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BULK TRANSPORT OF WASTE SLURRIES TO INLAND AND OCEAN DISPOSAL SITES

SUMMARY REPORT

U.S. DEPARTMENT OF THE INTERIOR ● FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

BULK TRANSPORT OF WASTE SLURRIES TO INLAND AND OCEAN DISPOSAL SITES

SUMMARY REPORT

by

BECHTEL CORPORATION

for the

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
DEPARTMENT OF THE INTERIOR

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27 Abstract

This three volume study is principally concerned with the development of regional land and ocean pipeline disposal systems for digested sewage sludge and maintenance dredgings In Volume I two study cases are presented, namely, a land disposal system for Northeast Ohio (Cleveland-Canton) and an ocean disposal system for the Baltimore-Washington region. A systems approach is used, in which collection, transportation, and disposal aspects are examined in light of technical, economic and social requirements. Various transport modes are compared, including pipeline, ocean tankers, railroads, and trucks.

To a lesser extent, the study also considers the expansion of such systems to include fly ash and water treatment plant sludge. In Volume II present methods and costs of disposal for all four wastes are reviewed. Environmental criteria are presented for examining both land and ocean sludge disposal alternatives in terms of a general solution for two broad metropolitan regions, namely, the Great Lakes region from Buffalo to Milwaukee and the Atlantic Coast region from Boston to Norfolk.

Results of a loop test program utilizing 12" and 16" pipe for pumping digested sludge, fly ash, and sludge-fly ash slurries are included in Volume III as well as corresponding rheological tests with a ½" small tube viscometer and a rotational lab viscometer. A procedure for predicting head losses is given, as well as a review of the state of the art of pipelining of waste materials.

This report was submitted in fulfillment of contract number 14-12-156 under the sponsorship of the Federal Water Pollution Control Administration.

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CONTENTS

FIGURES

FOREWORD

In April, 1968, a contract was issued by the Federal Water Pollution Control Administration to Bechtel Corporation for determining the technical feasibility and economics of transporting sewage treatment plant sludge and dredging spoils by currently available transport systems for both land and ocean disposal To insure the general application of this concept, regional considerations were stressed Fly ash and water treatment plant sludge were also investigated for possible inclusion in the disposal system

This is a summary report of the total work covered under this contract It provides information on the conclusions and costs reached in the study and the institutional problems that must be considered. Details of the study can be obtained from the individual volumes entitled

Volume I · The Waste Management Concept

Volume II · Criteria For Waste Management

Volume III. Technical Aspects of Pipelining of Waste Materials

SECTION 1

INTRODUCTION

In recent years, it has become apparent that the industrial successes of American society have been achieved at a great cost to the nation in terms of environmental and social effects. Current trends indicate that unless rapid, aggressive and effective action is taken, such problems as air and water pollution will eventually achieve crisis proportions on a national scale

Up to now, progress in these areas generally has been on a narrow front, as administrations have moved, under pressure, to alleviate an intolerable and specific local condition In short, we, as a nation, have been reacting to problems, rather that acting on a broad front to develop ultimate or long-term solutions.

One of the many problems which modern society has inherited, and is rapidly compounding, is that of disposal of waste materials It is obvious that effective management of our wastes is essential if society is to have access to clean sources of water and safe recreation areas. At present, enormous quantities of objectionable material ranging from raw sewage to highly toxic chemicals are discharged to the nation's waterways The far-reaching effects of these practices are well established For example, Lake Erie is seriously polluted with municipal and industrial effluents, and was referred to recently as "the first large scale warning that we are in danger of destroying the habitability of the earth."

Rhetoric, such as that given above, is quite common these days Although this type of discussion serves to generate a necessary feeling of alarm, it is rarely accompanied by a viable course of action as to how to solve a specific pollution problem. This report addresses itself to the development of a specific waste management system, which collects, transports and disposes of selected waste materials in a socially, technically and economically satisfactory fashion A systems analysis approach, emphasizing regional considerations is utilized It further examines the feasibility of constructing and operating a demonstration project. The proposed system is entirely feasible today and may be implemented quickly

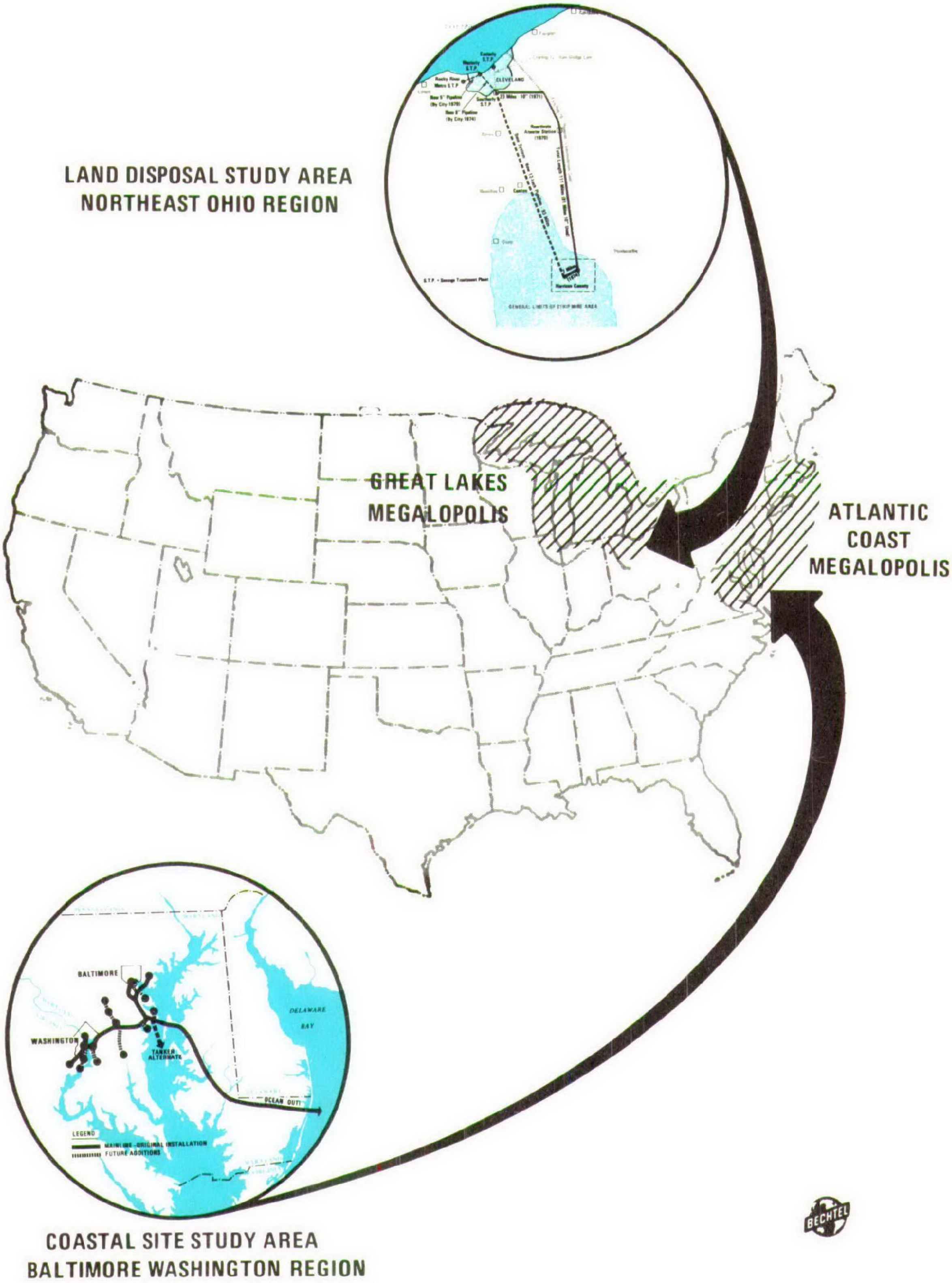
The two areas considered in this report are presented in Figure 1 A land disposal concept is investigated for the Great Lakes Megalopolis from Buffalo to Milwaukee, while ocean disposal is examined for the Atlantic Coast Megalopolis from Boston to Norfolk. The physical size of these areas is such, that to realistically analyze the problem, it is necessary to concentrate on specific cases which are representative of the type of waste disposal problems encountered in the areas as a whole, and which lend themselves to regional integration. The Northeast Ohio region and the Baltimore-Washington region have been selected as specific study areas. However, the methodology presented may be applied for analysis of other regions throughout the nation

The study is concerned mainly with the development of regional disposal systems for digested sewage sludge and maintenance dredgings. In many areas, disposal of these two wastes presents a major problem. However, to a lesser extent, the study also considers the expansion of such systems to include other wastes which lend themselves to regional disposal, such as power plant fly ash and water treatment plant sludge.

