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GUIDANCE FOR LAND IMPROVEMENT USING DREDGED MATERIAL.(U)
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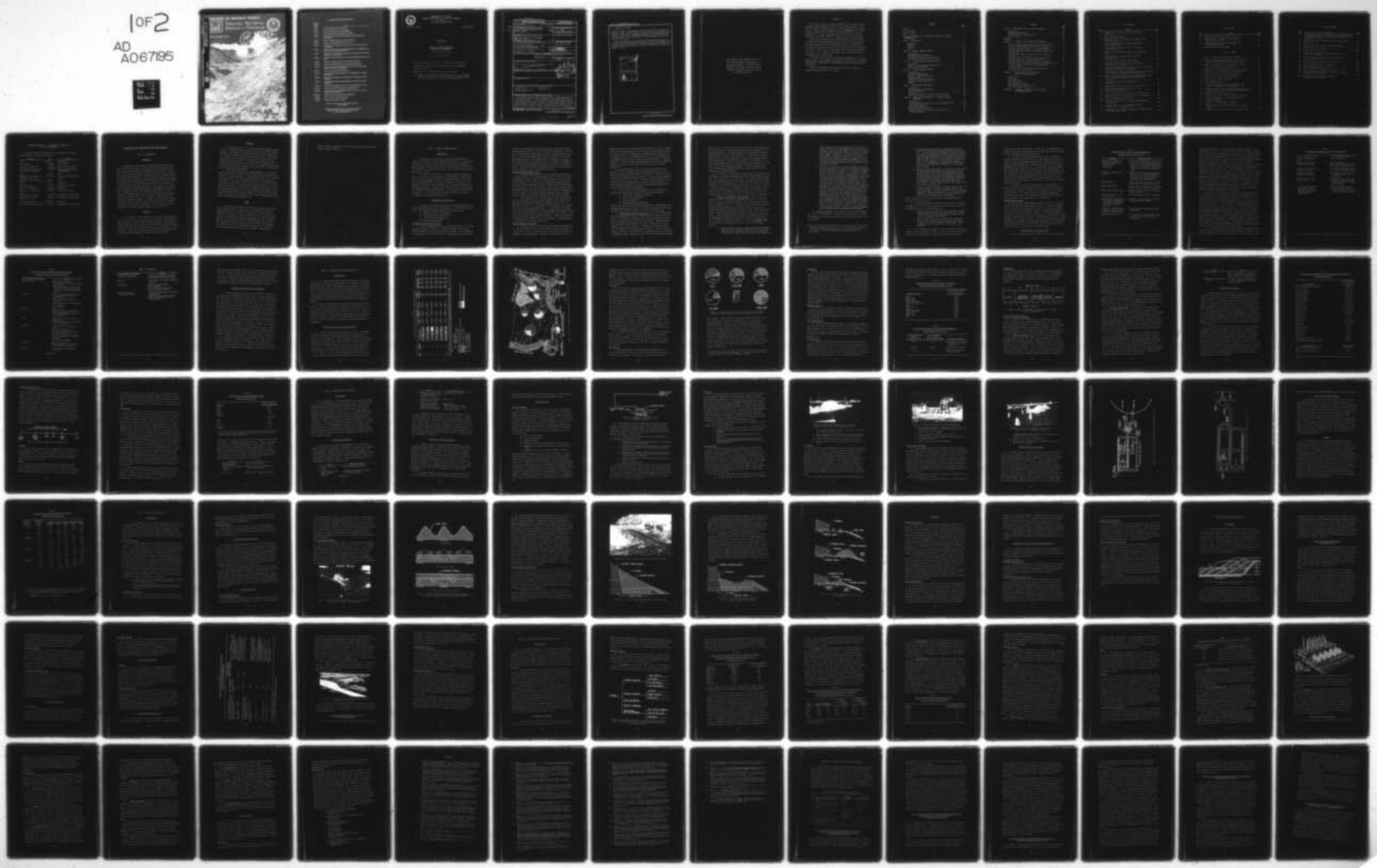

SYNTHESIS OF RESEARCH RESULTS

DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT DS-78-21

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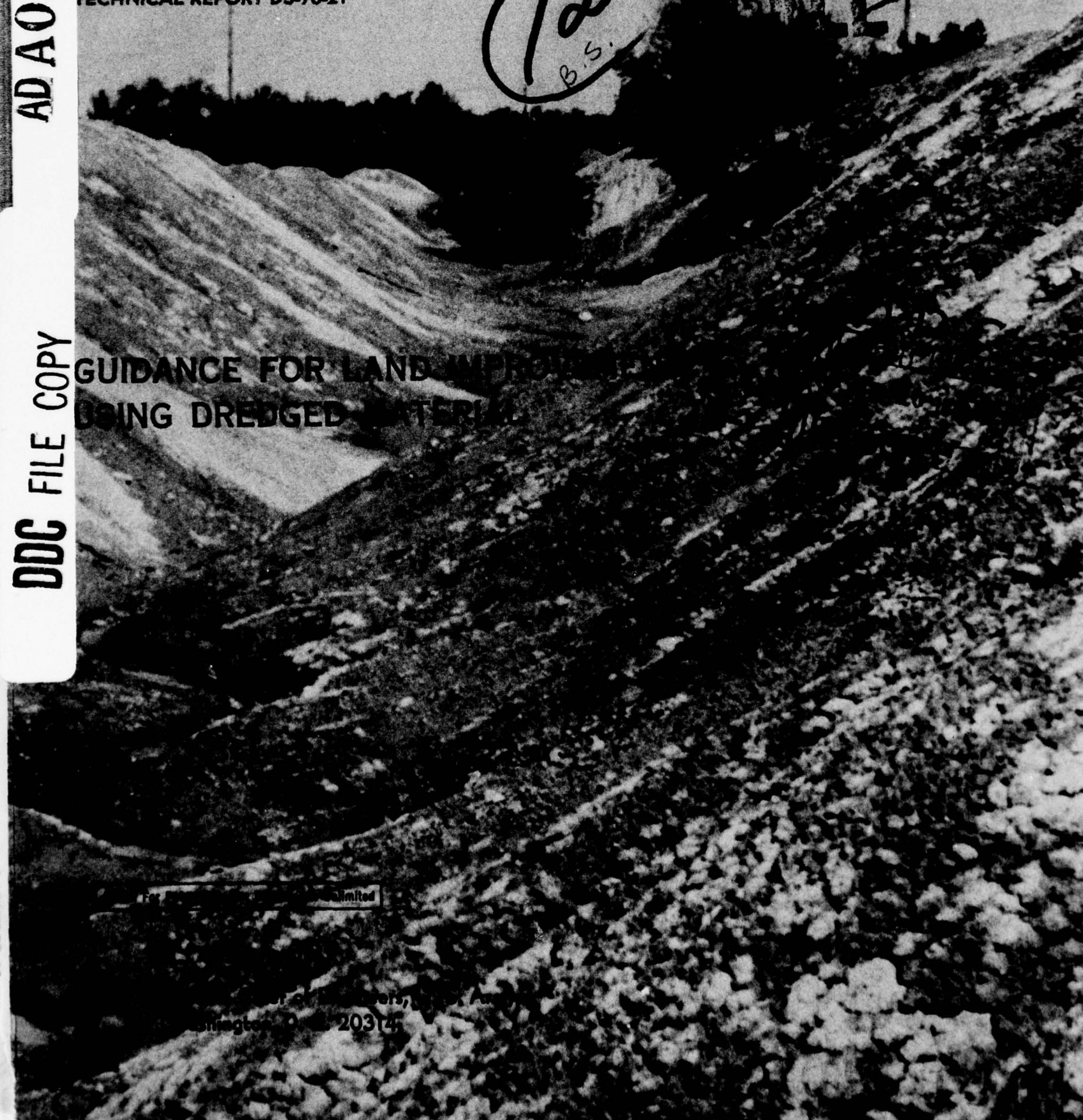

GUIDANCE FOR LAND IMPROVEMENT [illegible] USING DREDGED MATERIAL

[illegible] Unlimited

[illegible] of Engineers, [illegible] Army [illegible] Washington, D.C. 20314

THE DMRP SYNTHESIS REPORT SERIES

Technical Report No.	Title
DS-78-1	Aquatic Dredged Material Disposal Impacts
DS-78-2	Processes Affecting the Fate of Dredged Material
DS-78-3	Predicting and Monitoring Dredged Material Movement
DS-78-4	Water Quality Impacts of Aquatic Dredged Material Disposal (Laboratory Investigations)
DS-78-5	Effects of Dredging and Disposal on Aquatic Organisms
DS-78-6	Evaluation of Dredged Material Pollution Potential
DS-78-7	Confined Disposal Area Effluent and Leachate Control (Laboratory and Field Investigations)
DS-78-8	Disposal Alternatives for Contaminated Dredged Material as a Management Tool to Minimize Adverse Environmental Effects
DS-78-9	Assessment of Low-Ground-Pressure Equipment in Dredged Material Containment Area Operation and Maintenance
DS-78-10	Guidelines for Designing, Operating, and Managing Dredged Material Containment Areas
DS-78-11	Guidelines for Dewatering/Densifying Confined Dredged Material
DS-78-12	Guidelines for Dredged Material Disposal Area Reuse Management
DS-78-13	Prediction and Control of Dredged Material Dispersion Around Dredging and Open-Water Pipeline Disposal Operations
DS-78-14	Treatment of Contaminated Dredged Material
DS-78-15	Upland and Wetland Habitat Development with Dredged Material: Ecological Considerations
DS-78-16	Wetland Habitat Development with Dredged Material: Engineering and Plant Propagation
DS-78-17	Upland Habitat Development with Dredged Material: Engineering and Plant Propagation
DS-78-18	Development and Management of Avian Habitat on Dredged Material Islands
DS-78-19	An Introduction to Habitat Development on Dredged Material
DS-78-20	Productive Land Use of Dredged Material Containment Areas: Planning and Implementation Considerations
★ DS-78-21	Guidance for Land Improvement Using Dredged Material
DS-78-22	Executive Overview and Detailed Summary
DS-78-23	Publication Index and Retrieval System

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DEPARTMENT OF THE ARMY
WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS
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IN REPLY REFER TO: WESEV

15 March 1979

Errata Sheet

No. 1

GUIDANCE FOR LAND IMPROVEMENT USING DREDGED MATERIAL

Technical Report DS-78-21

December 1978

1. Page 24, paragraph 27, last line: Change to read as follows:

Malkasian,[1] Wakeford and Macdonald,[8] and Engineer Regulation 1105-2-200 Series.[10]

2. Page 82, item 10. Delete and insert the following:

10. Office, Chief of Engineers, Department of the Army, "Planning Process: Multiobjective Planning Framework," Engineer Regulation 1105-2-200 Series, 10 Nov 1975, Washington, D. C.

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Dredged material disposal
Land development
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report discusses certain dredged material disposal alternatives and provides guidelines and concepts in planning for land improvement projects using dredged material. It draws information from Dredged Material Research Program (DMRP) research reports, literature surveys, field demonstrations, and greenhouse studies to provide guidance in land improvement projects. Environmental, technical, economic, social, and legal aspects of projects are presented as well as outlines of project planning procedures and dredged material

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20. ABSTRACT (Continued).

CONT

transport systems. Three dredged material land improvement techniques are detailed: surface mine reclamation, sanitary landfill, and agricultural use. Planning, construction, and equipment considerations are presented for each technique. Local, state, and Federal government sources who have jurisdiction or expertise in the various aspects of land improvement projects are included in the report.

The report describes techniques for land improvement which utilize dredged material productively as alternatives to conventional disposal methods in regions where land acquisition is difficult and open-water disposal infeasible. The Appendices provide summaries of DMRP research upon which this report is based.

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PREFACE

This report provides concepts and guidelines for planning and implementing land improvement projects using dredged material. It synthesizes research conducted as part of Tasks 3B and 4C of the Dredged Material Research Program (DMRP) sponsored by the Office, Chief of Engineers, U. S. Army. The report was written as part of the DMRP Productive Uses Project (PUP), Mr. Thomas R. Patin, Project Manager.

The project was conducted by the Environmental Engineering Division (EED) of the Environmental Laboratory (EL), U. S. Army Engineer Waterways Experiment Station (WES), under the general supervision of Dr. John Harrison, Chief, EL; Dr. Roger T. Saucier, Special Assistant, EL; and Mr. Andrew J. Green, Chief, EED. The work was under the direct supervision of Mr. Raymond L. Montgomery, Chief, Design and Concept Development Branch (DCDB), EED.

This report was written by Ms. Patricia A. Spaine and Mr. José L. Llopis, DCDB, and Dr. Eugene R. Perrier, Ecosystems Research and Simulation Division. This report is also being published as Engineer Manual 1110-2-5009.

Director of WES during this study was COL John L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres	4046.873	square metres
cubic yards	0.7645549	cubic metres
dollars per cubic yard	1.3079505	dollars per cubic metre
dollars per cubic yard per mile (U. S. statute)	0.8127227	dollars per cubic metre per kilometre
feet	0.3048	metres
gallons (U. S. liquid) per day per square foot	40.745853	litres per day per square metre
horsepower (550 ft-lbf/sec)	745.6999	watts
inches	2.54	centimetres
inches per yard	2.777777	centimetres per metre
miles (U. S. statute)	1.609344	kilometres
miles (U. S. statute) per hour	1.609344	kilometres per hour
pounds (mass) per acre	0.00012085	kilograms per square metre
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
tons (2000 lb mass)	907.18474	kilograms
tons (2000 lb mass) per acre	0.22417	kilograms per square metre

GUIDANCE FOR LAND IMPROVEMENT USING DREDGED MATERIAL

PART I: INTRODUCTION

Background

1. Recognition of the inherent ecological value of many areas that have historically been used as dredged material disposal sites has resulted in environmental constraints on open-water and land disposal. These constraints have increased the values placed on coastal and riparian wetlands and have accented the need for alternate methods of dredged material disposal. As land uses have changed, areas available for dredged material disposal have become scarce, and the concept of productive use of dredged material, such as *in land improvement*, has become economically more attractive. The mission of the Dredged Material Research Program (DMRP) included investigation of productive uses of dredged material. The Productive Uses Project (PUP) was charged with exploring possible uses of dredged material and dredged material containment areas. In PUP studies, dredged material was viewed as a manageable resource. A number of work units were designed and managed under the DMRP to explore the potential uses of dredged material in land improvement strategies and to determine the cost effectiveness of utilizing dredged material in such projects.

Purposes

2. The purpose of this report is to provide the Corps of Engineers and local planners with guidelines for planning and implementing land improvement projects involving dredged material. This report addresses only *three land improvement* alternatives for dredged material: surface mine reclamation, sanitary landfills, and agricultural land enhancement. Other uses exist and guidance on them is presented in reports by Walsh and Malkasian[1] and Lee, Engler, and Mahloch.[2]

Approach

3. Within the realm of the Corps' maintenance dredging responsibility, the foremost problem facing Districts is disposal of dredged material. This report is therefore written from the vantage point of the Corps field elements faced with the disposal task. Land improvement projects are alternatives for disposing of dredged material. Guidelines presented in Part II (General Planning Process), Part III (Dredged Material Characteristics), and Part IV (Dredged Material Transport) of this report can be applied to any project that requires total project planning for land disposal.

4. When project feasibility is being determined, land improvement concepts and alternatives are considered during the intermediate stages of the planning process. Varied approaches were used in the PUP to investigate the three land improvement alternatives addressed in this report. The sanitary landfill alternative was developed through a thorough literature review of landfilling practices but was not field tested under the PUP. The strip mine reclamation alternative was drawn from present reclamation practices and an ongoing field demonstration of using dredged material in area reclamation. The agricultural alternative was examined in a greenhouse study in which dredged material was mixed with marginal agricultural soils.

Scope

5. Information is presented in the form of concepts and guidance from literature surveys, field studies, and laboratory studies conducted under the PUP of the DMRP. Dredged material rehandling and transport are discussed as well as construction at the productive uses site and other major cost components associated with land improvement projects. The alternative uses for dredged material such as surface mine reclamation, sanitary landfill, and agricultural soil amendment are presented in the form of guidelines outlining their feasibility with recommendations based upon research findings. References are

made to reports, regulations, and Federal guidelines when applicable to specific project problems.

PART II: GENERAL PLANNING PROCESS

Introduction

6. Although this report presents only three alternatives for using dredged material in land improvement projects (i.e., surface mine reclamation, sanitary landfills, and agricultural land enhancement), there are many other such possible uses. Dredged material can be used as construction or landfill material and can be blended to make desired types of soil covers.

7. The intent of this Part is to provide planning guidance for full utilization of a plentiful Corps resource material, dredged material, in land improvement projects. The planning process outlined in the following paragraphs is a logical progression of steps to be considered in planning a land improvement project using dredged material. The planning process is presented with detailed guidance and a listing of information sources where available. The reports by SCS Engineers[3] and Raster et al.[4] were the primary sources of information used in developing the following planning process.

Preliminary Data Collection

8. Preliminary data must be gathered before fundamental decisions can be made concerning any land improvement project using dredged material. The essential preliminary data include the following:

- a. Dredging locations and quantities.
- b. Dredged material characteristics.
- c. Land improvement alternatives.
- d. Transportation network.

Dredging locations and quantities

9. Records of dredging locations and quantities should be reviewed and collated, and the locations of future maintenance and new work dredging operations should be identified and plotted. This information can then be used in the initial phase of the planning process and will

be useful for delineating areas for conducting a survey of potential land improvement projects, if they have not been identified. The volume of material being dredged must be known on an annual basis to estimate the rate at which materials can be made available for the land improvement project. Since volumes must be estimated on the basis of past dredging records, an accurate estimate of volume to be dredged as a function of time throughout the planning period is often difficult to obtain. Shoaling and subsequent dredging are subject to fluctuations in local hydrology that often cannot be predicted.

Dredged material characteristics

10. Dredged material characteristics determine its potential as a suitable material for land improvement projects. Therefore, these characteristics must be known for a proper evaluation of land improvement alternatives. The time frame for determining dredged material characteristics should extend past that for the study of land improvement alternatives. This will permit the results of the study of land improvement alternatives to be considered in designing the sampling and testing program. The detailed testing program can then be designed around specific land improvement alternatives that appear feasible.

11. The dredged material sampling program must be planned carefully to ensure that samples are representative. The samples tested must provide information regarding the characteristics of the "as delivered" material; i.e., the condition of the material as it would be delivered at the land improvement site. It is important to remember that there can be differences in materials sampled from different locations in the same dredged material containment area as a result of sedimentation processes during disposal activities. Detailed descriptions of dredged material characteristics and references to recommended testing procedures are presented in Part III.

Land improvement alternatives

12. The basic precept of land improvement using dredged material as a resource should be to match the resource material with need. The overall effect of such a policy would be a reduction in the number of unproductive dredged material containment areas and an easing of the

demand for land for use as containment areas where such land is limited. If some of the dredged material can be used in land improvement projects, the scope and hence the overall cost of dredged material disposal can be reduced. Also, use of dredged material as both a supplemental and a replacement source can help conserve existing supplies of certain raw materials. In some instances, dredged material can provide a financial return to the owner and partially offset the cost of the disposal operation.[5]

13. Seeking productive uses is a major responsibility of the planner, and, to successfully meet this responsibility, he must be aware of the needs for soils within project areas. Research by Bartos[6] concluded that dewatered dredged material is a soil, can be analyzed as a soil, and can be used as a soil. This fact should encourage the productive use of dredged material as a natural resource in urban and other development projects, especially in areas where landfill needs can be met by available dredged material.

14. Research under the DMRP indicated that the following are promising land improvement alternatives using dredged material:

a. Landfill and construction material.

b. Surface mine reclamation.

c. Sanitary landfill.

d. Agricultural land enhancement.

The landfill and construction material alternative is summarized in the paragraphs immediately following. The other alternatives listed above are discussed in detail in Parts V, VI, and VII, respectively.

15. Landfill and construction material. A need for landfill and construction materials exists in inland as well as coastal regions of the U. S.[7] However, the feasibility for using materials from coastal sources decreases with increasing distance inland. Dredged material can be competitive with material from other sources only if it is economical and readily available. In addition, problems associated with the quality of the material must be resolved. A key to finding workable solutions to the disposition of dredging material and locating environmental and/or economic uses lies with local and regional planning

agencies.[7] One of the first steps in promoting the use of dredged material as landfill and construction material is close coordination with planning agencies. As a landfill material, dredged material should be competitive with material from other sources. However, more ingenious dredged material disposal operations are needed to eliminate problems that presently exist. The two major problems cited by agencies contacted during DMRP research[7] were contamination and extremely high water content of fine-grained dredged material. Economic dewatering and solids treatment are considered essential to enable productive use of large amounts of dredged material.

