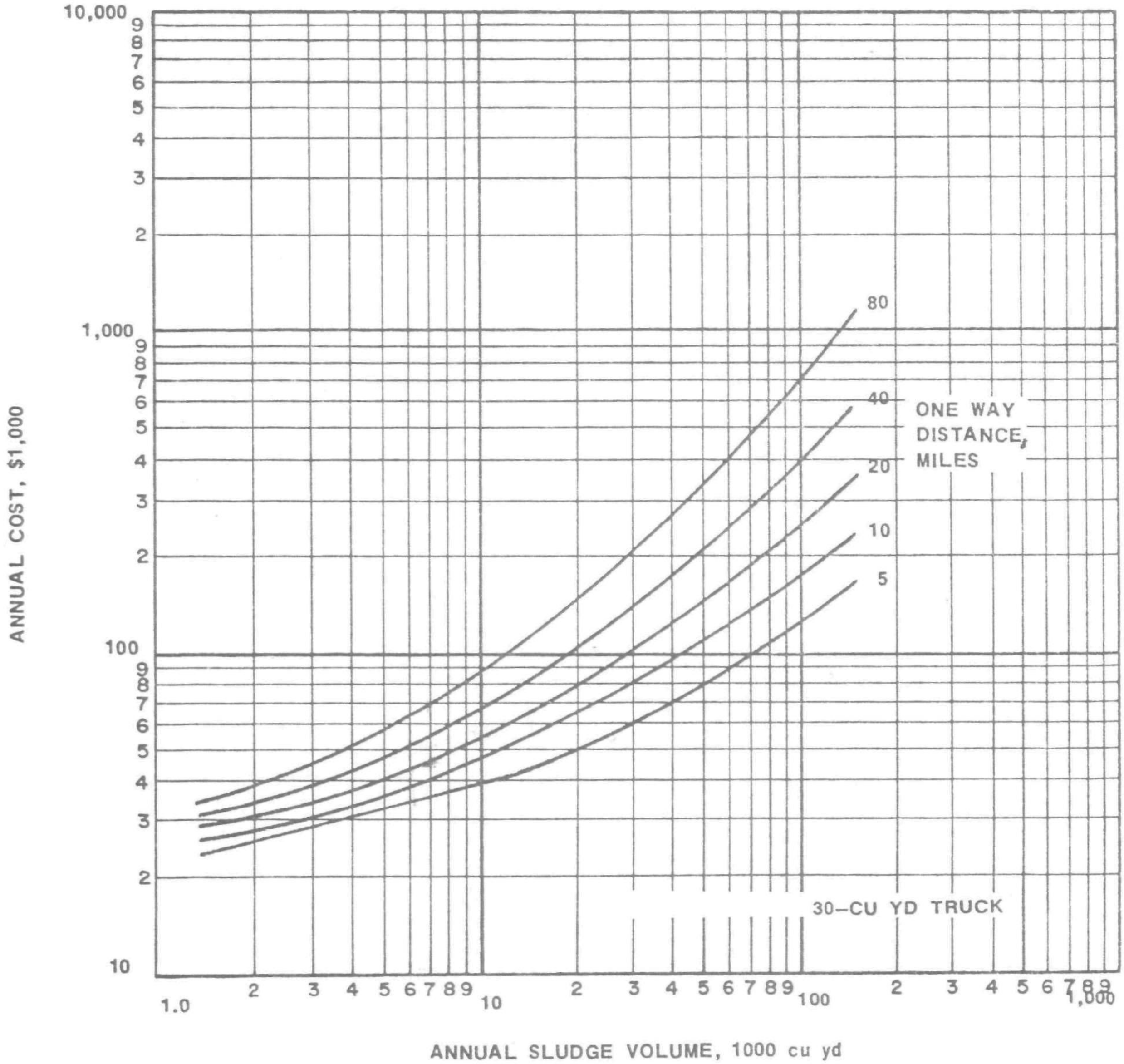

Figure 8. Truck transport total annual cost with loading and unloading facilities, dewatered sludge, 1975.

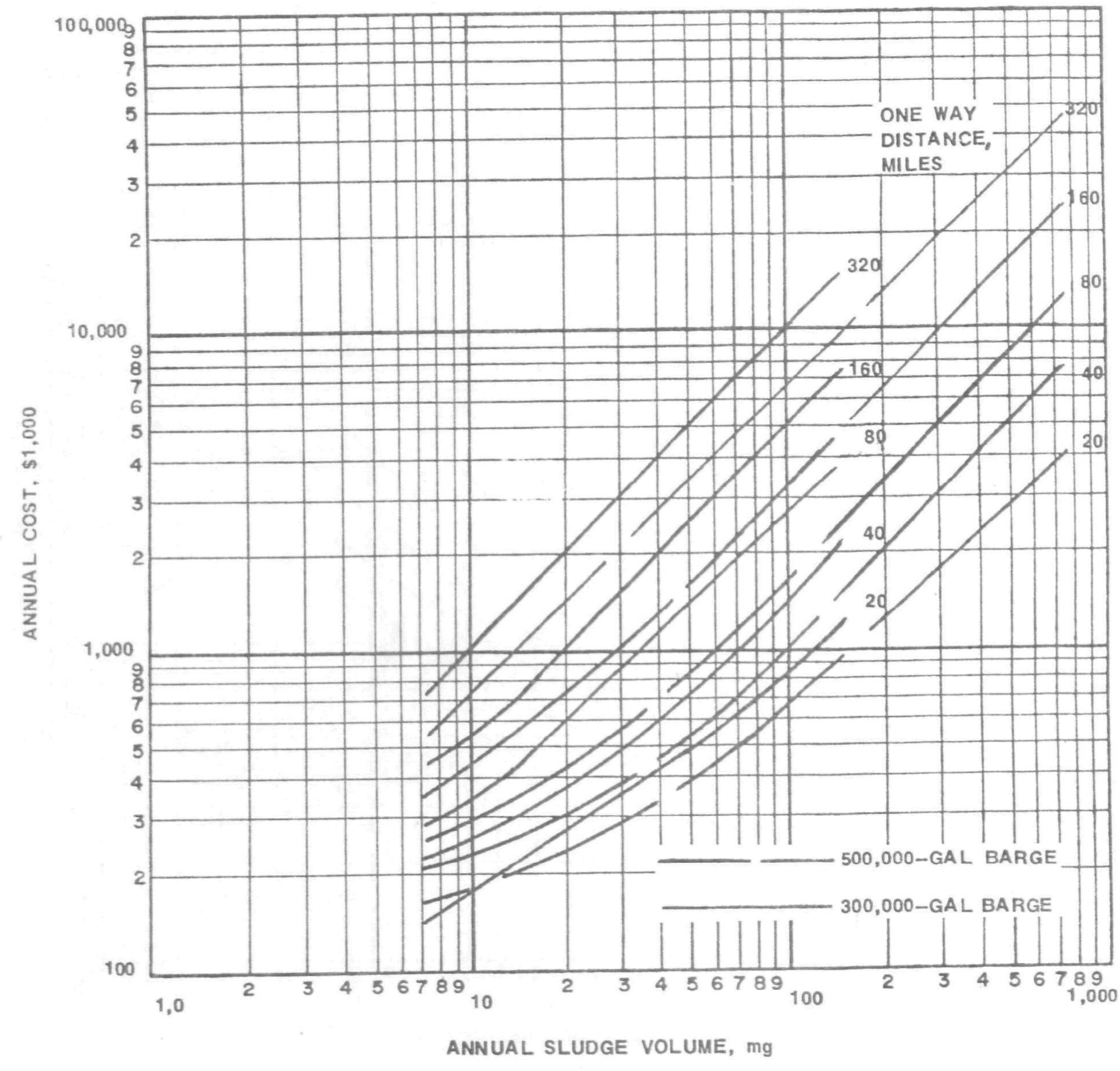

Figure 9. Barge transport total annual cost without facilities, 4 percent liquid sludge, 1975.

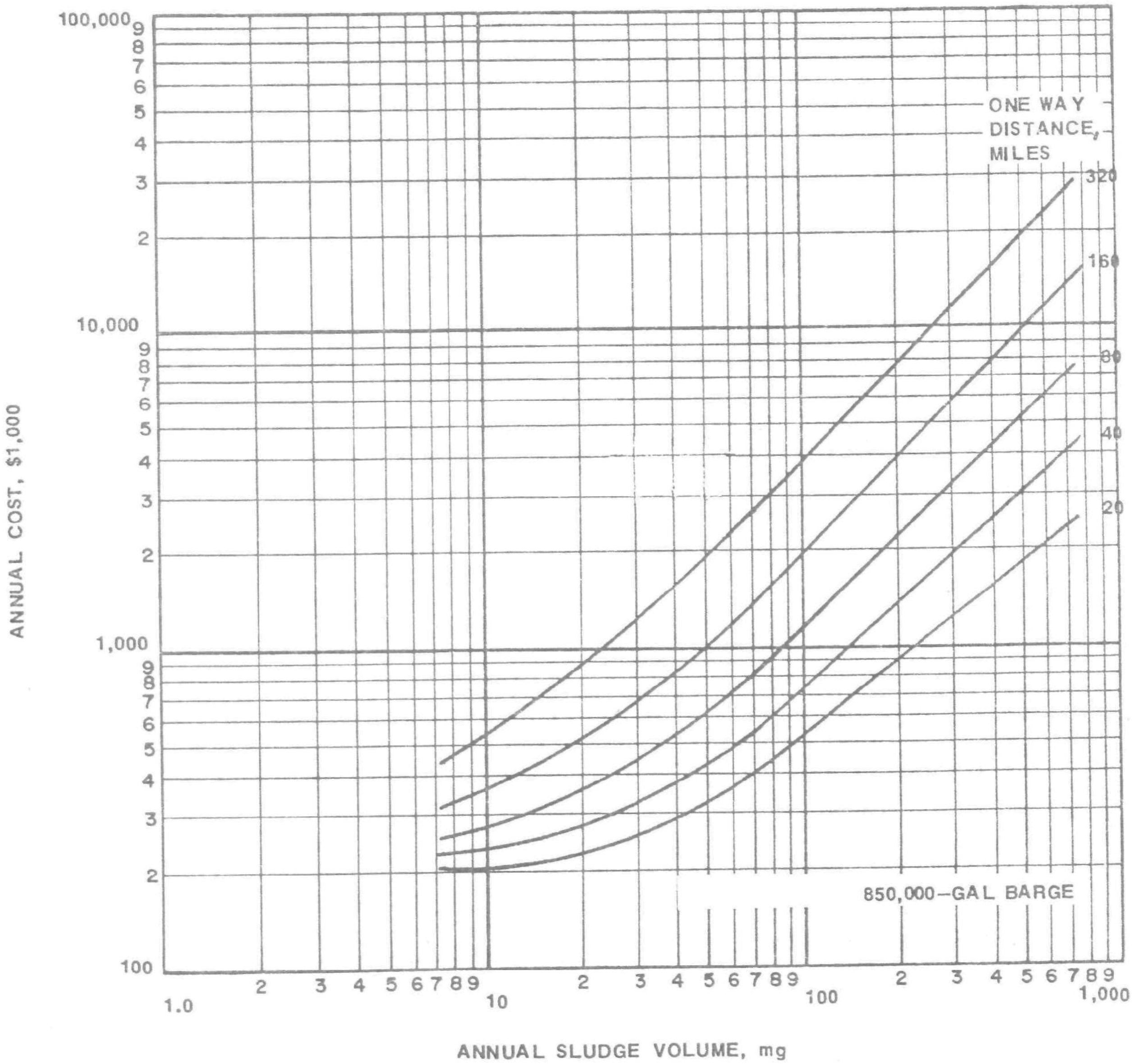

Figure 10. Barge transport total annual cost without facilities, 4 percent liquid sludge, 1975.

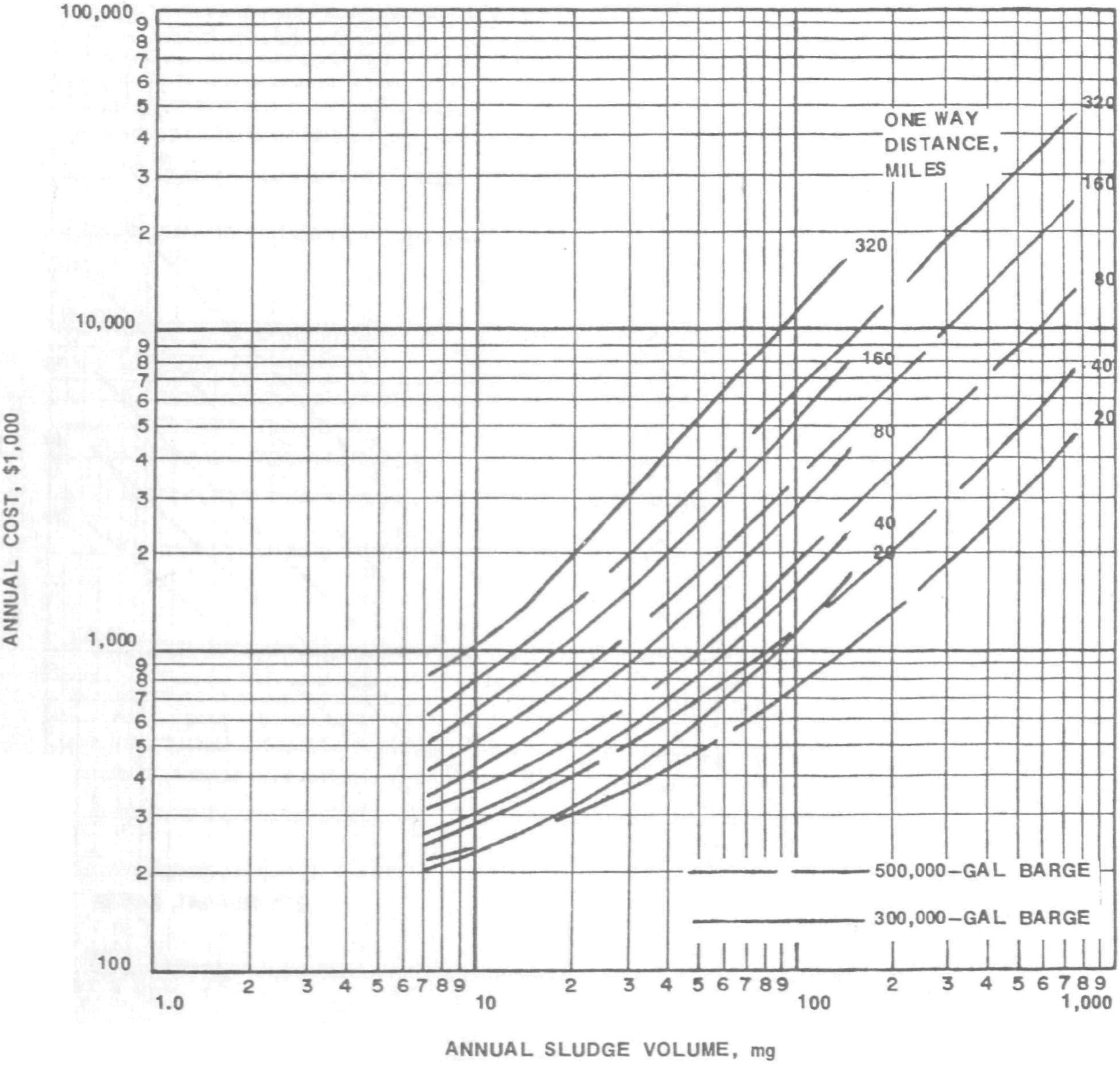

Figure 11. Barge transport total annual cost with loading and unloading facilities, 4 percent liquid sludge, 1975.

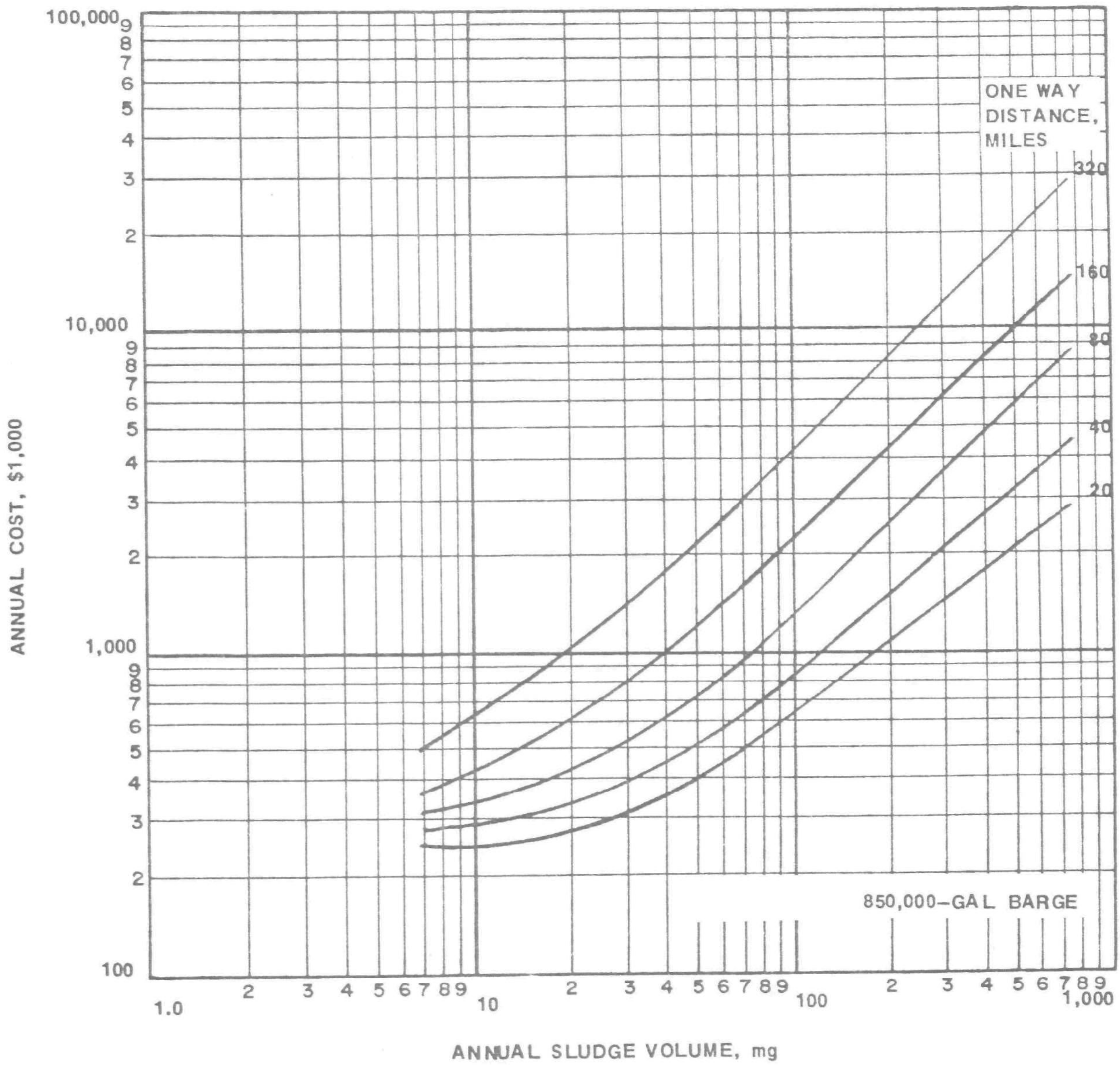

Figure 12. Barge transport total annual cost with loading and unloading facilities, 4 percent liquid sludge, 1975.

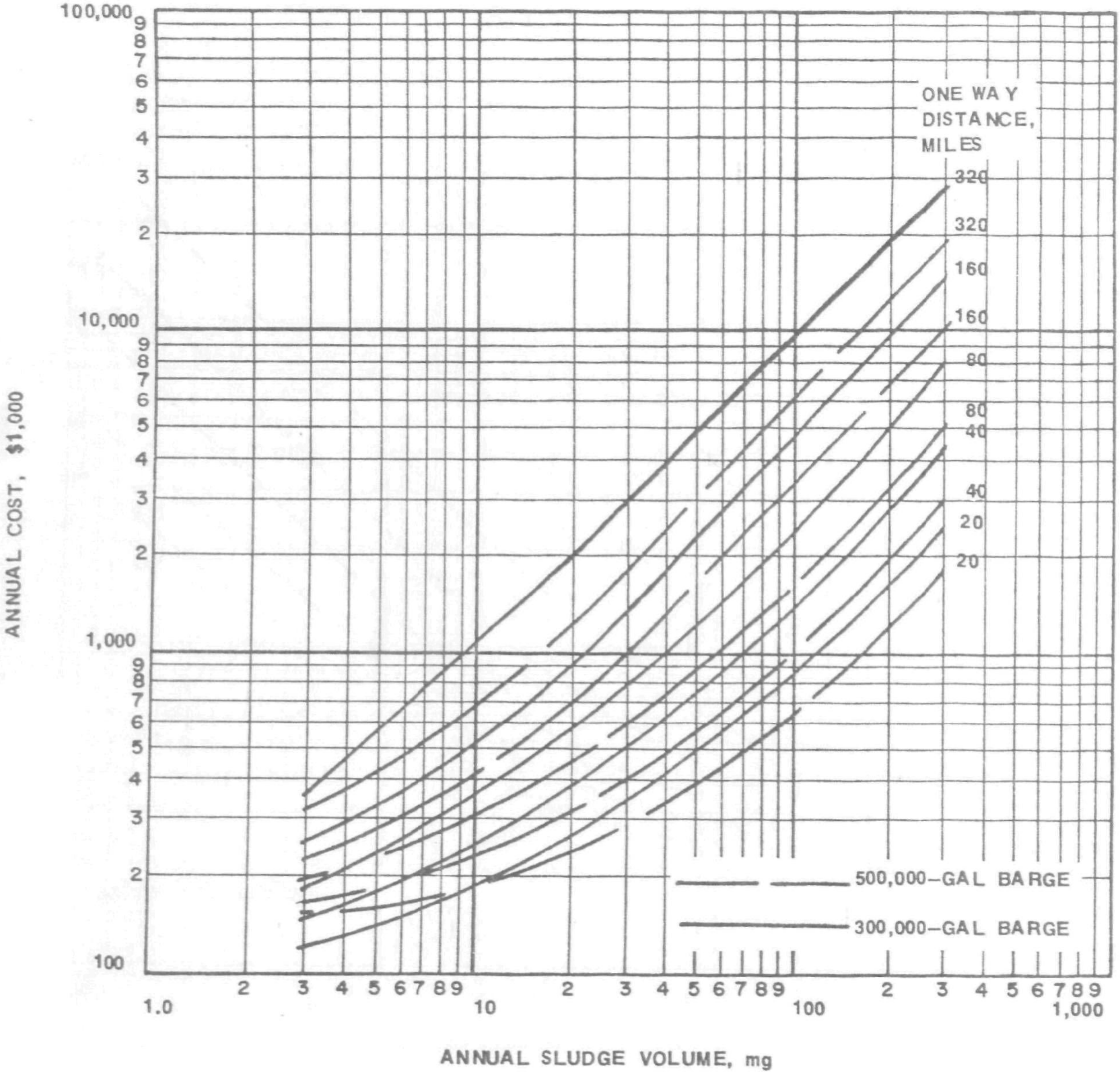

Figure 13. Barge transport total annual cost without facilities, 10 percent liquid sludge, 1975.