Figure 1

F.W.P.C.A. Waste Management Study

GENERAL LOCATION MAP



SECTION 2

THE WASTE MANAGEMENT CONCEPT
(Volume I)

GENERAL CONCLUSIONS

- For an immediate solution to the national problem of disposal of digested sludge, a land disposal system is recommended This concept has broad national applicability, will allow marginal lands to be upgraded, and can be effectively controlled to assure that there will be no environmental degradation Disposal to the waters of the continental shelf offers substantial economic benefits, but it suffers from the significant unknown factors relating to the ecological effects.

- A regional waste management system is technically and economically feasible, even if limited to sewage sludge alone Further, such a system can be significantly more effective in pollution control than local waste treatment and disposal, since it can provide for the ultimate disposal of all the wastes accepted by the system in a safe and socially acceptable fashion

- The cost benefit ratio of a sludge land disposal system is so favorable that it is recommended that the Federal Government, in cooperation with the State of Ohio and the City of Cleveland, immediately embark on a demonstration project to prove the viability of the concept.

- Wastes such as dredgings, fly ash and water treatment plant sludge may also be included in a regional waste management system Dredging disposal costs would exceed those of present methods, so implementation is dependent on the value that society places on disposing of such wastes in an ecologically satisfying manner. Fly ash could be added to digested sludge in relatively large amounts, with little increase in disposal costs Water treatment plant sludges could be successfully incorporated into the regional waste management system, by use of the sanitary sewer system and result in improving the system economics.

TRANSPORTATION METHODS

Railroad, tanker, truck and pipeline transport modes were investigated The costs of collection and transportation of the wastes studied demonstrate that pipeline transportation yields significant economies in comparison to the other modes evaluated Only for very small plants (producing less than about 5 tons per day of digested sludge solids) is waste collection by trucking more economical that pipeline transportation

A general method for evaluating pipeline transportation costs for digested sludge and maintenence dredgings is presented in the Appendix It allows pipeline capital and annual operating costs to be determined for a wide range of distance and waste quantities

THE LAND DISPOSAL SYSTEM: NORTHEAST OHIO

The ultimate regional waste disposal system for the Northeast Ohio Region, capable of serving the needs of this area through the year 2000, is presented in Figure 2. This system is based upon expansion of an initial 2-year demonstration program system to pick up additional sources of waste materials. In addition to a sludge disposal system, it includes a parallel 12-inch diameter pipeline system for the transportation of maintenance dredgings. The estimated capital cost of the sludge disposal portion of the ultimate system is $14.8 million The disposal costs, including collection, average $25 per ton over a 29-year period (1972-2000). This is compared with costs of $30 to $42 per ton by the most widely used in-plant disposal methods. The extension of the system to full regional capacity is dependent upon the implementation of the Metro Sewer Plan proposed by the F.W P.C.A. in the "Lake Erie Report" For the dredgings disposal system, the estimated capital cost is $10.3 million and the total disposal cost is $4.32 per ton of solids. The cost by present methods ranges from $1.33 to $3.22 per ton. Therefore , the dredgings system can only be justified on the basis of other benefits to society, such as, it offers permanent removal of the material from the lake environment and it allows the material to be used as fill to level lands that have been strip-mined

THE DEMONSTRATION PROJECT: NORTHEAST OHIO

The cost/benefit ratio and the higher degree of pollution control provided by a regional waste management system warrant the immediate undertaking of a demonstration project to further validate the concept. The basic facility for the recommended demonstration project is summarized in Figure 3 and includes the transportation of digested sludge from Cleveland as a 3.5 percent slurry by a 93-mile, 12-inch diameter pipeline for disposal in strip mine land in Southern Ohio. In the demonstration project, sludge will be disposed of by a lagooning system with an experimental program of land irrigation carried on at the same time. This experimental work will verify the agricultural benefits of land disposal and will supplement other field studies of sludge disposal. The demonstration project considers the transportation of the entire digested sludge production of the two largest treatment plants in Cleveland, which represent about 65 percent of the total sludge production in the Northeast Ohio region The project will prove the efficacy of the regional land disposal concept, define the costs, determine the public acceptance, establish environmental control procedures, and will be capable of expansion into the full regional system. The total cost of the demonstration project (including operating costs for 2 years) is $10 8 million. It is recommended that the demonstration be funded primarily by the Federal Government in cooperation with the State of Ohio.

However, Cleveland is in a unique position in that an unused 10-inch pipeline runs from a point east of the city to the proposed disposal area. It is one of the reasons that this region was chosen as a study area As shown in Figure 3, eighty-one miles of this existing pipeline could be utilized by constructing a new 23-mile 10-inch spur line from Cleveland's Southerly Sewage Treatment Plant. Due to its smaller size, this system cannot handle the ultimate volume possible in the 12-inch case, but it significantly reduces the initial risk capital required to demonstrate the concept $6 2 million vs $10 8 million or $4.6 million less (see Figure 3). It is adequate to handle Cleveland's projected 1985 tonnages with an average cost in the order of $27/ton. Preliminary discussions with the present owners of this line, Consolidation Coal Company, indicate interest in either selling or leasing the line and this alternative should be investigated.

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INSTITUTIONAL MANAGEMENT CONSIDERATIONS: NORTHEAST OHIO

The successful implementation of a land disposal system to accommodate the safe and useful disposal of sewage treatment plant sludge and dredging spoils, requires imaginative thinking and a high degree of cooperation on the part of all public authorities and private interests involved. The sheer volume of the wastes, the physical nature of the material, and the requirements for informing the general public of the beneficial aspects of the recommended disposal scheme, impose serious demands in the formulation of the disposal system

In the Northeast Ohio region, two principal jurisdictional bodies exist for the development of a regional waste management system They are the Ohio Water Development Authority (OWDA) and the City of Cleveland. The OWDA was created in March 1968 and assigned broad responsibility for the development and utilization of the state's water resources The Authority is empowered to finance projects by the issuance of revenue bonds, payable from charges guaranteed by the municipalities to whom the service is furnished (i e through a tariff) The Authority can also purchase land for right-of-way, condemn property, construct facilities, operate directly or engage an organization to operate the facilities. The City of Cleveland, under present law, can only own and operate facilities within its own jurisdictional boundaries

System Institutional Management and Financing

There are four basic institutional management routes which may be utilized to carry out this venture As already noted, there are two physical systems – (a) a new 12-inch and (b) a modification of the existing 10-inch line For each of these systems, there are two methods of financing – private and state In all cases, it is recommended that the collection facilities (i e feeder pipelines) be provided by the respective cities and that the transportation and disposal system for the demonstration project be operated by a private concern

The cases under a new 12-inch system are outlined in Figure 4. It should be noted that private ownership, although quite appealing on the surface. has some serious economic drawbacks. A preliminary appraisal indicates that a private company would have to charge in excess of $35/ton in order to show a decent rate of return on investment This is probably in excess of what the municipalities would be willing to pay It is a direct result of the higher "capital charges" which private industry must build into a rate structure in order to allow for profit, federal and state income taxes and ad valorem taxes which a publicly-owned facility would avoid