16. In addition to improvements in the quality of dredged material, improvements are needed in disposal operations to make dredged material more readily available to potential users. One suggestion made repeatedly during DMRP research was to stockpile processed (dewatered, decontaminated, etc.) dredged material in locations that would be convenient to potential users. Such a program would have to be carefully conducted to be successful since sand and gravel operators (and possibly other potential users) generally will not avail themselves of a processed dredged material source until at least a 10-year supply is guaranteed.[7]

17. Guidance for productive uses approach. The first step in planning for land improvement using dredged material is to conduct a survey to identify potential markets or users. However, the planner must be careful at this point. Because of legal complexities regarding dredged material ownership, state royalties, etc., the report by Wakeford and Macdonald[8] should be reviewed and legal and/or real estate experts should investigate Federal, state, and local laws that might pertain. Wakeford and Macdonald concluded that "material disposed of to other than governmental tax-supported or nonprofit organizations, e.g., a commercial enterprise, must be sold at its fair market value." The following are considerations leading to the sale of dredged material:

a. If the District attempts to deal directly with "consumers" (such as persons needing landfill), it will be in direct competition with commercial suppliers of raw materials. If the District allows its price to float (via competitive bids) in order to sell a large quantity of processed dredged material at a "fair market price," it will tend to take business away from commercial suppliers of similar materials and perhaps force them to cut prices to recover sales volume. Clearly, there would be strong opposition from commercial suppliers to such a District policy. Alternatively, the District could set prices that do not undercut those charged by commercial suppliers. (Note that Wakeford and Macdonald[8] cite many instances of sales and donations apparently without serious opposition from commercial suppliers.)

b. The District could avoid the direct competition issue by dealing with commercial suppliers via competitive bidding, with the commercial suppliers then retailing the dredged material products to consumers. It is possible, however, that the bids received will not entirely cover the District's costs for processing and transporting the material. Selling the material under these circumstances would give an appearance of subsidization, which conflicts with past Corps policy of requiring the beneficiary to bear the added costs for disposing of dredged material used for his benefit. This official policy, however, has been abrogated in recent years. Many Districts are incurring added costs to prevent alleged environmental degradation with the "beneficiary" being the American people. In a specific case, the St. Paul District absorbed additional transport costs for removing dredged material from an environmentally sensitive floodplain, thus making it available for productive uses. Beneficiaries included local governments (e.g., the City of Minneapolis, Minn.) and a commercial firm.* Wakeford and Macdonald[8] suggest that the subsidy issue might be side-stepped if the Corps would "place the material on state-owned or controlled sites . . . and encourage the states to let competitive or negotiated contracts to reclaim the material, <u>even if they (the states) have to subsidize the contractor</u>."

18. <u>Market/user survey.</u> If a specific land improvement alternative has not been identified, a market/user survey must be performed. The market/user survey performed during the planning phase seeks to do the following:

---

* Personal communication from Mr. Dennis Cin, Construction Operations Division, U. S. Army Engineer District, St. Paul, Minn., and Mr. Thomas E. Raster, Acres American Incorporated, Buffalo, N. Y., 8 Oct 1976.

a. Identify potential customers for dredged material products (both raw material suppliers and/or actual consumers). Adverse locations of customers (because of distance or relative inaccessibility from possible disposal areas) could preclude productive use of the dredged material and therefore affect the type of processing at the reusable site. Customer location can also influence reusable site location. For example, it would generally be advantageous from a transportation standpoint to locate a reusable site on the same side of the river as a potential major customer.

b. Quantify the potential demand. If the survey shows a substantial demand for products requiring extra processing (e.g., American Society for Testing and Materials Fine Aggregates) but little demand for unclassified material, then the District must weigh the advantages of reducing the waste disposal problem by the amount of dredged material that could be consumed versus the added costs for the equipment and multistage handling needed for the processing. To assist in this decision, the survey should assess revenue possibilities.

c. Determine possible revenue. If revenues from the sale of a specific product can offset the added costs for the extra processing, site design should include the necessary equipment. Even if the added cost is not entirely offset, sufficient savings might accrue from reduced waste disposal costs to justify the extra processing.

Refer to Raster et al.[4] for more information regarding market/user surveys for dredged material.

19. If the dredged material characteristics have been determined beforehand, then specific land improvement alternatives can be used in the market/user survey. The advantages are:

a. Survey costs will be reduced since the planner can immediately focus on customers for specific products rather than covering the entire spectrum of customers for all possible dredged material products.

b. Survey results will be more accurate since interviews with potential customers can be specific rather than tentative in terms of products and quantities. Revenue estimates by the customers will be more serious and precise.

20. If the planner must conduct the survey without the benefit of knowing specific products and production rates, the survey becomes more of a poll to determine local raw material needs and possible unit

revenues given various supply rates. Later, when the dredged material characteristics have been determined, the planner can assess his ability to meet the demands revealed by the survey.

21. Although the survey eventually boils down to a canvass of possible dredged material customers, the first target of the surveyors should be groups and government agencies with a planning function; e.g., regional planning commissions, economic development councils, highway departments, port authorities, etc. These agencies establish development trends (hence, future raw material needs) via recommendations on land use policies, controls on sewer and water services, building codes, etc. Reikenis, Elias, and Drabkowski[7] provide an overview of future landfill and construction material needs on a regional basis for the coastal states. This same type of assessment on a local, more detailed basis may be needed.

22. Because of the large annual volumes of dredged material, survey efforts should concentrate on potential volume customers, such as those listed in Table 1. However, the District should not neglect small customers. The cumulative effect of individual homeowners, neighborhood nurseries, etc., hauling off stockpiled excess material to be used as fill or soil conditioner can be significant.

Transportation network

23. The regional transportation network must serve the transportation needs from the dredged material source to the land improvement site. Research on dredged material transport is reported by Souder et al.[9] and discussed in detail in Part IV. Transport of material is expected to be one of the largest expenses in a land improvement operation where dredged material is used. Therefore, transport will strongly influence site location and design. The transport investigation should begin after the potential land improvement alternatives have been identified and should focus on modes linking possible sources with sites, rather than try to cover the entire regional network.

Identification of Possible Sites

24. The site selection process begins with listing all potential

Table 1

Potential Major Customers for Dredged Material Products (After Raster et al.[4])

Customer	Typical Needs
Raw material suppliers (sand and gravel mining and processing operations)	Material needs dictated by consumer being served. Requirements might be as simple as clean, organically free material or as stringent as separated coarses with a particular grain-size cutoff
Developers, construction firms	Landfill (classified and unclassified); subsidence fill; road embankments; earthfill dams; levees; shoreline restoration; aesthetic treatments (mounding, soil conditioner)
Mining industry	Fill and nutrient-rich cover for strip mines, quarries, underground mines
Highway departments	Material for road base; fill for embankments; sand to spread on icy roads
Asphalt and concrete plants	Sand for portland cement and asphaltic concrete mixes
Solid waste agencies and private firms	Cover for sanitary landfill operations
Environmental organizations and agencies (the Corps and state environmental and natural resources bodies)	Material for wildlife habitat creation (wetlands, bird islands)
Recreation agencies (local parks and recreation departments and the Corps)	Fill for parkland development; beach nourishment
Agricultural interests	Soil conditioner; nutrient-rich cover; fill for erosion-prone fields and streambanks

land improvement sites. All vacant lands should be considered. Area maps supplied by the U. S. Geological Survey (USGS) or local governments showing significant land uses (water bodies, roads, residential neighborhoods, parks, and environmentally or historically sensitive areas) are required for site location. Ground reconnaissance and documents obtained from local planners and organizers can add to the map information. Examples of organizations with land use information are the U. S. Department of the Interior, Bureau of Land Management; U. S. Department of Agriculture (USDA) Forest Service and Soil Conservation Service; oil companies; utility companies; farmers' associations; and military installations. Information from more sophisticated techniques, such as aerial photography, false infrared imagery, and Earth Resources Technological Satellite (ERTS) mosaics, can also supplement site information. Site ownership information, available in the records of the county assessor, should be tabulated and initial contacts made. In addition, governmental agencies with jurisdiction over land use, disposal operations, and water quality regulations must be contacted.

25. Factors in determining the feasibility of site selection are site accessibility, available transport modes, environmental concerns, site characteristics, institutional concerns, public attitudes, and compatibility of land use with adjacent properties. All-weather routes that will require little or no maintenance or upgrading must exist to and from the sites. Air, water, and noise pollution regulations must be examined to determine their applicability. Laws to be considered and responsible regulatory agencies that may be involved in site selection are listed in Table 2. Hydrologic, geologic, morphologic, and climatologic conditions at the site determine pollution potential from runoff, erosion, and percolation. Information sources that describe these conditions are listed in Table 3. Regulations on noise from on-site equipment operation and along transport routes through residential areas are generally controlled by local ordinances.

26. A cost-benefit analysis should be made of the remaining potential sites after a thorough screening of the proposed site list. The major cost components of the total project are: process center capital

Table 2

Primary Laws and Agencies (After SCS Engineers[3])

Act	Responsible Agency
Rivers and Harbors Act of 1899	Corps of Engineers
Federal Water Pollution Control Act of 1972	Corps of Engineers Environmental Protection Agency State water quality agencies
Fish and Wildlife Coordination Act of 1958	U. S. Fish and Wildlife Service State fish and wildlife agencies
National Environmental Policy Act of 1969	All Federal agencies whose actions affect the human environment
Coastal Zone Management Act of 1972	Designated state coastal zone management agencies through the Federal Office of Coastal Zone Management
State and local laws and ordinances governing land use, public works, material resources, health, etc.	State and regional land use planning agencies, natural resources agencies, and numerous local government units

Table 3

Sources for Basic Information on Prospective Land Improvement Sites (After SCS Engineers[3])

For Information Concerning	Contact
Area base maps	County road departments
	City, county, and regional planning departments
	USGS offices and outlets for USGS map sales (such as engineering supply stores and sporting goods stores)
Site maps	USDA, Agricultural Stabilization and Conservation Service
	USGS offices
	County agricultural extension services
	Surveyors and aerial photographers in the area
	Local companies
Geology	USGS reports
	State geological survey reports
	Professional geologists in the area
	Geology departments of state universities
Soils	USDA, Soil Conservation Service
	USGS reports
	Geology and agronomy departments of state universities
Hydrology	Private and public suppliers of water
	USGS water supply papers
	State and regional water quality protection agencies
	USDA, Soil Conservation Service
	State or Federal water resources agencies
	Local health departments
Topography	USGS topographic maps
	USDA, Agricultural Stabilization and Conservation Service
Vegetation	County agricultural extension services

(Continued)

Table 3 (Concluded)

For Information Concerning	Contact
Vegetation (Continued)	Agriculture departments of state universities, local arboretums
Land use	City, county, and regional planning agencies
Meteorology	National Weather Service Nearby airports U. S. Air Force installations National Climatic Center
Wildlife use and/or terrestrial biology	State and Federal fish and wildlife departments National Marine Fisheries Service Wildlife departments of state universities

and operation and maintenance (O&M) costs, land improvement capital and O&M costs, transport system costs, and related environmental protection costs; e.g., monitoring requirements and runoff diversion structures. The greatest percentage of total project expense can be attributed to such factors as volume of dredged material, equipment needs, site topography, labor, transport modes, land, and contractural agreements.

Preliminary Designs and Cost Estimates

27. Preliminary designs and cost estimates should be made for the remaining land improvement alternatives after a thorough screening of all the potential alternatives. At this point in the planning process, only suitable and cost-effective land improvement sites should remain for consideration. Further coordination of project plans with governing agencies should determine the prime land improvement site and complete the site selection process. Land improvement project details should be developed and submitted to the responsible governing agencies for approval. A variety of cost-sharing arrangements and acquisition agreements can be made. The report by SCS Engineers[3] provides a comprehensive checklist for contaminated dredged material and examines all factors that must be evaluated in selecting a site which is environmentally sound and acceptable to the society at large. This checklist should prove useful in examining any land improvement project, no matter what the quality of the dredged material. Other helpful planning documents prepared by or for the Corps of Engineers are Walsh and Malkasian,[1] Wakeford and Macdonald,[8] and Engineer Manual Series 200.[10]

28. Depending on state regulations, numerous follow-up steps to the land improvement project may be required. These steps may be as simple as returning leased lands to the owner or as complicated as meeting state environmental agency monitoring requirements. Postproject monitoring of groundwater is recommended to determine the level of water quality.

PART III: DREDGED MATERIAL CHARACTERISTICS

Introduction

29. In an analysis of dredged material proposed for use in land improvement projects, the major objective is to identify the physical, engineering, and chemical characteristics of the material. Such information allows the planner to evaluate the suitability of the material for use in a number of alternative land improvement projects. It is essential that the physical, engineering, and chemical characteristics of the dredged material be determined during the initial stages of planning since the project might prove unfeasible due to unsuitable material.

30. Each land improvement alternative requires dredged material which has certain characteristics. The specific requirements of the three land improvement alternatives presented in Parts V, VI, and VII are discussed in more detail in those Parts of this report. This Part presents discussions of the physical, engineering, and chemical characteristics of channel sediments and dredged material in containment areas. References are cited for guidance on the laboratory testing procedures.

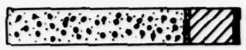
Physical and Engineering Characteristics

31. A number of standard soil properties are used to determine the physical and engineering characteristics of dredged material.[6] Soil tests include grain-size analyses, plasticity analyses, and organic content determinations. The engineering properties tests include compaction, consolidation, and shear strength. The study by Bartos[6] illustrated that dredged material is not simply the waste product of dredging but is in fact made up of various types of soil that can be classified under the Unified Soil Classification System (USCS).[11]

32. Table 4 and Figure 1 present the ranges of classification test data determined for dredged material from 400 samples obtained

Table 4

Ranges of Classification Test Data Determined for Dredged Material (from Bartos[6])*

Region	Total No. Samples	Type Material**	Grain Size† D_{10}, mm	D_{60}, mm	D_{90}, mm	Percent Passing No. 200 Sieve	Atterberg Limits LL	PL	PI	Organic Content, %
A	89		81 <0.001-0.24	89 <0.001-0.42	89 0.0065-0.80	89 1-99 63	66 32-202 104	65 17-71 35	65 9-144 69	60 0.17-10.64 3.95
B	93		90 <0.001-0.47	89 <0.001-7.50	90 0.0057-12.00	93 1-100 26	34 21-273 100	33 15-90 35	33 1-183 68	9 0.13-9.61 5.76
C	74		46 <0.001-5.00	74 0.0019-78.00	20 0.008->78.00	74 0.5-99 50	38 29-152 89	38 17-82 41	38 9-98 48	10 0.32-9.74 4.53
D	34		34 <0.001-0.46	34 0.007-1.10	34 0.031-7.00	34 0.5-99 46	18 21-161 72	18 19-69 34	18 2-92 38	34 0.09-13.45 3.67
E	110		109 <0.001-0.45	110 0.0053-2.70	110 0.027-10.30	110 0.0-99 27	33 28-99 55	33 17-43 25	33 5-57 30	10 0.28-6.53 2.77
Nation	400		360 <0.001-5.00	396 <0.001-78.00	397 0.0057->78.00	400 0-100 40	189 21-273 88	187 15-90 35	187 1-183 55	123 0.09-13.45 3.95

Note: For the purpose of this table, silts plot below the A-line and clays plot above the A-line on a plasticity chart.

* Conclusions drawn on basis of data shown apply only to samples tested for this study. Data entries for each region are shown in the following format:

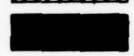
xx	Number of samples
xx-xx	Range of values
xx	Average value, if meaningful

** Legend for material types is as follows:

 Sand and gravel (>50% retained on #200 sieve).

 Silt (low-plasticity fines).

 Clay (high-plasticity fines).

 Organic material (soil with organic matter present)

† D_{10} = Grain size at 10% passing.
D_{60} = Grain size at 60% passing.
D_{90} = Grain size at 90% passing.

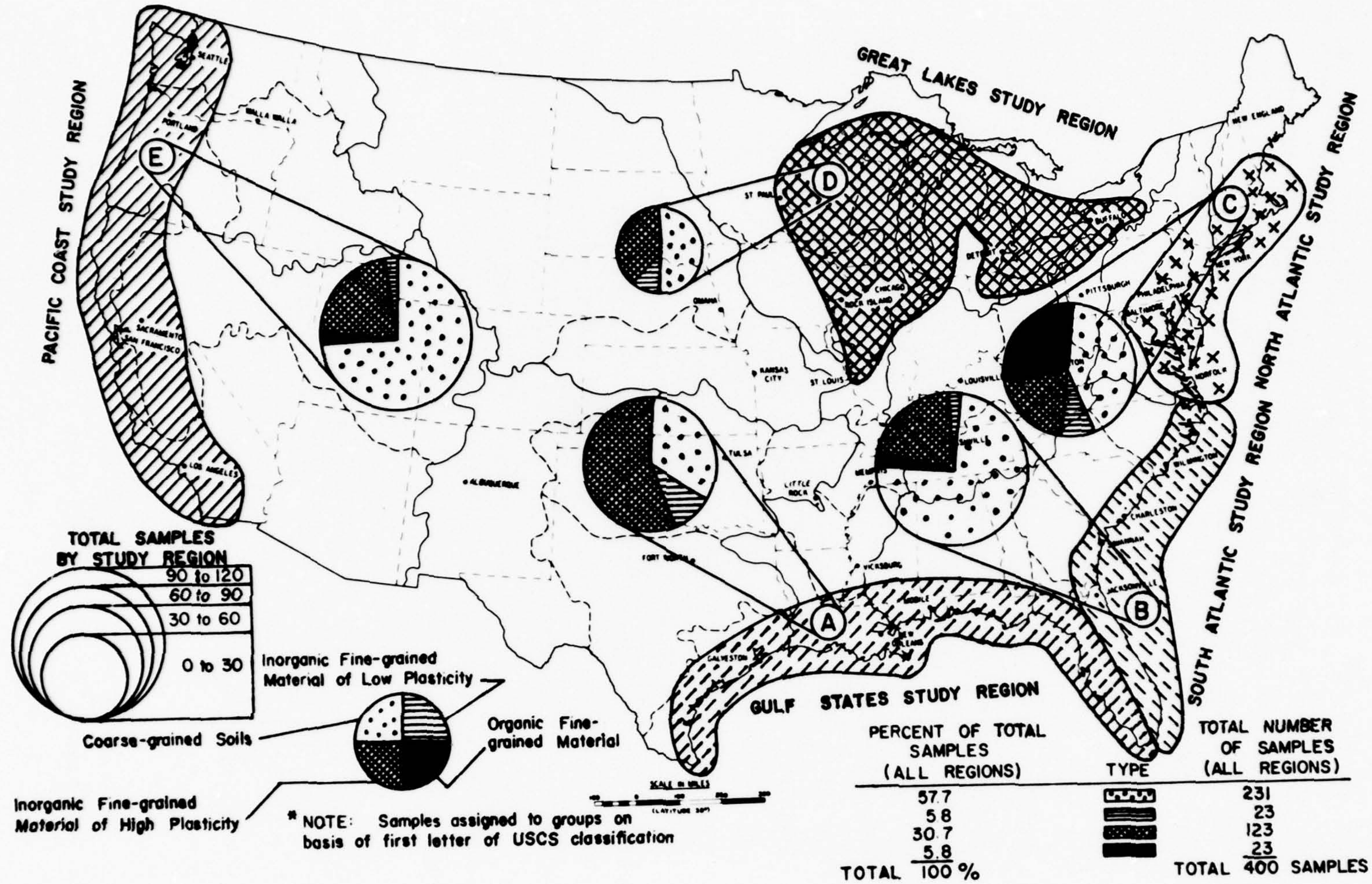


Figure 1. Types* of dredged material samples by region (from Bartos[6])

throughout the U. S.[6] The table shows that soils ranging from sands to fine clay and organic particles were represented among the materials dredged. Figure 1 shows the types of dredged materials found in various regions of the U. S. This figure is intended to be only an indicator of the types of material found in the various regions and not a quantitative representation.

Grain size

33. Grain size is the principal physical characteristic to be determined when considering dredged material for productive uses. Numerous physical and chemical properties are related to grain size. Grain size is also the basis of most soil classification systems. The land improvement guidelines presented in this report for the productive uses of dredged material include both engineering and agricultural projects. For this reason, both the USCS[11] and the USDA[12,13] classifications are used. Distinct differences arise between the two classification systems that can be attributed to their application. The USCS method for naming soils emphasizes characteristics that indicate how the material will behave as a construction material, whereas the USDA method emphasizes soil properties that, to an appreciable extent, determine the agricultural value of the soil. The USCS method is the standard and accepted method for classifying dredged material by the Corps. For certain productive uses, it may be necessary to further investigate the dredged material using the USDA method[13] to determine the agricultural potential of dredged material as a soil amendment.