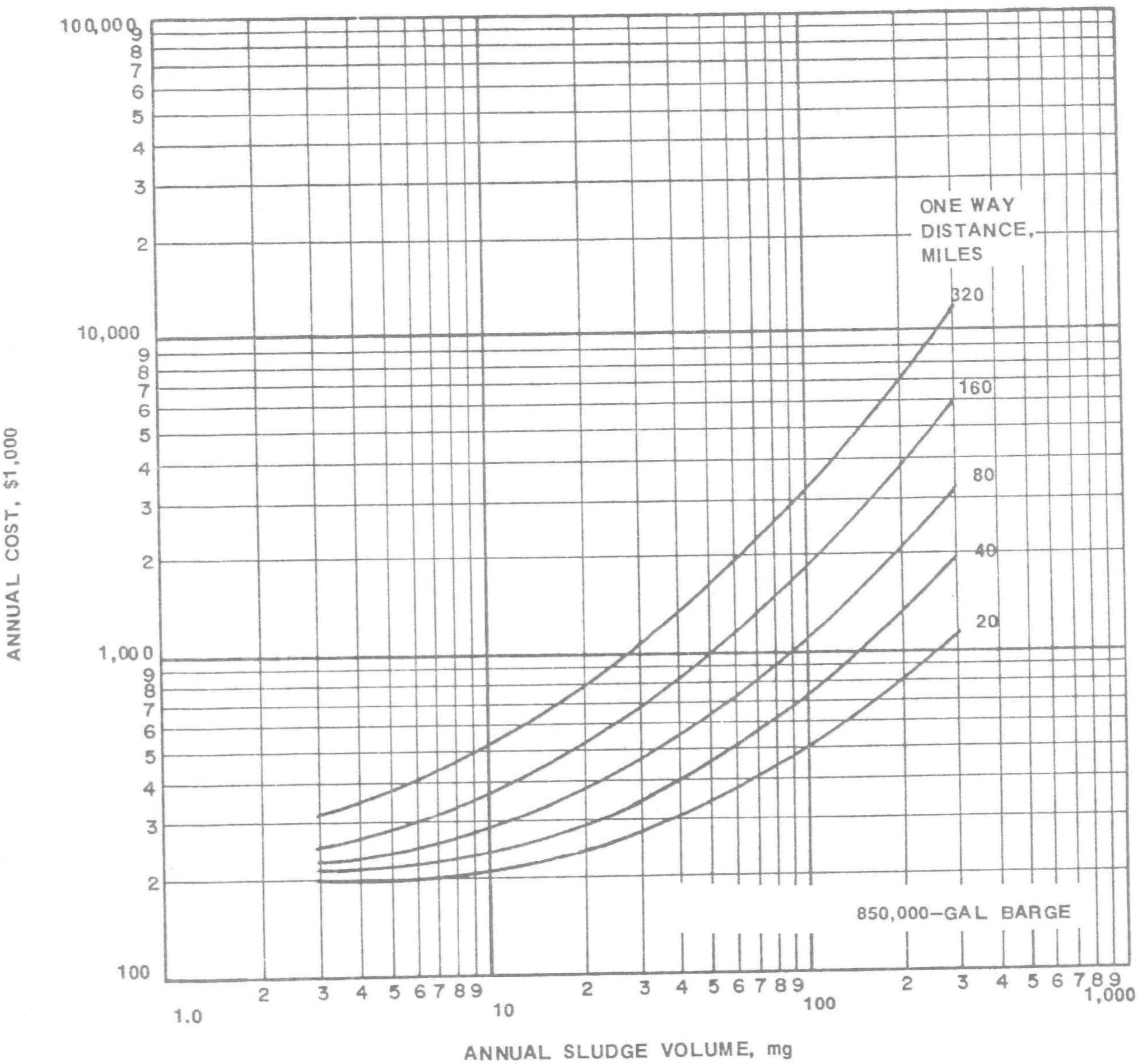

Figure 14. Barge transport total annual cost without facilities, 10 percent liquid sludge, 1975.

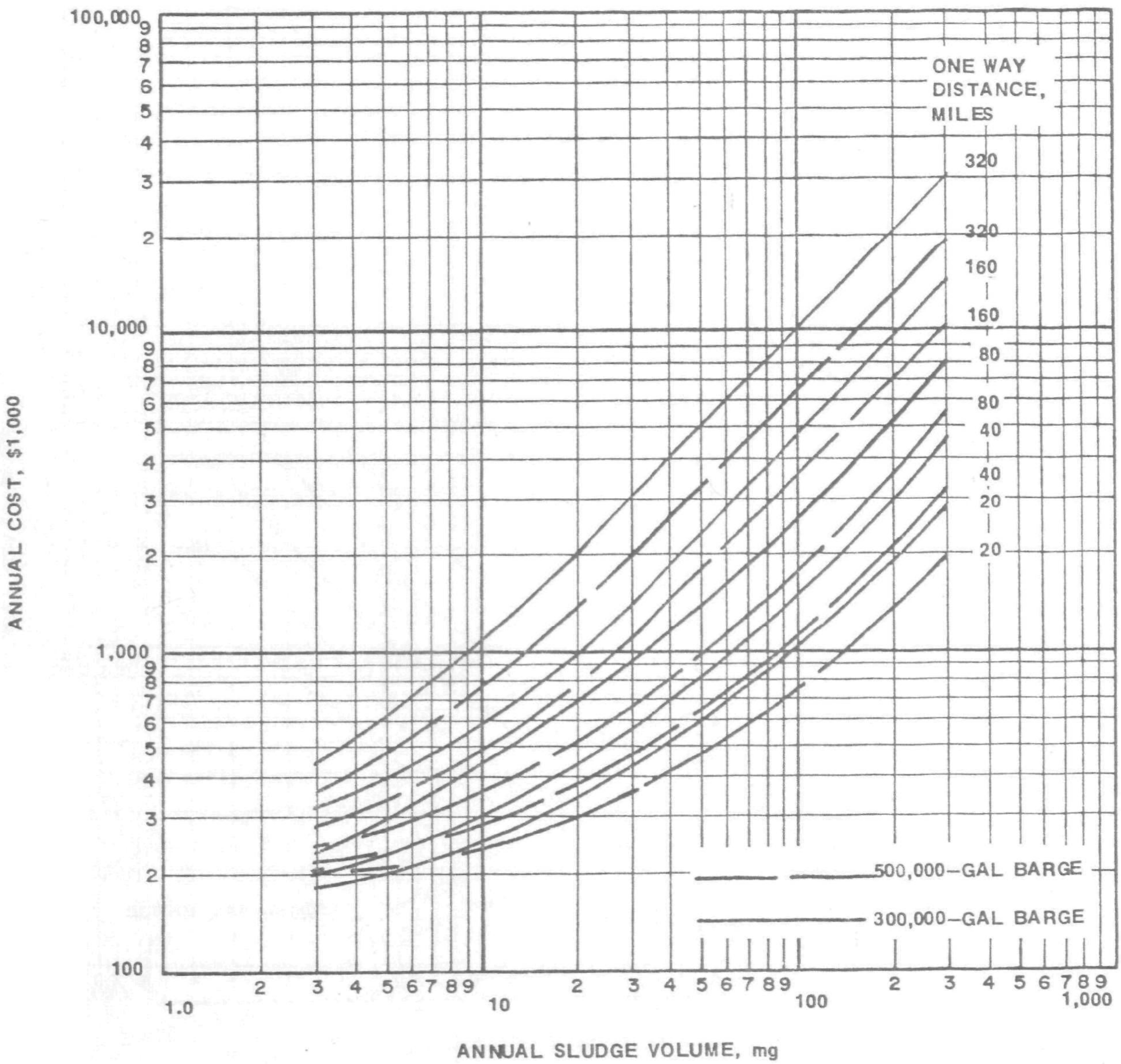

Figure 15. Barge transport total annual cost with loading and unloading facilities, 10 percent liquid sludge, 1975.

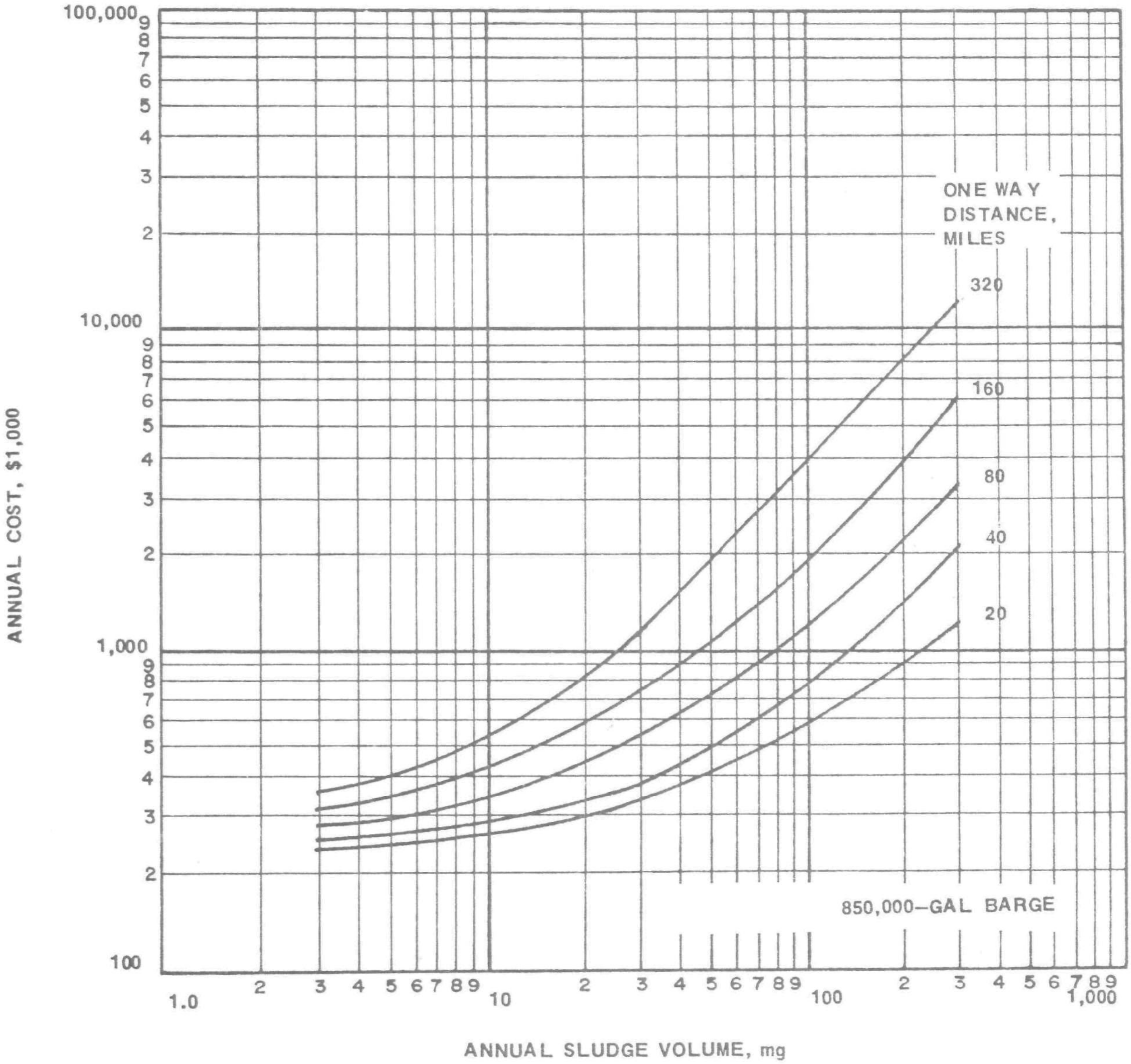

Figure 16. Barge transport total annual cost with loading and unloading facilities, 10 percent liquid sludge, 1975.

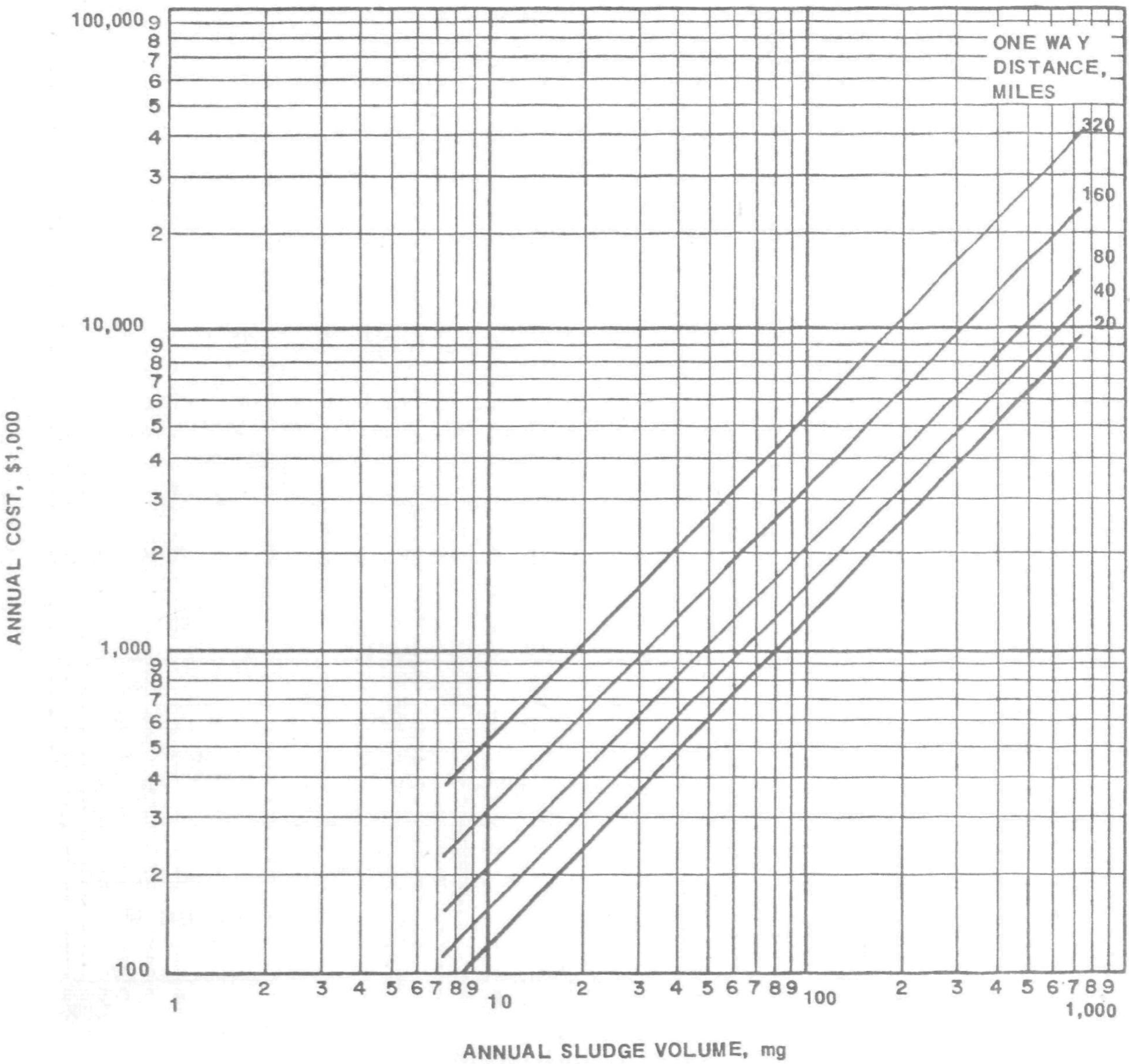

Figure 17. Railroad transport total annual cost without facilities, liquid sludge, 1975.

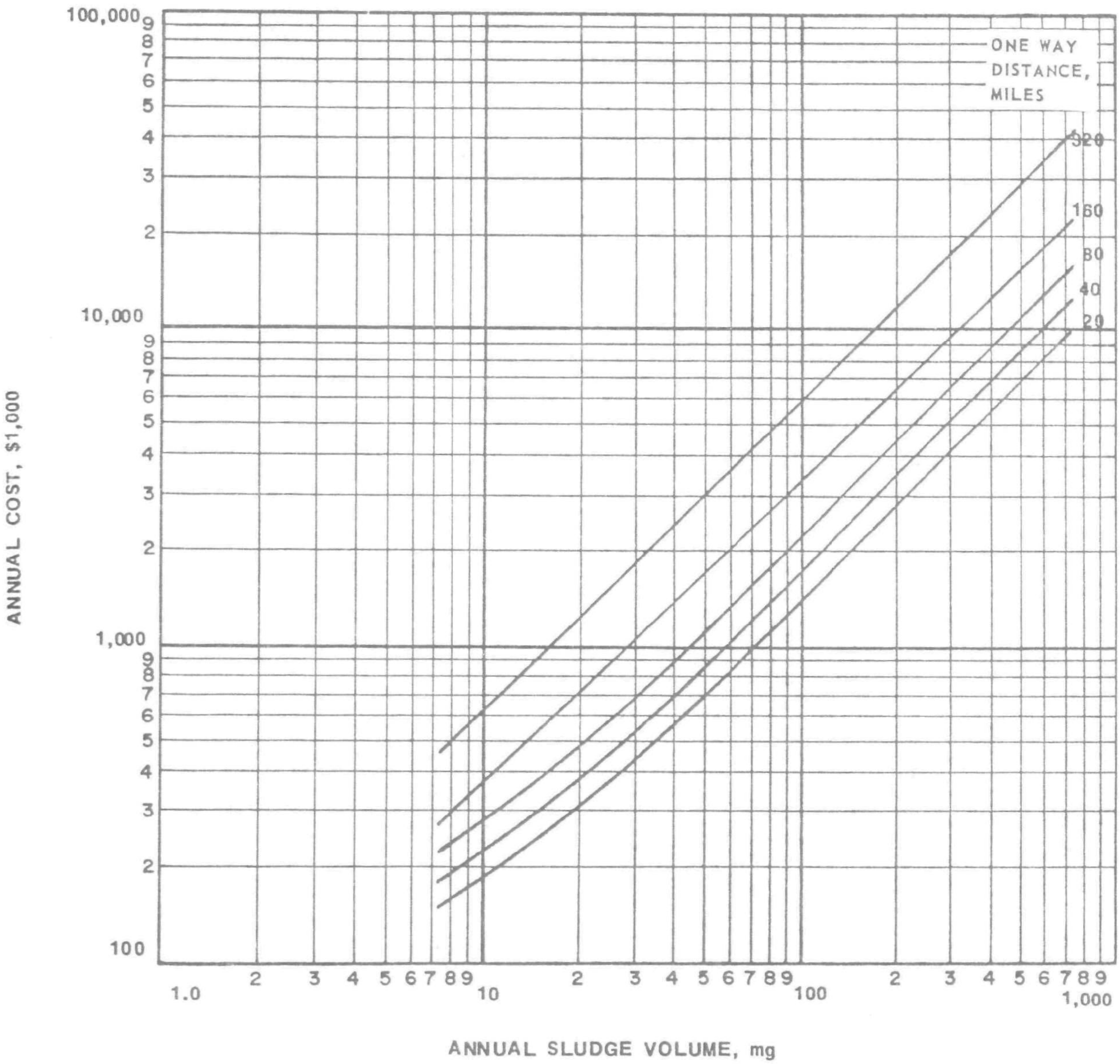

Figure 18. Railroad transport total annual cost with loading and unloading facilities, liquid sludge, 1975.