The cases which consider utilization of the existing 10-inch Consolidation Coal line are shown in Figure 5 It is important to note that no price has been set in this study on the value of this existing facility to the waste system The actual payment would, of course, be subject to negotiation

THE OCEAN DISPOSAL SYSTEM: BALTIMORE-WASHINGTON

A regional waste management system, involving ocean disposal for the Baltimore-Washington Region is presented in Figure 6 The digested sludge system shown, capable of serving the needs of this region through the year 2000, is based upon pipeline collection and transportation with an 80-mile ocean outfall utilized for disposal Although significant economic gain would result from the use of a shorter outfall to the continental shelf waters, substantial questions remain concerning the long-term effects on the marine environment A major research and development program will be necessary before these potential savings can be realized

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The estimated initial capital investment for the system is $53.5 million and future additions will total $8.1 million. The unit disposal costs for the period 1975 to 2000 will range from $55.00 per ton for the initial year, down to $23 10 for the final year, with an average cost of $27.80 per ton of dry solids

These disposal costs compare very favorably with costs projected for other disposal methods. For example, sludge incineration costs recently projected for Washington, D.C. are in the range of $52 to $58 per ton of dry solids. In addition, the pipeline-ocean disposal system will completely eliminate pollution of local waterways, due to loss of digester solids and nutrient discharge.

INSTITUTIONAL MANAGEMENT CONSIDERATIONS: BALTIMORE-WASHINGTON

Whereas a great deal of imaginative thinking and a high degree of cooperation on the part of all involved public authorities and private interests is necessary in the Northeast Ohio system, it is even more critical in the Baltimore-Washington disposal system. This is a result of the fact that the system directly involves

- Sixteen Municipalities
- The State of Virginia
- The State of Maryland
- The District of Columbia
- The Federal Government
- International Waters

This is much more complex than the proposed land disposal system, which was entirely within the State of Ohio Although there are a number of existing regional organizations in the area, none of these are sufficiently empowered to handle the proposed disposal system.

In light of these institutional problems, it is felt, at this stage, that a private enterprise alternative would not be practical and that a regional public body is the only feasible solution. Such a body could be modeled after the Delaware River Basin Compact, which was formed by the States of Delaware, New Jersey, New York and Pennsylvania and the Federal Government to manage the water resources of the Delaware River Basin Numerous similar jurisdictional bodies exist, such as the St Lawrence Seaway Authority, and the New York Port Authority. It is a recommendation of this study that a new jurisdictional body be formed by the respective states and the District of Columbia under the auspices of the Federal Government. The body should have broad jurisdictional powers, including the ability to own and operate facilities, issue bonds, accept grants from the Federal Government and exert the right of eminent domain.

The first job of this body would be to investigate, in depth, the effects of dumping the proposed quantities of digested sludge into the ocean. Currently, there is no law or international treaty to control dumping of wastes in international water. Because of its implications, many federal agencies would probably be interested in participating in this phase.

The second task of the proposed body would be to demonstrate the ocean disposal concept, utilizing the results of the investigation. This might entail, for example, an interim two-year sludge disposal program to specific sites from one or more plants in which detailed monitoring would be conducted. Following the successful demonstration of the concept, of course, a full scale regional system could be implemented.

A detailed formulation of the structure of the proposed jurisdictional body was beyond the scope of this study, since it must be done in cooperation with high level officials from the respective governments. This should probably be carried out by a commission, charged with the task of formulating a new jurisdictional structure, subject to ratification by the involved governments. The commission could be formed by congressional statute, such as those enacted for the formation of various basin commissions. Alternately, an autonomous commission could be formed, similar to the Washington Metropolitan Transit Authority, with the capability of obtaining revenue for capital and operating expenses from the respective participants.

It should be emphasized that, although institutional management problems of ocean disposal in the Baltimore-Washington region are difficult and complex, the economies that can be realized justify the expenditure of enormous energies to develop the type of inter-regional organization necessary to carry out the proposed plan.

SECTION 3

CRITERIA FOR WASTE MANAGEMENT
(Volume II)

This volume serves mainly to provide backup information for development of the regional land and ocean disposal systems outlined in Volume I. It discusses projected waste quantities, present methods and costs of disposal, environmental considerations, waste treatment, and land and ocean distribution systems. The major conclusions are summarized as follows

WASTE QUANTITIES

Due to the ever increasing growth of population and expansion of industrial output, the quantity of all waste materials is generally expected to increase from now to the year 2000. However, as shown in the table below, digested sludge loads will nearly triple because of higher levels of wastewater treatment and wider use of garbage grinding equipment. Furthermore, since digested sludge is usually produced at a solids concentration of only three to five percent and much of the pollutional matter is contained in the liquid phase, the waste quantities represent a far larger problem than is indicate on a mere dry tonnage basis.

Projected Waste Quantities
dry tons/day

	1968	1975	2000
Great Lakes Region			
Digested Sludge	1,350	1,670	3,760[1]
Maintenance Dredgings	16,700	16,700	16,700
Power Plant Fly Ash	9,470	11,480	5,920
Filter Plant Residue	217	247	407
Atlantic Coast Region			
Digested Sludge	2,190	2,740	6,120[1]
Maintenance Dredgings	51,000	54,800	67,500
Power Plant Fly Ash	7,320	8,520	3,040
Filter Plant Residue	173	197	323

1 Includes waste chemical sludge from tertiary treatment

LIMITATIONS OF PRESENT METHODS OF DISPOSAL

Concurrent with rising waste volumes is a steadily decreasing number of suitable disposal alternatives. A prime example is sludge disposal for large cities. Increased urbanization of the areas surrounding the treatment plants has nearly eliminated lagooning as an attractive method of disposal

Recently, sludge incineration has gained wide acceptance. However, the increasing awareness of society as to the effect of all forms of pollution makes it doubtful that this can be considered the ultimate solution. Although present technology can result in minimal emmission of particulate matter and odors, higher air pollution standards will require control of other emissions which are not yet classed as pollutants. Lately, the oxides of nitrogen from stationary sources have received increased concern At present, neither removal from stack gases nor reduction through modification of the combustion process appear feasible without incurring a significant economic penalty.

Furthermore, tertiary treatment of municipal sewage may result in a substantial increase in the volume of inorganic material for disposal The resulting change in sludge properties will add to the fuel cost while increasing the amount of ash for disposal. Thus, in the future, all sludge combustion processes may become substantially more expensive to operate

A similar situation exists with respect to the disposal of maintenance dredgings Traditionally they have been discharged to nearby open water as a matter of economy. Currently there are strong objections to continuing this policy, particularly in the Great Lakes region. Although the effects of dredgings disposal on the receiving area are still largely unknown, the material is sometimes heavily polluted and so this procedure must be considered, at least in these cases, as being undesirable.

In the case of fly ash from power plants, land fill in nearby areas is currently the most widely used method of disposal. This procedure is acceptable from an environmental standpoint and is economic as well. However, the increase in land use over the next few decades will reduce the feasibility of using this alternative in many metropolitan areas. In spite of increased utilization, waste disposal may become a significant problem until nuclear power growth results in a falloff in coal burn.

Chemical coagulation residues from rapid sand filter plants are usually discharged back to the water source This method is destined to decrease in use over the near future, as obviously, this results in some degradation of the receiving water. In some cases, the residue is discharged to sanitary sewers where it eventually ends up as part of the waste-water treatment plant sludge. This alternative is just a simple transfer of the problem and therefore does not represent a final solution, unless the waste water sludge disposal problem is adequately answered.