34. The USDA[12] has classified and mapped most of the agricultural areas in the U. S. In the USDA method, soils are given a textural classification dependent on the grain-size distribution (sand = 2.00 to 0.05 mm; silt = 0.05 to 0.002 mm; and clay = $<$0.002 mm). Figure 2 shows the proportions of sand, silt, and clay in various agricultural soil types.[14]

Bulk density

35. The bulk density of a material gives an indication of the size and arrangement of various particles, whereas particle density or specific gravity reflects the nature of the particles comprising a

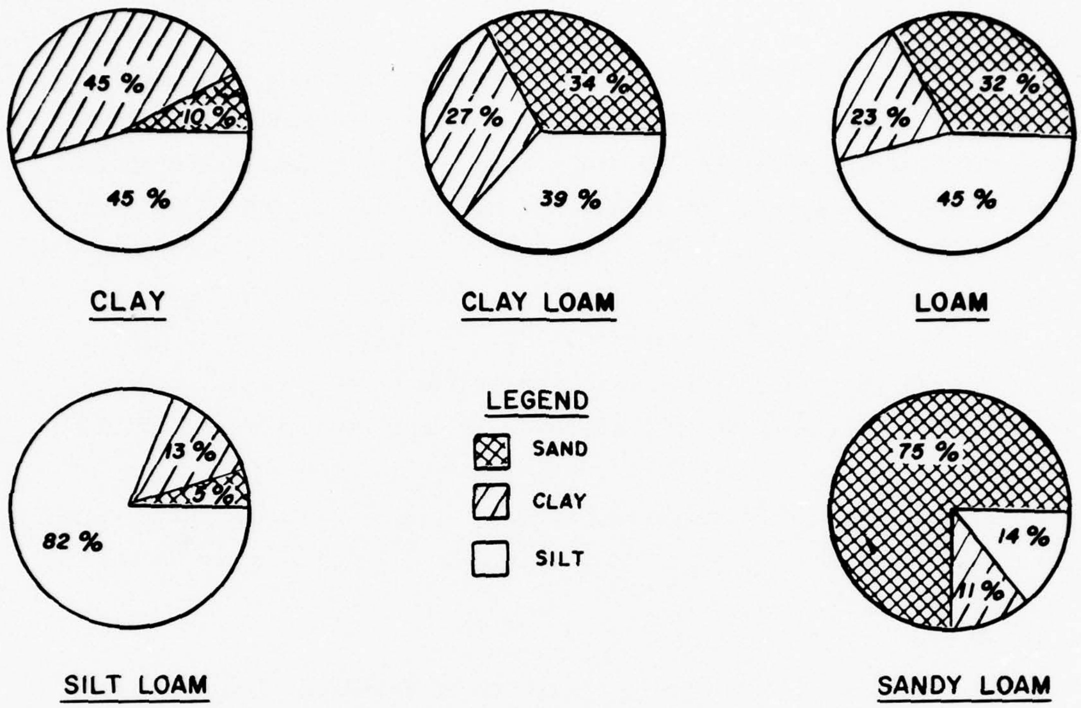


Figure 2. Percent of sand, silt, and clay in soils of various grain-size distributions and textural classes (from Cale[14])

given material. Bulk density is a weight measurement by which the entire soil volume is taken into consideration. The bulk density of dredged material is usually low for fine-grained material (<62.4 lb/ft^3*), whereas the bulk density of a highly productive agricultural loam soil can range from 70 to 86 lb/ft^3. These low bulk densities in fine-grained dredged material[15] can be attributed to the sedimentation process and the amorphous nature of the clay. The bulk density is needed for converting water percentage by weight to water content by volume for estimating the weight of a volume of material too large to weigh conveniently, such as the weight of dredged material in a disposal site, or estimating the volume of dredged material in a dump truck, barge, or railroad car.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 8.

Plasticity

36. For USCS classification, the Atterberg liquid limit (LL) and plastic limit (PL) must be determined in order to evaluate the plasticity of fine-grained samples of sediment. The LL is that water content above which the material is said to be in a semiliquid state and below which the material is in a plastic state. Similarly, the water content which defines the lower limit of the plastic state and the upper limit of the semisolid state is termed the PL. The plasticity index (PI), defined as the numerical difference between the LL and the PL, is used to express the plasticity of the sediment. Plasticity analyses should be performed on the separated fine-grained fraction (< No. 200 sieve) of sediment samples. A detailed explanation of the LL and PL test procedures and apparatus can be found in Appendix III of Engineer Manual EM 1110-2-1906.[16]

Specific gravity

37. Values for the specific gravity of solids for fine-grained sediments and dredged material are required for determining void ratios, conducting hydrometer analyses, and consolidation testing. Procedures for conducting the specific gravity test are given in Appendix IV of EM 1110-2-1906.[16]

USCS classification

38. When classifying sediment samples, the fine-grained portion which passes the No. 200 sieve should be classified separately from the coarse-grained portion retained on the No. 200 sieve, regardless of which fraction comprises the greatest percentage by weight. Additional information regarding the USCS classification may be found in Reference 11.

Water retention

39. Water retention characteristics of soil describe the energy relation of soil to water which in turn can be used to determine the availability of water to plants. This soil property describes the moisture storing capacity of a soil and is strongly influenced by the arrangement of the solid components of soil and the quantity of fine particles and organic matter. The soil water retention characteristics

determine the available water capacity of a soil (Table 5).[15] The available water capacity of a field soil is defined as the amount of water a crop can remove from the soil before its yield is seriously affected by drought (Table 6).[15]

Table 5

Available Water Capacity of Soils of Different Textural Classes (from Gupta et al.[15])

Textural Class	Available Water Capacity in. of Water per in. of Soil Depth
Sand	0.015
Loamy sand	0.074
Sandy load	0.121
Fine sandy loam	0.171
Very fine sandy loam	0.257
Loam	0.191
Silt loam	0.234
Silt	0.256
Sandy clay loam	0.209
Silty clay loam	0.204
Sandy clay	0.185
Silty clay	0.180
Clay	0.156

Table 6

Available Water Capacity Suitable for Agricultural Crops (from Gupta et al.[15])

Available Water Capacity in. Water/in. Soil	Total Available Water Capacity in. per yd of Soil Depth	Recommended Plants
<0.05	1.8	Not suitable for most agicultural crops unless irrigated
0.05-0.075	1.8-2.7	Best suited for grasses
>0.075	2.7	Suitable for most agricultural crops

Permeability

40. The permeability of a soil material expresses the ease with which water will move or pass through it (Figure 3). The permeability is determined by a number of factors; however, the size of the soil pores and the magnitude of the soil water retention are the most important.

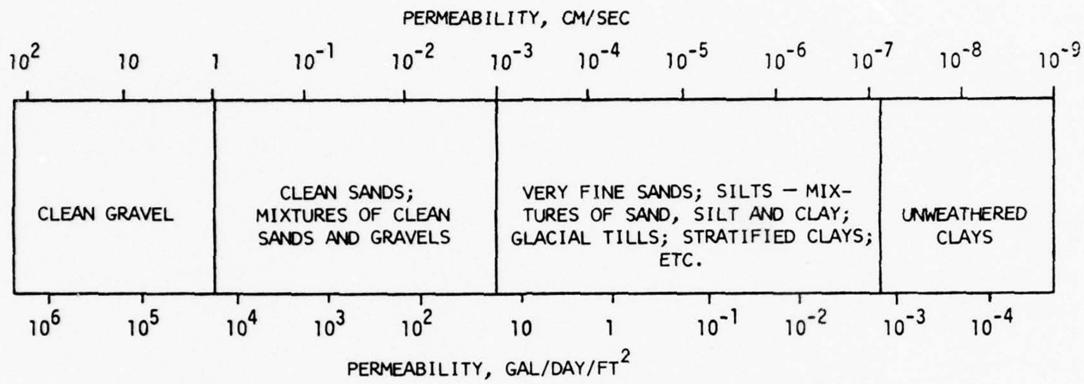


Figure 3. Range in permeability of different soil classes (after SCS Engineers[3])

Properties of dredged material in confined disposal areas

41. Johnson et al.[17] investigated the applicability of conventional techniques for densifying dredged material. For that study, some knowledge of the properties of dredged material in disposal areas, where densification would be implemented, was required. Most of the following discussion is taken from that report, which contains more detailed information as well as pertinent references to source material.

42. Physical properties. When pumped into a disposal area, dredged slurry can have a dry solids content ranging from near 0 to approximately 40 percent by weight. Generally, this value is about 13 percent. As the slurry flows across the disposal area, the solid particles settle from suspension: coarse particles near the inlet (dredge pipe), fine particles farther into the area, and finest materials in the immediate vicinity of the outlet. As the disposal operation progresses, additional coarse-grained dredged material may accumulate in a

mound near the inlet, displacing the soft fine-grained dredged material.

43. After the disposal operation is terminated, the surface water is drained from the disposal area. A surface crust begins to form on the fine-grained dredged material as it desiccates. With time, surface and base drainage cause some lowering of the groundwater table; the surface crust continues to increase in thickness; secondary compression effects develop; and consolidation occurs as the effective weight of the dredged material above the groundwater level is increased from a submerged weight to a saturated weight. The dredged material below the surface crust remains very soft and weak.

44. Data show that the water content of fine-grained dredged material in disposal areas is generally less than 1.5 times the LL of the material, and it is possible that in freshwater areas the water content is about equal to the LL. The LL of dredged material is generally less than 200, with most values being between 50 and 100.

45. Engineering properties. The surface crust associated with fine-grained dredged material usually has a very low water content (often near the shrinkage limit) that increases slightly with increasing depth of the crust. The crust is usually overconsolidated due to the increase in effective stress caused by high negative pore pressure resulting from evaporation. Below the surface crust, however, the fine-grained dredged material is extremely soft and weak, with water content usually showing little change from the time of deposition (1.0 to 1.5 times the LL). Density and shear strength increase very slightly, if at all, with increasing depth.

46. Data show that engineering properties (strength, compressibility, etc.) are generally better near the inlet than the outlet because the coarse-grained material settles near the dredge discharge. The engineering properties of the fine-grained material in the containment area near the outlet are poorer and improve very slowly with time.[6,18] In general, it has been found that dredged material is a soil at a high water content and if dewatered it exhibits properties expected of soil with a high potential for productive uses.[6] References that should be consulted for engineering properties are:

Text	Tests
EM 1110-2-1906[16]	Grain size, plasticity, organic content, compaction, consolidation, shear strength, and permeability
Methods of Soil Analysis, Part I[19]	Soil water retention, available water capacity, infiltration rate, and air permeability

Chemical Characteristics

47. Dredged material characteristics reflect the population, industry, and land uses of an area. SCS Engineers[3] discuss the ranges of chemical characteristics found in selected dredged material as presented in Table 7. The chemical constituents of dredged material help determine the suitability of that material for a particular land use. Chemical analysis of the dredged material must be made to indicate potential detrimental effects on the environment in a land disposal project. Three potential problem areas exist depending on the presence of available chemical constituents in the dredged material: plant toxicity, surface water contamination, and groundwater contamination. Plant uptake of chemicals may also present problems if growth or reproduction potential of the plant is altered or if harmful chemicals are passed into the food web.

48. At present, no Federal disposal criteria exist with regard to the application of dredged material to upland areas. Guidance must therefore be drawn from related scientific fields where criteria or interim acceptable limits are established. Mang et al.[21] summarized water quality limits and standards from the Environmental Protection Agency (EPA), the National Academy of Sciences (NAS), the National Technical Advisory Committee (NTAC), and various state agencies. These criteria have been placed on public water supply, fresh water (aquatic life), agriculture water (irrigation), marine water (aquatic life), and groundwater sources. Research studies[2,15] have indicated numerous chemical constituents and characteristics to be used for evaluating dredged material for land application.

Table 7

Concentrations of Chemical Constituents and Characteristics

(After Chen et al.[20])

Constituent	Range Expected in Concentration ppm
Total sulfides (acid soluble)	100-3,000
Oil and grease	100-5,000
Organic nitrogen	100-2,000
Ammonia (NH_4-N)	100-2,000
Total nitrogen	200-4,000
Total phosphorus	500-2,000
Calcium (Ca)	600-17,000
Chloride (Cl)	40-20,000
Magnesium (Mg)	4,000-13,000
Potassium (K)	17,000-24,000
Sodium (Na)	12,000-40,000
Cadmium (Cd)	0.05-70
Chromium (Cr)	1-200
Copper (Cu)	0.05-600
Iron (Fe)	1,000-50,000
Lead (Pb)	1-400
Manganese (Mn)	24-550
Mercury (Hg)	0.2-2.0
Nickel (Ni)	15-150
Zinc (Zn)	30-500
Chlorinated pesticides	nil-10
Polychlorinated biphenyls (PCB's)	nil-10

Characteristic	Range Expected
Chemical oxygen demand (COD)	1.0-13%
Total organic carbon (TOC)	0.5-5%
pH	6-9

Cation exchange capacity

49. The capacity of soil particulates to adsorb nutrients which become available for plant growth is called the cation exchange capacity (CEC). Adsorbed or sorbed nutrients are readily available to higher plants and easily find their way into the soil solution. The grain size and organic content of sediments determine to a large extent the capacity of that material to sorb and desorb cations, anions, oil and grease, and pesticides. Silts and clays with relatively high organic contents can sorb and fix large amounts of plant nutrients as well as many other constituents (Figure 4). The CEC of dredged material governs the sorption of nitrogen, potassium, and other cations; heavy metals; and some pesticides. The nutrient content of dredged material varies widely as does that of different soils. Generally, fine-grained dredged material contains considerably more nutrients than coarse-grained material.

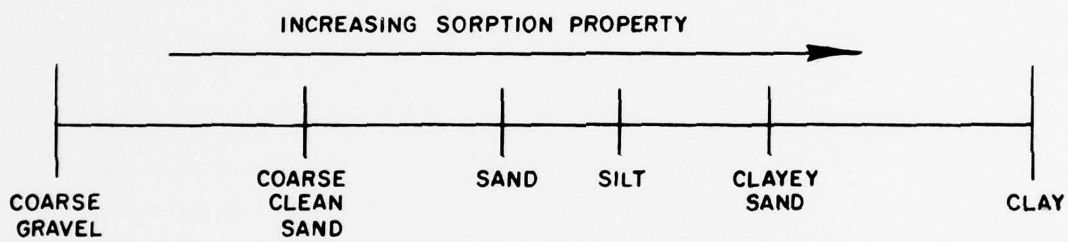


Figure 4. Sorptive properties of selected soils

Nitrogen

50. The total nitrogen content of dredged material varies widely with geographic location. The most predominant form of nitrogen in inorganic sediments is ammonium nitrogen. In organically enriched sediments, however, organic nitrogen predominates, even though ammonium concentrations can be very high.

Sulfur

51. Lee, Engler, and Mahloch[2] found that sediments in a South Carolina tidal marsh developed high acidity when drained and dried. These sediments contained up to 5.5 percent total sulfur. When drained, sulfides were oxidized to sulfate with a resultant decrease in sediment

pH from 6.4 to as low as 2.0. This effect may be a serious problem in dredged material containing high levels (usually greater than 0.1 percent) of nonvolatile sulfide, predominantly iron and manganese sulfide. This is especially true if the dredged material is not limed or its acidity not otherwise counteracted by application to an alkaline upland soil.

Heavy metals

52. A wide range of heavy metal concentrations has been reported in a number of sediments from rivers, harbors, and bays throughout the U. S. and Canada. Some of the major sources of heavy metals include industrial and sewage discharges, urban and highway runoff waters, and snow removal. Wastes from metal plating industries that have found their way into some sediments contain significant amounts of copper, chromium, zinc, nickel, and cadmium. Chemical partitioning studies of sediments have shown that these metals occupy the least stable of the sediment fractions and that the sediment chemistry dominates the mobility and availability of the contaminant as well as the indigenous metals.

53. An important consideration with heavy metals is the solubility of specific constituents whose concentrations are high since soluble forms are readily available to the biological food web. The potential of a heavy metal to become a contaminant depends greatly on its form and availability rather than on its total concentration within a dredged sediment.[2] Heavy metals may be fixed in a slightly soluble form in dredged material containing excessive sulfide. The land application of dry oxidized dredged material may increase the solubility of heavy metal sulfides. However, under oxidizing conditions, the levels of pH and heavy metal hydroxyl and oxide formation become the important factors, and sulfur no longer governs the solubility and availability of heavy metals.[15]

54. Until Federal criteria are set, guidelines for dredged material disposal must be taken from other research areas, such as sludge disposal. The USDA has been investigating the application of sewage sludge to agricultural lands. Chaney et al.[22] presents recommended maximum limits on the metal content of sludge (Table 8). The

Table 8

Metal Contents in Digested Sewage Sludges

(After Chaney et al.[22])*

Element	Domestic Sludge Concentration, ppm
Zinc	2000
Copper	1000
Nickel	200
Cadmium	15 or 1.0 % of Zn
Boron	100
Lead	1000
Mercury	10
Chromium	1000

* Typical sludge from communities without excessive industrial waste inputs or with adequate abatement.

concentrations of heavy metals found in Table 8 compare faborably with the ranges of concentrations presented in Table 7. Thus, in most cases, the heavy metal contents of dredged material fall below the maximum allowable limits recommended in domestic sewage applied to land. If higher concentrations of chemical constituents are found in dredged material, it should not be used in a land improvement project without prior treatment to remove or reduce contaminants. References that should be consulted for water and soil analyses are:

Texts	Tests
Standard Methods[23]	Water chemical analyses
Methods of Soil Analysis, Part II[24] USDA[25]	Nutrient analyses, lime requirement, trace elements
Lee et al.[26]	Heavy metals, chemical extraction

PART IV: DREDGED MATERIAL TRANSPORT

Introduction

55. The transportation of dredged material is a critical consideration in a land improvement project feasibility study. While both land improvement projects and common dredged material disposal operations require land acquisition and site feasibility studies, only land improvement projects involve, in almost all cases, the added expense of transporting dredged material to land areas not adjacent to the project waterway. The fundamental features of transport systems and general guidance for analysis of technical and economic feasibility are provided in this Part. The primary information source for this Part is a report by Souder et al.[9] The information presented here is intended to acquaint planners with the magnitude and scope of the transport system and provide some cost-effective analysis information for five transport modes: hydraulic pipeline, rail haul, barge movement, truck haul, and belt conveyor movement.

General Planning Steps

56. Since the transport of dredged material can be a major cost item in determining the economic feasibility of a project, the transport system should be evaluated early in the site selection stage of the planning process. Legal, political, sociological, environmental, physical, technical, and economic aspects should be examined in relation to availability of transport routes. A sequence of five steps must be followed when selecting a transport route:

Step	Information Source
1. Identify available routes	Maps, ground reconnaissance
2. Classify nature (wet/dry) of dredged material	Productive use needs and sources of dredged material

(Continued)

Step	Information Source
3. Determine annual volume of dredged material and duration of project	Dredged material source
4. Estimate cost of available transport modes	Souder et al.[9]
5. Identify and evaluate technical, environmental, legal, and institutional requirements	Souder et al.[9] Specific sources: Local, state, and Federal regulations and agencies

57. Federal and state regulations and local ordinances control transport procedures which can impact on project viability. Problems to be considered are: allowable noise levels along transport routes (Noise Control Act of 1972), air pollution emission levels (Clean Air Act of 1970), traffic and shipment regulations in specific zones, truck weight limits (Highway and Safety Regulations), and accidental spill responsibility. Other considerations that are transport mode specific will be mentioned later in this Part when the specific transport modes and limitations are discussed.

Elements of Transport Systems

58. Transport systems involve three major operations: loading, transporting, and unloading. The loading and unloading activities are situation dependent and are the major cost items for short distance transport. The hydraulic pipeline is the only mode which requires a unique rehandling activity; all other transport modes may interchange loading and unloading operations to suit the specific site needs. Loading, unloading, and transporting operations can be separated into detailed components (i.e., backhoes, service roads, rail spurs, cranes, conveyors, etc.) and each component examined for capacity, operational schedule and cycle, and costs of equipment and of operation and maintenance.

59. Important planning considerations are summarized below after each transport mode to ensure that unforeseen problems do not arise

subsequent to the selection of that transport mode. The considerations should delineate viability of any particular transport mode.

Transport Modes

Hydraulic pipeline

60. The hydraulic pipeline is the only transport system recommended for movement of dredged material in slurry form. Assuming government construction, contractor operation, and no easement cost, this system can be economically competitive for distances up to 125 miles. The conditioning step requires a rehandling dredge and fluidizing system. Control of density and flow to minimize operational problems is an essential conditioning process unique to the hydraulic pipeline mode. Raster et al.[4] suggest criteria to be used in selecting a rehandling (or secondary) dredge for operation within a containment area. The criteria include:

- a. Unit cost of dredging.
- b. Ease of transportation.
- c. Minimum downtime.
- d. Small size to allow maneuverability in a small basin.
- e. Capability to dredge in shallow water to minimize dike height.
- f. Maximum cutter width to reduce the number of passes.

Numerous dredges fitting these criteria are on the market. Some have additional features such as cutterheads capable of following natural contours of the basin bottom without damage to natural or man-made seals, wheel attachments for the cutterhead to allow dredging operations in plastic or rubber-lined basins, and capability of dredging forward and backward. The fluidizing system is needed to supply water from the closest source to maintain flotation of the dredge. A schematic of rehandling operations for hydraulic pipeline transport is displayed in Figure 5. Unloading facilities are unnecessary since the dredged material slurry is usually pumped out of the pipeline into a containment area.