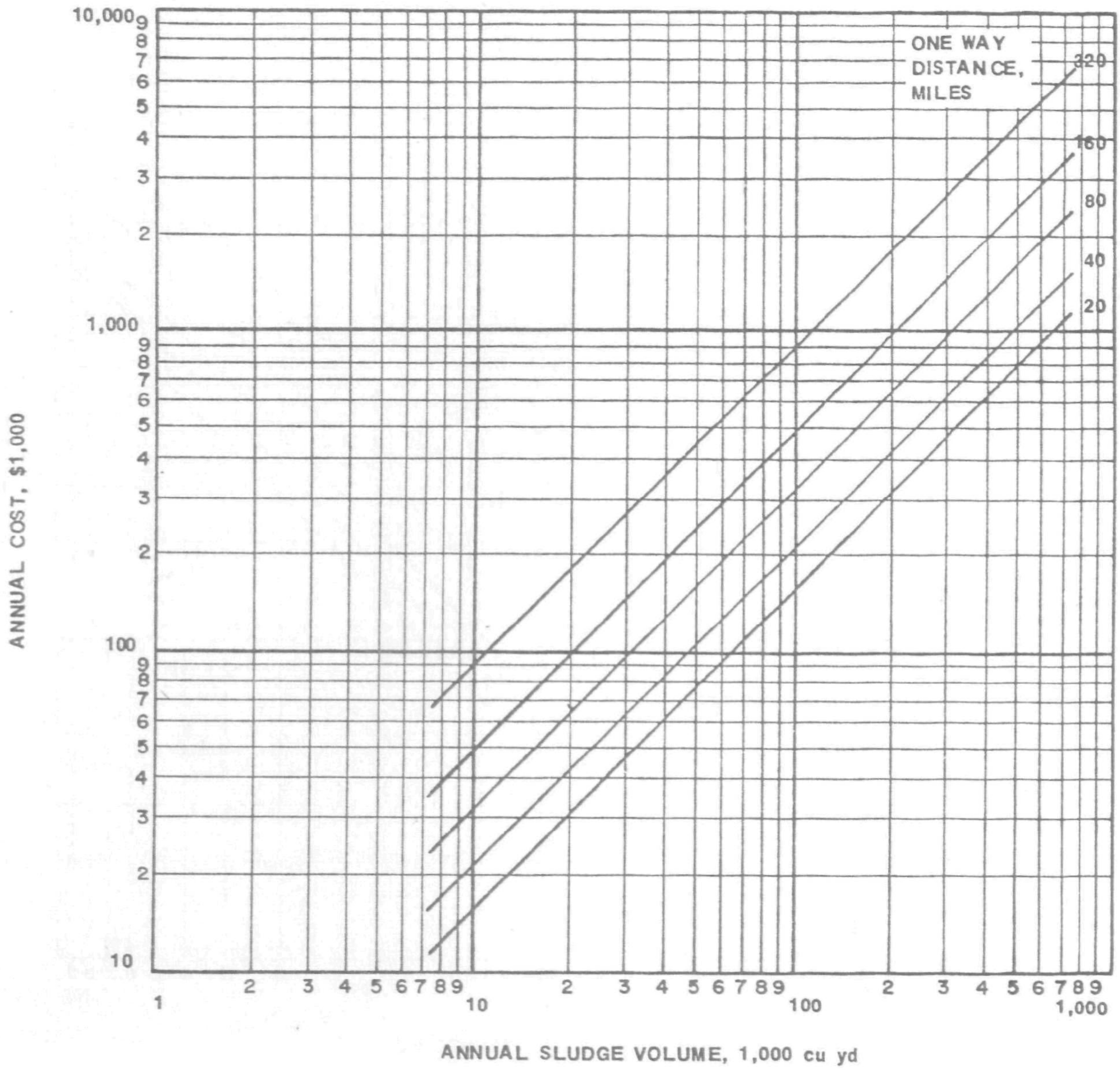

Figure 19. Railroad transport total annual cost without facilities, dewatered sludge, 1975.

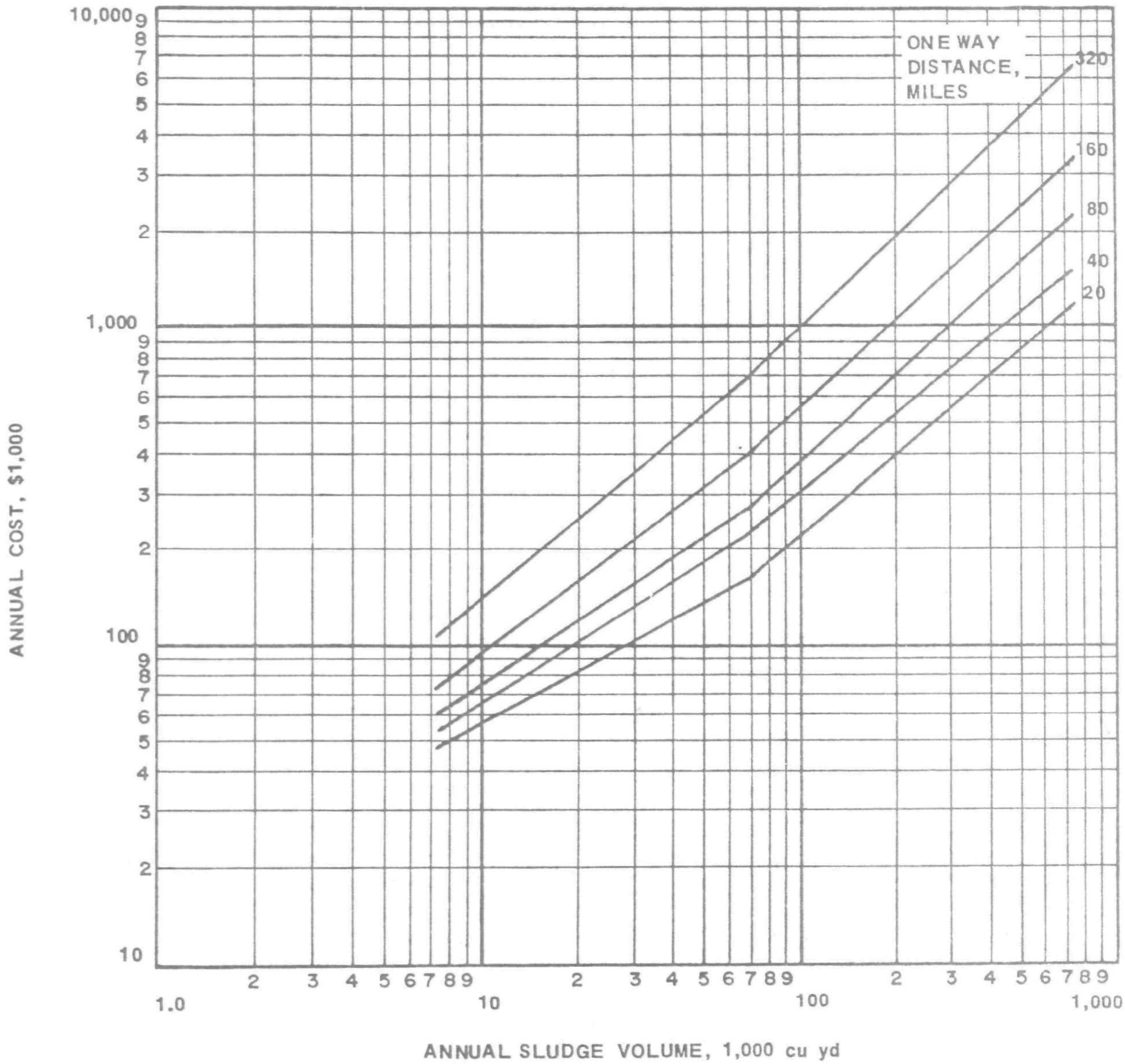

Figure 20. Railroad transport total annual cost with loading and unloading facilities, dewatered sludge, 1975.

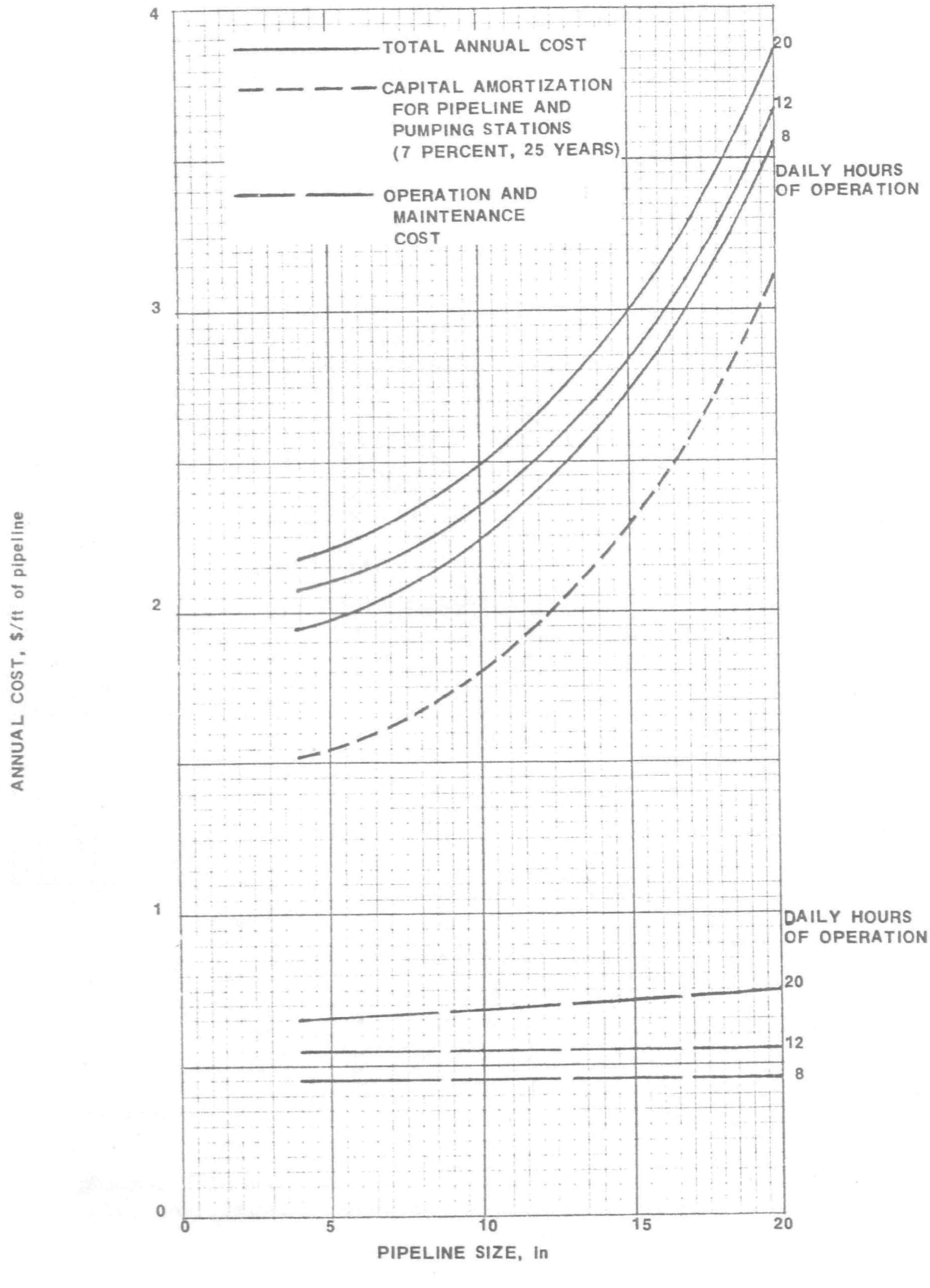

Figure 21. Pipeline transport costs, liquid sludge, 1975.

TABLE 1. FIGURE NUMBER INDEX FOR TRANSPORT MODE TOTAL ANNUAL COST

	Liquid sludge		Dewatered sludge	
Mode	Without facilities	With facilities	Without facilities	With facilities
Truck	1 & 2	3 & 4	5 & 6	7 & 8
Barge	9 - 12	13 - 16	---	---
Railroad	17	18	19	20
Pipeline	21	21	---	---

The third method, an alternative to the second manual method, is to develop new total cost curves periodically with updated unit cost input using the Executive Computer Program. Periodic development of total cost curves will greatly simplify manual determination of transport costs and should reduce the chance of error inherent in making the manual calculations. Use of the computer to develop updated curves will allow more points to be calculated and plotted, thus making the curves more widely applicable.

It is beyond the scope of this work to provide a complete computer program for calculation of transport costs; however, a program can be developed using the information in this report.

The data contained in this report are intended primarily as an aid in determining costs for various transport modes. Final comparisons between alternative transport modes for a given situation should then be made after all costs applicable to each mode are compiled. The information in this report is not intended to give a direct comparison between modes, however, certain generalized observations can be developed.

DEWATERED SLUDGE

1. Total annual cost for railroad is less than truck for all annual sludge volumes and distances studied herein with and without facilities.

2. Railroad facilities are more capital intensive than truck facilities.

3. Transport equipment can be leased in both cases.

LIQUID SLUDGE

1. Truck is the least expensive mode for one way distances of 20 miles or less and sludge volumes less than 10 to 15 mg per year.

2. Pipeline is the least expensive mode for all cases when the annual sludge volume is greater than approximately 30 to 70 mg (depending on distance).

3. Pipeline is not economically attractive for annual sludge volumes

of 10 mg or less because of the high capital investment.

4. Pipeline is capital intensive and the terminal points are not easily changed. Pipeline is ideal for large volumes of sludge transported between two fixed points.

5. Rail and barge are comparable over the 7 to 700 mg volume range for long haul distances.

6. Barge is more economical than rail for short to medium distances for annual sludge volumes greater than 30 mg.

SECTION 3

METHODS AND ASSUMPTIONS

GENERAL

The solids content of sludges from similar unit processes vary from plant to plant. All parameters and costs in this study are based on the units pertinent to the haul rather than units basic to the characteristics of the sludge. Liquid sludge costs are based on gallons of liquid transported and dewatered on cubic yards. The solids content of each form of sludge can vary over a range with minor changes in the actual transport cost. There will be essentially no change with liquid sludges in the range of 1 to 5 percent solids. In theory, there will be some change in costs with dewatered sludges if the density varies from the assumed 55 lb/cu ft. If the actual density is less than that assumed, it is possible for the truck to carry a larger volume load without exceeding legal weight limits. Conversely, the theoretical truck volume capacity will be less if the actual density is higher than the assumed density. These differences should decrease or increase the number of annual truckloads respectively and thus change the annual costs somewhat. Normally, the trucks will have a fixed capacity and will be loaded conservatively based on maximum expected sludge density and, therefore, it is unlikely that savings would be realized in actual operations. Potential average change in costs would be plus or minus 10 to 15 percent for variations in sludge density of plus or minus 10 lb/cu ft above and below the assumed 55 lb/cu ft. This estimate is based on judgement and could vary widely from case to case.

The costs can be converted to other units, such as dollars per dry ton-mile, after the total costs for a case have been determined.

Transport, for purposes of this study, is considered to be point to point movement of sludge rather than movement and ultimate disposal such as barging or pumping to sea. Costs for these forms of movement and disposal can be determined using the method herein, but this is not a basic goal of the study.

The methods developed and presented in this study are organized so costs for a particular case can be determined by manual calculations or programmed into the MERL, Cincinnati, Executive Computer Program. Most information is developed in basic units such as gallons of fuel or manhours so that current costs can be applied at the time of calculation. Some items must be presented in 1975 dollars, such as facilities costs, and a method of escalation is suggested for each of these cases.

MODE AND SLUDGE TYPE

The types of sludge studied and the transport modes are shown in Table 2.

TABLE 2. TYPES OF SLUDGE STUDIED, BY TRANSPORT MODE

	Form of sludge		
	Liquid, percent solids		
Transport mode	4	10	Dewatered
Truck	x	-	x
Barge	x	x	-
Railroad	x	-	x
Pipeline	x	-	-

The 4 percent liquid is typified by an anaerobically digested sludge, the 10 percent a settled, digested sludge (lagoon storage for example), and the dewatered sludge is a typical vacuum filter cake. Both of the liquid sludges can be pumped, and the dewatered sludge can be moved with belt conveyors.

FACTORS IN CALCULATION

The factors that must be considered in calculation of total transport costs for each mode are listed and referenced to the applicable figure or table. Because the facilities costs are subject to wide variation, depending on climate, designer, and other factors, they are presented separately. Facilities cost information from other sources can be used in making cost determinations if desired.

1. Truck Transport

<u>Point to Point Costs</u>

Truck fuel - Figures 22 and 23.
Truck maintenance - Tables 3, 4, and 5 and Figures 24 and 25.
Truck operator - Figures 26 and 27.
Amortization of truck capital cost - Tables 3, 4, and 5.

<u>Facility Costs</u>

Amortization of facilities capital costs - Tables 6 and 7.
Facilities operation and maintenance - Tables 6 and 7.

2. Barge Transport

<u>Point to Point Costs</u>

Towing (tug) service - Figures 28 and 29.
Tug operating time (information only) - Figures 30 and 31.
Barge maintenance - Tables 8, 9, and 10.
Amortization of barge capital cost - Tables 8, 9, and 10.

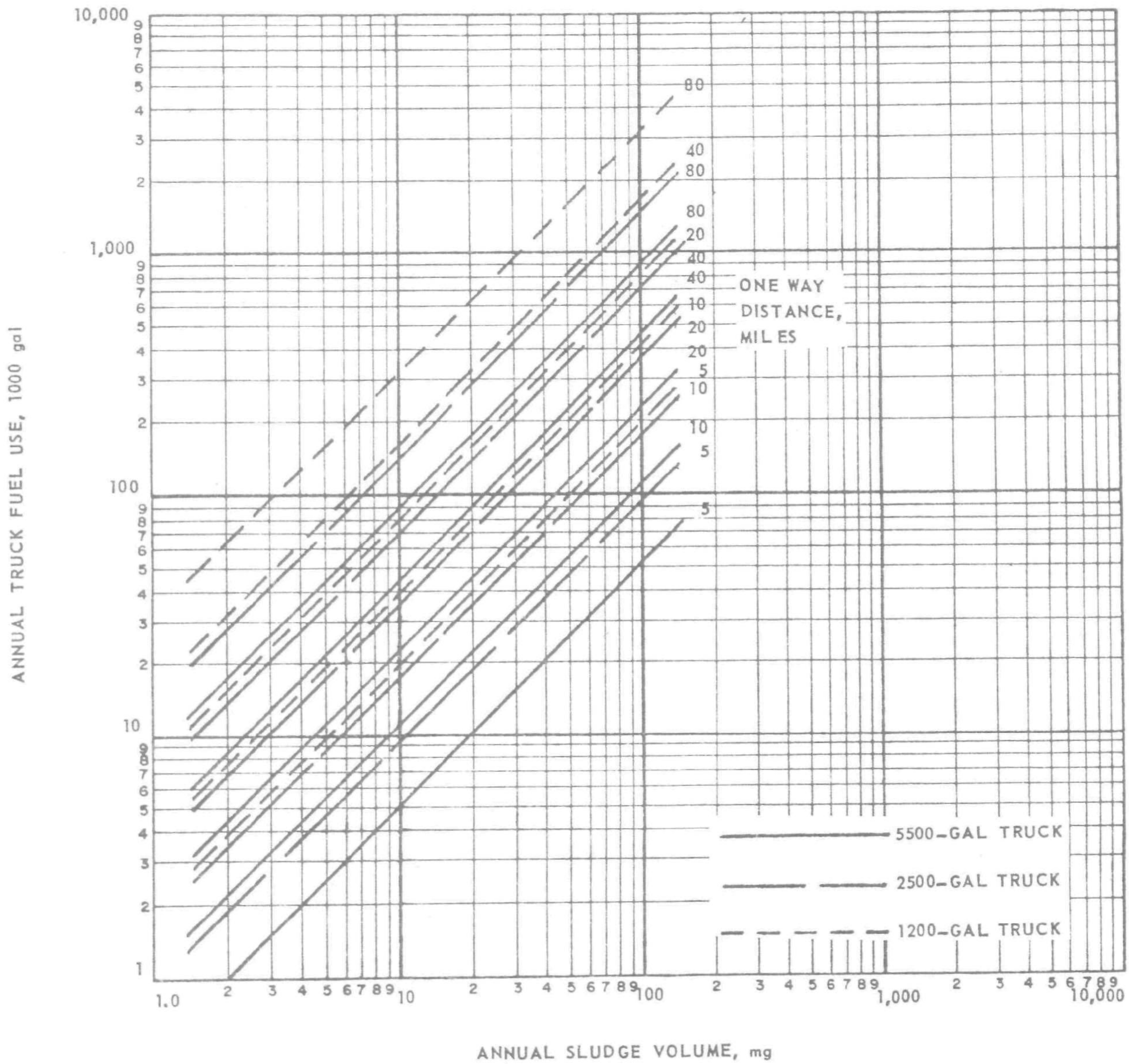

Figure 22. Truck fuel requirements, liquid sludge, 1975.

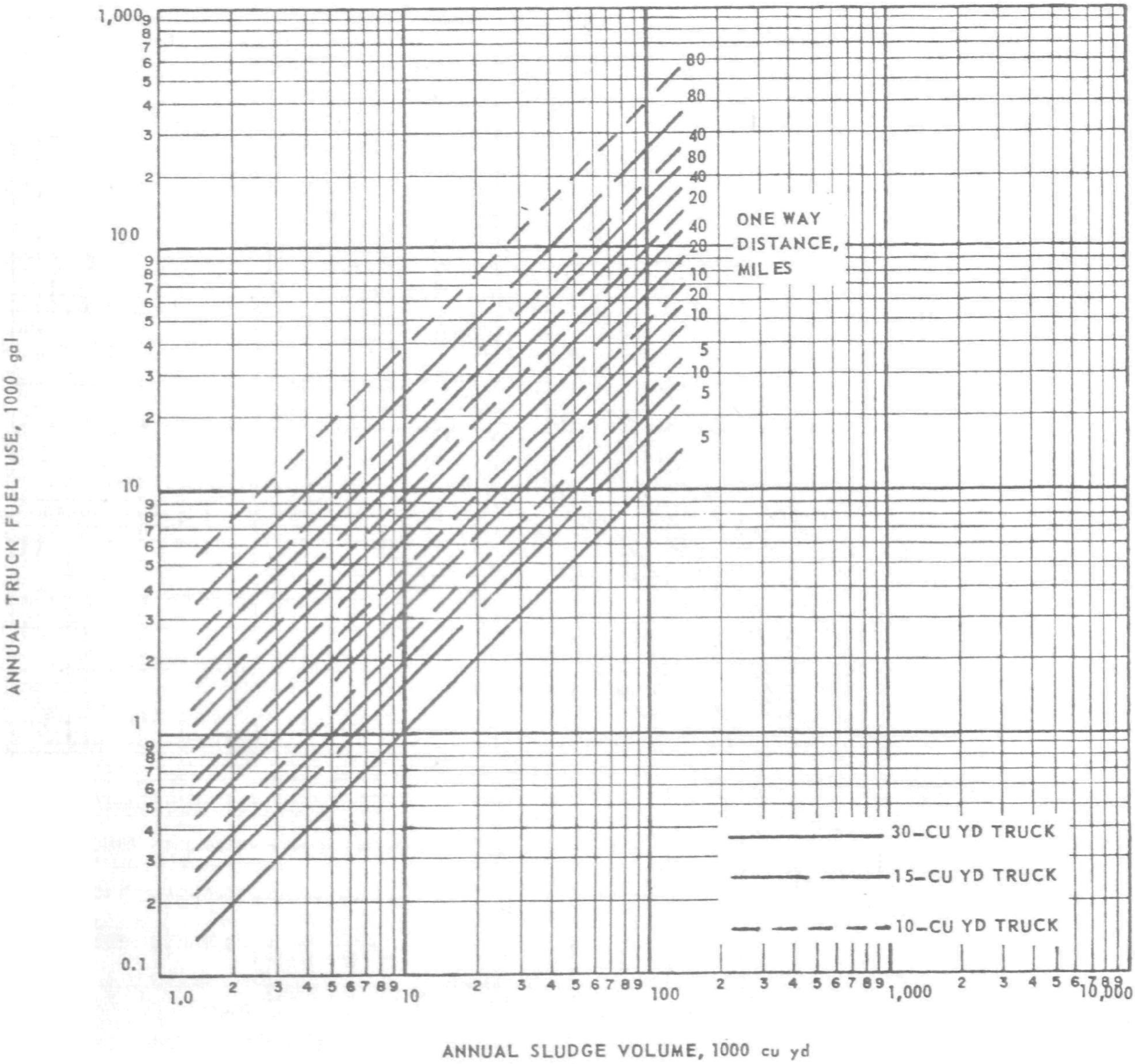

Figure 23. Truck fuel requirements, dewatered sludge, 1975.