ENVIRONMENTAL CONSIDERATIONS FOR LAND AND OCEAN DISPOSAL

It is a conclusion of this study that land disposal is a viable solution for the waste materials considered. Suitable disposal areas are available within one hundred miles of most metropolitan regions. The process is particularly appealing as it can allow marginal lands to be upgraded by utilization of the same nutrients which are a problem in inland bodies of water like Lake Erie. Furthermore, the operation can be effectively controlled to assure that there will be no environmental degradation–by means of seasonal storage, regulated application rates and monitoring of ground and surface water. These precautions will prevent excess nitrates in ground water, heavy metal build-up in the soil, or transmission of communicable disease agents.

On the basis of limited current information, ocean disposal of digested sludge to the continental shelf area at this time does not appear to be a practical long-range solution for the Atlantic Coast Megalopolis. Although this seems to be a suitable alternative for the Pacific coast communities where relatively great depths of water occur close to shore, the continental shelf on the Atlantic extends up to one hundred miles from shore. The waters on this shelf are not renewed sufficiently to obtain the desirable 3×10^4 dilution in the year 2000 of the total digested plus waste chemical sludge production from the Atlantic metropolitan areas. This dilution requirement is dictated by transparency, nutrient, and dissolved oxygen considerations

Although shelf disposal may not be feasible for the whole Atlantic region, it still may be possible for a portion of this area to utilize this disposal method. Furthermore, by means of new technology, it may be feasible to alter the sludge characteristics so as to allow a lower dilution. Present studies are under way on the effects of waste disposal on ocean biota which should help clarify this situation. Until additional data are available, however, the only rational approach is to refrain from adding significant additional waste material to the Atlantic shelf.

SECTION 4

TECHNICAL ASPECTS OF PIPELINING OF WASTE MATERIALS (Volume III)

The analysis of various modes of waste transportation, presented in Volume I, indicated that pipelining offered significant economic advantages. In order to confirm the technical feasibility, a series of tests were performed. A second objective was to develop a reliable procedure for the design of such pipelines. The results of this work are discussed in this volume and are summarized in the following text

TEST PROGRAM

The prime component of either a land or ocean regional waste management system is the collection and transportation network. In order to successfully design a pipeline system to transport solid wastes, an understanding of the technology of solids-liquid flow is required. To this end, a series of laboratory and pipeline loop tests were performed. The object of the test program was to arrive at a suitable design procedure by correlation of measured friction losses which would satisfy the following requirements:

- The recommended design procedure should enable a commercial pipeline to be hydraulically designed from laboratory measurement of basic flow parameters.
- The recommended design procedure must be applicable to widely differing materials.
- The recommended design procedure must be applicable to commercial pipe diameters.
- Since commercial slurry pipelines normally operate in the turbulent flow regime, the design model must include a reliable criterion for the prediction of the laminar/turbulent transition.

Digested sewage sludge and fly ash were chosen as representative materials for the tests. The physical characteristics of these materials differ widely Fly ash is a fast settling, high density material, sludge solids are fibrous, have low density and have extremely low settling rates. However, it was expected, and was also demonstrated, that both materials – sludge because of its fibrous nature and fly ash because the particles are very fine – would be transported in homogenous flow in the turbulent regime. Samples taken from the top and middle of the pipe test sections confirmed that this was indeed the case.

These materials, individually and in differing combinations, were tested at various velocities in ½-inch, 12-inch and 16-inch pipe test sections at a number of solids concentrations, thus providing a very wide range of data. In order to ensure successful operability, shutdown and startup tests were also performed on fly ash and a fly ash/sludge mixture.

The test program was performed at the experimental facilities of the Hanna Coal Company Division of Consolidation Coal, located at Cadiz, Ohio. As a public service, the facilities were provided for the tests without charge. The sludge was obtained from the Southerly Sewage Treatment Plant in Cleveland and fly ash was obtained from Ohio Edison's Sammis Plant at Stratton, Ohio.

To provide information relevant to transportation of other waste materials, laboratory analyses were performed on samples of digested sludge from the District of Columbia Water Pollution Control Plant, maintenance dredgings from Cleveland Harbor, and water treatment plant sludge from the Nottingham Filtration Plant in Cleveland.

HYDRODYNAMIC DESIGN

Various correlation procedures were applied to the hydraulic data for flow of these waste materials in pipes It was shown that a model assuming homogeneous suspension of the solids gives good prediction of friction losses for a wide range of pipe diameters. An example of the accuracy of prediction of hydraulic test data is shown in Figure 7.

The basis of this model is that flow of a homogeneous suspension is very similar to that of a true, or Newtonian, fluid. Provided that a suitable viscosity of the slurry can be obtained, head losses can be calculated from the standard friction factor-Reynolds Number relationships for Newtonian fluids. It was determined that for a slurry exhibiting plastic properties, the coefficient of rigidity is a suitable viscosity with which to define the Reynolds number.

The homogeneous model is a reliable procedure for the design of pipeline waste disposal systems only if accurate information as to system rheology is available A rotational viscometer was used in this study to generate such rheological data. In the turbulent regime, which is the area of interest to commercial pipelines, the study materials are transported as homogeneous fluids (with certain concentration limitations in the case of fly ash) The data show that the Hedstrom critical velocity gives a good prediction of the laminar/turbulent transition, and is, therefore, a useful method of ensuring that a given system will be in the turbulent flow regime

Digested sludge and sludge/fly ash mixtures are closely represented by the homogeneous model Indeed, it appears that adding fly ash to digested sludge is an ideal method of tranporting fly ash (or similar waster materials), since addition of significant quantities of fly ash (10·1 on sludge solids) does not result in a large increase in friction losses. Data for fly ash/water slurries indicated a slight dampening of turbulence due to the presence of solids.

OPERABILITY

Laboratory and test loop data show that pipelines transporting these waste materials can be successfully restarted following a shutdown The findings of the tests are supported by the fact that successful installations for the transportation of both sludge and fly ash have been in operation for a number of years.