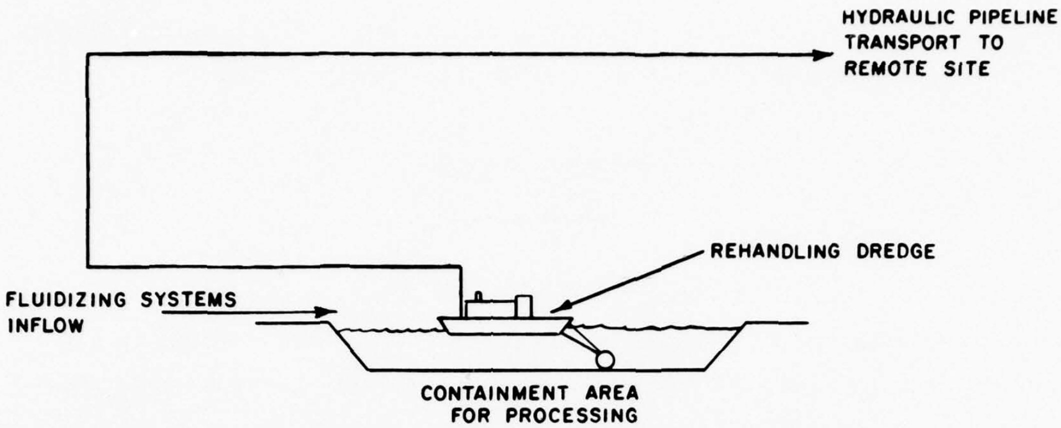


Figure 5. Schematic of rehandling system for hydraulic pipeline

61. The pipeline to the land improvement site would include a pneumatic or centrifugal hydraulic pump booster system and would be automated to the maximum extent possible. For comparative purposes, sensitivity analyses on the costs of the pump booster system are provided in the report by Souder et al.[9]

62. The following items should be taken into consideration in any planning for pipeline transport:

- a. Slurry movement of saline dredged material to a freshwater environment is not recommended.
- b. Dewatering requirements before a productive use application may be a cost burden and may require treatment of decanted water.
- c. Building codes, easement acquisition, utility relocation, climatological factors, and urban area disruption from construction may be obstacles.
- d. Confining dikes must be provided and could be a significant cost item.
- e. Right-of-way acquisition.

63. Real estate and right-of-way easements are very site-specific items of political as well as economic concern. These items can impact greatly on the cost of hydraulic pipeline system and therefore should be given due consideration in any cost-benefit analysis and in the final cost evaluation. The cost guidelines do not take into account these costs due to the uniqueness of each case.

Rail haul

64. Rail haul using the unit train concept is technically feasible and economically competitive with other transport modes for hauling dredged material distances of 50 to 300 miles. A unit train is a dedicated train reserved to carry one commodity (dredged material) from specific points on a tightly regulated schedule. Facilities are required for rapid loading and unloading to make the unit train concept work and to enable benefits from reduced rates on large volumes of bulk movement. Bottom dump cars or rotary car dumpers are needed to meet the rapid loading and unloading requirements. Economic feasibility demands the utilization of existing railroad tracks; however, the building of short intermediate spurs may be required to reach disposal areas.

65. The following items should be taken into consideration in any planning for rail haul transport:

- a. Dredged material must be dry enough to free-fall from cars.
- b. Scheduling and length of unit trains are often strictly regulated.
- c. State regulations may require open hopper cars to be covered.
- d. Dual use of hopper cars may require washing of cars between uses and treatment of wash water to prevent contaminant transfer.

Barge movement

66. Depending upon the volume of material to be moved, barge movement can be an economically competitive transport mode for the movement of dredged material up to 300 miles. Barge haul was used in the Sacramento District to remove 7,000,000 yd^3 of dredged material from Grand Isle (Figure 6). To ensure reasonable costs, a barge unit should consist of familiar and available equipment such as one tugboat (1,000 hp) and two dry cargo scows (1,500-yd^3 capacity each). In addition, loading and unloading mooring docks capable of accommodating the two cargo scows simultaneously must exist with roadways between the docks and disposal areas.

67. The following items should also be taken into consideration:

- a. Thorough information must be obtained about the waterway;

Figure 6. Tugboat and barge transporting dredged material (photo courtesy of Sacramento District)

i.e., navigation depth, allowable speed, lock size, traffic density and patterns, etc.

b. Often regulations exist concerning cleanup responsibilities with associated fines for spills in inland waters.

c. Climatic conditions may affect operational schedules.

d. A user charge for waterways may become a reality in the future.

Truck haul

68. Truck haul of dredged material can be economically competitive for distances up to 50 miles. At greater distances, transport by truck is labor and fuel intensive and not economically justifiable. The simplicity of loading and unloading requirements and the relative abundance of available roadways make truck hauling technically the most attractive transport mode (Figure 7). Costs analyses are based on utilizing 25-ton dump trucks with 18.5-yd^3 capacities and assume that routes exist which are adequately upgraded and maintained. Economic feasibility of truck hauling is based on rates established by negotiation with trucking companies and include all associated driver and fuel costs.

69. The following items should also be taken into consideration:

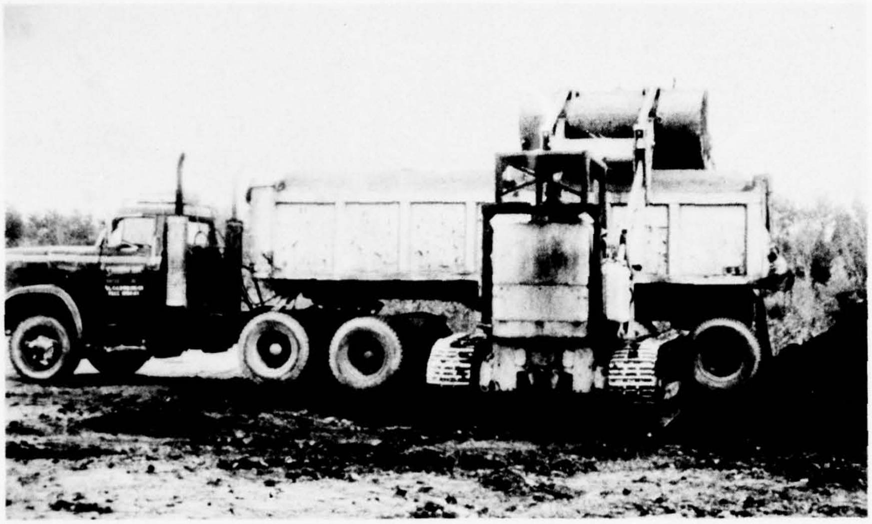


Figure 7. Truck haul utilized by the Chicago District

a. State highway and safety regulations cover a variety of elements (gross weights of trucks, weight per axle, etc.).

b. Emission and noise standards.

c. Local ordinances designating truck routes.

d. Traffic control of truck operations during winter months in northern climates.

e. Weight limits on bridges and roadways.

Belt conveyor movement

70. Belt conveyor systems are employed to transport relatively dry dredged material for short distances. They are technically feasible and cost competitive for distances up to 50 miles. Belt specifications vary in width (30 to 70 in.), flight length (900 to 26,000 ft), and speed (7 to 90 mph). Systems can be designed to suit project needs excluding certain terrain difficulties. Because of system flexibility, belt conveyors fit neatly into many loading and unloading operations. The California Highway Department, under an agreement with the Sacramento District, uses dozers and conveyors to load dredged material onto barges (Figure 8).

71. The following items should be taken into consideration in any planning for belt conveyor transport:

a. Building codes, easement acquisition, utility relocation,

Figure 8. A 36-in. belt conveyor loading operation (photo courtesy of Sacramento District)

climatological factors, and urban area disruption for construction may be obstacles.

b. Material pileup due to system failure.

c. Malfunctions of sequential belt systems resulting in entire system stoppage.

Loading and Unloading Elements

72. Loading and unloading elements may incur high costs which can restrict project viability. Souder et al.[9] present several examples of loading and unloading options and schematics of scenarios associated with various dry material transport modes. Selected schematics are presented in Figures 9 and 10. A pair of backhoe excavators and a series of conveyor belts provide rapid loading of unit trains (Figure 9). The barge haul scheme uses backhoes for excavation and loading directly into dump trucks which make the intermediate haul to the scows (Figure 10). In this report, cost comparisons are based on the loading and unloading component scenarios presented by Souder et al.[9] The truck haul loading element components are similar to the rail loading components which include excavation backhoes and a series of belt conveyors.

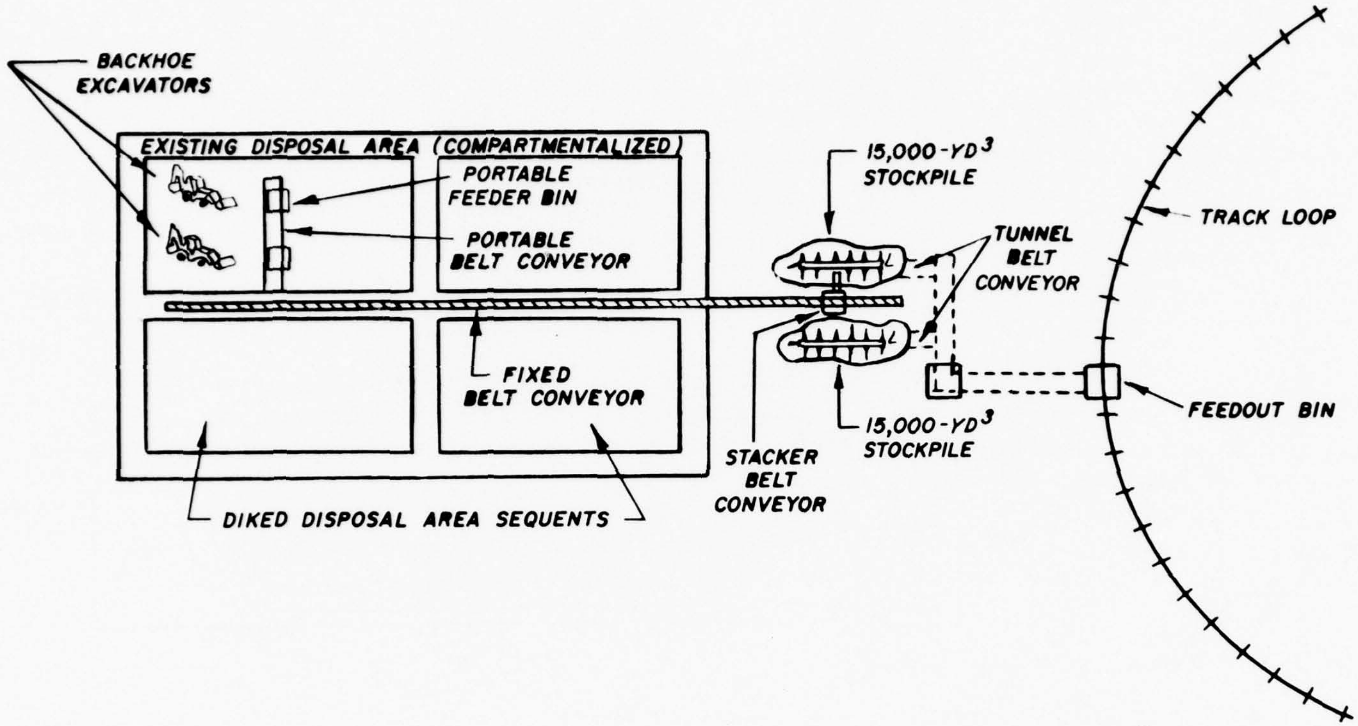


Figure 9. Unit train rail loading facility (from Souder et al.[9])

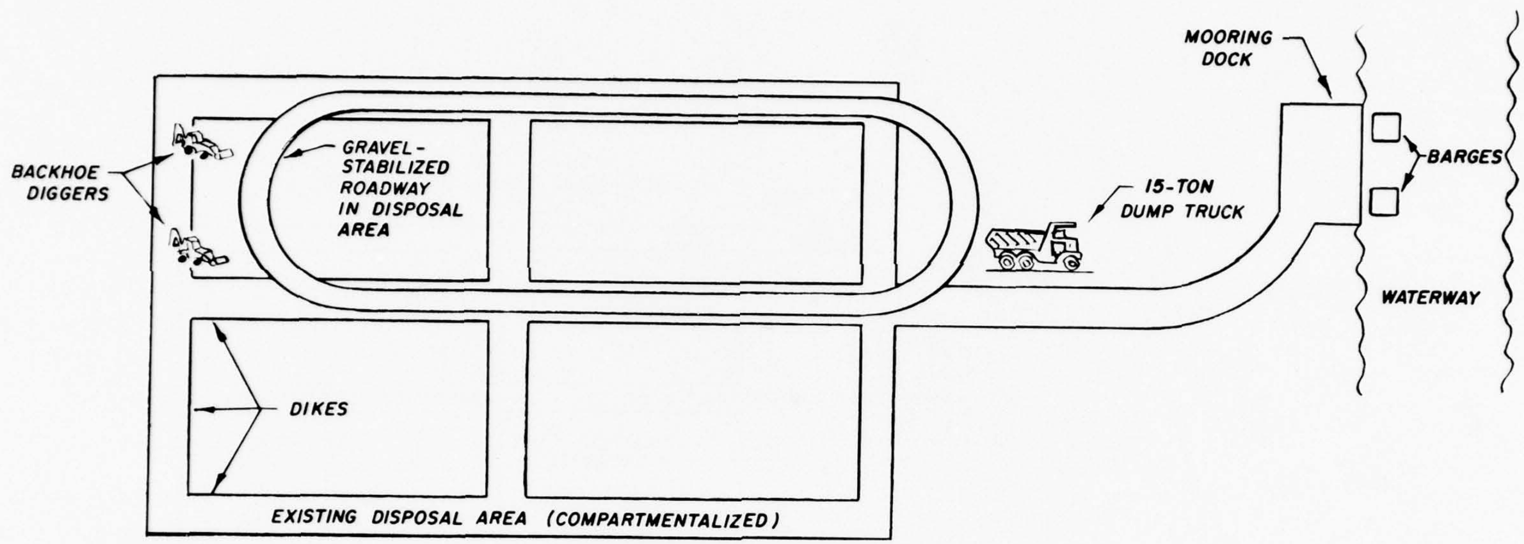


Figure 10. Barge loading operation (from Souder et al.[9])

The unloading system is simply back-dumping at the productive uses site.

Analysis of Cost Effectiveness

73. Transport cost can account for 90 percent or more of total land improvement budget costs. The cost figures presented in this section are meant to serve as examples for planning and do not represent definitive cost estimates. Table 9 is included to provide insight into the cost relationships for various modes of transport. The table provides total system costs for all five transport modes. Transport costs are reported in dollars per cubic yard of dredged material moved. Costs are recorded for distances of 10, 20, 100, and 250 miles and for annual quantities of 500,000, 1,000,000, 3,000,000 and 5,000,000 cubic yards. This breakdown shows that economic feasibility is limited by distance for most transport modes and shows the economies of scale for larger annual volumes of material shipped. Real estate and right-of-way costs for the hydraulic pipeline system are not included in the cost estimating procedure.

Summary

74. An evaluation of site conditions and available routes is essential to every project and ultimately determines the selected transport mode. However, a few general conclusions can be drawn. Truck haul is the most convenient and easily operated mode of transportation available and is the recommended transport mode for short distances. At intermediate distances, trucking becomes less economically competitive but remains the most operationally sound mode. Rail haul and barge movement of dredged material are feasible over a wide range and are the only viable modes for distances beyond 125 miles. The only valid constraints on barge and rail modes of transport are route availability, lack of flexibility in time constraints, and proximity to land improvement sites. Belt conveyors are always the most expansive mode of transport but can be used effectively in rapid loading and unloading procedures. When transporting dredged material slurry, the hydraulic pipeline is the only valid transport mode.

Table 9

Comparison Costs of Various Transport Systems, Quantities, and Distances

Annual Quantity yd3	Transport Distance miles	Cost, $/yd3, For Cited Transport System				
		Pipeline	Rail	Barge	Belt	Truck
500,000	10	2.47	*	2.47	8.98	4.57
	20	3.14	*	3.14	15.15	6.61
	100	9.54	7.18	4.71	*	13.69
	250	*	9.32	7.41	*	*
1,000,000	10	1.46	*	2.92	5.39	3.73
	20	1.91	*	3.14	13.47	4.19
	100	6.45	5.39	4.49	*	12.91
	250	*	7.58	7.18	*	*
3,000,000	10	.79	*	2.70	2.25	3.17
	20	1.12	*	2.92	3.93	3.56
	100	4.10	4.21	4.49	*	12.35
	250	*	5.34	7.35	*	*
5,000,000	10	.67	*	2.81	1.68	3.05
	20	.90	*	2.92	3.14	3.42
	100	3.48	4.04	4.38	13.58	12.07
	250	*	6.06	7.07	*	*

Note: The general cost estimates in this table are taken from Souder et al.[9] and McMahon.[27] These costs are adjusted to March 1978 dollars.

* Indicates not competitive economically.

PART V: SURFACE MINE RECLAMATION

Introduction

75. As a consequence of recent public awareness of the adverse environmental impacts of surface mining, state and Federal laws now direct mine operators to submit a reclamation plan when applying for a mine license and/or permit. However, there remain many abandoned surface mines which continue to be sources of erosion and acid runoff. Without proper reclamation, these lands remain unproductive and aesthetically displeasing.

Pollution reduction

76. Various techniques have been developed to control acid mine drainage from surface mine spoils.[28] The primary purpose of these techniques is to reduce air and water contact with the acid generating mine spoils. Methods which accomplish this are reducing slopes, thereby reducing runoff velocities and erosion, and establishing plants on the mine spoils. A balance must be struck between slope reduction and increased infiltration capacity. Attempts to establish vegetative cover on highly acidic mine spoils have usually resulted in low survival rates. The lack of a vegetative cover on mine spoils will result in erosion and futher exposure of acid generating pyrites (FeS_2) to air and water.

77. In order to reduce adverse effects of mine spoils, placement of a topsoil or topsoil substitute suitable for vegetative growth such as dredged material is recommended.[29] Application of dredged material to surface mine spoils can accomplish the following:

- a. Provide a cover that will reduce the infiltration of water and the diffusion of air to the pyrite material, thus reducing acid mine drainage.
- b. Provide a suitable growing medium for vegetation, making the site environmentally beneficial and aesthetically pleasing.

Prereclamation planning

78. Planning must be coordinated with the landowner and, if the mine is an active surface mine, the mining operator. Before reclamation

activities can commence, the planners must familiarize themselves with state reclamation laws which include the final grade of the area, cover requirements, and vegetation requirements.

Information sources

79. Assistance for various aspects of surface mine reclamation can be obtained from state reclamation departments, county agricultural extension offices, the USDA Soil Conservation Service, and other local, state, and Federal agencies.