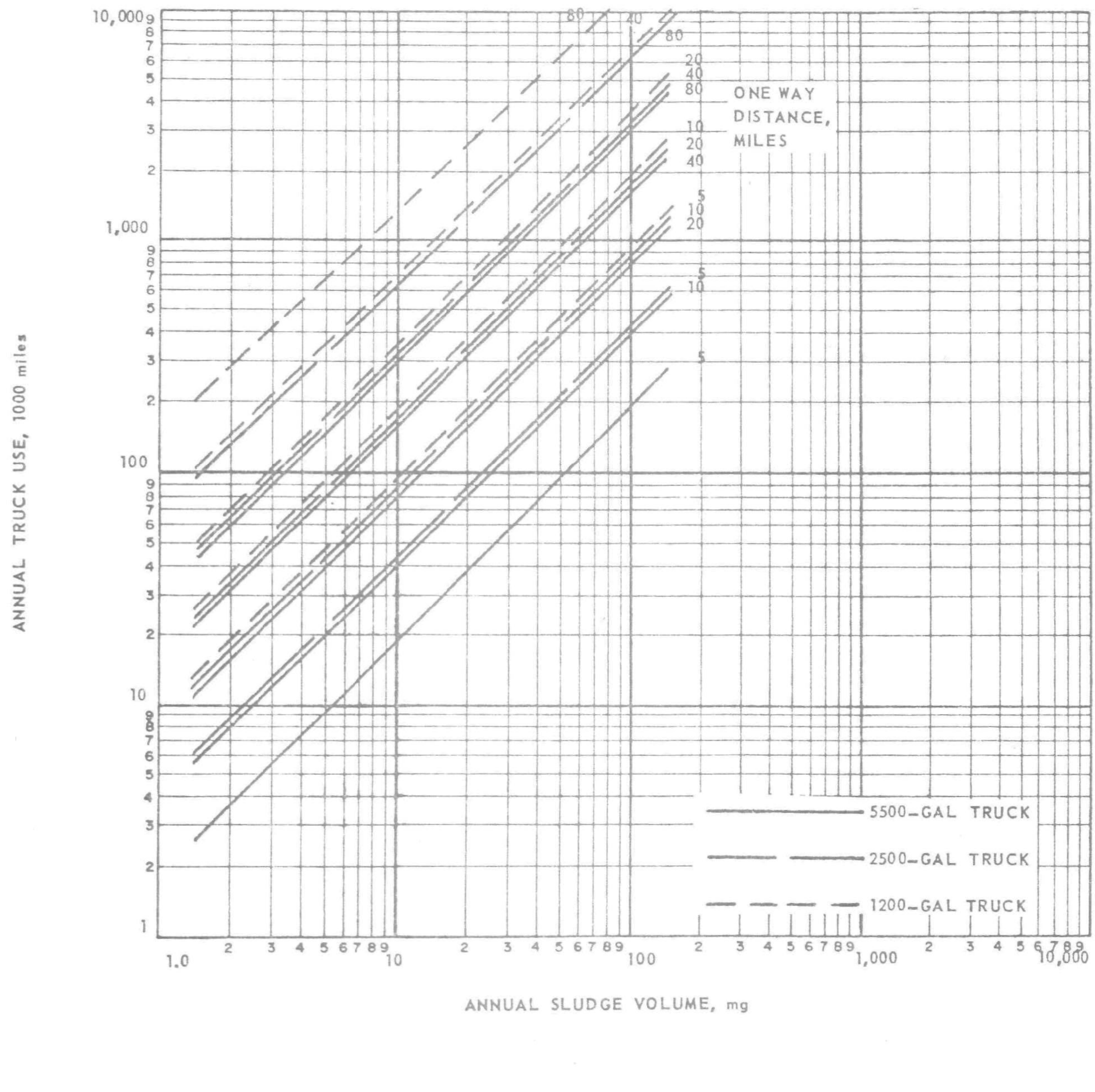

Figure 24. Truck use, liquid sludge, 1975.

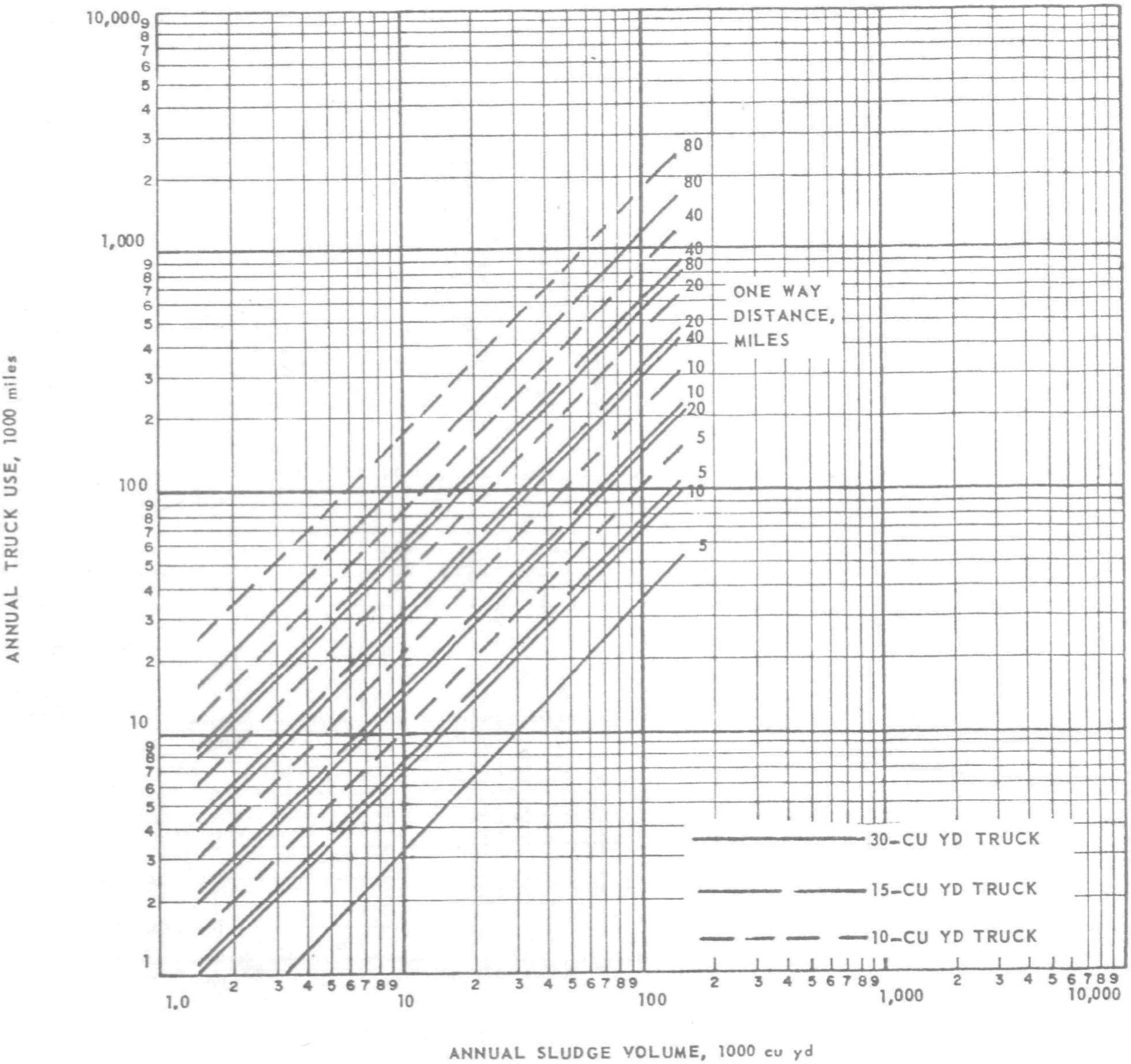

Figure 25. Truck use, dewatered sludge, 1975.

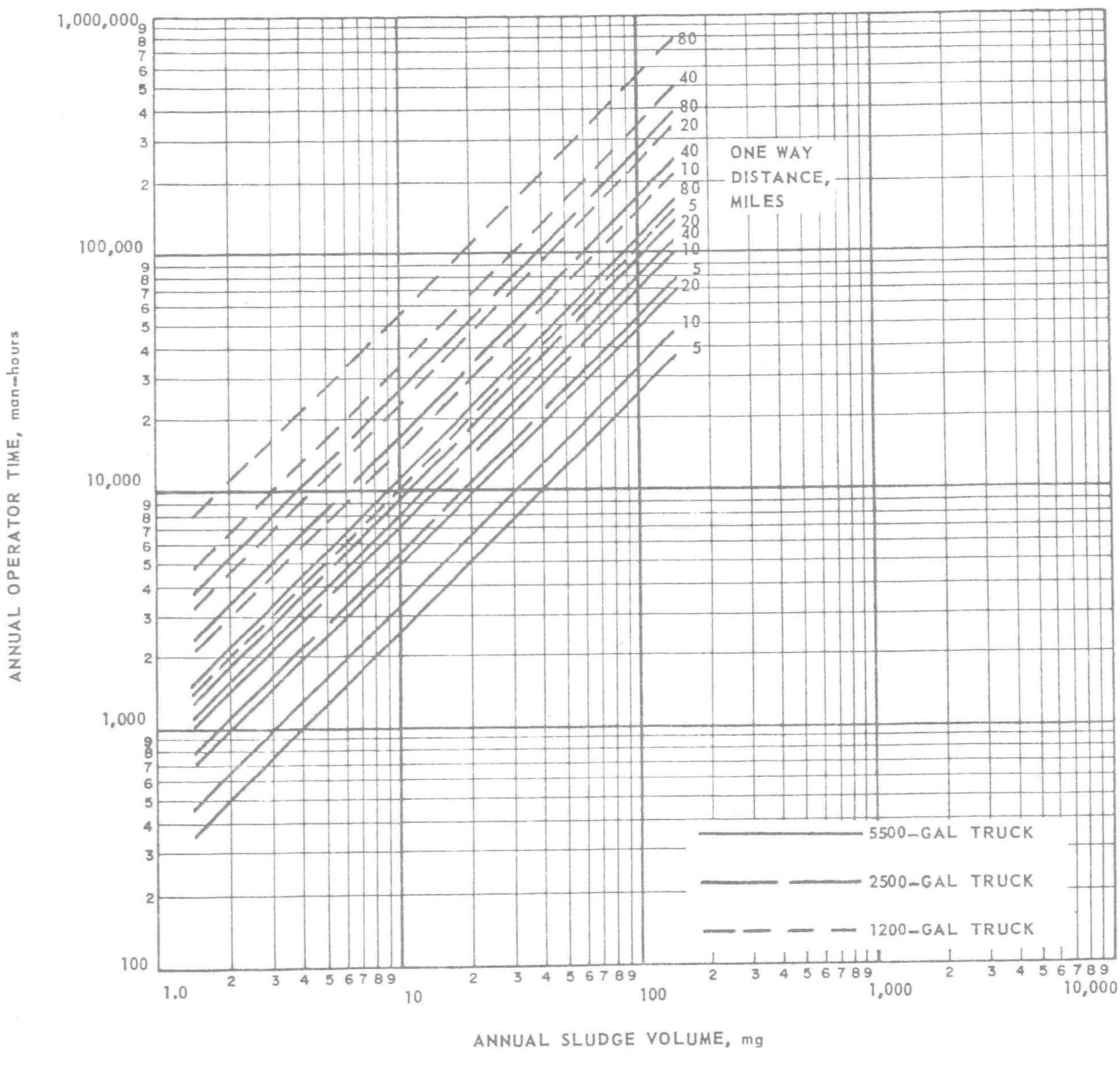

Figure 26. Truck operator, liquid sludge, 1975.

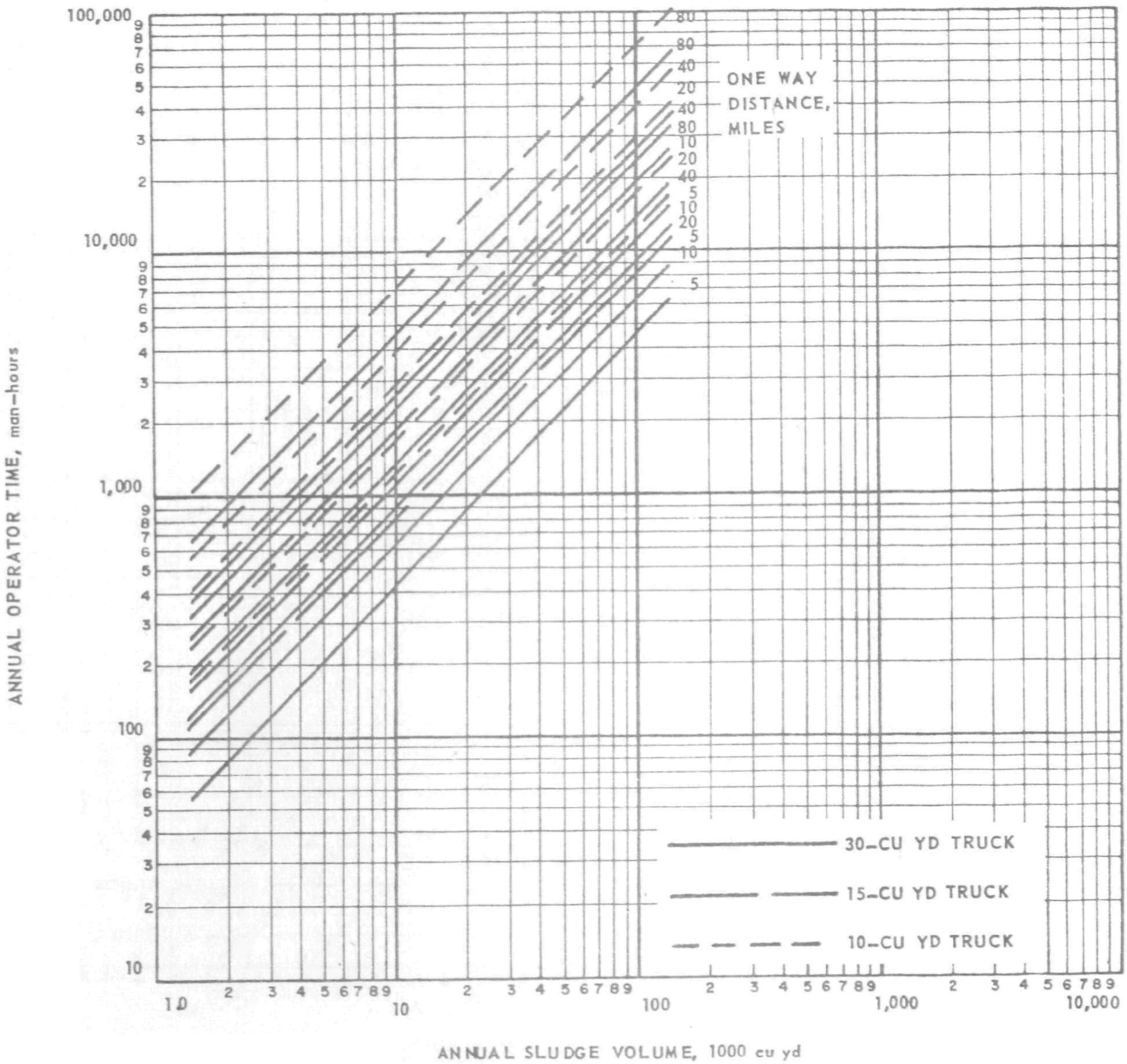

Figure 27. Truck operator, dewatered sludge, 1975.

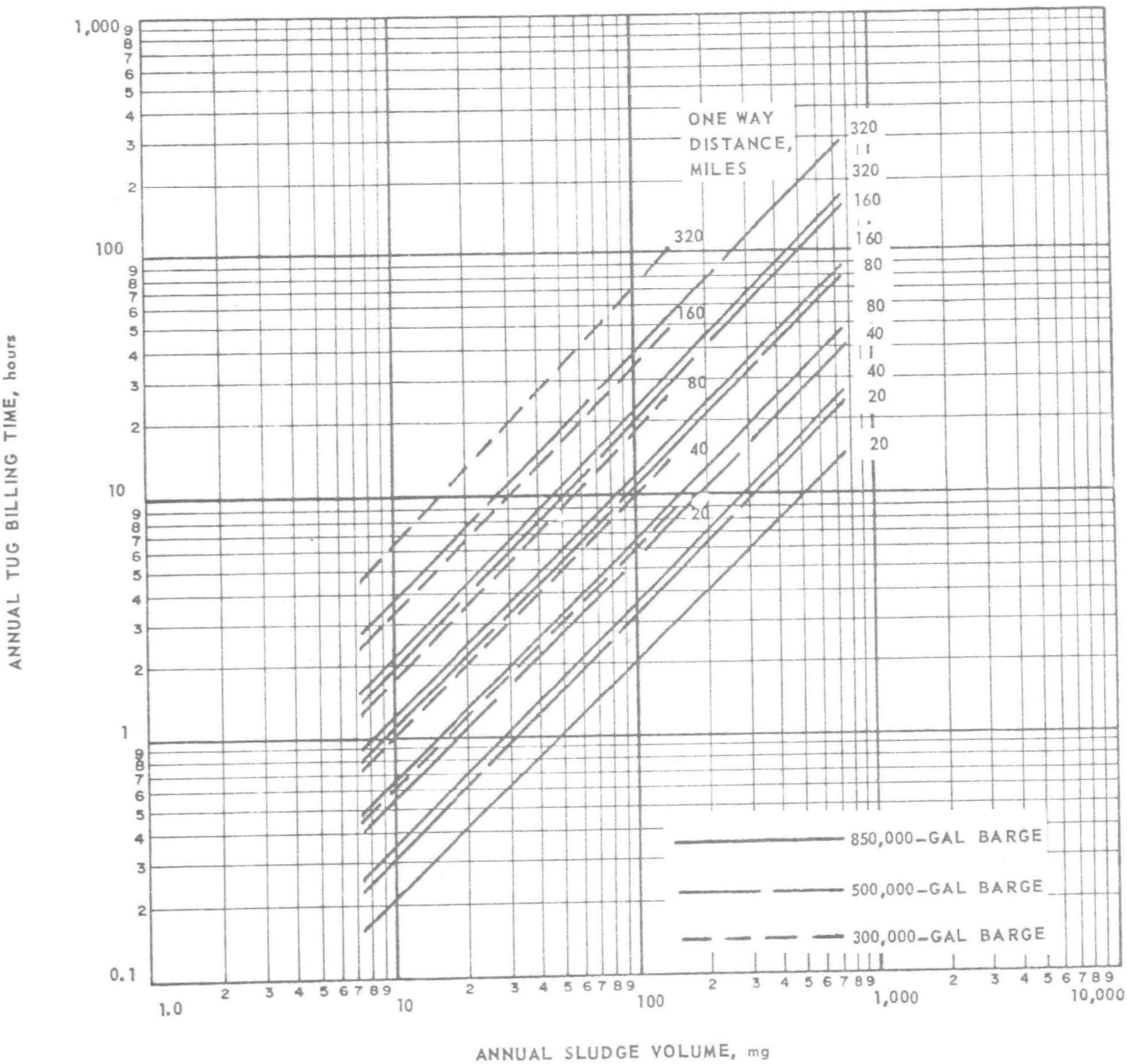

Figure 28. Barge tug billing time, 4 percent liquid sludge, 1975.