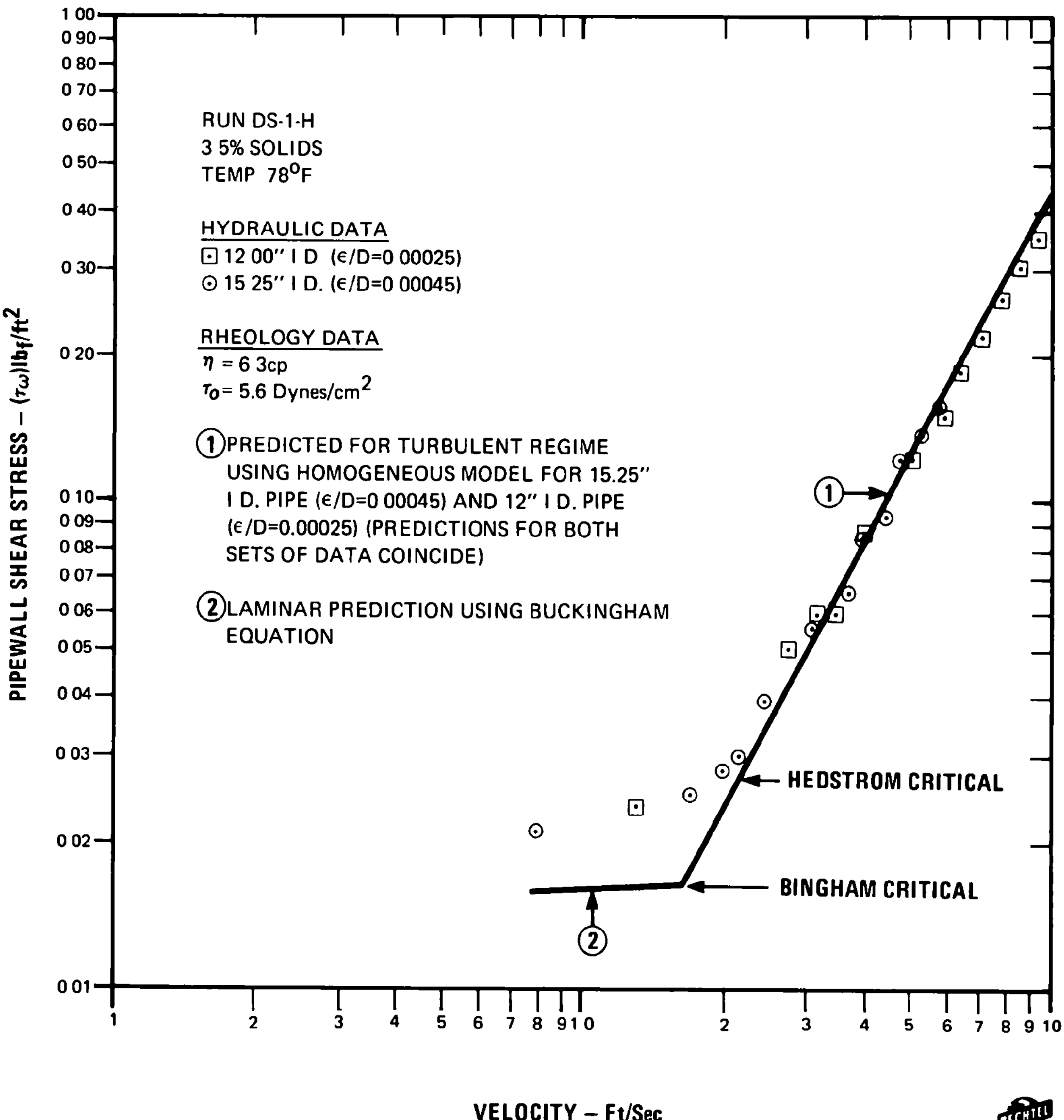
CORROSION

The corrosion rates to be expected in the pipelining of sludge, maintenance dredgings, fly ash, and fly ash/sludge mixtures were evaluated by laboratory tests. The test procedure used has been related to actual rates experienced in a commercial pipeline, and is a reliable method of establishing pipeline corrosion rates. The tests show that corrosion rates for the waste materials are very moderate (1 to 2 mils per year) and will present no significant problems in a cross-country pipeline

Figure 7

COMPARISON OF PREDICTED AND MEASURED FRICTION LOSSES

SOUTHERLY DIGESTED SLUDGE



SECTION 5

APPENDICES

ECONOMICS OF PIPELINING WASTE MATERIALS

In the analysis of the study areas in this report, it has been shown that pipelines can offer significant economic advantages over other means of transportation of waste materials. This finding may be of interest to pollution control authorities for other areas, which may have widely differing waste volumes and transportation distances than those encountered in the detailed case studies The following information will allow an evaluation of pipeline costs for transportation of digested sludge and dredgings for a wide range of combinations of distance and waste quantity

Extraction of pipeline capital and annual operating costs from Figures 8 to 13 is relatively simple However, the use and limitations of the figures do warrant some discussion

DIGESTED SLUDGE TRANSPORTATION COSTS

The capital costs of pipeline systems for transportation of 3 5 percent digested sludge are given in Figures 8 and 9 Figure 8 shows pipeline installation costs as a function of throughput (i e pipe diameter) for downtown, suburban and rural construction Figure 9 shows the remaining capital cost items as a function of distance transported for various throughput levels. The total capital cost of a pipeline system, including installation, pipe, pump stations, right-of-way and indirect costs are included in Figures 8 and 9. The following is an example of the use of the tables.

Example Determine the capital cost of a pipeline to transport digested sludge from a sewage treatment plant producing 500 tons of solids per day to a disposal site 100 miles away. The pipeline route will have 10 miles through downtown areas, 20 miles through suburbs and 70 miles through open country.

Pipe Installation Costs

	Unit Cost From Fig. 8 $/ton mile	Miles	Tons/day Transported	Cost ($)
Downtown	115	10	500	575,000
Suburban	75	20	500	750,000
Rural	58	70	500	2,040,000
			Total Cost	$3,365,000

Capital Cost (Excluding Pipe Installation)

From Figure 9, unit transportation cost for 500 tons/day and 100 miles distance is $180 per ton-mile

Therefore capital cost (excluding pipe installation)

$$= 180 \times 100 \times 500$$

$$= \$9,000,000$$

Total Capital Cost

Total Capital Cost = 3,365,000 + 9,000,000
Total Capital Cost = $12,365,000

Figure 10 shows the annual direct operating costs of sludge pipelines as a function of distance for various throughput levels The costs include power, labor, supplies and maintenance

For the example given above, the unit annual operating cost for a 100 mile, 500 ton per day sludge pipeline, from Figure 10 is $8 per daily ton-mile.

Therefore, the total direct operating cost of the pipeline is

$$8 \times 500 \times 100 = \$400,000 \text{ per year}$$

DREDGINGS TRANSPORTATION COSTS

Figures 11 to 13 show the capital and direct operating costs for the pipeline transportation of maintenance dredgings. The curves are based on dredgings at 25 percent solids by weight and should be used in the same way as Figures 8 to 10.

Capital costs obtained from these figures include installation, pipe, pump stations, right-of-way and indirect costs. Operating costs include power, labor, supplies and maintenance