Dredged Material Requirements

80. Dewatered dredged material can be used for surface mine reclamation in much the same way as topsoil or agricultural soil. However, when construction is considered as the final land use for the reclaimed mining area, the tests for consolidation, shear strength, and permeability should be performed on the dredged material as well as the mine spoil. Fractions of dredged material having different grain sizes can be mixed to provide a surface with desirable physical and engineering properties. Almost any desired soil property can be obtained by dewatering, mixing, and compacting dredged material.[6]

81. Fine-grained dredged material can be used as a cover on mine spoils for the establishment of vegetation. Dewatered dredged material having a loam texture (SM, ML, or CL by USCS classification) is the most desirable for vegetation purposes. The dredged material should be tested for pH, organic content, and soluble salts. The dredged material should have a near neutral (6.0 to 7.5) pH, a minimum organic content of 1.5 percent by weight, and a low amount of soluble salts (500 ppm or less).[30]

Site Considerations

Site preparation and dredged material placement

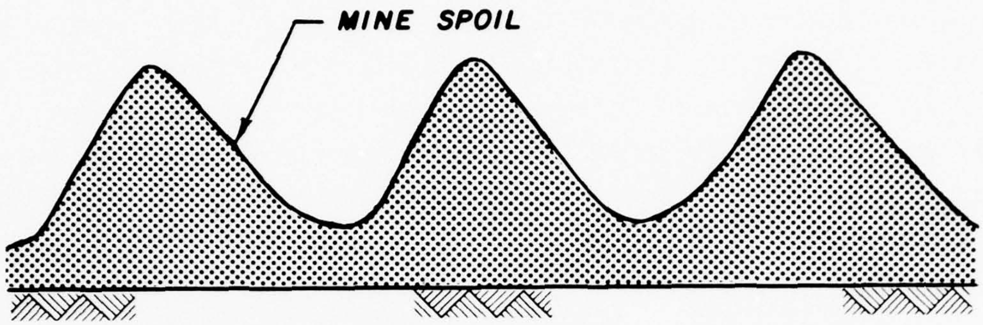
82. The amount and method of site preparation needed at surface mines are dependent on the topography, the method of mining performed

(area, contour, open pit, etc.), and the final land use. Site preparation consists chiefly of regrading the surface mine to a configuration that will accommodate a dredged material cover at a desired thickness and slope to support vegetation. The two principal surface mining techniques are area and contour mining.[29] Basic site preparation techniques for reclaiming area and contour surface mines are discussed below. Information on various mining techniques and reclamation methods are documented in publications of the U. S. Environmental Protection Agency (EPA)[28] and USDA.[29]

Area mined land reclamation

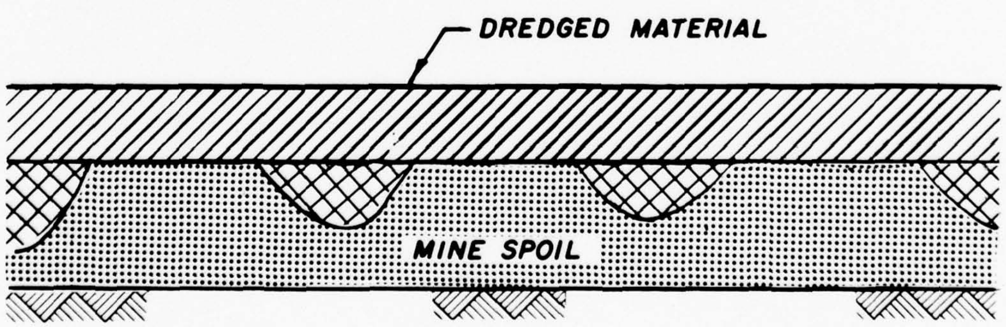
83. The area mining method produces the characteristic topography of a series of parallel ridges or piles of mine spoil.[29] Site preparation consists of leveling mine spoil ridges or piles to a width specified by law and/or final land use. Leveling or "striking off" mine spoil ridges is accomplished by bulldozing the ridges as shown in Figure 11. The mine spoil piles should be leveled to a topography where conventional earthmoving equipment can spread dewatered dredged material to a desired thickness (Figure 12). This method is being field tested by the Chicago District (see Appendix B).[31]

Figure 11. A bulldozer "striking off" the mine spoil ridges prior to covering with dredged material



a. Prereclamation

b. Grading the mine spoil



c. Application of dredged material

Figure 12. Schematic diagram showing operational techniques used to reclaim a surface mine spoil with dredged material

84. An alternate concept of reclaiming area mines is by the use of slurried dredged material. Although this method has not been field tested, it appears promising. This method consists of hydraulically pumping dredged material in a pipeline onto a prepared area mine. This form of reclamation is only feasible for area mines located within pumping distance of an active dredging operation or rehandling basin as discussed in Part IV. Preparation of the site consists of grading mine spoils to a fairly uniform level and the construction of dikes around the area to contain the slurried dredged material. Because of the slurry's high water content, it must be pumped in lifts and allowed to dry before adding the next lift. The depth of each lift is dependent on the final land usage and time constraints.[32] If the area is to be used for foundation material to support lightweight structures, the lifts of slurried dredged material should be limited to about 36 in. so that drying will be enhanced.[33] The dredged material should be allowed to dry to a moisture content near its plastic limit before adding the next lift.[32] If the area being reclaimed is not planned to support structures and is mainly being reclaimed for recreation or vegetation establishment, the depth of each lift may be increased and the amount of time between lifts may be shortened.

Contour mined land reclamation

85. The reclamation of contour mines is more difficult due to the hilly terrain in areas where this type of mining occurs (Figure 13). This technique of mining requires removal of the overburden by starting at the outcrop of the coal seam and proceeding along the contour around the hillside. The highwall is located on the uphill side, while a rim and steep downslope are covered by the spoil material cast down the hillside. Being above the grade of local drainage, water from the pits flows directly into natural waterways.[34]

86. Reclamation of contour mines involves backfilling and terracing the disturbed land to the approximate original contour or to a contour compatible with the surrounding terrain. This requires placing dredged material into strip pits and over the mine spoil which was cast downhill (Figure 14).

Figure 13. Backfilling of surface mined area (from McNay[35])

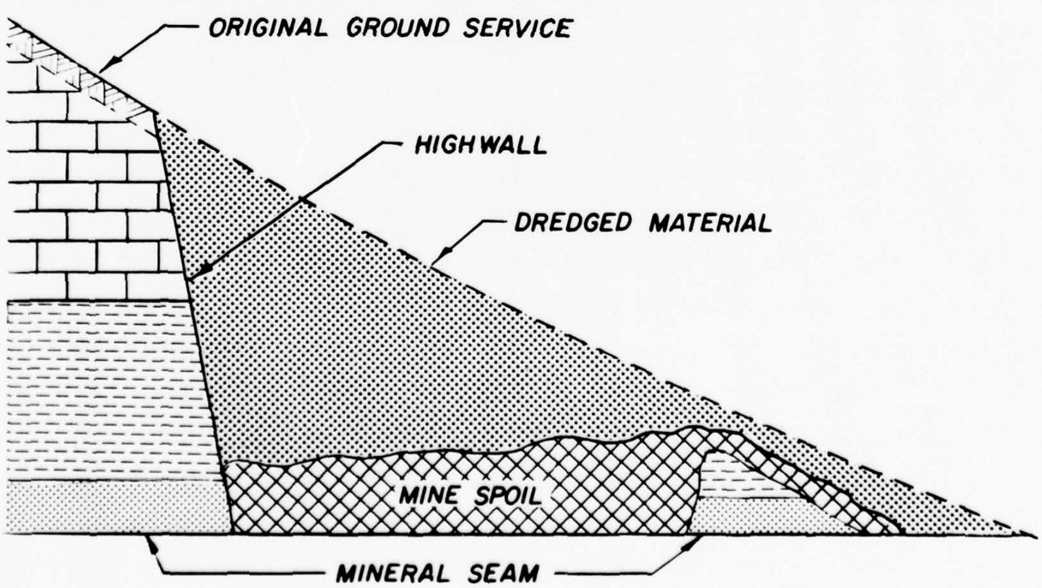


Figure 14. Cross-sectional view of contour backfill technique (from EPA[28])

87. There are different regrading techniques that may be employed for reclamation purposes. The choice of which regrading technique to use depends on many variables, including final land use, terrain, amount of dredged material, and state and Federal reclamation requirements. The use of dredged material for contour mine reclamation has not been field tested. The techniques described below are extracted from proven reclamation methods using conventional topsoil.

88. Three concepts for using dredged material on contour mine backfill are shown in Figures 14-16. The use of dredged material to reclaim the mine to the original ground surface level and contour is demonstrated in Figure 14. The mine spoil on the downslope is also covered with dredged material to provide a vegetative media. Figure 15 shows the use of the Georgia V-ditch technique which does not fill to the original soil surface but leaves a highwall and fill section to be leveled to support vegetative as well as agronomic production. The slope reduction technique, as shown in Figure 16 permits stockpiling of dewatered dredged material before final grading to original slopes and contours.

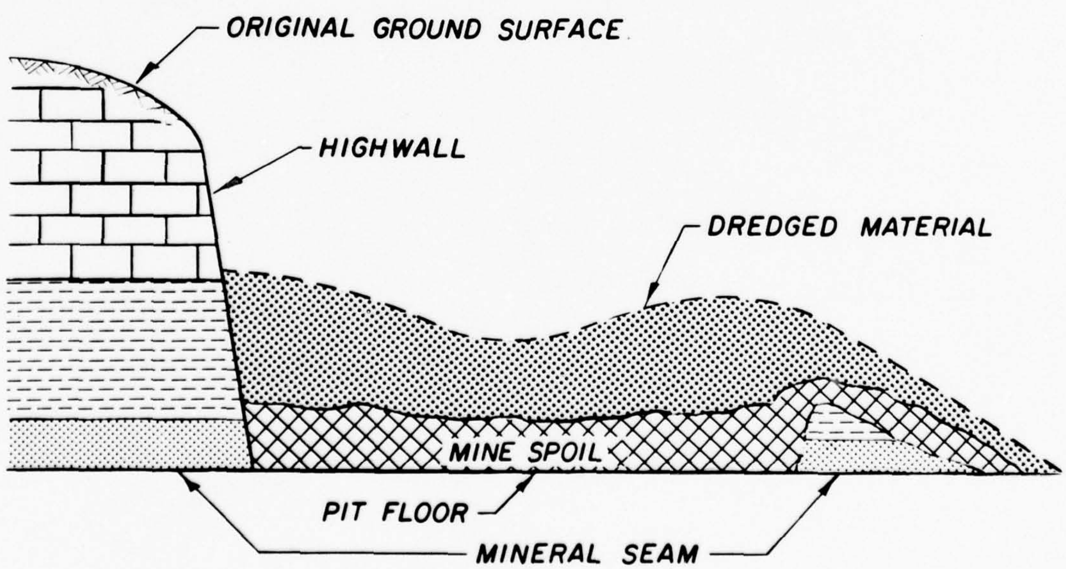


Figure 15. Cross-sectional view of the Georgia V-ditch backfill technique (from EPA[28])

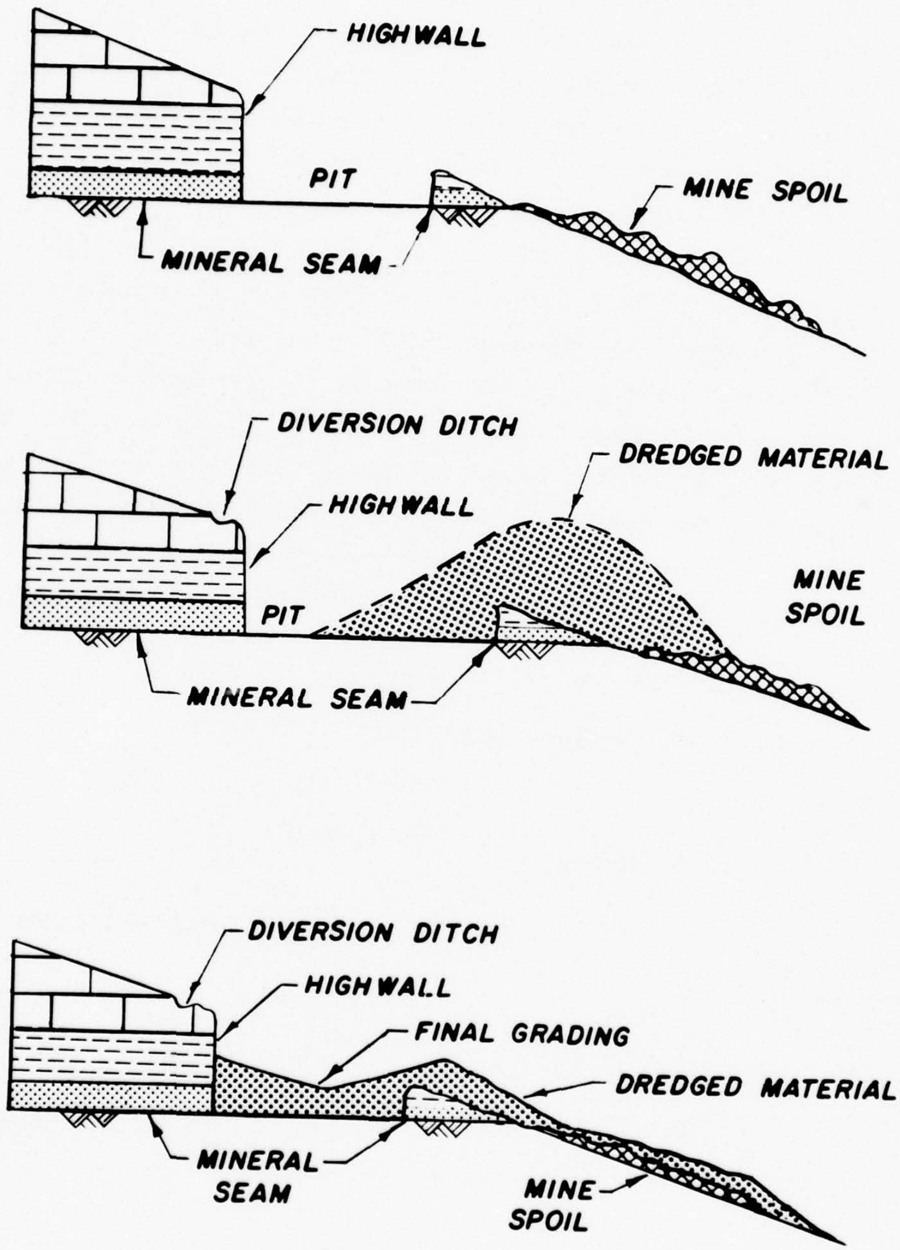


Figure 16. Schematic of slope reduction technique (from EPA[28])

Operations

Vegetation selection

89. Establishment of a quick vegetative cover is important at reclamation sites for it is one of the most effective erosion control methods.[31] The most important factor to consider when selecting vegetation is the final land use. The planner must know whether the area is to be used for farming, grazing, construction, temporary soil stabilization, restoration for aesthetics, etc. Should the plans call for agricultural use of the reclaimed area, the reader or user is referred to Part VII of this report for more in-depth study concerning agricultural potential. On the other hand, DMRP synthesis reports (Technical Reports DS-78-15, 17, and 19; Lunz, Diaz, and Cole,[36] Hunt et al.,[37] and Smith,[38] respectively) on wildlife habitat development should be consulted if wildlife habitat is desired for the final use of the site.

90. When selecting vegetation, the planner should choose a plant that will be able to adapt to the dredged material conditions such as pH, moisture, grain-size distribution, and fertility level. The plant selected should be adaptable to the climatic conditions (sunlight exposure, temperature, wind exposure, rainfall) found at the site. It is best to choose vegetation native to the area (see Appendix C). The vegetation selected should be easily propogated.[39] A list of candidate species should be made to determine the cost effectiveness of each. More than one species should be planted to ensure successful establishment of a vegetative cover.[28]

Seedbed preparation

91. It is desirable to roughen or cultivate the dredged material surface before seeding in order to reduce the velocity of rainfall runoff and increase water infiltration to seedbed depth. The surface of the dredged material should not be compacted because compaction impedes seedling emergence. Common methods for preparing the surface of the dredged material are scarification, tracking, and contour benching or plowing. Scarification is accomplished by discing or harrowing along the ground contour. Tracking is formed by the cleats of a crawler

tractor as it runs up and downhill. The grooves made by the cleats run parallel to the contour. Contour benching is performed on long slopes to build terraces to reduce the velocity of rainfall runoff.[40] Terracing is performed with a bulldozer running parallel to the contour and allowing the soil to dribble off the edge of the blade. Furrowing of a terrace is performed by repeated plowing parallel to the contour.[39]

92. Dredged material should not be placed on a slope that is in a frozen or muddy condition or when the subgrade is excessively wet or in a condition that may be detrimental to proper grading and the proposed seeding.

Planning Procedure for Surface Mine Reclamation

93. The following procedure provides a step-by-step approach for surface mine reclamation using dredged material. This procedure is intended to supplement the general planning process in Part II when considering reclamation of mined lands.

Preliminary dredged material data collection

94. The dredging operation or containment area should be described in terms of location and quantity. Critical dredged material characteristics should be determined by examination of physical and engineering characteristics, settling properties, and for evidence of contaminants.

Identification of potential sites

95. Mined areas should be located and identified on maps, and initial contacts with land owners should be made to solicit support. The potential demand for dredged material should be defined in terms of volume as a function of time and dredged material characteristics (processed or unprocessed material). The mined areas should be assessed for transportation capabilities as well as qualitative considerations such as social and environmental concerns. Field investigations of potential sites should include such general factors of the site as geology, groundwater, effluent standards, ambient water quality, land

costs, drainage, surrounding land use, and vegetation of adjacent lands.

Formulation of prelimi-
nary plans (feasibility)

96. Preliminary layouts, general construction plans, and cost estimates should be drawn up to assess alternatives. Impractical, costly, or otherwise unsatisfactory sites should be identified. Additional coordination with landowners is necessary to determine final land use (construction, recreation, natural) and thus better define dredged material requirements of the site. Preliminary plans should be submitted to the governing regulatory agency (state and/or Federal).

Site selection and final plans

97. Selection of the mined site should be made on the basis of preliminary plans and agency coordination. Additional field studies should be conducted at the chosen site so that final plans may be developed. Items such as topography, groundwater, and foundation soils should be examined. Coordination of final plans with the mine owner is needed, keeping the final land use in mind. Preliminary plans should be firmed up by examining technical and environmental considerations. Among those considerations are grade and slope of the reclaimed area, earthmoving requirements, transport system requirements, and construction practices for sediment control during active phases of the project. Detailed cost estimates should be drawn up and cost sharing agreements negotiated with landowners. Finally, Corps and landowner responsibilities should be well defined.

98. This procedure should highlight the major steps in project planning for surface mine reclamation. Additional guidance can be drawn from earlier sections of this report, Appendix B, and literature cited.

PART VI: USES OF DREDGED MATERIAL IN SANITARY LANDFILL OPERATIONS

Introduction

99. Sanitary landfilling is an engineering method for the land disposal of solid waste. In a sanitary landfill operation, solid waste is spread on the ground and compacted to the maximum density practical. At the end of each working day, all solid waste delivered to the site during the day is covered with compacted soil. This constitutes a solid waste cell. A sanitary landfill consists of one or more lifts of solid waste cells. If two or more lifts are placed, each lift is covered by an intermediate cover. All completed sanitary landfills are covered with a thick final layer of soil. Figure 17 shows the cross section of a two-lift sanitary landfill.[41]

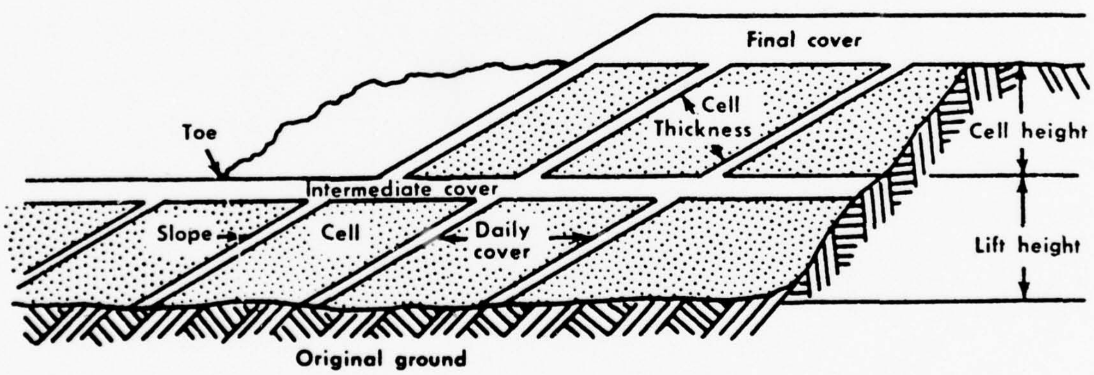


Figure 17. Cross section of cell construction for a sanitary landfill (from Bartos[41])

100. Governmental agencies responsible for the management of solid waste are experiencing difficulties in obtaining suitable sites on which to operate environmentally sound solid waste disposal operations. A major portion of the solid waste generated in this country is ultimately placed on land in sanitary landfills. The location of a sanitary landfill is often constrained by cover material requirements and

availability and by site characteristics related to potential adverse environmental impact. Bartos[41] reports that dredged material can satisfactorily perform the functions of a cover material, thereby making it possible to locate sanitary landfills at sites previously considered unsuitable due to a lack of native cover soil. The information presented here is taken from Bartos' report and is intended to aid planners in determining the suitability of dredged material for productive use in solid waste management schemes and to provide guidance for development of possible landfill projects.

Dredged Material Characteristics and Compatible Uses

101. The potential uses for dewatered dredged material in a sanitary landfilling operation are as a material for covers, liners, gas vents, leachate drains, and gas barriers. Part III contained a discussion of physical and chemical characteristics to be considered when using dredged material in a land improvement project. Some dredged material grain-size distributions are generally more suitable than others. The possible uses in landfilling and the suitable soil types, as classified by the USCS, are discussed below.

Cover

102. The solid waste in a sanitary landfill is covered daily with at least 6 in. of material to prevent an unsightly appearance, control vectors at the site, prevent internal fires, and control surface water infiltration. Landfills with two or more lifts must have intermediate covers 12 in. deep between lifts. The intermediate cover must fulfill all functions of a daily cover for up to 12 months and must be trafficable to assist vehicle support and movement. Dredged material characteristics of a desirable cover material are easy workability, moderate cohesion, and significant strength. A mixture of sand, silt, and clay (SM or SC) has been shown to be a suitable cover material; if a gravel (GM or GC) is fairly well graded with 10 to 15 percent sand and 5 percent or more fines, it can make an excellent cover. The only dredged materials eliminated for use as cover are

highly organic materials (OH and OC) and peat (Pt). Due to difficulty in handling, dredged material should not be used in the slurry state. On the other hand, the use of dewatered dredged material as cover is operationally feasible because the material can be easily hauled, spread, and compacted by conventional earthmoving equipment.