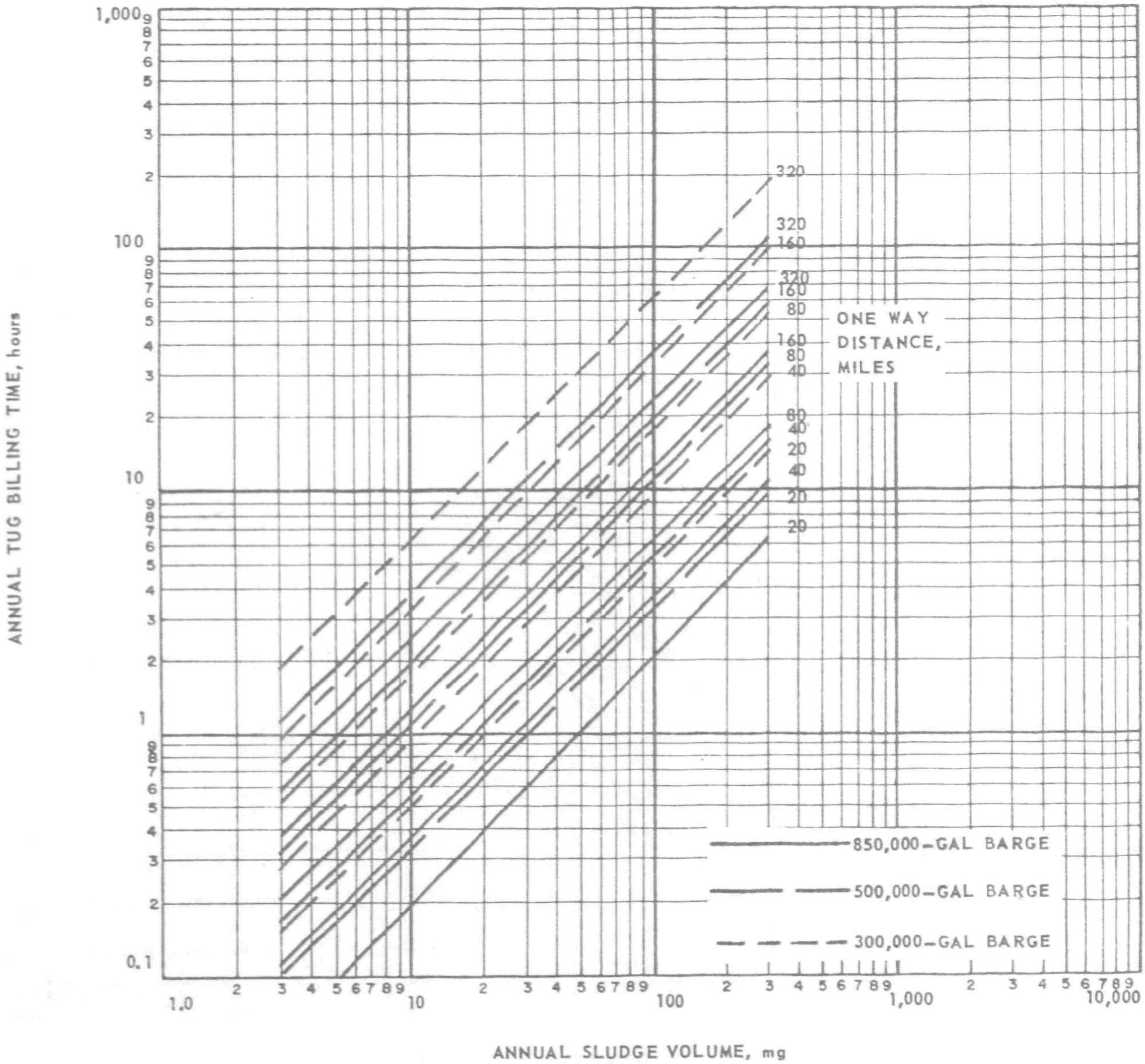

Figure 29. Barge tug billing time, 10 percent liquid sludge, 1975.

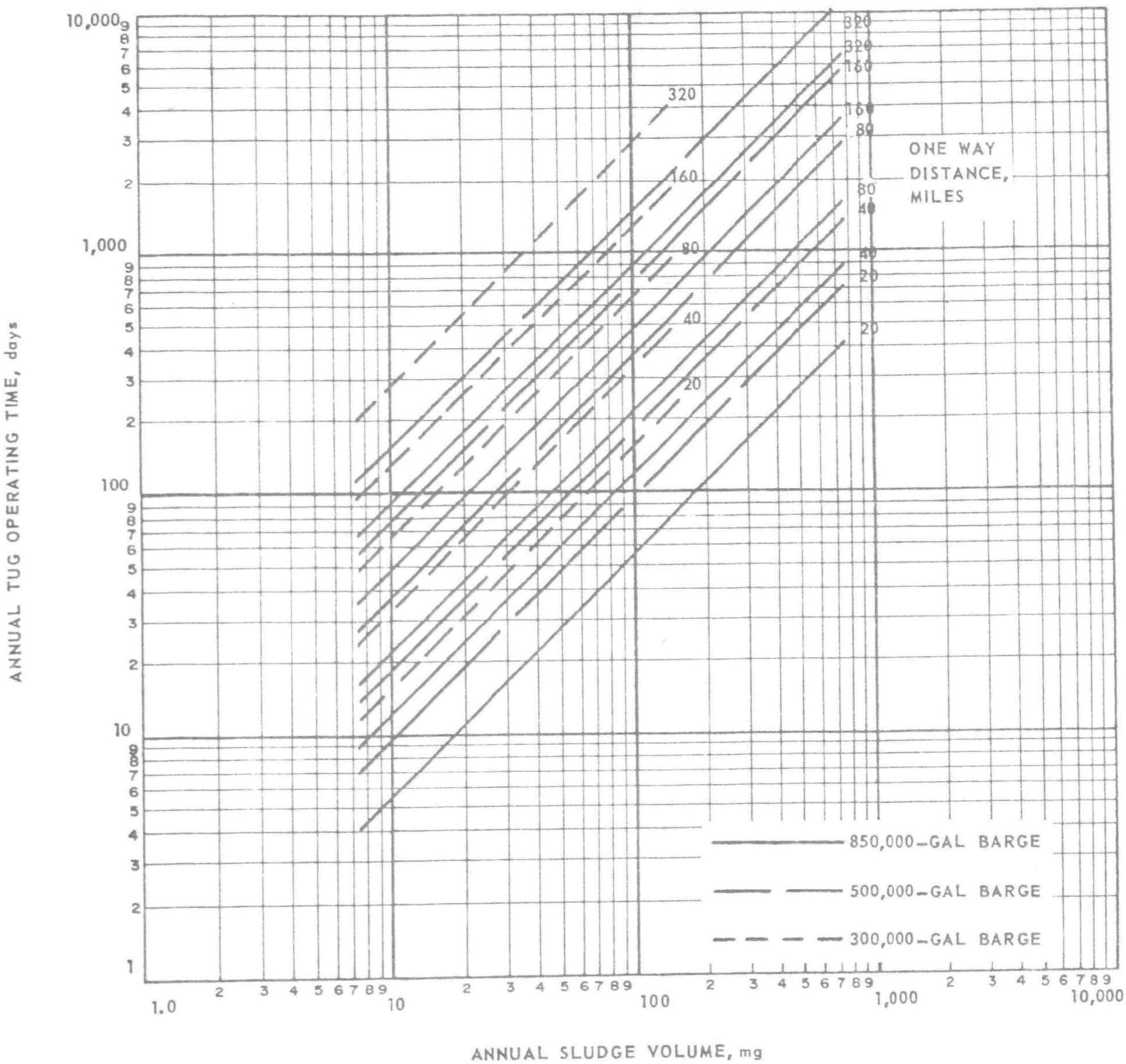

Figure 30. Barge tug operating time, 4 percent liquid sludge, 1975.

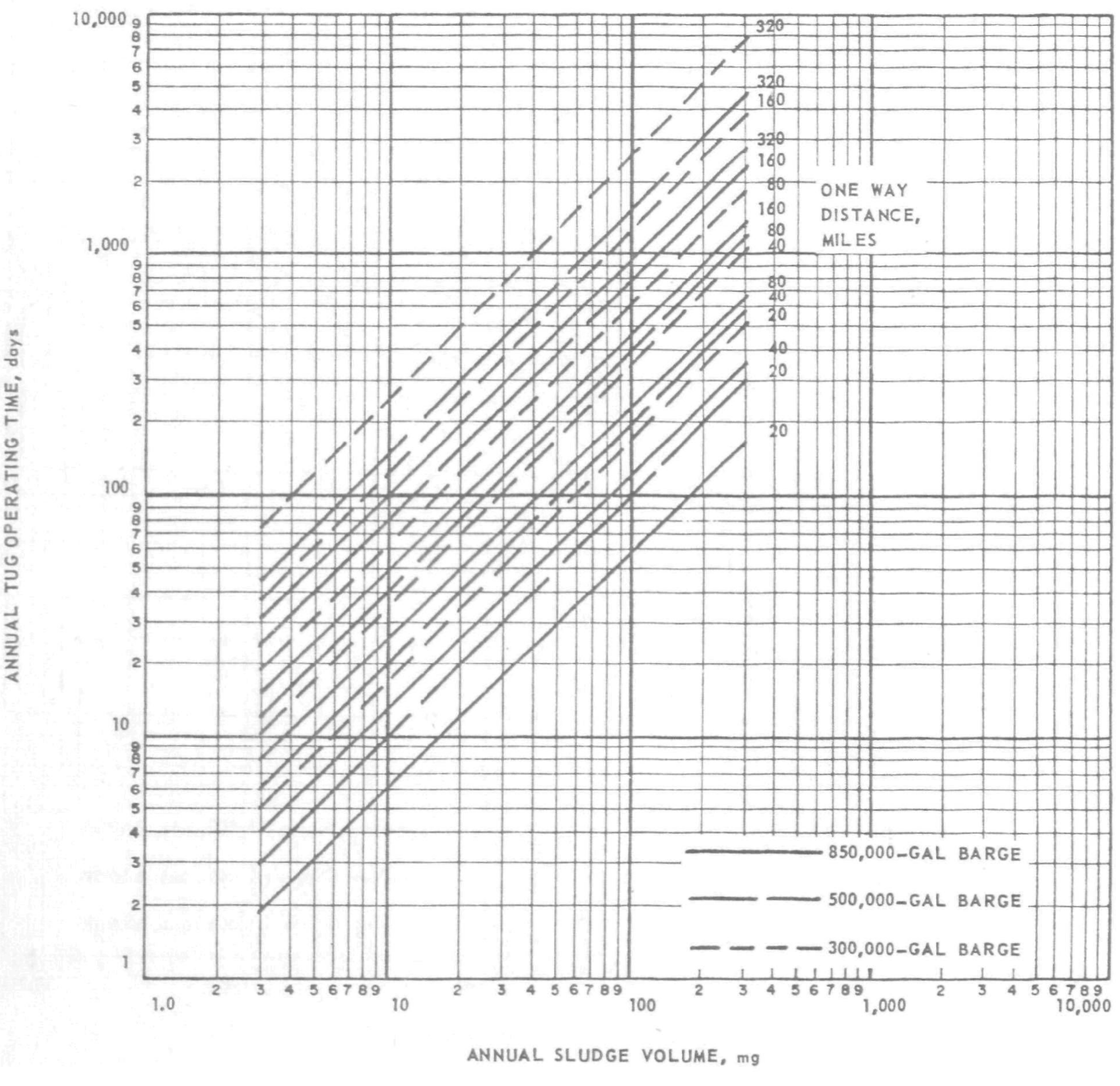

Figure 31. Barge tug operating time, 10 percent liquid sludge, 1975.

TABLE 3. TRUCK DATA, 1975 (*)

Type sludge	Capacity	Type of truck	Capital cost, $ (‡)	Fuel use, mpg	Operation Cost, $/mile (+) (≠)
Liquid	1200 gal	2-axle tanker	25,000	4.5	0.20
Liquid	2500 gal	3-axle tanker	42,000	4.5	0.25
Liquid	5500 gal	Semi, tanker	55,000	3.5	0.30
Dewatered	10 cu yd	2-axle dump	25,000	4.5	0.20
Dewatered	15 cu yd	3-axle dump	42,000	4.5	0.25
Dewatered	30 cu yd	Semi, dump	50,000	3.5	0.30

(*) This information was developed from personal contacts with eight Sacramento area truck and trailer dealers.

(+) Excluding operator and fuel.

(‡) Based on Wholesale Price Index for Item 141102, motor trucks, of 150.2.

(≠) Based on Wholesale Price Index for Item 1412, motor vehicle parts, of 170.3.

TABLE 4. TRUCK OPERATION SUMMARY, LIQUID SLUDGE, 1975

Annual sludge volume, mg	One-way distance, miles	Trips per year 1200 gal	Trips per year 2500 gal	Trips per year 5500 gal	Trucks needed (*) 8 hr/day operation (22 hr/day operation) (#) 1200 gal	Trucks needed 2500 gal	Trucks needed 5500 gal	Truck use 1,000 miles/year 1200 gal	Truck use 2500 gal	Truck use 5500 gal	Truck fuel (+) 1,000 gal/year 1200 gal	Truck fuel 2500 gal	Truck fuel 5500 gal	Truck operators (≠) 1,000 man-hours/yr 1200 gal	Truck operators 2500 gal	Truck operators 5500 gal
1.5	5	1,250	600	273	1(1)	1(1)	1(1)	13	6	3	2.9	1.3	0.8	1.6	0.8	0.3
	10	1,250	600	273	1(1)	1(1)	1(1)	25	12	6	5.6	2.7	1.6	2.1	1.0	0.5
	20	1,250	600	273	2(1)	1(1)	1(1)	50	24	11	11.1	5.3	3.1	3.2	1.6	0.7
	40	1,250	600	273	2(1)	1(1)	1(1)	100	48	22	22.2	10.7	6.3	4.8	2.3	1.0
	80	1,250	600	273	4(2)	2(1)	1(1)	200	96	44	44.4	21.3	12.6	7.9	3.8	1.7
5	5	4,167	2,000	909	2(1)	1(1)	1(1)	42	20	9	9.3	4.4	2.6	5.3	2.5	1.2
	10	4,167	2,000	909	3(1)	2(1)	1(1)	83	40	18	18.4	8.9	5.1	7.1	3.4	1.5
	20	4,167	2,000	909	4(2)	3(1)	1(1)	167	80	36	37.1	17.8	10.3	10.8	5.2	2.4
	40	4,167	2,000	909	6(3)	3(2)	2(1)	333	160	73	74.0	35.6	20.9	16.0	7.7	3.5
	80	4,167	2,000	909	12(4)	6(2)	3(1)	667	320	145	148.2	71.1	41.4	26.5	12.7	5.8
15	5	12,500	6,000	2,727	5(2)	3(1)	2(1)	125	60	27	27.8	13.3	7.7	15.8	7.6	3.5
	10	12,500	6,000	2,727	7(3)	4(2)	2(1)	250	120	55	55.6	26.7	15.7	21.3	10.2	4.6
	20	12,500	6,000	2,727	12(4)	6(2)	3(1)	500	240	109	111.1	53.3	31.1	32.3	15.5	7.0
	40	12,500	6,000	2,727	18(7)	9(4)	4(2)	1,000	480	218	222.2	106.7	62.3	48.0	23.0	10.5
	80	12,500	6,000	2,727	35(12)	17(6)	8(3)	2,000	960	436	444.4	213.3	124.6	79.5	38.1	17.3
50	5	41,667	20,000	9,091	17(6)	8(3)	4(2)	417	200	91	92.7	44.4	26.0	52.7	25.3	11.5
	10	41,667	20,000	9,091	24(9)	12(4)	6(2)	833	400	182	185.1	88.9	52.0	71.0	34.1	15.5
	20	41,667	20,000	9,091	39(13)	19(7)	9(3)	1,667	800	364	370.4	177.8	104.0	107.7	51.7	23.5
	40	41,667	20,000	9,091	58(24)	28(12)	13(6)	3,333	1,600	727	740.7	355.6	207.7	160.0	76.8	34.9
	80	41,667	20,000	9,091	116(39)	56(19)	26(9)	6,667	3,200	1,455	1,481.6	711.1	415.7	264.9	127.2	57.8
150	5	125,000	60,000	27,273	50(18)	24(9)	11(4)	1,250	600	273	277.8	133.3	78.0	158.1	75.9	34.5
	10	125,000	60,000	27,273	70(25)	34(12)	16(6)	2,500	1,200	546	555.6	266.7	156.0	213.1	102.3	46.5
	20	125,000	60,000	27,273	116(39)	56(19)	26(9)	5,000	2,400	1,091	1,111.1	533.3	311.7	323.1	155.1	70.5
	40	125,000	60,000	27,273	174(70)	84(34)	38(16)	10,000	4,800	2,182	2,222.2	1,066.7	623.4	479.9	230.3	104.7
	80	125,000	60,000	27,273	350(116)	167(56)	76(26)	20,000	9,600	4,364	4,444.4	2,133.3	1,246.9	794.8	381.5	173.4

(*) 360 days per year.

(+) See Table 3.

(≠) Based on truck operating hours plus 10 percent.

(#) Allows average of 2 hours per day for maintenance.

TABLE 5. TRUCK OPERATION SUMMARY,
DEWATERED SLUDGE, 1975

Annual sludge volume, 1000 cu yd	One way distance, miles	Trips per year			Trucks needed,(*) 8 hours/day operation (24 hours/day operation)(#)			Truck use, 1,000 miles/year			Truck fuel,(+) 1,000 gal/year			Truck operators,(≠) 1,000 man-hours/yr		
		10 cu yd	15 cu yd	30 cu yd	10 cu yd	15 cu yd	30 cu yd	10 cu yd	15 cu yd	30 cu yd	10 cu yd	15 cu yd	30 cu yd	10 cu yd	15 cu yd	30 cu yd
1.5	5	150	100	50	1(1)	1(1)	1(1)	1.5	1	.5	.3	.2	.2	.2	.1	.1
	10	150	100	50	1(1)	1(1)	1(1)	3	2	1	.7	.4	.3	.3	.2	.1
	20	150	100	50	1(1)	1(1)	1(1)	6	4	2	1.3	.9	.6	.5	.3	.1
	40	150	100	50	1(1)	1(1)	1(1)	12	8	4	2.7	1.8	1.1	.7	.4	.2
	80	150	100	50	1(1)	1(1)	1(1)	24	16	8	5.3	3.6	2.3	1.2	.6	.3
5	5	500	333	167	1(1)	1(1)	1(1)	5	3	2	1.1	.7	.6	.6	.4	.2
	10	500	333	167	1(1)	1(1)	1(1)	10	7	3	2.2	1.6	.9	.9	.6	.3
	20	500	333	167	1(1)	1(1)	1(1)	20	13	7	4.4	2.9	2.0	1.3	.9	.4
	40	500	333	167	1(1)	1(1)	1(1)	40	27	13	8.9	6.0	3.7	1.9	1.3	.6
	80	500	333	167	1(1)	1(1)	1(1)	80	53	27	17.8	11.8	7.7	3.2	2.1	1.1
15	5	1,500	1,000	500	1(1)	1(1)	1(1)	15	10	5	3.3	2.2	1.4	1.9	1.3	.6
	10	1,500	1,000	500	1(1)	1(1)	1(1)	30	20	10	6.7	4.4	2.9	2.6	1.7	.9
	20	1,500	1,000	500	2(1)	1(1)	1(1)	60	40	20	13.3	8.9	5.7	3.9	2.6	1.3
	40	1,500	1,000	500	3(1)	2(1)	1(1)	120	80	40	26.7	17.8	11.4	5.8	3.8	1.9
	80	1,500	1,000	500	5(2)	3(1)	1(1)	240	160	80	53.3	35.6	22.9	9.5	6.4	3.2
50	5	5,000	3,333	1,667	2(1)	2(1)	1(1)	50	33	17	11.1	7.3	4.9	6.3	4.2	2.1
	10	5,000	3,333	1,667	3(1)	2(1)	1(1)	100	67	33	22.2	14.9	9.4	8.5	5.7	2.8
	20	5,000	3,333	1,667	5(2)	4(2)	2(1)	200	133	67	44.4	29.6	19.1	12.9	8.6	4.3
	40	5,000	3,333	1,667	7(3)	5(2)	3(1)	400	267	133	88.9	59.3	38.0	19.2	12.8	6.4
	80	5,000	3,333	1,667	14(5)	10(4)	5(2)	800	533	267	177.8	118.4	76.3	31.8	21.2	10.6
	5	15,000	10,000	5,000	6(3)	4(2)	2(1)	150	100	50	33.3	22.2	14.3	19.0	12.7	5.8
	10	15,000	10,000	5,000	9(3)	6(2)	3(1)	300	200	100	66.7	44.4	28.6	25.6	17.1	8.5
	20	15,000	10,000	5,000	14(5)	10(4)	5(2)	600	400	200	133.3	88.9	57.1	38.8	25.9	12.9
	40	15,000	10,000	5,000	21(9)	14(6)	7(3)	1,200	800	400	266.7	177.8	114.3	57.6	38.4	19.2
	80	15,000	10,000	5,000	42(14)	28(10)	14(5)	2,400	1,600	800	533.3	355.6	228.6	95.4	6.36	31.8

(*) 360 days per year.
(+) See Table 3.
(≠) Based on truck operating hours plus 10 percent.
(#) Allows average of 2 hours per day for maintenance.

TABLE 6. TRUCK FACILITIES CAPITAL AND OPERATION AND MAINTENANCE DATA, LIQUID SLUDGE, 1975 (*)

Item	Annual sludge volume, mg				
	1.5	5	15	50	150
Capital Cost, $ (**):					
Loading pump, pipe, hose (‡)	7,500	7,500	8,500	14,000	20,000
Loading truck encl. (≠)	5,000	7,000	10,000	20,000	25,000
Truck ramp for unloading (≠)	15,000	15,000	30,000	50,000	75,000
Unloading truck encl. and office	10,000	10,000	15,000	20,000	30,000
Total	37,500	29,500	63,500	104,000	150,000
Annual amortization	3,218	3,390	5,450	8,924	12,870
Operation and maintenance per year:					
Electrical energy, kwh (Pumping, heat, light)	25,000	35,000	55,000	90,000	145,000
Maintenance supplies, $ (+)	1,500	2,000	3,000	3,500	4,000
Operation and maintenance manpower, man-hours (+)	1,000	1,500	2,000	3,000	4,000

(*) Assumptions: Pumps and piping sized to fill truck in 20 minutes maximum; no storage at plant, use plant sludge storage; storage at unloading site is a part of another unit process; gravity unloading at disposal site.

(**) EPA treatment plant index = 232.5.

(+) Estimated from Black & Veatch Report[(1)] and Adjusted to EPA Treatment Plant Index.

(‡) Estimated from Richardson Engineering Services[(2)].

(≠) Based on $30/sq ft for office and $20/sq ft for truck enclosure.

TABLE 7. TRUCK FACILITIES CAPITAL AND OPERATION AND MAINTENANCE DATA, DEWATERED SLUDGE, 1975(*)

Item	Annual sludge volume, cu yd				
	1.5	5	15	50	150
Capital Cost, $ (**):					
Conveyor (≠)	10,000	10,000	10,000	20,000	20,000
Loading hopper (‡)	10,000	10,000	10,000	15,000	20,000
Loading truck encl. (≠)	5,000	5,000	5,000	10,000	10,000
Truck ramp	15,000	15,000	15,000	20,000	30,000
Unloading truck encl. and office (≠)	10,000	10,000	10,000	15,000	25,000
Total	50,000	50,000	50,000	80,000	105,000
Annual amortization ($)	4,290	4,290	4,290	6,865	9,010
Operation and maintenance per year:					
Electrical energy, kwh	22,000	32,000	50,000	82,000	135,000
Maintenance supplies, $ (+)	1,500	2,000	3,000	3,500	4,000
Operation and maintenance manpower, man-hours (+)	1,000	1,500	2,000	3,000	4,000

(*) Assumptions: Equipment sized to fill truck in 20 minutes maximum; loading hopper sized for one truck load and gravity discharge into truck; storage at unloading site is a part of another unit process; gravity unloading at disposal site (Dump or power ram for truck unloading).