FIGURE 8

F.W.P.C.A. Waste Management Study

ECONOMICS OF PIPELINE TRANSPORTATION

OF DIGESTED SLUDGE

PIPELINE INSTALLATION COSTS vs. CAPACITY FOR THREE CONSTRUCTION ZONES

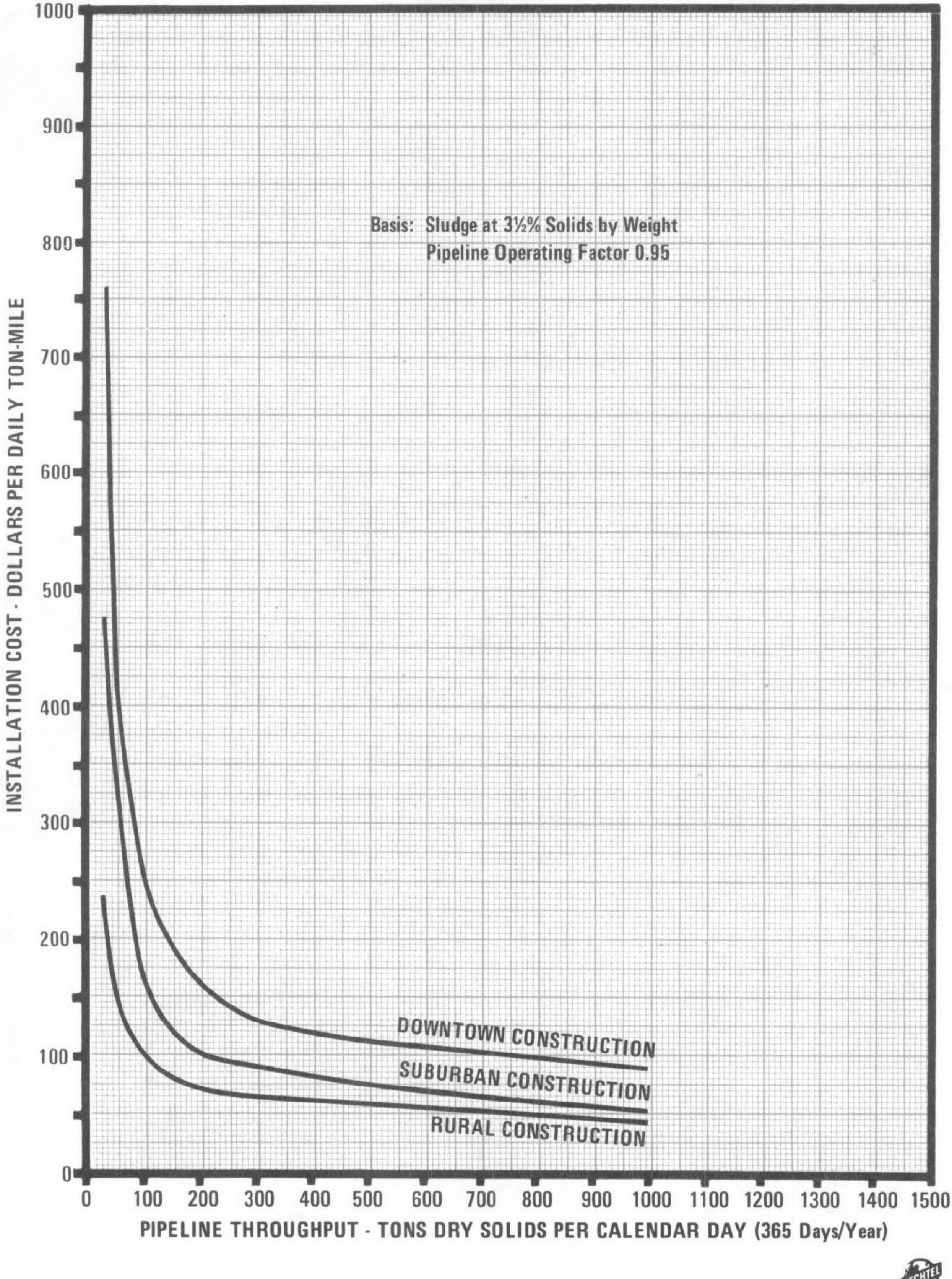


FIGURE 9

F.W.P.C.A. Waste Management Study

ECONOMICS OF PIPELINE TRANSPORTATION

OF DIGESTED SLUDGE

CAPITAL COSTS (Excluding Installation) vs. DISTANCE

FOR VARIOUS THROUGHPUT LEVELS

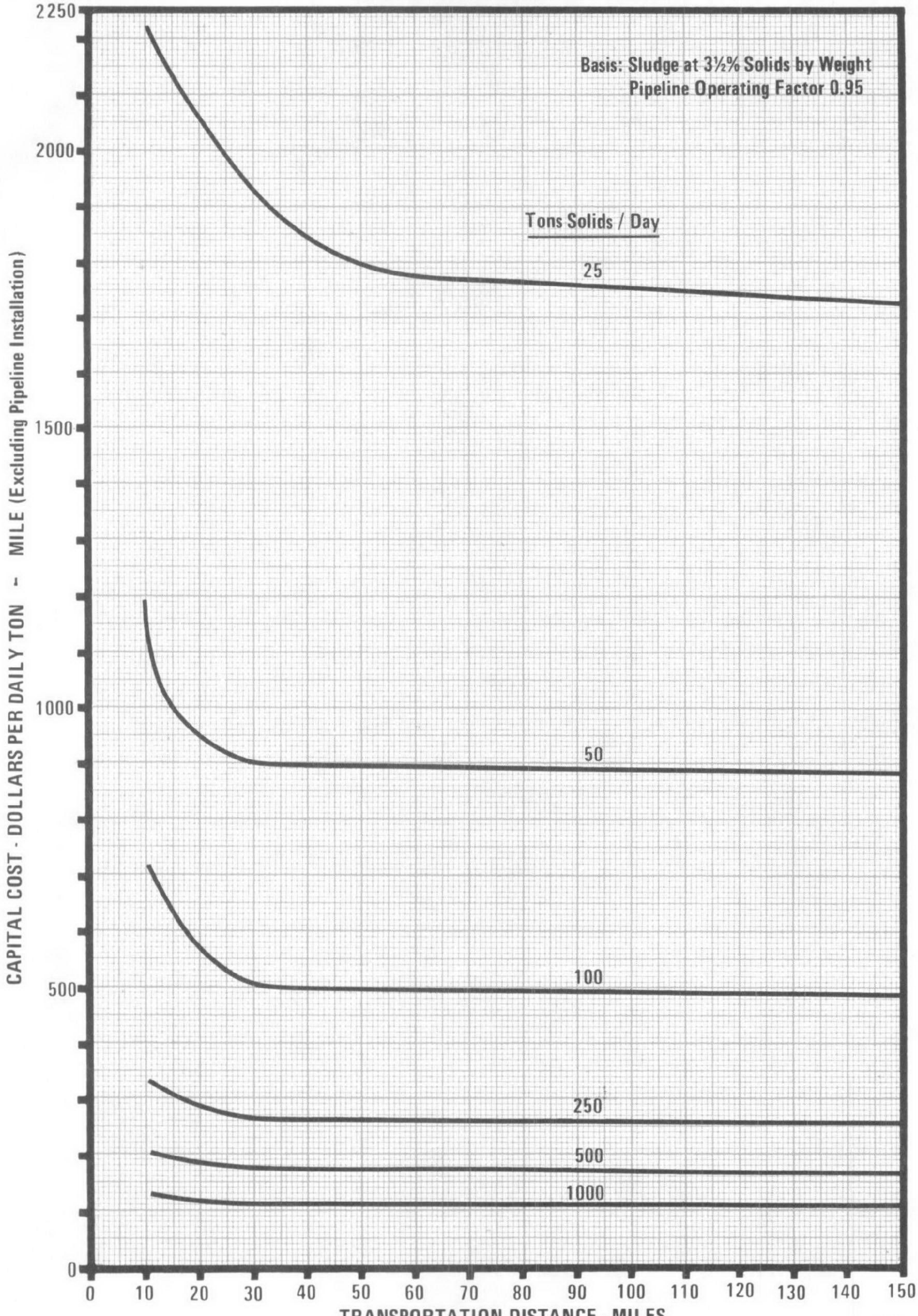


FIGURE 10

F.W.P.C.A. Waste Management Study
ECONOMICS OF PIPELINE TRANSPORTATION
OF DIGESTED SLUDGE
DIRECT OPERATING COSTS vs. DISTANCE
FOR VARIOUS THROUGHPUT LEVELS