Liners and barriers

103. Barriers and liners serve the same purpose; i.e., to prevent the migration (lateral and vertical) of leachate water or decomposition gases. The suitability of the dredged material for this use is determined by the permeability of the material. Dredged material classified CL or CH is likely to be suitable for use in constructing a liner or barrier. Attempts should be made to keep these barriers and liners saturated to prevent cracking and to keep pore spaces filled with water to prevent gas leaks.

Gas vents and leachate drains

104. Gas vents are used to direct the flow of gas to the atmosphere where it is harmlessly dissipated, and leachate drainage layers are used to intercept leachate and drain it to an area where it can be collected for treatment or recirculation.[41] The controlled ventilation of gas requires that the vent be more pervious than the surrounding soil, and a leachate drain must also be very pervious so that leachate will be drained quickly away from the solid waste. To be suitable for venting gas or draining leachate, the dredged material must consist of sand or gravel with little or no fines (GW, GP, SW, SP) and must be much more pervious than the soils at the site.

Site Characterisitics

Site selection

105. The selection of the solid waste disposal site will be the decision of the governing sanitary district. Site suitability and site management options will be evaluated by the sanitary district. The offer of dredged material to these districts allows them to consider sites initially screened out due to the lack of natural soil cover.

Transport systems

106. In order for dredged material uses in solid waste management to be economically attractive, the landfill site must be within a reasonable distance of the dredged material supply (see Part IV). Souder et al.[9] report a proximity of 50 miles to be recommended in order to keep the unit cost of shipment down. Truck haul is the only mode of transport recommended because of its convenience, feasibility of operation, and ease of fitting into landfilling schemes.[40]

Operational Management

Economics

107. The success of any attempt to use dredged material in solid waste management will be dependent upon the economic feasibility of the project for each of the agencies concerned. Since each operation involving the use of dredged material in solid waste management is unique, economic feasibility is evaluated on a case-by-case basis. There should be a net benefit to all agencies involved. Table 10 provides guidance in evaluating the project feasibility for both the solid waste management agency and the Corps.[41]

Project coordination

108. There must be an evaluation of the sanitary district needs and the dredged material availability in terms of volume, soil type, and joint project duration. The use of dredged material is dependent upon meeting the solid waste management project objectives, final land use master plans, and time schedules. Close coordination between agencies is needed throughout project planning and operation. Backup plans including equipment needs and storage capacity must be made by both agencies to provide for operational delays.

Sanitary Landfill Operation

109. The area method is used when the terrain is rough and irregular, when the groundwater table is at or near the surface, or when the

Table 10

Factors Influencing Economic Feasibility of Using Dredged Material in Solid Waste Management

Economic Factors	Unit of Expression	Distribution of Costs and Benefits*: Costs	Benefits	Remarks
Additional storage capacity gained by removal of dredged material from containment area	Value of additional storage capacity, $\$/yd^3$		D	Value of additional storage is the cost of obtaining storage by the least expensive method (dike raising, dewatering, etc.)
Cost of dewatering dredged material	$\$/yd^3$	S and/or D		Dewatering costs could conceivably be borne by both agencies, depending on local conditions
Cost of site improvements required to permit transportation of dredged material to existing transportation facility	$ - lump sum	S and/or D		May not be required in many cases
Cost of purchasing dredged material	$\$/yd^3$	S	D	Dredged material could be donated by District (see Reference 10), in which case there is neither cost nor benefit
Cost of hauling	$\$yd^3$	S		Costs of hauling equal amounts of borrow and dredged material are expected to differ only when haul distances differ
Cost of purchasing borrow	$\$/yd^3$		S	Benefit is cost saved by using dredged material
Cost of hauling borrow	$\$/yd^3/mile$		S	Benefit is cost saved by using dredged material

* D = cost/benefit accrues to District.
S = cost/benefit accrues to solid waste management agency.

native soil is not suitable for use as a cover. Dredged material is suited to this method of landfilling as borrow material and must be imported. Dredged material meeting cover requirements listed in an earlier section can be used in this operation. Liners and barriers may be required in the cell construction, and suitable dredged material can be utilized for those functions also. In the area method, solid waste is spread on the ground in thin (6-in.) layers and compacted. Bartos[41] suggests 10 ft as the maximum thickness for a lyer of solid waste. Soil or dredged material is imported to the sanitary landfill and used as a final cover for the compacted waste.

110. Figure 18 is a schematic of the area method of sanitary landfilling. To reduce scheduling and operational problems, it would be advantageous to stockpile dredged material for covers, lining, and barriers at the landfill site.

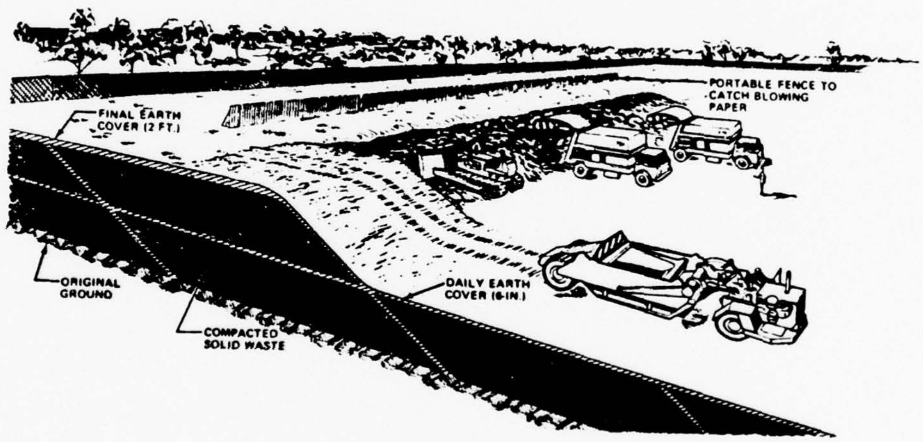


Figure 18. Schematic of the area method for a sanitary landfill (from Bartos[41])

111. Variations of the area methods can be utilized at a single sanitary landfilling site. Bartos[41] presents several case studies such as hill creation and outlines new concepts of solid waste management using dredged material.

Planning Procedure for Sanitary Landfill Uses of Dredged Material

112. This section of the report highlights the general procedure

for initiating a project utilizing dredged material in sanitary landfill operations. The planner should remember that in this productive use the Corps is simply providing a useful material to a sanitary district; therefore, site selection and construction and operation of the landfill are not the responsibility of the Corps.

Preliminary dredged
material data collection

113. The dredged material source (dredging operation or containment area) should be defined in terms of location and quantity. Critical dredged material characteristics should be determined by examining physical and engineering characteristics and settling properties and by noting any evidence of contaminants. The available dredged material should be viewed in terms of suitability for sanitary landfill use; i.e., as covers, liners, barriers, vents, drains. The dredging area should be assessed for available transport modes.

Interagency coordination

114. Contact the regional sanitary districts and describe dredged material suitability in terms of landfill uses. Determine the sanitary district's quantity needs and scheduling requirements. Compare the district's material needs with the dredged material quality, quantity, and suitability of uses available. Negotiate cost sharing agreements. Detail Corps and landowner responsibilities. These responsibilities may be for transportation of dredged material, unexpected adverse environmental impacts at the landfill, and monitoring requirements at the landfill site.

115. This summary may be used as a supplement to the general planning process in Part II when considering utilizing dredged material in sanitary landfilling. Additional guidance should be drawn from literature cited, earlier sections of this report, and local, state, and Federal publications concerned with sanitary landfill techniques.

PART VII: AGRICULTURAL VALUE OF DREDGED MATERIAL

Introduction

116. An attractive alternative for disposing of dredged sediments is to use these materials beneficially to amend marginal soils for agricultural purposes.[15] Marginal soils are not intensively farmed because of inherent limitations such as poor drainage, unsuitable grain size, and poor physical and chemical conditions. They may also be of low productivity because of high water tables or frequency of flooding. There are millions of acres of these marginal soils conveniently located near waterways.

117. Walsh and Malkasian[1] have noted several areas where there is currently extensive interest in the agricultural use of dredged material. For example, about 500 acres of the Old Daniel Island Disposal Area in South Carolina has been successfully truck farmed for the past 8 years. Presently, the Tulsa District has approximately 2600 acres of dredged material containment areas leased for use as grazing land.

118. When dredged material is free of nuisance weeds and has the proper balance of nutrients, it is similar to productive agricultural soils and can be beneficial for increasing crop production when incorporated or mixed. By the addition of dredged material, the physical and chemical characteristics of a marginal soil can be altered to such an extent that water and nutrients become more available for crop growth. In some cases, raising the elevation of the soil surface with a cover of dredged material may improve surface drainage and reduce flooding and therefore lengthen the growing season. Dredged material characteristics which influence plant growth and guidance for dredged material incorporation and use as a cover are discussed in this Part.

Planning Considerations

119. The planner must consider the chemical and physical analyses, the site locations, weed infestation potential, and possible salinity

problems before deciding upon the suitability of dredged material as a medium for agricultural purposes. Figure 19 demonstrates priority listing of these factors to be used when the planner is considering the feasibility of an agricultural use for dredged material at the containment site.

Chemical analyses

120. Since dredging operations may take place in waterways containing industrial wastes and sediment runoff from agricultural areas, dredged material can contain heavy metals, oil and grease, and high nutrient concentrations from fertilizer runoff.

121. Heavy metals. Heavy metal uptake by plants is dependent on a number of factors, two of which are: (a) the form and concentration of metals in the rooting media, and (b) the type and variety of the

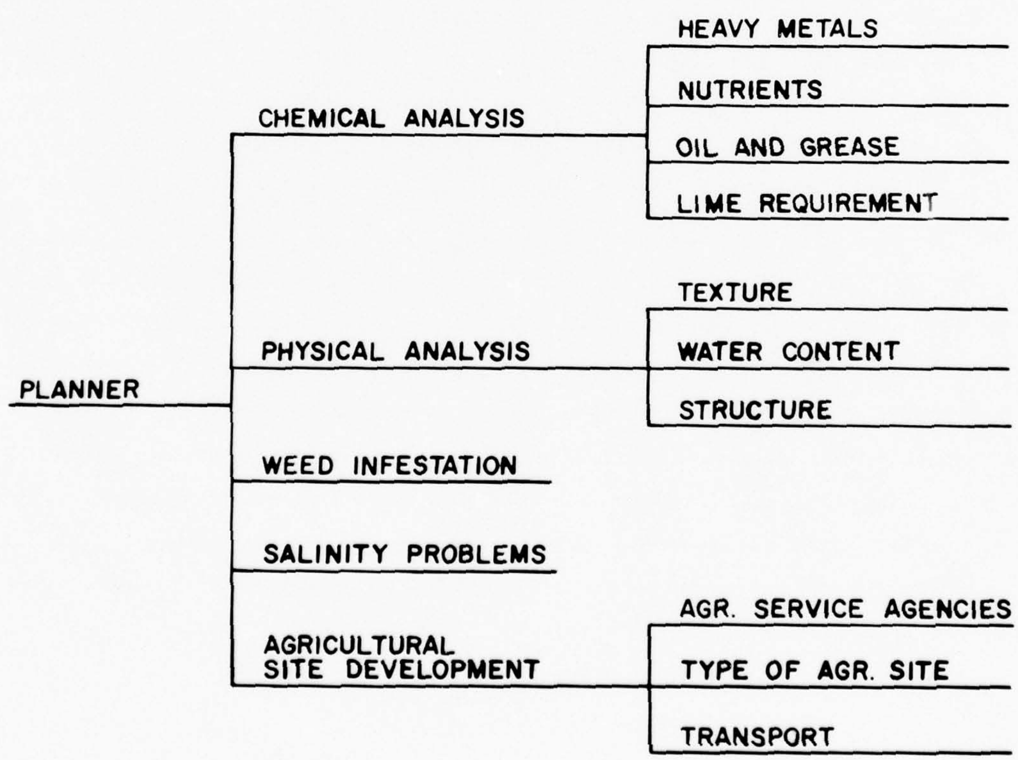


Figure 19. Decisional factors to be considered at the dredged material containment area before applying dredged material for agricultural purposes

plant. Research has shown that the heavy metal uptake by plants is normally much less than the heavy metal content of the rooting media.[2,15] Table 11 shows the range in the concentration of heavy metal uptake by agronomic and common vegetable food crops grown under normal conditions and the suggested plant tolerance levels.[15]

Table 11

Average Range of Heavy Metal Uptake by Plants for Selected Food Crops* and Suggested Plant Tolerance Levels (from Gupta et al.[15])

Element	Average Range ppm	Suggested Tolerance Level, ppm
Cadmium, Cd	0.05-0.20	4
Copper, Cu	3-40	150
Iron, Fe	20-300	850
Manganese, Mn	15-150	325
Nickel, Ni	0.01-1.0	4
Lead, Pb	0.1-5.0	10
Zinc, Zn	15-150	350
Boron, B	7-75	200
Chromium, Cr	0.1-0.5	2

* Corn, soybeans, tomatoes, beets, lettuce, peas, potatoes, melons, squash, alfalfa, clover, wheat, oat, barley, and pasture grasses.

122. The question as to whether or not to produce food or nonfood crops depends upon the chemical contaminants present in the dredged material. Agricultural service agencies, such as the USDA Science and Education Administration, EPA Office of Air, Land, and Water Use, and the local offices of the Agricultural Extension Service, can assist with guidelines and answers to specific questions. While research has shown that relationships exist between the extractable heavy metals in the soil and the heavy metal uptake by certain plants,[26] these data are important to the application of dredged material on soils if a food crop is to be grown but are less important when nonfood crops are to be produced. An example of a nonfood crop is the growing of Christmass trees on dredged material containing high concentrations of heavy metals.[42] A further example is the uptake of minimal amounts of heavy metals in

the heads of grain plants making them a good food crop selection even if larger amounts of heavy metals are present; however, the heavy metals may concentrate in the leaves making these grain crops less desirable when harvested as a forage.

123. Nutrients. The nutrient analyses of a dredged material should provide data to determine the nutrient availability and to establish recommended fertilizer applications for vegetative production. The chemical constituents of dredged material which require greatest attention other than heavy metals are nitrogen, phosphorus, potassium, metallic metals, and organic compounds. Although medium- and fine-grained dredged material is normally high in nutrients available for plant uptake, the levels of these nutrients are usually not high enough to limit plant growth. However, nitrogen, which is usually in the ammonium form, will undergo nitrification to nitrate rapidly in an aerobic soil. Nitrate is the readily available form of nitrogen for plant uptake or loss by surface runoff and leaching into groundwater. An estimate of recommended rates of fertilizer[13,15] can be taken from Table 12, or for more specific recommendations the state Soil Testing Service or local Agricultural Extension Service can be contacted.

Table 12

Amount of Nitrogen, Phosphorus, and Potassium Determined by Soil Test and Recommended Annual Amounts of Fertilizer (after Buckman and Brady[13] and Guta et al.[15])

Relative Level	Nitrogen, lb/acre		Phosphorus, lb/acre		Potassium, lb/acre	
	Test	Fertilizer	Test	P_2O_5* Fertilizer	Test	K_2O** Fertilizer
Low	0-50	150	0-10	80	0-100	150
Medium	51-100	100	11-20	60	101-200	110
High	100-200	50	21-30	40	201-300	60
Very high	>200	0	>30	0	>300	0

* $P_2O_5 \times 0.44 = P$.
** $K_2O \times 0.83 = K$.

124. Oil and grease. Research has shown that the oil and grease content of some dredged material is considerably higher than that of marginal soil. However, depressed yields attributable to high oil and grease content have not been shown. Possible effects of the high oil and grease content on soil properties or plant growth are an apparent slower wetting of the soil materials and a tendency to restrict water uptake by the plants.

125. Lime requirements. Lime requirements for dredged material vary, but, if the pH of the material is below 6.5, it should be amended with ground agricultural limestone ($CaCO_3$) before being applied to marginal soil for agricultural production. Large amounts of sulfur in the dredged material will require heavy applications of lime to neutralize the acidity as well as succeeding applications to maintain neutral conditions. A soil pH below 4.0 indicates the presence of free acids resulting from the accumulation of sulfate and nitrate ions; a pH below 5.5 suggests the presence of toxic quantities of exchangeable aluminum, iron, and manganese; and a pH from 7.8 to 8.2 may indicate an accumulation of the bicarbonate ion and the uptake of elements will be detrimental to plant growth.[13] General recommendations for the amount of limestone to apply to an acid soil of loam texture[15] are presented in Table 13. More exact recommendations can be obtained locally.

Table 13

Agricultural Limestone Recommendations for a Loam Soil (from Gupta et al.[15])

Soil pH	Tons of Lime per acre to Bring Soil to ph 6.5
3.0-4.0	55
4.0-5.0	50
5.0-5.5	40
5.5-6.0	30
6.0-6.5	15

Gupta et al.[15] suggested that lime requirements be determined from incubation studies for dredged material containing high levels of sulfur as well as continuous monitoring of the field conditions. A rule of thumb for lime requirements of high sulfur dredged material is to double the usual lime requirement.

Physical analyses

126. The physical characteristics of dredged material as described in Part III can assist the planner in making critical judgments of the best use of dredged material to ensure against adverse impacts on agricultural lands. The texture and water content are essential tests to aid the planner in characterization of dredged material deposits within a containment area.

127. Texture. Textural classification helps to determine not only the nutrient-supplying ability of soil materials, but also the supply and exchange of water and air that are so important to plant life. Therefore, an important criterion is to adjust the texture of the final mixture of dredged material and marginal soil to approximate a loam (USDA classification). Using the USCS classification system, a dredged material of loam texture contains silts and clays whose liquid limit is less than 50; e.g., SM, ML, CL, or OL (see Figure 2, Part III). Mixing a fine-textured dredged material (silt and clay) with a coarse-textured marginal soil (sand) to the proportions of a loam would improve its physical and chemical characteristics for crop production. Sandy, coarse-grained dredged material is generally low in organic matter content, available nutrients, and heavy metal concentrations. Dredged material of this type may have potential as an amendment to heavy impermeable clay soils, improving structure and permeability. For beneficial surface applications without incorporation with existing soils, it would be preferable to apply dredged material of loam textures only. Sandy loams are generally preferred for vegetable root crops such as carrots, beets, potatoes, peanuts, etc., whereas loam to silt-loam soils are preferred for row crops, orchards, small grains, etc.

128. Water content. When placing dredged material on agricultural lands, it is desirable to have the water content of the material

within the plastic limit range. This will present fewer problems in handling, placing, and mixing. If dredged material is to be placed in slurry form, the lift thickness should be limited to 18 in. This thickness of dredged material will usually dry within a 6-month period to the point where farming operations can begin.

Weeds

129. Weed infestation is generally a serious problem in many inactive fine-grained dredged material containment areas. Prior to the transport of dredged material to an agricultural site, an extensive weed control program should be initiated to avoid serious weed problems to the agricultural producer. For example, the planner could apply a herbicide or remove the top 6-in. vegetative layer of the containment area with a bulldozer before the transport of dredged material to the agricultural site.[29]

Salinity

130. If the dredged material is from a coastal or tidal region, special attention must be given to salinity because crops may be difficult to establish. The electrical conductivity of a soil water extract gives an indication of the total concentration of soluble salts in the soil. The term "soluble salts" refers to the inorganic soil constituents that are soluble in water. Excess soluble salts not only limit the availability of water to plants but also restrict growth. A general guide[25] to crop responses to salinity under average conditions is given in Table 14. Salt-tolerant plant species are available but are not economically productive. Techniques for treating dredged material with high salinity problems are available and must be completed before the material is transported to an agricultural site.[43]

Agricultural site selection

131. As noted in Part IV, the distance and mode of transportation utilized for the movement of dredged material will determine the major costs of its application to agricultural lands. Thus, the agricultural site selected should be in reasonable proximity to the dredged material disposal site and adaptable to the long-range disposal needs of the Corps.

Table 14

Recommendations for Plant Growth on Saline Soils (from USDA[25])

Electrical Conductivity mmho/cm*	Plant Growth Condition
<2	Salinity effects largely negligible
2-4	Yields of sensitive crops may be restricted
4-8	Yields of many crops will be restricted
8-16	Only tolerant crops yield satisfactorily
>16	Only very tolerant crops yield satisfactorily

* Accepted units.

132. Agricultural service agencies. In most areas of the country, a variety of suitable locations of marginal soils can be found by contacting the local agencies of the USDA, Soil Conservation Service and Forest Service as well as the local Agricultural Extension Service. Soil classification and land use maps are available from these agencies as is direct assistance in locating marginal soils suitable for amendment with dredged material.