(**) EPA treatment plant index = 232.5.

(+) Estimated from Black & Veatch Report[1].

(‡) Estimated from Richardson Engineering Services[2].

(≠) Based on $30/sq ft for office and $20/sq ft for truck enclosure.

TABLE 8. BARGE CHARACTERISTICS, 1975[*]

Size, gal	Average 1975 capital cost, $	Annual amortization, $/year[+]	Barge maint. cost, $/year	Tug size, total hp	Tug billing rate (total), $/hour	Tug fuel consumption, gal/day
300,000	1,000,000	94,000	15,000	1,200	140	2,000
500,000	1,250,000	118,000	20,000	2,000	150	2,500
850,000	1,750,000	165,000	25,000	2,000	150	2,500
1,000,000	1,950,000 (‡)	184,060	28,000	2,500	160	3,000
2,000,000	3,000,000 (≠)	283,170	35,000	2,500	160	3,000

(*) These data were developed from personal communications with two barge and tug operators.
(+) Calculated at 7 percent over 20-year life.
(‡) Cost obtained from Fader paper[5] and escalated to 1975 prices.
(≠) Estimated.

TABLE 9. BARGE OPERATION SUMMARY, 4 PERCENT LIQUID SLUDGE, 1975

Annual sludge volume, mg	One way distance miles	Barges required			Trips per year			Tug billing time, hours per year			Tug fuel calculation time, days per year		
		300,000 gal	500,000 gal	850,000 gal	300,000 gal	500,000 gal	850,000 gal	300,000 gal	500,000 gal	850,000 gal	300,000 gal	500,000 gal	850,000 gal
7.5	20	1	1	1	25	15	9	431	259	156	12	7	4
	40	1	1	1	25	15	9	719	431	259	24	14	9
	80	1	1	1	25	15	9	1,294	776	466	48	28	17
	160	1	1	1	25	15	9	2,444	1,466	880	96	56	35
	320	1	1	1	25	15	9	4,744	2,846	1,708	192	112	69
15	20	1	1	1	50	30	18	863	518	311	24	14	9
	40	1	1	1	50	30	18	1,438	863	518	48	28	17
	80	1	1	1	50	30	18	2,588	1,553	932	96	56	35
	160	1	1	1	50	30	18	4,888	2,933	1,760	192	112	69
	320	1	1	1	50	30	18	9,488	5,693	3,416	384	224	138
75	20	1	1	1	250	150	89	4,313	2,588	1,536	120	70	43
	40	1	1	1	250	150	89	7,188	4,310	2,559	240	140	85
	80	2	1	1	250	150	89	12,938	7,760	4,606	480	280	171
	160	3	2	1	250	150	89	24,438	14,660	8,700	960	560	341
	320	5	3	2	250	150	89	47,438	28,460	16,888	1,920	1,120	682
150	20	2	1	1	500	300	177	8,630	5,180	3,053	240	140	85
	40	2	1	1	500	300	177	14,380	8,630	5,089	480	280	170
	80	3	2	2	500	300	177	25,880	15,530	9,160	960	560	339
	160	6	4	2	500	300	177	48,880	29,330	12,302	1,920	1,120	679
	320	10	6	4	500	300	177	94,880	56,930	33,586	3,840	2,240	1,357
750	20	-	4	2	2,500	1,500	883	----	25,880	15,232	---	700	423
	40	-	6	3	2,500	1,500	883	----	43,100	25,386	---	1,400	846
	80	-	9	6	2,500	1,500	883	----	77,600	45,695	---	2,800	1,693
	160	-	16	10	2,500	1,500	883	----	146,660	86,313	---	5,600	3,385
	320	-	30	18	2,500	1,500	883	----	284,600	167,550	---	11,200	6,770

TABLE 10. BARGE OPERATION SUMMARY, 10 PERCENT LIQUID SLUDGE, 1975

Annual sludge volume, mg	One way distance, miles	Barges required			Trips per year			Tug billing time, hours per year			Tug fuel calculation time, days per year		
		300,000 gal	500,000 gal	850,000 gal	300,000 gal	500,000 gal	850,000 gal	300,000 gal	500,000 gal	850,000 gal	300,000 gal	500,000 gal	850,000 gal
3	20	1	1	1	10	6	4	173	104	69	5	3	2
	40	1	1	1	10	6	4	288	173	115	10	6	4
	80	1	1	1	10	6	4	518	311	207	19	12	8
	160	1	1	1	10	6	4	978	587	391	38	23	16
	320	1	1	1	10	6	4	1,898	1,139	759	77	46	31
6	20	1	1	1	20	12	7	345	207	121	10	6	4
	40	1	1	1	20	12	7	575	345	201	19	12	7
	80	1	1	1	20	12	7	1,035	621	362	38	23	14
	160	1	1	1	20	12	7	1,955	1,173	684	77	46	27
	320	1	1	1	20	12	7	3,795	2,277	1,328	153	92	54
30	20	1	1	1	100	60	35	1,730	1,040	604	50	30	17
	40	1	1	1	100	60	35	2,880	1,730	1,006	100	60	34
	80	1	1	1	100	60	35	5,180	3,110	1,811	190	120	67
	160	1	1	1	100	60	35	9,780	5,870	3,421	380	230	134
	320	2	1	1	100	60	35	18,980	11,390	6,641	770	460	268
60	20	1	1	1	200	120	71	3,450	2,070	1,125	100	60	34
	40	1	1	1	200	120	71	5,750	3,450	2,041	190	120	68
	80	2	1	1	200	120	71	10,350	6,210	3,674	380	230	136
	160	2	2	1	200	120	71	19,550	11,730	6,940	770	460	272
	320	4	3	2	200	120	71	37,950	22,770	13,472	1,530	920	544
300	20	3	2	1	1,000	600	353	17,300	10,400	6,089	500	300	169
	40	4	2	2	1,000	600	353	28,800	17,300	10,149	1,000	600	338
	80	6	4	2	1,000	600	353	51,800	31,100	18,268	1,900	1,200	677
	160	11	7	4	1,000	600	353	97,800	58,700	34,506	3,800	2,300	1,353
	320	20	12	7	1,000	600	353	189,800	113,900	66,982	7,700	4,600	2,706

Facility Costs

Amortization of facilities capital cost - Tables 11 and 12.
Facilities operation and maintenance - Tables 11 and 12.

3. Railroad Transport

Point to Point Costs

Railroad tariffs - Tables 13 and 14 and report text.
Rail tank car lease (including maintenance), Liquid Sludge - Table 13.

Facility Costs

Amortization of facilities capital cost - Tables 15 and 16.
Facilities operation and maintenance - Tables 15 and 16.

4. Pipeline Transport

Pumping and pumping station electrical energy - Table 17.
Operation and maintenance labor - Table 18.
Operation and maintenance supplies and parts - Table 18.
Amortization of pipeline and pumping station capital cost - Tables 19, 20, 21, and 22.

SLUDGE VOLUME

The range of annual sludge volume used for each transport mode is shown in Table 23. In some cases it was not practical for a specific mode to cover the full range because of practical limits. Each volume is roughly related to a secondary treatment plant size.

TRANSPORT DISTANCE

The range of transport distance assumed for each mode is shown in Table 24.

TRANSPORT CYCLE TIMING

The assumed transport speeds, loading, and unloading times are shown in Table 25. The actual speed of rail movements is meaningless because the transit time includes other factors such as switching, train make up, weighing, and similar delays in movement. The total point to point transit time is more meaningful for rail movements and is a major factor in determining the number of cars to be leased. The transit time is not important for dewatered sludge cars if the railroad furnishes the cars. The transit time will vary greatly from case to case and the objective when using leased cars is to reduce the time to a minimum. Table 26 shows some typical times and the magnitude of the problem.

DAILY OPERATING SCHEDULE

Certain limitations may be placed on daily operating schedules for

TABLE 11. BARGE FACILITIES CAPITAL AND OPERATION AND MAINTENANCE DATA, 4 PERCENT LIQUID SLUDGE, 1975 (*)

Item	Annual sludge volume, mg				
	7.5	15	75	150	750
Capital Cost, $:					
Sludge storage at loading facility (+)	102,000	102,000	252,000	252,000	405,000
Loading and unloading pumping (+)	78,000	78,000	154,000	154,000	154,000
Loading and unloading piping (‡)	20,000	20,000	40,000	40,000	40,000
Loading and unloading docks and facilities [12]	200,000	200,000	200,000	200,000	300,000
Total	400,000	400,000	646,000	646,000	899,000
Annual Amortization	34,324	34,324	55,433	55,433	77,143
Operation and Maintenance Per Year:					
Maintenance, man-hours (+)	680	680	1,640	1,640	2,400
Operation, man-hours/barge load	12	12	12	12	12
Operation and maintenance supplies, $ (+)	4,200	4,200	12,600	12,600	20,000
Dock maintenance, $	6,000	6,000	6,000	6,000	10,000
Electrical energy, kwh (pumping, light, heat etc.)	35,000	40,000	90,000	140,000	480,000

(*) Assumptions: Pumps and piping sized to fill barge in 4 hours; storage at plant equal to one days production or 2 barge loads minimum; storage at unloading area is a part of another unit process.

(+) Estimated from Black & Veatch Report[1] and adjusted to EPA Treatment Plant Index = 232.5.

(‡) Estimated from Richardson Engineering Services [2].

TABLE 12. BARGE FACILITIES CAPITAL AND OPERATION AND MAINTENANCE DATA, 10 PERCENT LIQUID SLUDGE, 1975(*)

Item	Annual sludge volume, mg				
	3	6	30	60	300
Capital Cost, $:					
Sludge storage at loading facility (+)	102,000	102,000	102,000	252,000	252,000
Loading and unloading pumping (+)	78,000	78,000	78,000	154,000	154,000
Loading and unloading piping (‡)	20,000	20,000	20,000	40,000	40,000
Loading and unloading docks and facilities [12]	200,000	200,000	200,000	200,000	200,000
Total	400,000	400,000	400,000	646,000	646,000
Annual Amortization	34,324	34,324	34,324	55,433	55,433
Operation and Maintenance Per Year:					
Maintenance, man-hours (+)	680	680	680	1,640	1,640
Operation, man-hours/barge load	12	12	12	12	12
Operation and maintenance supplies, $ (+)	4,200	4,200	4,200	12,600	12,600
Dock maintenance, $	6,000	6,000	6,000	6,000	6,000
Electrical energy, kwh (pumping, light, heat etc.)	32,000	34,000	50,000	82,000	140,000

(*) Assumptions: Pumps and piping sized to fill barge in 4 hours; storage at plant equal to one days production or 2 barge loads minimum; storage at unloading area is a part of another unit process.

(+) Estimated from Black & Veatch Report[1] and adjusted to EPA Treatment Plant Index = 232.5.

(‡) Estimated from Richardson Engineering Services[2].

TABLE 13. RAILROAD OPERATION SUMMARY, LIQUID SLUDGE

Annual sludge volume, mg	One way distance, miles	Car size, gal (*)	Car loads year	Car loads day	Load time (+), hours	Unload time (+), hours	Transit time (‡) hours	Round trip time, hours	Cars required	Annual volume (≠) tons
7.5	20	20,000	375	1	5	5	96	106	5	31,238
	40	20,000	375	1	5	5	96	106	5	31,238
	80	20,000	375	1	5	5	144	154	7	31,238
	160	20,000	375	1	5	5	168	178	8	31,238
	320	20,000	375	1	5	5	192	202	9	31,238
15	20	20,000	750	2	5.5	5.5	96	107	9	62,475
	40	20,000	750	2	5.5	5.5	96	107	9	62,475
	80	20,000	750	2	5.5	5.5	144	155	13	62,475
	160	20,000	750	2	5.5	5.5	168	179	15	62,475
	320	20,000	750	2	5.5	5.5	172	203	17	62,475
75	20	20,000	3,750	10.4	6	6	91	108	47	312,375
	40	20,000	3,750	10.4	6	6	96	108	47	312,375
	80	20,000	3,750	10.4	6	6	144	156	68	312,375
	160	20,000	3,750	10.4	6	6	168	180	78	312,375
	320	20,000	3,750	10.4	6	6	192	204	89	312,375
150	20	20,000	7,500	21	7	7	96	110	97	624,750
	40	20,000	7,500	21	7	7	96	110	97	624,750
	80	20,000	7,500	21	7	7	144	158	139	624,750
	160	20,000	7,500	21	7	7	168	182	160	624,750
	320	20,000	7,500	21	7	7	192	206	181	624,750
750	20	20,000	37,500	104	19	19	96	134	581	3,123,750
	40	20,000	37,500	104	19	19	96	134	581	3,123,750
	80	20,000	37,500	104	19	19	144	182	789	3,123,750
	160	20,000	37,500	104	19	19	168	206	893	3,123,750
	320	20,000	37,500	104	19	19	192	230	997	3,123,750

(*) 20,000-gal rail car full maintenance lease rate is $445/month from GATX.

(+) Times based on information provided by GATX; however their numbers have been modified to fit the study conditions.

(‡) Based on information provided by Southern Pacific Railroad, Sacramento.

(≠) For billing purposes

TABLE 14. RAILROAD OPERATION SUMMARY, DEWATERED SLUDGE

Annual sludge volume, 1,000 cu yd	One way distance, miles	Car size,(*) cu yd	Car loads year	Car loads day	Annual volume,(+) tons
7.5	20	50	150	0.4	5,569
	40	50	150	0.4	5,569
	80	50	150	0.4	5,569
	160	50	150	0.4	5,569
	320	50	150	0.4	5,569
15	20	50	300	0.8	11,138
	40	50	300	0.8	11,138
	80	50	300	0.8	11,138
	160	50	300	0.8	11,138
	320	50	300	0.8	11,138
75	20	100	750	2	55,688
	40	100	750	2	55,688
	80	100	750	2	55,688
	160	100	750	2	55,688
	320	100	750	2	55,688
150	20	100	1,500	4	111,375
	40	100	1,500	4	111,375
	80	100	1,500	4	111,375
	160	100	1,500	4	111,375
	320	100	1,500	4	111,375
750	20	100	7,500	21	556,875
	40	100	7,500	21	556,875
	80	100	7,500	21	556,875
	160	100	7,500	21	556,875
	320	100	7,500	21	556,875

(*) Based on use of rail company cars.
(+) For billing purposes.

TABLE 15. RAILROAD FACILITIES CAPITAL AND OPERATION AND MAINTENANCE DATA, LIQUID SLUDGE, 1975[*]

Item	Annual sludge volume, mg				
	7.5	15	75	150	750
Capital cost, $:					
Sludge storage at loading facility[+]	31,000	45,000	102,000	144,000	405,000
Loading pumping[+]	38,000	38,000	67,000	77,000	81,000
Loading piping and appurtences[‡]	10,000	12,000	49,000	50,000	50,000
Loading and unloading rail sidings and switches[‡]	37,000	43,000	80,000	156,000	372,000
Loading and unloading building and site work	64,000	64,000	84,000	136,000	248,000
Total	180,000	202,000	382,000	563,000	1,156,000
Annual amortization	15,446	17,334	32,780	48,311	99,196
Operation and maintenance per year:					
Maintenance, man-hours[+]	130	260	340	500	1,200
Operation, man-hours	4,124[≠]	4,124[≠]	9,000[#]	10,500[#]	28,500[#]
Operation and maintenance supplies, $[+]	475	727	2,237	3,635	10,000
Rail maintenance, $	2,000	3,000	4,000	8,000	20,000
Electrical energy, kwh	35,000	40,000	90,000	140,000	480,000

(*) Assumptions: Pumping and piping sized to fill 1, 2, 10, 20, & 100 unit car trains in 1.5, 2, 3, 15 hours respectively; storage at plant equal to one days production; storage at unloading area is a part of another unit process; rail cars discharge by gravity into unloading storage.

(+) Estimated from Black & Veatch Report[1] and adjusted to EPA Treatment Plant Index = 232.5.

(‡) Estimated from Richardson Engineering Services[2].

(≠) One man for total load and unload time.

(#) Two men for total load and unload time.

TABLE 16. RAILROAD FACILITIES CAPITAL AND OPERATION AND MAINTENANCE DATA, DEWATERED SLUDGE, 1975(*)

Item	Annual sludge volume, 1000 cu yd				
	7.5	15	75	150	750
Capital cost, $:					
Loading sludge hoppers(+)	24,000	24,000	28,000	56,000	112,000
Loading conveyors(+)	20,000	20,000	20,000	40,000	80,000
Loading and unloading rail sidings and switches(+)	37,000	37,000	37,000	73,000	258,000
Loading and unloading building and site work	64,000	64,000	64,000	84,000	160,000
Total	145,000	145,000	149,000	253,000	610,000
Annual amortization	12,442	12,442	12,786	21,710	52,344
Operation and maintenance per year:					
Maintenance, man-hours(≠)	130	260	340	500	1,200
Operation, man-hours	1,650(≠)	3,300(≠)		4,125(≠)	10,000(#)
Operation and maintenance supplies, $ (‡)	475	727	2,237	3,635	10,000
Rail maintenance, $	2,000	2,000	2,000	4,000	25,000
Electrical energy, kwh	92,000	92,000	92,000	169,000	308,000

(*) Assumptions: Loading storage hopper sized for one car load; gravity loading into car from storage hopper; storage at unloading area is a part of another unit process; rail cars dump by gravity into unloading storage.

(+) Estimated from Richardson Engineering Services[2].

(‡) Same as for liquid sludge case.

(≠) One man for total load and unload time.

(#) Two men for total load and unload time.

TABLE 17. PIPELINE PUMPING STATION ENERGY

Pipeline size, in	Power, kw/1000 gph - ft head	Annual energy, kwh/ft head for daily hours of operation shown (*)							
		Pumping only				Total station(+)			
		4	8	12	20	4	8	12	20
4	0.0078	81.8	163.5	245.3	408.8	90	180	270	450
6	0.0070	-	343.4	515.1	858.5	-	378	567	944
8	0.0070	-	613.2	919.8	1,533.0	-	675	1,012	1,686
10	0.0055	-	766.5	1,149.8	1,916.3	-	843	1,265	2,108
12	0.0048	-	924.0	1,386.0	2,310.0	-	1,016	1,525	2,541
14	0.0045	-	1,100.6	1,651.0	2,752.0	-	1,211	1,816	3,027
16	0.0050	-	1,752.0	2,628.0	4,380.0	-	1,927	2,891	4,818
18	0.0046	-	2,017.1	3,025.7	5,042.8	-	2,219	3,328	5,547
20	0.0045	-	2,358.5	3,537.7	5,896.2	-	2,594	3,891	6,486

(*) Motor efficiency = 90%[19]; pump efficiency = 80%; kw/1000 gph-ft head = $\frac{0.00315}{\text{(Pump eff) (Motor eff)}}$

(+) Total station energy = 1.10 x pumping energy.

TABLE 18. PIPELINE OPERATING AND MAINTENANCE LABOR AND SUPPLIES

Pipeline size, in(*)	Annual operation and maintenance labor, man-hours per pumping station	Annual operation and maintenance parts and supplies, $/pumping station(1)
4	700	640
6	720	670
8	780	750
10	820	820
12	840	890
14	870	940
16	910	1,680
18	940	1,750
20	980	1,840

(*) For short pipelines, use operation and maintenance labor and supplies cost for one pumping station as a minimum.

TABLE 19. PIPELINE SIZE, SLUDGE FLOW AND SLUDGE VOLUME

Pipeline size, in	Sludge flow rate, gpm @ 3 fps velocity	Pipeline capacity at 3 fps velocity for various daily hourly operating periods, mgd			
		4	8	12	20
4	120	0.03	0.06	0.09	0.14
6	280	-	0.13	0.20	0.34
8	500	-	0.24	0.36	0.60
10	800	-	0.38	0.58	0.96
12	1,100	-	0.53	0.79	1.32
14	1,400	-	0.67	1.01	1.68
16	2,000	-	0.96	1.44	2.40
18	2,500	-	1.20	1.80	3.00
20	3,000	-	1.44	2.16	3.60

TABLE 20. PIPELINE SLUDGE PUMPING CHARACTERISTICS

Pipeline size, in	Flow, gpm	Hydraulic loss, ft/ 100 ft (C=90)	Approximate head available each pumping station, ft(*)	Pump efficiency, percent	Pump station cost, $ (≠)	Pumping station spacing-level terrain, ft
4	120	2.10	400+	45	47,000	19,048
6	280	1.40	450+	50	57,000	32,143
8	500	1.02	260	50	71,000	25,490
10	800	0.82	230	64	88,000	28,049
12	1,100	0.61	230	73	108,000	37,705
14	1,400	0.45	210	78	123,000	46,667
16	2,000	0.45	210(‡)	70	154,000	46,667
18	2,500	0.39	225(‡)	76	185,000	57,179
20	3,000	0.33	200(‡)	78	216,000	60,606

(*) Based on non clog, centrifugal, 1,780 rpm pumps.
(+) Pumps in series for additional head.
(‡) Pumps in parallel for additional capacity.
(≠) EPA Treatment Plant Index = 232.5.

TABLE 21. PIPELINE COST(*) (13) (14)

Pipeline size, in	Pipeline cost, \$/ft(+)
4	15.25
6	16.25
8	17.75
10	19.25
12	20.75
14	23.75
16	25.75
18	28.25
20	32.75
30	44.25

(*) Assumes: No rock and no major unusual problems; one major highway crossing per mile; one single rail crossing per 5 miles' nominal number of driveways and minor roads; EPA Sewer Index - 248.7

(+) Costs for installed pipelines buried 3 - 6 ft; for 6 - 10 ft of depth add 15 percent and for hard rock excavation, add 70 percent to the costs.