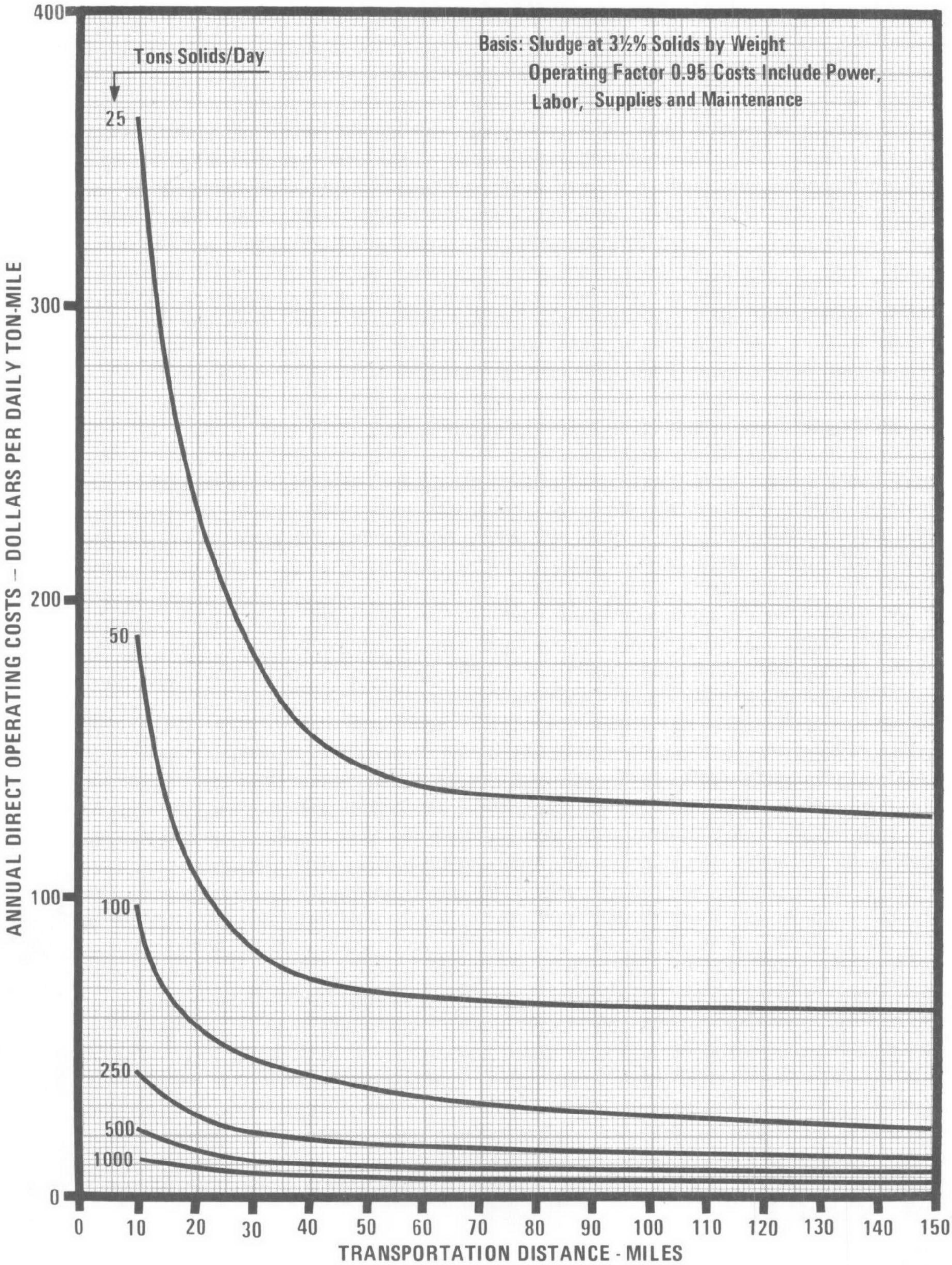


FIGURE 11

F.W.P.C.A. Waste Management Study

ECONOMICS OF PIPELINE TRANSPORTATION OF MAINTENANCE DREDGINGS PIPELINE INSTALLATION COSTS vs. CAPACITY FOR THREE CONSTRUCTION ZONES

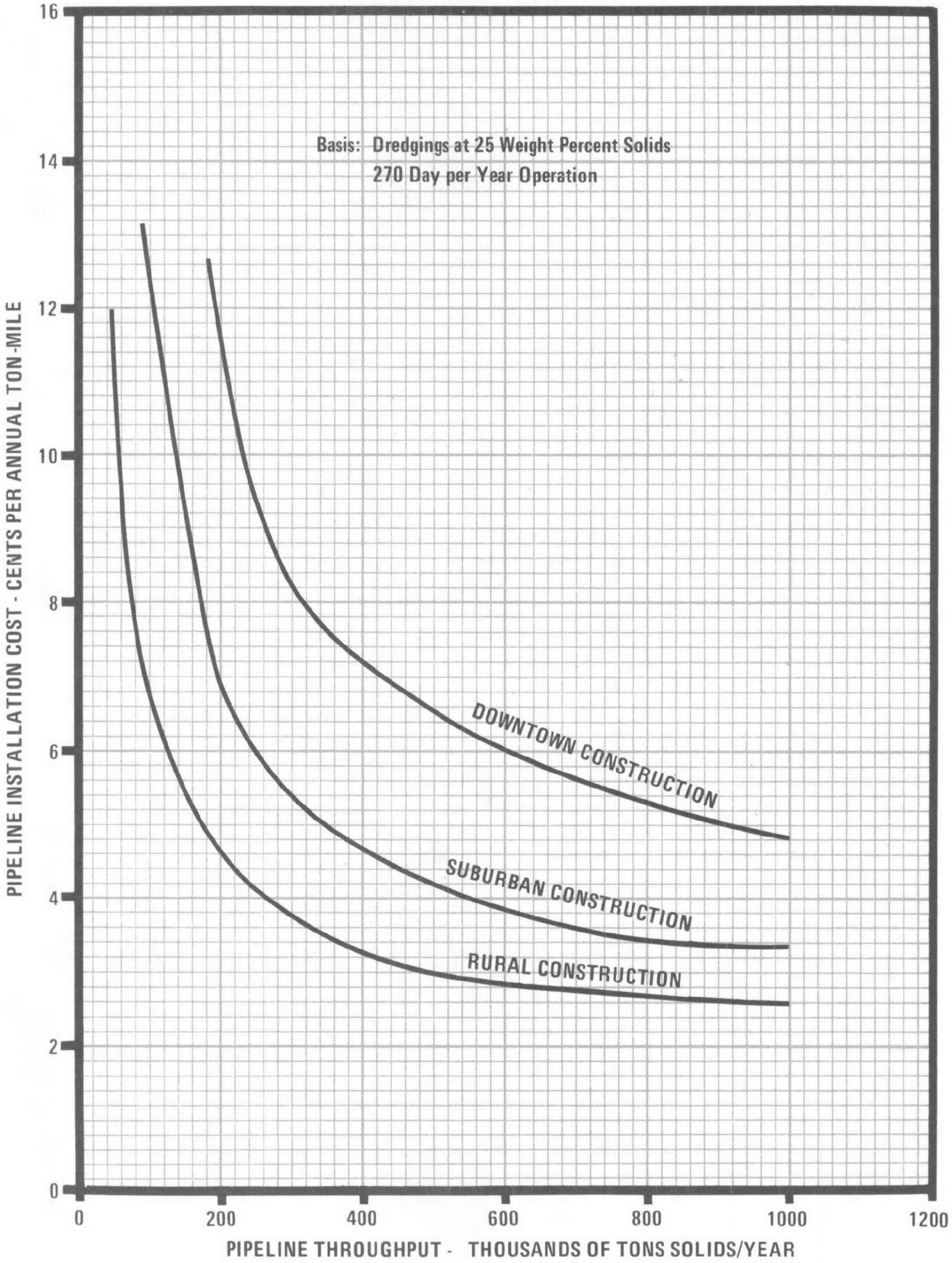


FIGURE 12

F.W.P.C.A. Waste Management Study
ECONOMICS OF PIPELINE TRANSPORTATION
OF MAINTENANCE DREDGINGS
CAPITAL COST (Ex Installation) vs. DISTANCE
FOR VARIOUS THROUGHPUT LEVELS