133. Type of agricultural site. The type of site determines its selection by the planner for the application of dredged material; i.e., a short-term or long-term disposal area. Short-term usage signifies completion of the transfer of dredged material from a containment area within 1 to 3 months to transport, spread, mix, and cultivate the dredged material for seedbed preparation at the agricultural site. Long-term usage implies that the agricultural site can be used as an active disposal area over a long period of time, say up to 5 or 10 years. This infers only a few acres of the agricultural site would be involved in the application of dredged material at any one time.

134. A schematic of a long-term disposal area is shown in Figure 20 where various levels of dredged material are being used for different activities. Shallow-rooted crops such as grasses, small grains, soybeans, vegetables, etc., can be cultivated in designated areas where dredged material is first applied (6- to 12-in. depth).

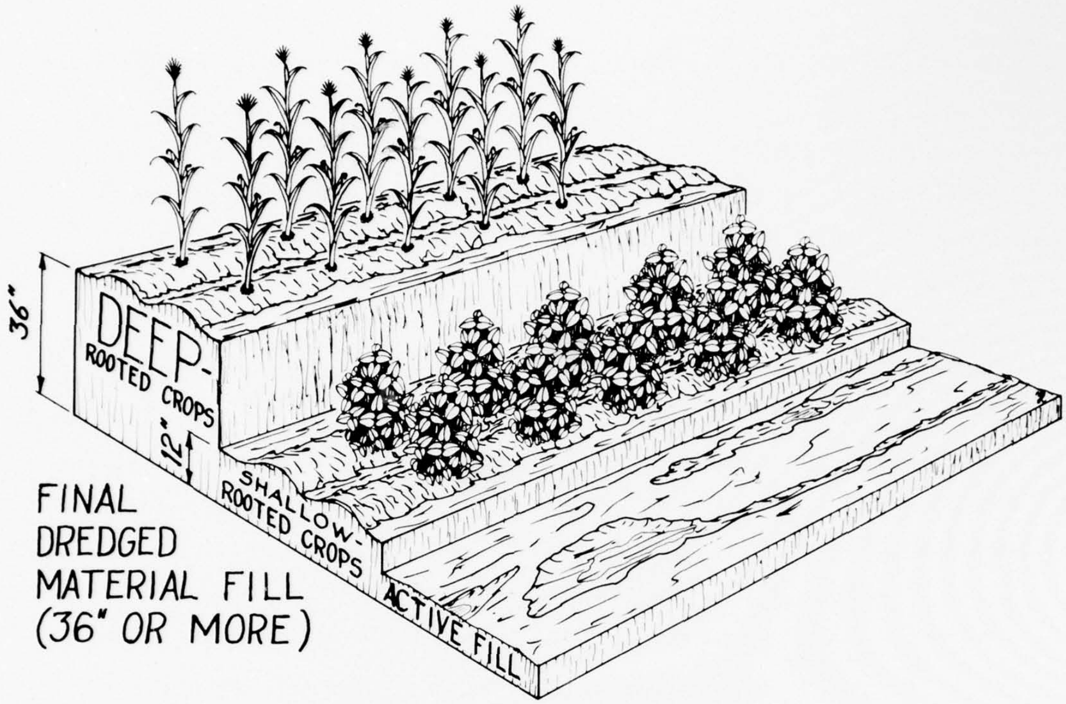


Figure 20. Long-term agricultural dredged material disposal site

However, as the application of dredged material is continued in specific areas of the field (3 ft or more in depth), deep-rooted crops such as corn, sorghum, cotton, alfalfa, trees, etc., can be successfully cultivated.

135. Transport. The accessibility to the dredged material containment area and the agricultural site determines project viability and mode of transport. The agricultural site may have limited access due to field roads, drainage ditches, and fence locations; therefore, access routes on a farm may require design and construction to facilitate the dumping and spreading of dredged material. If the application of dredged material is to be efficient and effective, scheduling of application should not interfere with normal farm operations. Access roads to the dumping site should circumvent the farmstead and avoid the location of poultry and livestock.

Agricultural Site Considerations

136. With an understanding of the characteristics of the dredged

material at the various disposal sites, the planner should consider the potential problems at the agricultural site. Factors which must be considered at the agricultural site are properties of the marginal soil, application depth of dredged material, land preparation needs, compaction, erosion potential, flood/drainage area, and seedbed preparation.

Incorporation

137. The beneficial effects of incorporating dredged material into marginal soils are (a) increased available water capacity, (b) increased nutrient supply when fine-grained dredged material is mixed with coarse-grained marginal soils, and (c) improved drainage when coarse-grained dredged material is mixed with fine-grained marginal soils.

138. Marginal soil. Marginal soils are not used for production of crops with a high economic return. These soils can be in the form of unproductive pastures, abandoned fields, fields requiring excessive irrigation, or areas in successive states of degradation. These soils can be made productive for a variety of economic crops by incorporating dredged material of desirable grain sizes to bring these marginal soils to a loam soil classification as discussed in Part III.

139. Depth. Plant growth can be limited by root development; therefore, it is important to increase the depth of rooting media with applications of dredged material. To obtain an optimal mixture under normal field conditions, the depth of dredged material to be incorporated is limited to a 6-in. cover. At this depth, a 16-in. moldboard plow can furrow to a depth of 12 in. using a tractor-plow combination. If incorporation of greater depths of dredged material is required, then special types of plows not common to normal farm operations must be used.

140. Land preparation. Tillage operations prior to the application of dredged material may be useful to control wet areas, speed surface drying, and eradicate weeds. The application of dry dredged material to level soil surfaces presents few problems when the soil surfaces are dry. If the agricultural site has poor drainage, the application of dredged material should be done after the area has had an opportunity to dry. Row drains can be constructed with a plow that

cuts through low areas to provide drainage into field laterals.

141. The addition of dredged material to slopes ranging from 5 to 10 percent may increase operational problems and the potential for erosion and the sediment content in runoff water. If steep slopes (greater than 10 percent) are to be used, then cultural practices should include terraces, grassed waterways, diversion channels, and supplemental practices such as contour farming, strip-cropping, and crop rotation.[40]

142. Compaction. The purpose of using dredged material is to improve the agricultural site; therefore, the application and spreading of the dredged material should not impair agricultural production by severely compacting the marginal soil. For example, soil compaction problems associated with the weight per axle load of large (25-ton) dump trucks may necessitate using smaller (9-ton) dump trucks which would reduce soil compaction but increase transportation costs by 25 percent.[27]

143. Seedbed preparation. The use of various types of tillage equipment is, to some extent, dependent on the type of crop to be produced. However, tillage operations such as plowing and harrowing are common to all types of seedbed preparation. Cultivation and planting of the newly incorporated mixtures should be accomplished as soon as possible because tillage will increase the infiltration of water and reduce surface runoff, therefore lowering the potential for erosion.

Cover

144. When the area to be covered is too rocky, gravelly, or otherwise unsuitable for cultivation, additions of dry dredged material to depths of 1 ft or more without incorporation may be required to improve the area for agronomic production. However, when dredged material is to be used as a surface cover, it is best that the texture approximate a loam for crop production.[15]

145. Depth. The depth of dry dredged material to be applied as a surface cover should approach 3 ft to ensure good drainage and an adequate rooting medium. Of course, as discussed earlier, a depth of 3 ft or more can be achieved by additions of 6-in. layers, and the

agricultural site can be used as an active dredged material disposal site for local dredging activities over a period of time.

146. Drainage/flood. When the soil depth is increased by additions of dredged material, the depth to the water table increases and reduces wet spots in the field, thus extending the period available for farming operations. If the area is intermittently flooded, additions of 3 ft or more of dredged material may completely eliminate the problem.

147. Erosion. Slopes greater than 10 percent are not cost-effective for the application of dredged material because the establishment of a vegetative ground cover is difficult. When the dredged material is to be placed on erodible slopes, the first step is to plant it to grass until the material has stabilized. If the agricultural site is a terraced area, it should be seeded to a permanent vegetation to prevent accelerated erosion. Flat or nearly level agricultural fields are the most satisfactory for dredged material application and farming operations.

148. Seedbed preparation. When the marginal soil is to be buried with much greater depths of dredged material, it must be leveled with a bulldozer and other tractor-plow or disc combinations used for seedbed preparation.

Crop Selection

149. To have a complete overview for applying dredged material to agricultural lands, the planner should be acquainted with the various crops that the farmer can select for economic production. Food crops, such as grains, small grains, row crops, pastures and orchards, and nonfood crops, such as lawn sod and related nursery products, are logical candidates for a productive use of dredged material.[38] Production of these crops is aesthetically pleasing, common throughout the Nation, and commercially attractive.

Food crops

150. Crop selection for food and forage use is dependent upon climate, culture, and regional markets (see Appendix C). The varieties

of agricultural crops selected for production can be obtained from county and local Agricultural Extension Services and the USDA Soil Conservation Service.

Nonfood crops

151. Whereas food crops may present a special problem for growth on contaminated dredged material, nonfood crops are affected only by the contaminant levels that limit plant growth. Quite often, nonfood crops such as lawn sod, foliage, plants, bulbs, shrubs and trees, and other nursery plants are highly perishable commodities.[42] Standards dictate that some of these commodities must be delivered and transplanted within 36 hours from harvest time. Therefore, nonfood crop production should be located within a 200-mile radius of the market. These markets are generally located in metropolitan areas where maintenance dredging takes place to keep shipping channels open. Therefore, market areas are areas often in supply of dredged material. The tables presented in Appendix C may be helpful in determining the kinds of vegetation available for commercial purposes. However, assistance with marketing information can be obtained from the USDA Forest Service, local nurseries, or the sources listed below:[35]

a. American Association of Nurserymen
200 Southern Building
Washington, DC

b. American Society for Horticultural Science
914 Main Street
St. Joseph, MO

c. American Sod Producers Assn.
9th and Minnesota Sts.
Hastings, NE

d. Lawn Institute
Rt 4, Kimberdale
Marysville, OH

e. National Christmas Tree Growers Assn.
225 East Michigan St.
Milwaukee, WI

f. Society of American Florists and Ornamental Horticulturists
901 North Washington St.
Alexandria, VA

REFERENCES

1. Walsh, M. R. and Malkasian, M. D., "Productive Land Use of Dredged Material Containment Areas: Planning and Implementation Considerations," Technical Report DS-78-20, Dec 1978, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

2. Lee, C. R., Engler, R. N., and Mahloch, J. L., "Land Application of Waste Materials from Dredging, Construction, and Demolition Processes," Miscellaneous Paper D-76-5, Jun 1976, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

3. SCS Engineers, "Feasibility of Inland Disposal of Dewatered Dredged Material: A Literature Review," Technical Report D-77-33, Nov 1977, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

4. Raster, T. E. et al., "Development of Procedures for Selecting and Designing Reusable Dredged Material Disposal Sites," Technical Report D-78-22, Jun 1978, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

5. Palermo, M. R., "Needs and Areas of Potential Application of Disposal Area Reuse Management (DARM)," Technical Report D-78-27, Jun 1978, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

6. Bartos, M. J., Jr., "Classification and Engineering Properties of Dredged Material," Technical Report D-77-18, Sep 1977, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

7. Reikenis, R., Elias, V., Drabkowski, E. F., "Regional Landfill and Construction Material Needs in Terms of Dredged Material Characteristics and Availability," Contract Report D-74-2, May 1974, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

8. Wakeford, R. C. and Macdonald, D., "Legal, Policy, and Institutional Constraints Associated with Dredged Material Marketing and Land Enhancement," Contract Report D-74-7, Dec 1974, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

9. Souder, P. S. et al., "Dredged Material Transport Systems for Inland Disposal and/or Productive Use Concepts," Technical Report D-78-28, Jun 1978, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

10. Office, Chief of Engineers, Department of the Army, Engineer Manual Series 200, Washington, D. C.

11. Office, Chief of Engineers, Department of the Army, "The Unified Soil Classification System," Standard 619, 1960, Washington, D. C.

12. Lambe, T. W., Soil Testing for Engineers, John Wiley and Sons, New York, 1962.

13. Buckman, H. O. and Brady, N. G., The Nature and Properties of Soils, MacMillan, New York, 1960.

14. Cale, E. B., "Recommended Practices for Establishment and Maintenance of Turf," Technical Memorandum No. 3-361, Apr 1953, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

15. Gupta, S. C. et al., "The Agricultural Value of Dredged Material," Technical Report D-78-36, Jul 1978, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

16. Office, Chief of Engineers, Department of the Army, "Laboratory Soils Testing," Engineering Manual EM 1110-2-1906, 30 Nov 1970, Washington, D. C.

17. Johnson, S. J. et al., "State-of-the-Art Applicability of Conventional Densification Techniques to Increase Disposal Area Storage Capacity," Technical Report D-77-4, Apr 1977, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

18. Haliburton, T. A., Fowler, J., and Langan, J. P., "Perimeter Dike Raising with Dewatered Fine-Grained Dredged Material at Upper Polecat Bay Disposal Area, Mobile, Alabama," Miscellaneous Paper D-78-3, Aug 1978, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

19. Black, C. A., ed., "Methods of Soil Analysis: Part I," No. 9, 1965, American Society of Agronomy, Madison, Wisc.

20. Chen, K. Y. et al., "Research Study on the Effect of Dispersion, Settling, and Resedimentation on Migration of Chemical Constituents During Open-Water Disposal of Dredged Material," Contract Report D-76-1, Feb 1976, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

21. Mang, J. L. et al., "A Study of Leachate from Dredged Material in Upland Areas and/or in Productive Uses," Technical Report D-78-20, Jun 1978, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

22. Chaney, R. L. et al., "Recommendations for Management of Potentially Toxic Elements in Agriculture and Municipal Wastes," Jul 1974, Tractors Involved in Land Applications of Agricultural and Municipal Wastes, National Program Staff, Soil, Water and Air Sciences, Beltsville, Md.

23. Rand, M. C., Greenberg, A. E., and Taras, M. J., Editorial Board, Standard Methods for the Examination of Water and Wastewater, 14 ed., 1975, prepared and published jointly by American Public Health Association, American Water Works Association, and Water Pollution Control Federation, Washington, D. C.

24. Black, C. A., ed., "Methods of Soil Analysis: Part II," No. 9, 1965, American Society of Agronomy, Madison, Wisc.

25. U. S. Department of Agriculture, "Diagnosis and Improvement of Saline And Alkali Soils" Agricultural Handbook No. 60, 1954, Washington, D. C.

26. Lee, C. R. et al., "Prediction of Heavy Metal Uptake by Marsh Plants Based on Chemical Extraction of Heavy Metals from Dredged Material," Technical Report D-78-6, Feb 1978, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

27. McMahon, L. A., ed., 1977 Dodge Guide to Public Works and Heavy Construction Costs, Annual Addition No. 9, McGraw-Hill, New York, 1977.

28. U. S. Environmental Protection Agency, "Processes, Procedures, and Methods to Control Pollution from Mining Activities," EPA-430/9-73-011, Oct 1973, Washington, D. C.

29. U. S. Department of Agriculture, "Restoring Surface-Mined Land," Miscellaneous Publication No. 1082, Jun 1973, Washington, D. C.

30. U. S. Department of Agriculture, "Standards and Specifications for Soil Erosion and Sediment Control in Developing Areas," Jul 1975, Soil Conservation Service, College Park, Md.

31. Perrier, E. R., Llopis, J. L., and Spaine, P. A., "Area Strip Mine Reclamation Using Dredged Material: A Field Demonstration," Technical Report (in preparation), U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

32. Montgomery, R. L. et al., "Guidelines for Dredged Material Disposal Area Reuse Management," Technical Report DS-78-12 (in preparation), U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

33. Haliburton, T. A., "Guidelines for Dewatering/Densifying Confined Dredged Material," Technical Report DS-78-11, Sep 1978, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

34. Haynes, R. J. and Klimstra, W. D., "Illinois Lands Surface Mined for Coal," Cooperative Wildlife Research Laboratory, Southern Illinois University at Carbondale, Jun 1975, Carbondale, Ill.

35. McNay, L. M., "Surface Mine Reclamation, Moraine State Park, Pennsylvania," Bureau of Mines Information Circular 8456, 1970, U. S. Department of the Interior, Washington, D. C.

36. Lunz, J. D., Diaz, R. J., and Cole, R. A., "Upland and Wetland Habitat Development with Dredged Material: Ecological Considerations," Technical Report DS-78-15, Sep 1978, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

37. Hunt, L. J. et al., "Upland Habitat Development with Dredged Material: Engineering and Plant Propagation," Technical Report DS-78-17, Sep 1978, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

38. Smith, H. K., "An Introduction to Habitat Development on Dredged Material," Technical Report DS-78-19, Aug 1978, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

39. U. S. Environmental Protection Agency, "Erosion and Sediment Control, Surface Mining," EPA-625/3-76-006, Oct 1976, Washington, D. C.

40. Baxter, J. F., ed., 1977 Agricultural Engineers Yearbook, American Society of Agricultural Engineers, St. Joseph, Mich., 1977.

41. Bartos, M. J., Jr., "Use of Dredged Material in Solid Waste Management," Technical Report D-77-11, Sep 1977, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

42. Arthur D. Little, Inc., "A Feasibility Study of Lawn Sod Production and/or Related Activities on Dredged Material Disposal Sites," Contract Report D-75-1, Jan 1975, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

43. Luthin, J. M., ed., "Drainage of Agricultural Lands," No. 7, 1957, American Society of Agronomy, Madison, Wisc.

44. Bear, F. E., Chemistry of the Soil, Reinhold, New York, 1964.

45. U. S. Environmental Protection Agency, "Methods for Chemical Analysis of Water and Wastes," EPA-625/6-74-003a, 1974, Environmental Research Center, Cincinnati, Ohio.

46. U. S. Environmental Protection Agency, "Chemistry Laboratory Manual: Bottom Sediments," Dec 1969, Great Lakes Regional Committee on Analytical Methods, Cleveland, Ohio.

APPENDIX A: SUMMARIES OF PERTINENT DMRP RESEARCH

1. This Appendix presents a synthesis of research conducted under Tasks 3B and 4C of the Dredged Material Research Program (DMRP) plus other research pertinent to this study. Table A1 lists the work unit numbers, study/report titles and designations, and performing organizations (contractor, Environmental Laboratory (EL) of the U. S. Army Engineer Waterways Experiment Station (WES), and/or other government agency). The results of these efforts were used as a basis for development of guidelines presented in the main text of this report. The reports cited should be consulted for more detailed information.

Table A1

Summary of DMRP Research Pertinent to Land Improvement Projects

DMRP Work Unit	Study/Report Title	Performing Organization	Report Designation
3B01	Dredged Material Transport Systems for Inland Disposal and/or Productive Use Concepts	General Research Corporation	Technical Report D-78-28[9]
3B02	Feasibility of Inland Disposal of Dewatered Dredged Material: A Literature Review	SCS Engineers	Technical Report D-77-33[3]
4C02	Use of Dredged Material in Solid Waste Management	EL, WES	Technical Report D-77-11[41]
4C03	The Agricultural Value of Dredged Material	Agricultural Research Service	Technical Report D-78-36[15]
4C04	Area Strip Mine Reclamation Using Dredged Material: A Field Demonstration	U. S. Army Engineer District, Chicago, and EL, WES	See Appendix B[31]
4C05	Water Quality Analysis of Leachates	Argonne National Laboratory	Interim Report
4D01	A Feasibility Study of Lawn Sod Production and/or Related Activities on Dredged Material Disposal Sites	Arthur D. Little, Inc.	Contract Report D-75-1[42]
5C02	Classification and Engineering Properties of Dredged Material	EL, WES	Technical Report D-77-18[6]

Work Unit 3B01--Dredged Material Transport Systems for Inland Disposal and/or Productive Use Concepts (Technical Report D-78-28)

2. Souder et al.[9] identified and evaluated transport systems applicable to the inland movement of dredged material. The report is intended to provide generalized data which can be utilized in evaluating the economic potential of inland disposal alternatives for specific

applications across the country. Detail from both technical and economic points of view is provided.

3. Five basic transportation modes were examined: hydraulic pipeline, rail haul, barge movement, truck haul, and belt conveyor movement. With regard to the hydraulic pipeline slurry method, two pumping methods were analyzed: (a) centrifugal pumping systems, and (b) Pneuma pumping systems.

4. Research was conducted after an in-depth literature review of prior studies involving technical and economic aspects of alternative transportation modes. Research was conducted on the technical aspects of all five transportation modes. Detailed design data and parameters were developed for the hydraulic pipeline transport alternative. Equations were derived for detailed total and unit cost estimates (including material handling costs and transportation costs) for each transportation alternative based upon varying annual quantity movements with distance. Annual quantity movements ranged from 500,000 to 5,000,000 yd^3 per year for each application, and distances varied from 6 to 300 miles. In addition, they identified legal, institutional, environmental, and other potential constraining considerations which should be examined prior to the implementation of a desired transportation mode.

Work Unit 3B02--Feasibility of Inland Disposal of Dewatered Dredged Material: A Literature Review (Technical Report D-77-33)

5. SCS Engineers[3] assessed the feasibility of inland disposal of dewatered dredged material. Inland disposal is defined as the placement of dredged material at containment sites which are inland from the dredging project. The engineering, environmental, economic, social, and institutional factors associated with this method of disposal were identified from various information sources and are summarized in the report.