TABLE 22. PIPELINE CROSSING COSTS (13) (14)

Crossing	Unit cost(*), \$
Highway, two-lane	11,000
Highway, four-lane	13,000
Highway, divided multiple-lane	22,000
Railroad crossing (per track)	8,000
Small river	50,000
Major river	200,000

(*) These costs to be added to the applicable costs from Table 21.

TABLE 23. ANNUAL SLUDGE VOLUME

Liquid				Dewatered		Approximate secondary treatment plant size, mgd
Mg/year at 4 percent	Mode(*)	mg/year 10 percent	Mode	cu yd / year	Mode	
1.5	T-R	3	B	1,500	T	1
7.5	T-B-R	6	B	7,500	T-R	5
15	T-B-R-P	30	B	15,000	T-R	10
75	T-B-R-P	60	B	75,000	T-R	50
150	T-B-R-P	300	B	150,000	T-R	100
750	B-R-P		B	750,000	R	500
1,300	P					

(*) Mode Symbols: T = truck; B = barge; R = railroad; P = pipeline.

TABLE 24. TRANSPORT DISTANCE

One way distance, miles	Transport mode			
	Pipeline	Barge	Truck	Rail
5			X	
10	Any		X	
20	Distance	X	X	X
40		X	X	X
80		X	X	X
160		X		X
320		X		X

TABLE 25. TRANSPORT CYCLE TIMING

Mode		Average speed mph	Load time, minutes (hours)	Unload time minutes (hours)
Truck		25 for first 20 miles, 35 for rest	30	15
Barge		4	300	300
Railroad -	1 and 2 car unit	-	(5.5) (*)	(5.5) (*)
	4 and 10 car unit	-	(6) (*)	(6) (*)
	20 car unit	-	(7) (*)	(7) (*)
	100 car unit	-	(19) (*)	(19) (*)
Pipeline		-	-	-

(*) Includes 4 hours to makeup and spot cars.

TABLE 26. RAILROAD TRANSIT TIME (*)

One way distance, miles	Round trip transit time, days
20	4
40	4
80	6
160	7
320	8

(*) Based on information from Southern Pacific Railroad, Sacramento.

certain types of transport. This has been true for a case in Washington, D.C. where truck operations were restricted to daylight hours. The following assumptions have been made in this study regarding operations, however, this will vary widely.

Truck: 8 and 22 hours per day, 360 days per year (8 hours used for calculations).

Barge: 24 hours per day, 360 days per year as required.

Railroad: As required to load trains.

Pipeline: 8, 12, and 20 hours per day, 360 days per year.

TRANSPORT EQUIPMENT

There is a wide variety of equipment available for transporting sewage sludge. Each type of transport equipment is normally available in a number of configurations and sizes. For simplification, the following equipment was used as a basis for this study. Each size was applied to its practical limits and, in most cases, one size of equipment could not economically or practically cover the full range of sludge volume.

1. Truck
   - 1200-gal tank truck, gasoline
   - 2500-gal tank truck, diesel
   - 5500-gal semi-tank truck, diesel
   - 10-cu yd dump truck, gasoline
   - 15-cu yd dump truck, diesel
   - 30-cu yd semi-dump truck, diesel

   See Table 3 for truck characteristics

2. Barge
   - 300,000-gal barge
   - 500,000-gal barge
   - 840,000-gal barge

   See Table 8 for barge characteristics including 5,000,000 - and 2,000,000-gal sizes

3. Railroad
   - Single 20,000-gal tank cars
   - 10 unit tank train (20,000-gal cars)
   - 20 unit tank train (20,000-gal cars)
   - 100 unit tank train (20,000-gal cars)

   Tank cars must be provided by the shipper; either purchase, lease, or contract.

- 50-cu yd (35-ton) hopper or side dump car
- 100-cu yd (70-ton) hopper or side dump car

These cars are provided by the railroad when available. It is assumed in this study they are available, however, in actual cases they may have to be provided by the shipper.

4. Pipeline
   See Tables 19 and 20 for the pipeline and pumping station characteristics.

FACILITIES

A broad range of facilities (terminal installations) will be designed for sludge transport systems depending on climate, type of sludge, type of transport equipment, the design engineer, and other factors. The assumptions made for purposes of this study are shown in Table 27, realizing that wide deviations will be experienced in actual installations. In all cases it was assumed that these facilities were constructed concurrently with other plant construction work.

CAPITAL COSTS

All capital costs are amortized at 7 percent straight line over the following equipment life. All capital equipment is assumed to have zero residual value except trucks. Applicable amortization factors (capital recovery) are provided in Table 28.

Trucks, 6 years, 15 percent residual value.
Truck terminal facilities, 25 years.
Barges, 20 years.
Barge terminal facilities, 25 years.
Railroad cars, leased, 12 year, typical GATX terms.
Railroad terminal facilities, 25 years.
Pumping stations, 25 years.
Pipeline, 25 years.

OPERATION AND MAINTENANCE REQUIREMENTS

Operation and maintenance costs were calculated based on actual pumping time for energy, and on published estimating information or actual experience for other factors. Where published or actual information was not available the requirements were estimated. Where operation and maintenance personnel are required less than full time, it is assumed they can charge the balance of their time to other unit processes.

ESCALATION

Escalation factors are recommended for each item which is expressed in 1975 dollars. A summary of these escalation factors is shown in Table 29. All of these factors are readily available and continuously updated.

TABLE 27. TRANSPORT FACILITIES

Item	Transport mode			
	Truck	Railroad	Barge	Pipeline(#)
Liquid:				
Loading storage	No(+)	Yes	Yes	
Loading equipment	Yes	Yes	Yes	
Dispatch office	Yes	Yes	Yes	
Dock and control bldg.	N/A	N/A	Yes	
Railroad siding(s)	N/A	Yes	N/A	
Unloading equipment	Yes	Yes	Yes	
Unloading storage (*)	No	No	No	
Dewatered:				
Loading storage	Yes(≠)	Yes(≠)	N/A	N/A
Loading equipment	Yes	Yes	N/A	N/A
Dispatch office	Yes	Yes	N/A	N/A
Dock and control bldg.	N/A	N/A	N/A	N/A
Railroad siding(s)	N/A	Yes	N/A	N/A
Unloading equipment	Yes	Yes	N/A	N/A
Unloading storage	No(*)	No(*)	N/A	N/A

(*) Storage assumed to be a part of another unit process.
(+) Storage required for one or two truckloads is small compared with normal plant sludge storage.
(≠) Elevated storage for ease of gravity transfer to trucks and rail cars.
(#) Pipeline facilities consist of pipeline and pumping stations.

TABLE 28. AMORTIZATION FACTORS

Amortization period, years	Amortization rate, percent	Amortization factor (capital recovery factor)
6	6	0.20336
	7	0.20980
	8	0.21632
	10	0.22961
	12	0.24323
20	6	0.08718
	7	0.09439
	8	0.10185
	10	0.11746
	12	0.13388
25	6	0.07823
	7	0.08581
	8	0.09368
	10	0.11017
	12	0.12750

TABLE 29. SUMMARY OF ESCALATION FACTORS

Factor	Source	Base factor for this study
EPA Treatment Plant Index	EPA	232.5 (April, 1975)
EPA Sewer Index	EPA	248.7 (April, 1975)
WPI Item 1412 - Motor Vehicle Parts	U.S. Dept. of Labor(*)	170.3
WPI Item 141102 - Motor Trucks	U.S. Dept. of Labor	150.2
WPI Item 114 - General Purpose Machinery and Equipment	U.S. Dept. of Labor	174.8
WPI Item 107 - Fabricated Structural Metal Parts	U.S. Dept. of Labor	189.9
WPI Item 144 - Railroad Equipment	U.S. Dept. of Labor	201.8
WPI Item 11410207.03 - Centrifugal Pump, 1,000 gpm, 130 ft, 1750 rpm	U.S. Dept. of Labor	139.2
Railroad Rates	Railroad Rate Depts.	November 30, 1975

(*) U.S. Dept. of Labor Wholesale Price Indexes (WPI) are published monthly in "Wholesale Prices and Price Indexes", Library of Congress Catalog Number L53-140.

GENERAL ASSUMPTIONS

The following general assumptions and unit costs were used in this study as applicable.

1. Truck fuel $.60 per gal.

2. Electricity $0.04 per kwh.

3. All labor at $8.00 per hour including fringes.

4. General, overhead, and administrative costs at 25 percent of total operation and maintenance cost.

5. Level terrain for pipeline.

6. Where not needed full time, operation and maintenance personnel can charge balance of their time to other unit processes.

SECTION 4

SPECIAL TRANSPORT MODE CONSIDERATIONS

A number of assumptions must be made in a study of this type especially where manual calculations are required. As mentioned before, the computer program should be flexible enough to allow rather broad operating parameters. Some of the special considerations for each transport mode are outlined herein along with a discussion of some of the more influential parameters for each mode.

TRUCK TRANSPORT

In some cases, truck operations will be limited to daylight hours or to certain routes by local requirement. The study assumed 8 hour per day operation. The most cost effective utilization of capital equipment is continuous operation, but this may not be possible in all cases. The effect of the daily operation hours on number of trucks is shown in Tables 4 and 5. The effect is significant. There are many different types and configurations of trucks available, however, general purpose type trucks were selected for this study. This selection coincides with previous work.[20] Truck transport was based on agency ownership and operation of trucks and facilities. In many cases the trucks will be provided and operated by a contractor in which cases profit should be included in calculations.

BARGE TRANSPORT

In general, the larger barges are much more cost effective than smaller barges. Larger barges have deeper drafts and, therefore, may not be practical for many inland waterways. The major factor in barging is the cost of tug (towing) services and the larger barges minimize this cost. This is illustrated in the example in Appendix B. This study was based on barges up to 850,000-gal size, but barge data is included for larger barges up to 2,000,000-gal size. It is easy to incorporate these larger sizes in manual calculations as shown in Appendix B, but, practically, these larger barges may not be applicable to many cases. Barge transit times will be variable depending on traffic, draw bridges, locks, tides, currents, and other factors. The average speed of 4 mph used in this study is an average and speeds in open water may exceed 7 mph. The use of self propelled barges is practiced by New York City, but most agencies use standard barges and a towing service. The tug is a more versatile power unit and, in general, smaller crews can be used than with self propelled barges according to a west coast tug operator. The barge is normally unmanned during transit[5]. The tug crew is immaterial to this study, but may consist of 4 to 6 persons at an average hourly rate of $13.00 including fringes, according to west coast operators. The tug billing time is based on round trip transit time and unloading time plus 15 percent for miscellaneous use. The fuel calculation time is based on round trip transit time plus 15 percent.

Loading is normally accomplished by either a gravity pipeline[5] or pump(s) and pipeline[7] from a storage tank. A barge is normally filled in 2 to 5 hours according to personal communications with several existing operations.

Unloading requires a pump(s) and pipeline to a storage system[7]. The pump can be barge or dock mounted and can be diesel or electric.

Barge transport was based on agency ownership and operation of barges and facilities and contract towing. In many cases, the barge operation will be performed by a contractor and profit should be included in calculations.

RAILROAD TRANSPORT

A significant factor in rail transport relates to the cars and their use. Railroads may provide hopper type cars for dewatered sludge if they are available, however, the shipper will usually have to provide tank cars according to railroad companies. Tank cars are normally leased from a manufacturer on a full maintenance basis. The number of tank cars required is related to the round trip transit time and this time can be significant. This study was based on timing experienced by Southern Pacific in California. The times may be reduced in special cases and this will have a significant effect on the number of rail tank cars needed and, hence, on capital or lease costs.

Rail rates vary widely, but in general, rates in various parts of the country vary according to the following average according to an experienced rail traffic consultant.

Area	Approximate Railroad Rate Variation
North Central and Central	Average rate as outlined herein
Northeast	25 percent higher than average
Southeast	25 percent lower than average
Southwest	10 percent lower than average
West Coast	10 percent higher than average

The rates used in this study were adjusted to the average National level (North Central and Central). Obtaining representative typical rates from railroad companies is very difficult, however, the following average rates were used in this study. These rates were current on November 30, 1975 and can be adjusted by applying subsequent published rate increases.

One way distance, miles	Rate, $/net ton
20	2.10
40	3.00
80	4.10
160	6.50
320	12.50

The railroads generally allow a rebate of $0.06 to $0.20 per mile per car if the shipper provides the car. In this study, a rebate of $0.15 was assumed.

Rail transport was based on agency ownership and operation of the facilities, agency leasing and operation of tank cars, railroad supply of dewatered sludge cars, and railroad movement of all cars. There are very few past and present examples of rail transport of sewage sludge to use for guidelines.

PIPELINE TRANSPORT

A number of assumptions were made for this study, and most are related to past or present actual operations. The liquid sludge was assumed to be reasonably free of grit and grease, similar to anaerobic digester effluent.

Raw sludge can also be transported by pipeline, but the grease may require additional maintenance. The solids content does not affect the calculations within the range of 0 to 4 percent solids. The minimum pipeline size considered in this study is 4 in. Although the literature describes installations with smaller pipelines[8], these small pipelines represent special design cases, and are, therefore, not covered in this general study.

Sludge pumps are assumed to be of the dry pit, horizontal or vertical, nonclog or slurry centrifugal type operating at 1,780 rpm. Lower speed pumps are available and might be selected for specific projects depending on the special conditions. These pumps are relatively inefficient at low flows, but approach 80 percent efficiency at optimum conditions. They are widely used for sludge pumping applications[9][10][11]. Other types are used, but this study did not attempt to optimize the pumping for each pipeline size. The assumed pump characteristics are shown in Table 20 and are based on manufacturers' published data[12]. Because of the high friction loss in the 4 and 6 in pipelines the corresponding pumping stations for these lines contain more than one pump in series in order to develop higher pumping heads and minimize the number of stations. Two pumps are operated in parallel for the 16, 18, and 20 in pipelines because of the high flows. Each pumping station contains facilities for pipeline cleaning, pig handling, and macerators to assure a controlled maximum particle size in the pumped sludge. Operating experience from existing installations indicates that special conditioning of liquid sludge is not required prior to transport by pipeline except for macerators which are used in some installations. Most pipelines do have facilities for routine cleaning and plastic pigs are commonly used.

Pig insertion and retrieval facilities are included in the pumping stations and the operation and maintenance costs include those associated with the use of pigs.

The pipeline is based on use of cement lined cast iron or ductile iron which is typical for sludge pipelines. The cement lining provides long life and a smooth interior surface. A "C" factor of 90 is used for purposes of hydraulic calculations [9] [10]. Installation is assumed to be in normal soil conditions with average shoring and water problems typical to shallow force main installations. Installation is assumed to be above hard rock. The pipeline installed cost in Table 21 includes on major highway crossing per mile and one single track railroad crossing per five miles plus a number of driveway and several minor road crossings per mile. These costs should be typical for average installations to be expected for sludge pipelines. The pipeline costs were developed from recent Engineering News Record bid breakdowns [13] and a summary prepared by a major consulting engineer [14]. The construction cost of small pipelines has increased at a rate much greater than the construction indexes would indicate from past reported costs [15] [16] especially when considering an average number of driveway, road, highway, and rail crossings.

The literature indicates that sludge pipeline velocity can range from about 2.5 to 8 fps for satisfactory operation, but a velocity of 2.5 to 3.0 fps is used by a number of consultants in pipeline design [9] [10].

The pipelines in this study were designed based on an operating velocity of 3 fps. The resulting pipeline sizing agrees within one pipe size to that used by Smith [15] and developed by Linaweaver and Clark [16].

The depth of the pipeline will not affect the capital cost within the range of 3 to 6 ft of burial in normal soil. Most sludge pipeline installations will be within this depth range. For burial depths up to 10 ft the pipeline unit capital cost should be increased 15 percent.

Hard rock excavation can normally be avoided in installing pressure pipelines, but may be unavoidable in some areas. The pipeline unit capital cost should be increased 70 percent for those lengths where hard rock excavation is necessary.

The operation and maintenance costs for the pumping stations include pipeline operation and maintenance. The operation costs for the pipeline itself are insignificant to the other costs [15].

Sludge pumping station costs were determined from the Black & Veatch study [1] for raw wastewater pumping stations, adjusted for cost escalation using the EPA Treatment Plant Index, and then compared to actual and proposed sludge pumping stations [9] [17]. The estimated costs for raw wastewater pumping stations as presented in the Black & Veatch Study were felt to represent the closest relationship to the dilute sludge pumping stations in this study because they included some form of pretreatment and because special excavation costs were not included (piling, rock, and special dewatering). The costs correlated well with examples of dilute sludge pumping stations actually bid or studied.

The operation and maintenance labor and supplies will vary to a degree with the number of hours of operation per day, but the difference in the total costs is insignificant so these factors were considered constant for a given size pipeline.

Proper design of sludge pipelines should provide nearly 100 percent availability and, therefore, auxiliary sludge storage volume is not provided in this study. Normal plant sludge storage should be adequate.

Facilities at the discharge end of the pipeline such as lagoons, dewatering equipment, or spreading equipment are assumed to be a part of other unit processes.

Pipeline transport was based on agency ownership and operation of all portions of the system.

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METRIC CONVERSIONS

English Unit	Multiplier	Metric Unit
cu ft	0.028	cu m
cu ft	28.32	l
cu yd	0.765	cu m
ft	0.3048	m
fps	0.3048	mps
gal	0.003785	cu m
gal	3.785	l
gpm	0.0631	l/sec
hp	0.7457	kw
in	2.54	cm
lb	0.454	kg
lb/cu ft	0.016	g/cu m
mgd	3,785	cu m/day
mile	1.61	km
mpg	0.425	km/l
mph	1.6	km/h
sq ft	0.0929	sq m
mg	3,785	cu m
ton	0.907	metric ton

MANUAL CALCULATION OF TRANSPORT COST USING COST COMPONENTS

A. Point to point haul cost, $/year

1. Fuel

(Annual gal used, from Figure 22 or 23) (Cost, $) = $__________

2. Truck maintenance (excluding driver and fuel)

(Annual truck miles, from Figures 24 or 25) (Cost, $/mile, from Table 3) (Current WPI Item 1412 / 170.3) = $__________

3. Truck driver

(Annual driver man-hours, from Figure 26 or 27) (Cost, $/man-hour with fringes) = $__________

4. Total direct truck operation and maintenance

Add results of paragraphs 1, 2, and 3 = $__________

5. Total truck operation and maintenance with overhead and supervision

(Total direct truck operation and maintenance cost, $) (1.25) = $__________

6. Truck amortization

[(Total truck investment, from Table 3) − (Residual Value, Normally 15 percent of new)] (Current WPI Item 141102 / 150.2) (Amortization factor, from Table 28) + (Residual value) (Interest rate) = $__________

7. Total annual point to point truck haul cost

Add results of paragraphs 5 and 6. = $__________

B. Facilities cost, $/year

1. Facilities amortization (assume no residual value). Determine facilities capital cost from Table 6 or 7 or other information. Be sure to consider both loading and unloading facilities.

(Facilities capital cost, $) (Current EPA Plant Index / 232.5) (Amortization factor, from Table 28) = $__________

2. Facilities operation and maintenance, see Table 6 or 7.

a. Electrical energy

(Electrical energy, kwh) (Cost, $/kwh) = $__________

b. Operation and maintenance labor

$$\left(\begin{array}{c}\text{Labor,}\\ \text{man-hours}\end{array}\right)\left(\begin{array}{c}\text{Cost, \$/}\\ \text{man-hour}\\ \text{with}\\ \text{fringes}\end{array}\right) = \$\_\_\_\_\_\_\_\_\_\_$$

c. Maintenance supplies

$$\left(\text{Supplies, \$}\right)\left(\frac{\text{Current WPI Item 114}}{174.8}\right) = \$\_\_\_\_\_\_\_\_\_\_$$

d. Total direct facilities operation and maintenance
Add results of Paragraphs 2a, b, and c = $__________

3. Total facilities operation and maintenance with overheads and supervision

$$\left(\begin{array}{c}\text{Total direct}\\ \text{facilities}\\ \text{operation and}\\ \text{maintenance}\\ \text{cost, \$}\end{array}\right)\left(1.25\right) = \$\_\_\_\_\_\_\_\_\_\_$$

4. Facilities annual cost
Add results of Paragraphs 1 and 3 = $__________

C. Total annual cost
Add results of Paragraphs A7 and B4 = $__________

D. Total annual cost, $/dry ton-mile one way

1. Dewatered

$$\frac{\text{Total annual cost, \$}}{\left(\begin{array}{c}\text{Annual}\\ \text{volume,}\\ \text{cu yd}\end{array}\right)\left(\frac{27\text{ cu ft}}{\text{cu yd}}\right)\left(\frac{55\text{ lb}}{\text{cu ft}}\right)\left(\frac{\text{ton}}{2{,}000\text{ lb}}\right)\left(\frac{\text{Percent solids}}{100}\right)\left(\begin{array}{c}\text{One way haul}\\ \text{distance, miles}\end{array}\right)} = \$\_\_\_\_\_\_\_\_\_\_$$

2. Liquid

$$\frac{\text{Total annual cost, \$}}{\left(\begin{array}{c}\text{Annual}\\ \text{volume,}\\ \text{gal}\end{array}\right)\left(\frac{8.33\text{ lb}}{\text{gal}}\right)\left(\frac{\text{ton}}{2{,}000\text{ lb}}\right)\left(\frac{\text{Percent solids}}{100}\right)\left(\begin{array}{c}\text{One way haul}\\ \text{distance, miles}\end{array}\right)} = \$\_\_\_\_\_\_\_\_\_\_$$

E. Add contractor profit to any portions of work performed under private contract (normally 7 percent).

ILLUSTRATIVE MANUAL CALCULATION

A. Example for Metropolitan Denver Sewage Disposal District No. 1, 1975.

B. Conditions:[4]
1. Dewatered sludge, 16 percent solids
2. 24 hour, 7 day operation
3. Contract haul plus spreading, less facilities
4. 3,000 cu yd/week guaranteed minimum, 156,000 cu yd/year
5. 30 cu yd semi-trailer trucks
6. One way distance approximately 24 miles
7. Unit price haul and disposal 1975-76 $3.52; estimated haul only $2.30

C. Calculated cost, $/year

1. Fuel cost
(65,000 gal) x $0.60 = $39,000 (Figure 23)
2. Truck maintenance
(250,000 miles) x $0.30 = 75,000 (Figure 25 and Table 3)
3. Truck driver
(13,000 man-hours) x $8.00 = 104,000 (Figure 27)
Subtotal truck operation and maintenance = 218,000
4. Total truck operation and maintenance with overheads
($218,000) x 1.25 = 272,500

5. Truck amortization (3 year amortization, 10 percent interest for private company) Using formula from paragraph A.6, Appendix A, Cost = 53,520

6. Contractor profit (Total cost) (0.07) = 22,820

Total Calculated point to point cost = $348,840

D. Actual costs, Metropolitan Denver Sewage Disposal District No. 1 at minimum or $2.30 per cu yd. = $358,800

= $ 2.30/cu yd

E. The District of Columbia recently received a bid of $3.50/wet ton (approximately $2.36 per cu yd) for hauling dewatered digested sludge 26 miles one way with open dump vehicles.