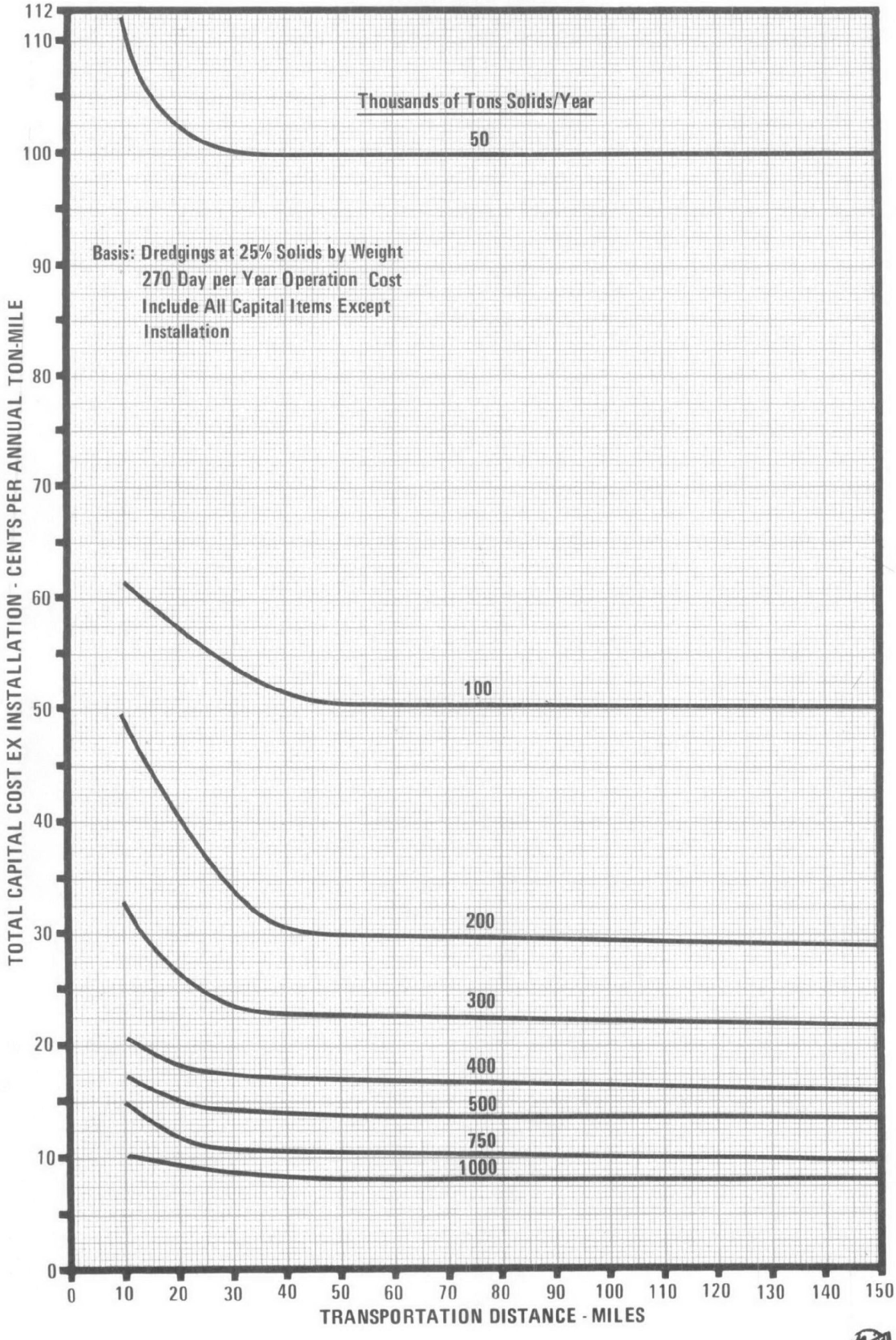


FIGURE 13

F.W.P.C.A. Waste Management Study
ECONOMICS OF PIPELINE TRANSPORTATION
OF MAINTENANCE DREDGINGS
DIRECT OPERATING COSTS vs. DISTANCE
FOR VARIOUS THROUGHPUT LEVELS

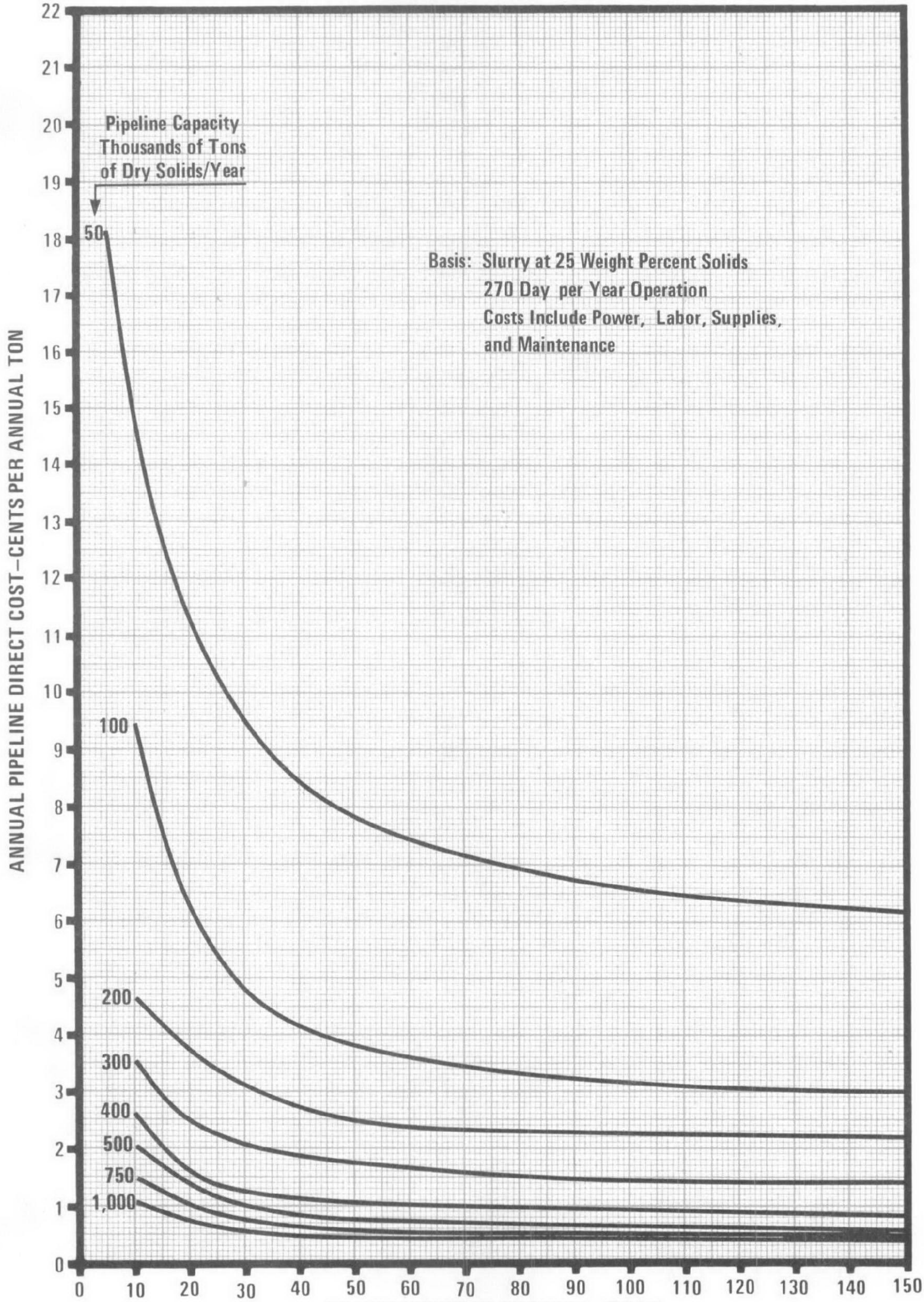


TABLE OF CONTENTS: VOLUME 1

THE WASTE MANAGEMENT CONCEPT

TABLE OF CONTENTS· VOLUME II

CRITERIA FOR WASTE MANAGEMENT

FLY ASH

- Disposal Methods
- Disposal Costs

WATER TREATMENT PLANT RESIDUES

- Chemical Coagulation Wastes
- Filter Backwash Water

ENVIRONMENTAL CONSIDERATIONS FOR REGIONAL LAND DISPOSAL SYSTEMS

EFFECT ON WATER ENVIRONMENT

- Pathogenic Microorganisms
- Viruses
- Chemical Additions

EFFECT ON SOILS AND CROPS

- Chemical Additions
- Historical Record

OTHER ENVIRONMENTAL EFFECTS

- Airborne Pollution
- Insect Vectors
- Crops as Vectors
- Soil Contact
- Nuisance Conditions

ENVIRONMENTAL CONSIDERATIONS FOR REGIONAL OCEAN DISPOSAL SYSTEMS

FACTORS OF CONCERN

DILUTION REQUIREMENTS

- Transparency
- Nutrients
- Dissolved Oxygen Concentration

SHELLFISH CONTAMINATION

- Viruses
- Heavy metals

CONCLUSIONS

TREATMENT OF WASTE MATERIALS

EVALUATION OF NEED

TREATMENT FOR COMMUNICABLE DISEASE AGENTS

- Storage
- Heat Treatment
- Chemical Disinfection
- Radiation and Other Physical Methods

TABLE OF CONTENTS: VOLUME III

TECHNICAL ASPECTS OF PIPELINING OF WASTE MATERIALS