APPENDIX B. BARGE TRANSPORT

MANUAL CALCULATION OF TRANSPORT COST USING COST COMPONENTS

A. Point to point haul cost, $/year

1. Barge maintenance

   (Barge maintenance cost, from Table 8) (Current WPI Item 107 / 189.1) (Number of barges from Table 9 or 10) = $__________

2. Towing cost

   (Tug billing time, hours/year, from Figure 28 or 29 or Table 9 or 10) (Tug billing rate, $/hour) = $__________

3. Barge amortization

   (Number of barges required, from Table 9 or 10) (Barge capital cost, $, from Table 8) (Amortization factor from Table 28) (Current WPI Item 107 / 189.1) = $__________

4. Tug fuel (information only), gal/year

   (Tug running time, days, from Table 9 or 10) (Tug fuel usage gal/day, from Table 8) = $__________

5. Total annual point to point haul cost

   Add results of paragraphs 1, 2, and 3 = $__________

B. Facilities cost, $/year

1. Facilities amortization

   Determine facilities capital cost from Table 11 or 12 or other information. Be sure to consider both loading and unloading facilities.

   (Facilities capital cost, $) (Current EPA Treatment Plant Index / 232.5) (Amortization factor, from Table 28) = $__________

2. Facilities operation and maintenance, see Tables 11 or 12.

   a. Sludge holding and pumping maintenance

      (Labor, man-hours) (Cost man-hour $/ with fringes) = $__________

   b. Sludge holding and pumping maintenance supplies

      (Supplies, $, from Table 14 or 15) (Current WPI Item 114 / 174.8) = $__________

c. Sludge holding and pumping operation

$\left(\text{Labor, man-hours/ barge trip}\right) \left(\text{Barge trips/ year, from Table 9 or 10}\right) \left(\text{Cost \$/ hour with fringes}\right)$ = $________

d. Dock maintenance

$\left(\text{Dock maintenance, \$}\right) \left(\frac{\text{Current WPI Item 114}}{174.8}\right)$ = $________

e. Electrical energy

$\left(\text{Electrical energy, kwh}\right) \left(\text{Cost, \$/kwh}\right)$ = $________

f. Total direct facilities operation and maintenance

Add results of paragraphs 2a,b,c,d, & e = $________

3. Total facilities operation and maintenance with overheads and supervision

$\left(\text{Total direct facilities operation and maintenance cost, \$}\right) (1.25)$ = $________

4. Facilities annual cost

Add results of paragraphs 1 and 3 = $________

C. Total annual cost

Add results of paragraphs A5 and B4 = $________

D. Total annual cost, $/dry ton-mile one way

$$\frac{\text{Total annual cost, \$}}{\left(\text{Annual volume, gal}\right)\left(\frac{8.33\text{ lb}}{\text{gal}}\right)\left(\frac{\text{ton}}{2{,}000\text{ lb}}\right)\left(\frac{\text{Percent solids}}{100}\right)\left(\text{One way haul distance, miles}\right)}$$ = $________

E. Add contractor profit to any portions of work performed under private contract (normally 7 percent)

ILLUSTRATIVE MANUAL CALCULATION

A. Example for City of Philadelphia, 1975.

B. Conditions:
1. Liquid sludge, approximately 10 percent solids
2. Contract barge operation
3. Discharge at sea
4. 150 million gal per year
5. Barge capacity approximately 2 million gal
6. One way distance 150 miles
7. Contract price $9.10/1,000 gal
8. Average 2 1/2 trips per week
9. Round trip time, 48 hours

C. Calculated cost, $/year

1. Barge maintenance ($35,000) (1)	=	$35,000
2. Towing cost (Round trip time) (Trips/year) (Hourly charge) (1.15) (48) (130) (160) (1.15)	=	1,148,160
3. Barge amortization (1) ($3,000,000) (0.09439)	=	283,170
4. Total annual barging cost	=	1,466,330
5. Contractor profit ($1,466,330) (0.07)	=	102,643
Total calculated cost	=	$1,568,973
	=	$10.46/1,000 gal

NOTE: The study figures were not used in this calculation because the barge size was greater than that used in the figures. The barge draft for large size barges may be too great for many applications, therefore, smaller barges were used in preparation of the figures in this study. This example illustrates the ease of calculating special cases using barge data in Table 8 and the basic formulas in Appendix B. This example also illustrates the economics of large barges. If a 850,000-gal barge size were used, the cost would have been approximately $21/1,000 gal or double. The difference is the increased towing time which is the major cost item.

MANUAL CALCULATION OF TRANSPORT COST USING COST COMPONENTS

A. Point to point haul cost, dewatered sludge, $/year

$$\left(\begin{array}{c}\text{Annual}\\\text{sludge}\\\text{volume,}\\\text{cu yd}\end{array}\right)\left(\frac{27\text{ cu ft}}{\text{cu yd}}\right)\left(\frac{55\text{ lb}}{\text{cu ft}}\right)\left(\frac{\text{ton}}{2{,}000\text{ lb}}\right)\left(\begin{array}{c}\text{Rail rate,}\\\text{\$/ton}\end{array}\right)$$

= $ ______________

This is the total point to point cost

B. Point to point haul cost, liquid sludge, $/year

1. Railroad charges

$$\left(\begin{array}{c}\text{Annual}\\\text{sludge}\\\text{volume,}\\\text{mg}\end{array}\right)\left(\frac{8.33\times10^{6}\text{ lb}}{\text{mg}}\right)\left(\frac{\text{ton}}{2{,}000\text{ lb}}\right)\left(\begin{array}{c}\text{Rail rate,}\\\text{\$/ton}\end{array}\right)$$

= $ ______________

(Current rail rate can be determined by escalating the rates in the study by subsequent increases)

2. Railroad mileage credit (for shipper supplied cars)

$$\left(\begin{array}{c}\text{Round trip}\\\text{haul distance,}\\\text{miles}\end{array}\right)\left(\begin{array}{c}\text{Trips}\\\text{per}\\\text{year}\end{array}\right)\left(\begin{array}{c}\text{Railroad}\\\text{mileage}\\\text{credit,}\\\text{\$/mile}\end{array}\right)$$

= $ ______________

3. Rail tank car leasing (including maintenance)

$$\left(\begin{array}{c}\text{Number of}\\\text{tank cars}\\\text{required,}\\\text{from Table}\\\text{13}\end{array}\right)\left(\begin{array}{c}\text{Annual full}\\\text{maintenance}\\\text{lease rate, \$}\end{array}\right)$$

= $ ______________

4. Total annual point to point haul cost, liquid sludge
   Add results of paragraphs B1 and 3 and subtract B2

= $ ______________

C. Facilities cost, $/year

1. Facilities amortization
   Determine facilities capital cost from Table 15 or 16 or other information. Be sure to consider both loading and unloading facilities.

$$\left(\begin{array}{c}\text{Facilities}\\\text{capital}\\\text{cost, \$}\end{array}\right)\left(\frac{\begin{array}{c}\text{Current EPA}\\\text{treatment}\\\text{plant index}\end{array}}{232.5}\right)\left(\begin{array}{c}\text{Amortization}\\\text{factor - from}\\\text{Table 28}\end{array}\right)$$

= $ ______________

2. Facilities operation and maintenance, see Tables 15 and 16.
   a. Sludge holding and pumping maintenance

$$\left(\begin{array}{c}\text{Labor,}\\\text{man-hours}\end{array}\right)\left(\begin{array}{c}\text{Cost,}\\\text{\$/man-hour}\\\text{with fringes}\end{array}\right)$$

= $ ______________

b. Sludge holding and pumping supplies

$$\left(\text{Supplies, } \$\right)\left(\frac{\text{Current WPI Item 114}}{174.8}\right) = \$\_\_\_\_\_\_\_\_$$

c. Sludge holding and pumping operation

$$\left(\text{Labor, man-hours}\right)\left(\text{Cost, \$/man-hour with fringes}\right) = \$\_\_\_\_\_\_\_\_$$

d. Rail maintenance

$$\left(\text{Rail maintenance, } \$\right)\left(\frac{\text{Current WPI Item 144}}{201.8}\right) = \$\_\_\_\_\_\_\_\_$$

e. Electrical energy

$$\left(\text{Electrical energy, kwh}\right)\left(\text{Cost, \$/kwh}\right) = \$\_\_\_\_\_\_\_\_$$

f. Total direct facilities operation and maintenance

Add results of paragraphs 2a, b, c, d, and e

3. Total facilities operation and maintenance with overheads and supervision

$$\left(\text{Total direct facilities operation and maintenance Cost, } \$\right)\left(1.25\right) = \$\_\_\_\_\_\_\_\_$$

4. Facilities annual cost

Add results of paragraphs 1 and 3 = $________

D. Total annual cost

1. Dewatered sludge

Add results of paragraphs A and C4 = $________

2. Liquid sludge

Add results of paragraphs B4 and C4 = $________

E. Total annual cost, $/dry ton-mile one way

1. Dewatered

$$\frac{\text{Total annual cost, } \$}{\left(\text{Annual volume, cu yd}\right)\left(\frac{27 \text{ cu ft}}{\text{cu yd}}\right)\left(\frac{55 \text{ lb}}{\text{cu ft}}\right)\left(\frac{\text{ton}}{2{,}000 \text{ lb}}\right)\left(\frac{\text{Percent solids}}{100}\right)\left(\text{One way haul distance, miles}\right)} = \$\_\_\_\_\_\_\_\_$$

2. Liquid

$$\frac{\text{Total annual cost, } \$}{\left(\text{Annual volume, gal}\right)\left(\frac{8.33 \text{ lb}}{\text{gal}}\right)\left(\frac{\text{ton}}{2{,}000 \text{ lb}}\right)\left(\frac{\text{Percent solids}}{100}\right)\left(\text{One way haul distance, miles}\right)} = \$\_\_\_\_\_\_\_\_$$

F. Add Contractor profit to any portions of work performed under private contract (normally 7 percent).

ILLUSTRATIVE MANUAL CALCULATION

A. Conditions:
1. Liquid sludge, 4 percent
2. 24 hour, 365 day operation
3. Tank cars owned by agency
4. 75 mg sludge per year
5. 160 mile one way haul
6. 20,000-gal tank cars
7. Complete operation by agency

B. Calculated cost, $/year
1. Railroad charges

$$(75 \times 10^6)\left(\frac{8.33}{2000}\right)(\$6.50) = \$2{,}030{,}438$$

2. Railroad mileage credit
(320) (3,750) ($0.15) = (180,000) credit
3. Rail tank car full maintenance lease
(78) ($5,640/year) = 439,920
4. Facilities amortization
(382,000) (0.08581) = 32,780
5. Facilities operation and maintenance
   a. Sludge handling and pumping maintenance
      (340) (8.00) = 2,720
   b. Sludge holding and pumping supplies = 2,237
   c. Sludge holding and pumping operation
      (9,000) (8.00) = 72,000
   d. Rail maintenance = 4,000
   e. Electrical energy = 1,800
   f. Total direct facilities
      operation and maintenance = 82,757
6. Total facilities operation and maintenance
with overheads and supervision
($82,757) (1.25) = $103,446
7. Facilities annual cost = 136,226
8. Total annual cost = $2,426,584
9. Cost per dry ton - mile one way

$$\frac{(2{,}000)\ (\$2{,}426{,}584)\ (100)}{(75 \times 10^6)\ (8.33)\ (4)\ (160)} = \$1.21$$

APPENDIX D. PIPELINE TRANSPORT

MANUAL CALCULATION OF TRANSPORT COST USING COST COMPONENTS

A. Determine pipeline size from project information or from sludge volume and daily hours of operation and Table 19.

B. Pipeline capital cost, $/year

1. Pipeline

$$\left(\text{Pipeline length, ft}\right)\left(\text{Unit cost, \$/ft, from Table 21}\right)\left(\frac{\text{Current EPA Pipeline Index}}{248.7}\right) = \$\_\_\_\_\_\_\_\_$$

Note: Increase costs for any deep trenching or rock excavation, see Table 21.

2. Extra railroad crossings, $

(Pipeline unit costs in Table 21 assume one crossing per 5 miles)

$$\left(\text{Rail crossings}\right)\left(\text{Unit cost, \$ from Table 22}\right)\left(\frac{\text{Current EPA Pipeline Index}}{248.7}\right) = \$\_\_\_\_\_\_\_\_$$

3. Major road crossings, $

(Pipeline unit costs in Table 21 assume one major road crossing per mile)

$$\left(\text{Major road crossings}\right)\left(\text{Unit cost, \$ from Table 22}\right)\left(\frac{\text{Current EPA Pipeline Index}}{248.7}\right) = \$\_\_\_\_\_\_\_\_$$

4. Pipeline amortization

$$\left(\text{Add results of paragraphs 1,2,3}\right)\left(\text{Amortization factor from Table 28}\right) = \$\_\_\_\_\_\_\_\_$$

C. Pumping station capital amortization and operation and maintenance, $/year

1. Electrical energy

$$\left(\text{Cost, \$/kwh}\right)\left(\text{Annual kwh/ft head, from Table 17}\right)\left[\left(\text{Pipeline length, 100 ft}\right)\left(\text{Hydraulic loss, ft/100 ft pipeline, from Table 20}\right) + \left(\text{Pipeline elevation change, } \pm \text{ ft}\right)\right] = \$\_\_\_\_\_\_\_\_$$

2. Number of pumping stations

$$\frac{\left(\text{Total system head, ft (Pipeline loss + elevation)}\right)}{\left(\text{Head per pumping station, from Table 20}\right)} = \text{pumping stations required}$$

3. Operation and maintenance labor

$$\left(\text{Number of pumping stations}\right)\left(\text{Operation and maintenance, man-hours, from Table 18}\right)\left(\text{Cost, \$/man-hour with fringes}\right) = \$\_\_\_\_\_\_\_\_$$

4. Operation and maintenance supplies and parts

$\left(\begin{array}{l}\text{Number of}\\ \text{pumping}\\ \text{stations}\end{array}\right) \left(\begin{array}{l}\text{Operation and}\\ \text{maintenance,}\\ \text{man-hours, from}\\ \text{Table 18}\end{array}\right) \left(\begin{array}{l}\text{Cost, \$/}\\ \text{man-hour}\\ \text{with}\\ \text{fringes}\end{array}\right)$ = $______________

5. Total operation and maintenance with overhead and supervision

$\left(\begin{array}{l}\text{Add results of}\\ \text{paragraphs 1,}\\ \text{3 and 4}\end{array}\right) (1.25)$ = $______________

6. Pumping station amortization

$\left(\begin{array}{l}\text{Number of}\\ \text{pumping}\\ \text{stations}\end{array}\right) \left(\begin{array}{l}\text{Cost per}\\ \text{station,}\\ \text{\$, from}\\ \text{Table 20}\end{array}\right) \left(\frac{\text{EPA Current Plant Index}}{232.5}\right) \left(\begin{array}{l}\text{Amortization}\\ \text{factor, from}\\ \text{Table 28}\end{array}\right)$ = $______________

D. Total annual cost

Add results of paragraphs B4 and C6 = $______________

E. Total annual cost, $/dry ton-mile

$$\frac{\text{Total annual cost, \$}}{\left(\begin{array}{l}\text{Annual}\\ \text{volume,}\\ \text{gal}\end{array}\right)\left(\frac{8.33 \text{ lb}}{\text{gal}}\right)\left(\frac{\text{ton}}{2{,}000 \text{ lb}}\right)\left(\frac{\text{Percent solids}}{100}\right)\left(\begin{array}{c}\text{Pipeline length,}\\ \text{miles}\end{array}\right)}$$ = $______________

F. Add contractor profit to any portions of work performed under private contract (normally 7 percent).

ILLUSTRATIVE MANUAL CALCULATION

A. Conditions:

1. Liquid sludge, 4 percent, digested
2. 30 miles
3. 75 mg sludge per year
4. Complete operation by agency
5. 12 hours pumping per day
6. Current EPA Pipeline Index - 248.7
7. No special extra crossings or excavation
8. Amortization over 25 years at 7 percent
9. No elevation change in pipeline
10. Electrical energy $0.02/kwh and labor $8.00/hour including fringes

B. Calculated cost

1. Pipeline size, from Table 19; 6 in, 75 mg per year or 0.2 mgd
2. Pipeline capital cost, $, Table 21
   (30) (5280) ($16.25) = $2,574,000
3. Pipeline amortization, $/year
   ($2,574,000) (0.08581) 220,875
4. Pumping station electrical energy, $/year, Table 17
   $(\$0.02)\ (567) \left[\frac{(30)\ (5280)}{100}\right] (1.4) + 0 = \$25{,}148$
5. Number of pumping stations, Table 20
   $\frac{2218}{450} = 5$
6. Operation and maintenance labor, $/year, Table 18
   (5) (720) ($8.00) = $28,000
7. Operation and maintenance supplies and parts, $/year, Table 18
   (5) ($670) (1) = $3,350
8. Total operation and maintenance with overhead and supervision, $/year
   ($25,148 + $28,800 + $3,350) (1.25) = $71,623
9. Pumping station amortization, $/year
   (5) ($57,000) (1) (0.08581) = $24,456
10. Total annual cost, $/year
    $220,875 + $24,456 + 71,623 = $316,954

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-77-216	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE TRANSPORT OF SEWAGE SLUDGE		5. REPORT DATE December 1977 (Issuing Date) 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) William F. Ettlich		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Culp/Wesner/Culp Clean Water Consultants Box 40 El Dorado Hills, California 95630		10. PROGRAM ELEMENT NO. 1BC611 11. CONTRACT/GRANT NO. Contract No. 68-03-2186
12. SPONSORING AGENCY NAME AND ADDRESS Municipal Environmental Research Laboratory--Cin.,OH Office of Research & Development U. S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final 14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES
Project Officer: Francis L. Evans, III, EPA-MERL-WRD, Cincinnati, OH 45268, 513/684-7610
Task Director: Dr. J. B. Farrell, EPA-MERL-WRD, Cinti., OH

16. ABSTRACT

This project was initiated with the overall objective of developing organized information pertaining to the costs of various sewage sludge transport systems. Transport of liquid and dewatered sludge by truck and rail and liquid sludge by barge and pipeline is included. The report contains the method used in preparing the cost data and the data is organized to facilitate manual calculation of total transport costs for a variety of conditions.

The data includes the installed cost for each system, sludge processing requirements, fuel consumption, manpower, and other operation and maintenance requirements. Loading, unloading, and sludge handling facilities construction costs and operation and maintenance requirements are tabulated separately from the requirements for direct hauling so the data can be applied to a variety of specific applications.

Results of the study are related in tabular and graphical presentations to appropriate single haul parameters; cubic yards for dewatered sludge and gallon for liquid sludge.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Sludge, Sludge digestion, Sludge disposal, Sludge drying, Transportation, Highway transportation, Marine transportation, Pipeline transportation, Rail transportation, Cost comparison, Cost analysis, Cost estimates, Prices	Sludge treatment, Sludge transport (truck, rail, barge, pipeline), Liquid sludge disposal systems, Dewatered sludge disposal systems, Ocean transportation	13B

18. DISTRIBUTION STATEMENT Release to public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 98
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ERRATA TO

TRANSPORT OF SEWAGE SLUDGE

(EPA-600/2-77-216, December 1977, NTIS PB278195/AS)

ERRATA CHANGES

Page 35, Figure 28 -- Change ordinate (y-axis) from ANNUAL TUG BILLING TIME, hours to ANNUAL TUG BILLING TIME, 1000 hours.

Page 36, Figure 29 -- Change ordinate (y-axis) from ANNUAL TUG BILLING TIME, hours to ANNUAL TUG BILLING TIME, 1000 hours.

Page 43, Table 7 -- Change Annual sludge volume, cu yd to Annual sludge volume, 1000 cu yd.

Page 53, Table 16 -- Change under 7.5 and 15 Annual sludge volume, 1000 cu yd heading, the last line in Table item--Electrical energy, kwh--from 92,000 to 40,000 under 7.5 heading and from 92,000 to 50,000 under 15 heading.

Page 54, Table 17 -- Change note bottom of Table shown as (*) Motor efficiency = 90%[19]; pump efficiency = 80%; kw/1000 gph-ft head = $\frac{0.00315}{\text{(Pump eff)(Motor eff)}}$

to

(*) Motor efficiency = 90%[19]; pump efficiency as shown in Table 20; kw/1000 gph-ft head = $\frac{0.00315}{\text{(Pump eff)(Motor eff)}}$.

Page 59, Table 23 -- Substitute Table 23 as shown below for Table 23 in report on Page 59.

TABLE 23. ANNUAL SLUDGE VOLUME

Liquid				Dewatered		Approximate secondary treatment plant size, mgd
Mg/year at 4 percent	Mode(*)	mg/year 10 percent	Mode	cu yd/ year	Mode	
1.5	T-R			1,500	T	1
7.5	T-B-R	3	B	7,500	T-R	5
15	T-B-R-P	6	B	15,000	T-R	10
75	T-B-R-P	30	B	75,000	T-R	50
150	T-B-R-P	60	B	150,000	T-R	100
750	B-R-P	300	B	750,000	R	500
1,300	P					

(*) Mode Symbols: T = truck; B = barge; R = railroad; P = pipeline.

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