6. A checklist was developed for use as a decisionmaking tool by officials who must provide inland sites for the final containment of dredged material and by officials who are required by state and/or

local agencies to develop a site plan or who must meet specific land use requirements. This checklist presents a step-by-step planning process for site selection and final site use. The planning process considers all factors necessary to provide a cost-effective containment site that is environmentally and socially compatible with its surroundings.

7. SCS Engineers[3] noted that public opposition to an inland containment site may arise due to physical and social aspects of site location. Further opposition may stem from the potential environmental problems caused by transportation and placement of the material. Depending on the contaminant content of dredged material, local climate, disposal method used, characteristics of the containment area, and transportation method, dredged material may be a source of adverse environmental impacts. However, proper site selection, design, and operation can adequately protect the environment in the vicinity of the site.

8. Regulatory agencies in many localities may control the selection of inland dredged material containment sites and subsequent material placement. State, local, and Federal agencies with jurisdiction over placement of waste, water quality, zoning, and other environmental issues should be consulted for laws and policies on land activities concerning a specific dredged material containment plan.

9. Development costs for an inland dredged material containment site include capital, operating, environmental protection, and transportation. These costs are site-specific and depend on the volume of dredged material to be placed, method of transportation, need for access road construction, types of equipment used onsite, site topography, prevailing wage rates, and land costs. The area's hydrogeological features will largely influence the type and hence the cost of water quality monitoring facilities needed.

Work Unit 4C02--Use of Dredged Material In Solid Waste Management (Technical Report D-77-11)

10. Bartos,[41] through an extensive literature review, investigated the feasibility of using dredged material in solid waste management

from the standpoint that dredged material could be used to replace natural soil as borrow or to create land on which to locate solid waste operations.

11. The uses for soil at sanitary landfills were investigated and were found to include cover, gas barriers and vents, impervious liners, and leachate collection underdrains. The suitability of dredged material for each of these uses was evaluated by comparing dredged material properties with the properties of soils known to be suitable. It was concluded that coarse-grained dredged material is suitable for use in venting decomposition gases, collecting leachate, and providing a trafficable covering when the infiltration of rainfall into the sanitary landfill is acceptable. Fine- or medium-grained dredged material was shown to be suitable for a number of uses, including as a gas barrier, impervious liners, and cover. Dewatering is required to ensure that fine- or medium-grained dredged material has the consistency of soil.

12. Economic and environmental factors which influence the use of dredged material in solid waste management were examined. Bartos[41] found that economic advisability will be determined in part by a comparison between the cost of dredged material dewatering and that of purchasing borrow material. Dewatering costs could conceivably be shared by the Corps and solid waste management authorities because both agencies would benefit. Environmental factors are site-specific. Dredged material contamination must be considered but is not expected to be a significant problem when dredged material is used in a properly operated sanitary landfill. Sufficient information on which to base incisive guidance concerning the use of contaminated dredged material is not yet available.

13. Concepts for using large amounts of dredged material in solid waste management were developed. One concept shows how a single parcel of land might be used first as a dredged material containment area and then as a sanitary landfill by using a modified trench method of sanitary landfill. Another concept, involving land creation using dredged material and hill construction by the area method of sanitary landfilling, demonstrates how dredged material can add flexibility to the

management of solid waste. A third concept, involving use of dredged material long after a sanitary landfill has been completed, involves the injection of dredged slurry into the voids within a sanitary landfill to extinguish and prevent underground fires and to reduce subsidence by filling the voids.

Work Unit 4C03--The Agricultural Value of Dredged Material (Technical Report D-78-36)

14. A possible alternative to the present practice of land disposal of dredged material is the application of this material to marginal or unproductive agricultural land with the intention of increasing its productivity.[17] However, very little is known about the effects of such an operation on the development of the agricultural land. The purpose of this study was to gather basic information about the physical and chemical properties of selected dredged material as they relate to agricultural potential and to develop guidelines on the suitability of dredged material for crop production as an amendment for marginal soils.

15. Samples of dredged material low in contaminants and marginal soils were collected for study from 10 locations in the eastern and central United States. Samples of the dredged material, marginal soil, and their mixtures were physically and chemically analyzed prior to greenhouse experiments in which ryegrass and barley were grown for plant analyses.

16. The dredged material samples had a wide variation in grain sizes ranging from sand to clay.[17] The marginal soils were chosen to represent extreme grain-size distribution differences from the dredged material. The bulk densities of the fine-grained dredged material samples were low when compared to similar textures of normal agricultural soil. Also, the water-holding capacities of fine-grained dredged material samples were extremely high.

17. The chemical properties of the selected dredged material samples were not greatly different from the chemical properties of three productive Minnesota soils used as controls. Some of the dredged material samples were high in organic matter and nitrogen and were

usually high in total sulfur and total phosphorus. Large amounts of sulfur in some of the dredged material samples required large applications of lime to neutralize the acidity. The heavy metal analyses demonstrated that the dredged material samples did not contain excessive amounts of contaminants to restrict plant growth or contaminate the harvested plant material. In addition, the oil and grease content of the dredged material was greater than that of the marginal soils but did not limit plant growth.

18. Plant yields in the greenhouse study were greater from the fine-grained dredged material samples than from the marginal soils. In general, yield ratios were greater than two for crops grown on fine-grained dredged material when mixed with coarse-grained marginal soil. The yields on the pure dredged material were equal to or greater than the yields on the control soils.

19. Dredged material can be used for increasing agricultural production when mixed with marginal agricultural soils.[17] However, caution should be exercised in using dredged material which is infested with weeds, is high in soluble salts, or has higher than normal concentrations of heavy metals.

Work Unit 4C04--Area Strip Mine Reclamation Using Dredged Material: A Field Demonstration

20. The objective of this study was to demonstrate the feasibility of surface mine reclamation using dredged material as a cover material. A site was selected adjacent to the Illinois River near Ottawa, Ill. Dredged material for the project was taken from a dredged material containment area owned by the Metropolitan Sanitary District of Greater Chicago and located about 72 miles from the demonstration site.

21. Dry surface materials were loaded on trucks and hauled to the demonstration site. No special processing was required of the dredged material at the containment area other than the stripping of plant material from the surface for weed control purposes. The dry surface crust in the containment area was easy to load on the trucks and spread over the demonstration plots at the Ottawa site. No problems were

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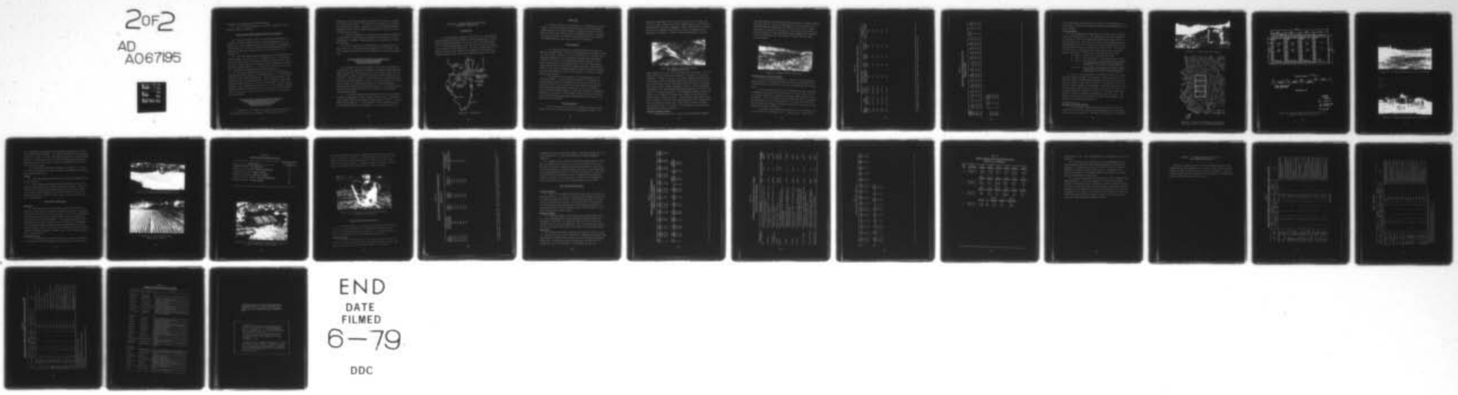

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encountered in transporting the dredged material.

22. A more detailed discussion is provided in Appendix B and in Perrier, Llopis, and Spaine.[31]

Work Unit 4C05--Water Quality Analysis of Leachates

23. During the autumn of 1977, the Argonne National Laboratory initiated a study on leachates from the Corps demonstration site at Ottawa, Ill., where dredged material had been applied to nonproductive coal mine spoil in an effort to reduce acid mine drainage pollution to surrounding lands and to improve the land for productive use (see Appendix B).

24. This study focused upon the migration of several chemical compounds and metal ions present in the dredged material. The installation of Parshall flumes, soil water lysimeters, and observation wells was made to sample runoff, soil water, and local groundwater associated with four demonstration plots: a control plot of mine spoil and three plots consisting of dredged material covering mine spoil.

25. Each water sample was split into a number of aliquots and preservatives added according to recommendations in U. S. Environmental Protection Agency (EPA) methodologies. The following parameters were determined: pH, acidity, alkalinity, chloride, specific conductance, cyanide, ammonia nitrate plus nitrite, total Kjeldahl nitrogen, orthophosphate, total phosphorus, redox potential, silica, sulfate, sulfide, alkali and alkaline earth metals (Ca, Mg, Na, K, and Sr), trace metals (Al, Cd, Cr, Cr, Fe, Mn, Ni, Pb, and Zn), and mercury. These data are now available.

Work Unit 4D01--A Feasibility Study of Lawn Sod Production and/or Related Activities on Dredged Material Disposal Sites (Contract Report D-75-1)

26. Multiple use of a diked containment area entails the use of the confined land area for placement of dredged material and for

beneficial uses such as agricultural production of lawn sod, nursery, and horticultural crops.[42] The purpose of this study was to evaluate the technical and economic feasibility of the use of dredged material containment sites for the commercial production of lawn sod or other horticultural activities.

27. Several containment site characteristics that were identified as detrimental to horticultural production included weeds, salinity, contaminants, inundation, dredging operations, accessibility, and market proximity.

28. It was found that the establishment of commercial horicultural production on suitable mature disposal sites is feasible. However, commercial production was not recommended for active containment sites.

Work Unit 5C02--Classification and Engineering Properties of Dredged Material (Technical Report D-77-18)

29. Standard tests of soil properties were used to determine the classification and engineering properties of dredged material samples.[6] Classification tests included grain-size distribution, plasticity, and organic matter content, and engineering tests included compaction, consolidation, and shear strength. Four standard soil classification systems were used for comparative purposes: (a) the Unified Soil Classification System, (b) the American Association of State Highway and Transportation Officials Classification System, (c) the Federal Aviation Administration System, and (d) the U. S. Department of Agriculture Classification System.

30. It was found that dewatered dredged material has engineering properties comparable to those of similar types of soil. Also, dewatered dredged material has characteristics similar to soils of the same grain-size distribution. It was concluded that for engineering purposes dredged material can be analyzed as a soil and used as a soil.

APPENDIX B: INTERIM REPORT ON SURFACE MINE RECLAMATION DEMONSTRATION

Introduction

1. The Environmental Laboratory (EL) of the U. S. Army Engineer Waterways Experiment Station (WES) is currently conducting a surface mine reclamation demonstration in Ottawa, Ill.[31] The demonstration site is located approximately 1 mile east of Ottawa on the Illinois River in LaSalle County (Figure B1). The site is being leased by the Corps of Engineers from Ottawa Silica Company which purchased the property sometime after coal mining operations ceased in the 1930's.

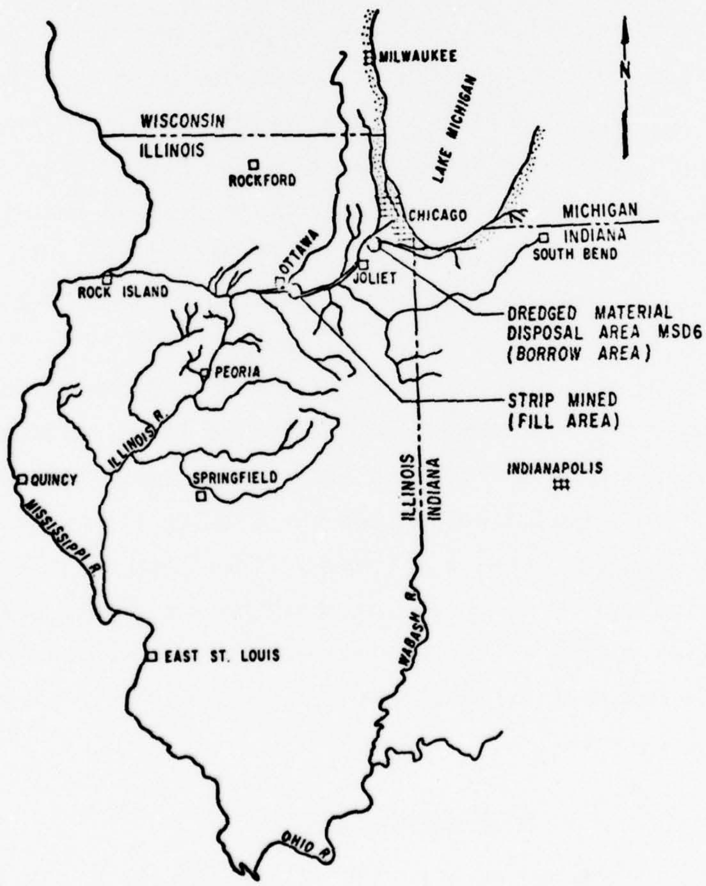

Figure B1. Location map

Objectives

2. The main objective of the project is to demonstrate the feasibility of reclaiming surface mine spoils using a cover of dewatered dredged material as a medium capable of supporting vegetation and as a means to reduce the effects of acid and sediment pollution. Information will be provided on runoff and soil water quality as affected by the dredged material, mine spoil, and their interactions.

Site Selection

3. An intensive search for a suitable field test site was conducted by the WES staff. Efforts were concentrated in the State of Illinois for a number of reasons: (a) over 100,000 acres of Illinois land were surface mined prior to legislation requiring mine land reclamation;[30] (b) the costs of confined dredged material disposal in the Great Lakes region has risen dramatically to the point where distant inland disposal can be economically competitive despite transportation costs; (c) the Illinois Waterway bisects a number of Illinois counties with abandoned lands and connects these counties to sources of dredged material near Chicago.

4. The Ottawa site was selected for the demonstration for the following reasons: (a) the owner was interested in reclaiming the property and was willing to cooperate with the project; (b) the site was within 700 ft of the Illinois River which makes it accessible to barges carrying dredged material (although it was later decided to use truck haul instead of barges); (c) the site was within a reasonable distance (72 river miles) of the dredged material source near Chicago; and (d) the site had been extremely degraded and was not likely to reclaim itself for decades.[27]

Site Description

5. The site consisted of a series of irregularly shaped parallel ridges of mine spoil covering an area of approximately 25 acres. The

ridges were approximately 600 to 1200 ft long, 40 to 50 ft wide, and 20 to 30 ft high. The mine spoil was composed mainly of clay with intermixed lignite and pyrite fragments. These ridges had been a significant source of sediment pollution from erosion as indicated by the photograph in Figure B2. A gently sloping (approximately 3 percent)

Figure B2. Ridges of mine spoil before earthmoving operations

plain extends 750 ft south of the site to the Illinois River. The following excerpt from Haynes and Klimstra[34] is descriptive of the site conditions: "Mining of the No. 2 coal seam in LaSalle County and the Davis Dekoven seams in Williamson and Saline counties have [sic] produced spoil-banks that were recognized as the most toxic in the State. These spoils did not support vegetation because of the low proportion of productive soil and correspondingly high proportion of acid clay and shale in the surface materials." The fundamental chemical process involved is the formation of sulfuric acid (H_2SO_4) by the exposure of pyrite (FeS_2) to oxygen and water. As the surface erodes, more pyrite will be exposed so that the acid generating process will continue until the spoil banks have eroded flat. This process has been occurring since mining ceased in the 1930's. This extremely poor condition for revegetation is shown in Figure B2.

Source of dredged material

6. Dredged material for the project was obtained from disposal

area MSD6 owned by the Metropolitan Sanitary District of Greater Chicago. The borrow area is located on land adjacent to the north bank of the Cal-Sag Channel at approximate river mile 313.0 just east of Ridgeland Avenue in Alsip, Ill. (Figure B3). This area was utilized by the Federal Government in 1973 during maintenance dredging work performed in the Cal-Sag Channel for the disposal of dredged material moved from the channel.

Figure B3. Dredged material borrow area

Planning phase of site development

7. Prior to actual project design, a series of field investigations was made by the Chicago District and EL to provide needed input concerning both the surface mine site and the dredged material disposal area.

8. At the surface mine site, two observation wells were installed to determine the elevation and fluctuation of the water table as well as to permit sampling to determine the chemical characteristics of the groundwater. Cores of the mine spoil were taken and tested to determine the permeability and soil classification of the mine spoil (Table B1). Chemical analyses of samples of dredged material crust from the containment area are shown in Table B2.

9. A predesign and coordination meeting was held on 18 August 1976 at the offices of the Chicago District. Many agencies provided input

Table B1

Physical Characteristics of Mine Spoil, Ottawa, Ill.

Sample Number	Date Collected	Depth of Sample ft	Unified Soil Classification Group Symbol*	Liquid Limit	Plastic Limit	Plasticity Index	Permeability $K_{20} \times 10^{-8}$ cm/sec
1-76 2	16 Oct 76	3.0-5.0	CH	75	31	44	2.1
2-76 4	19 Oct 76	10.0-12.0	CH	60	27	33	3.3
2-76 7	19 Oct 76	20.0-22.0	CH	53	25	28	2.2
3-76 1	21 Oct 76	0.0-2.0	CH	53	28	25	7.4
4-76	21 Oct 76	0.0-2.0	CH	56	30	26	5.8

* Typical name of group symbol; CH - inorganic clays of high plasticity, fat clays.

Table B2

Chemical Analysis of Dredged Material Crust

Parameters (mg/kg)

Sample Number	Ca	Cd	Cr	Cu	Fe	Pb	Mg	Ni	K	Na	Zn	Mn	TKN	TP	NH_3-N	CN	Hg
MSG-1	58,700	17.4	269	214	47,800	918	19,600	68.6	25,100	3200	2050	609	2770	16.3	21	0.8	1.00
MSG-2	52,900	10.0	150	123	41,400	452	26,000	58.5	19,800	3900	1260	536	2310	31.9	31	0.5	1.00
MSG-3	60,000	16.2	176	165	46,000	578	26,400	68.3	23,200	4070	1860	621	2350	31.1	20	0.6	1.21
MSG-4	46,400	28.9	266	194	49,400	714	21,500	75.4	24,600	3970	1980	602	2730	18.9	21	0.8	0.94

	$S^=$	NO_3-N	Oil & Grease
MSG-1	10	0.8	13,200
MSG-2	7	3.3	3,900
MSG-3	9	0.8	9,100
MSG-4	17	54.0	10,200

to the preliminary field design, site selection, identification of environmental concerns, and technical review and recommendations to the project design.

Site preparation

10. Site preparation was performed in July 1977 under the direction of the Chicago District. The demonstration site was constructed by leveling two mine spoil ridges with dozers and forming a raised plateau (Figure B4). The test site consists of four diked plots, each approximately 170 by 75 ft (Figure B5). The 5-ft-high dikes were constructed from mine spoil and covered with sheets of PVC. The purpose of the dikes was to segregate runoff from each plot for monitoring purposes (Figure B6). The four test plots are described below:

a. Plot 1 - Control plot, untreated mine spoil.

b. Plot 2 - Mine spoil with a 3-ft dredged material cover.

c. Plot 3 - Five tons/acre of crushed agricultural limestone incorporated into the top 6 in. of mine spoil overlaid by a 3-ft cover of dredged material.

d. Plot 4 - 7.5 tons/acre of crushed agricultural limestone incorporated into the top 6 in. of mine spoil overlaid by a 3-ft cover of dredged material.

11. Prior to the transportation of dredged material, the borrow area was cleared, stripped, and excavated. Clearing consisted of the complete removal of objectionable materials from the borrow area such as trees, timbers, logs, brush, and debris. Stripping of the site to the 6-in. depth consisted of the removal of all plant material for weed control purposes below the ground surface. After the 6-in. layer of top material had been removed, the next 18 in. of material was stockpiled as a source of material for placement on the test plots. The material was excavated with a front end loader and stockpiled in the center of the borrow area (Figure B7).

Transportation and placement of dredged material

12. The stockpiled dredged material was loaded by a front end loader onto trucks whose capacity was approximately 15 yd^3 and hauled to the test site (Figure B8). The Corps used truck haul in preference

Figure B4. Leveling mine spoil ridges

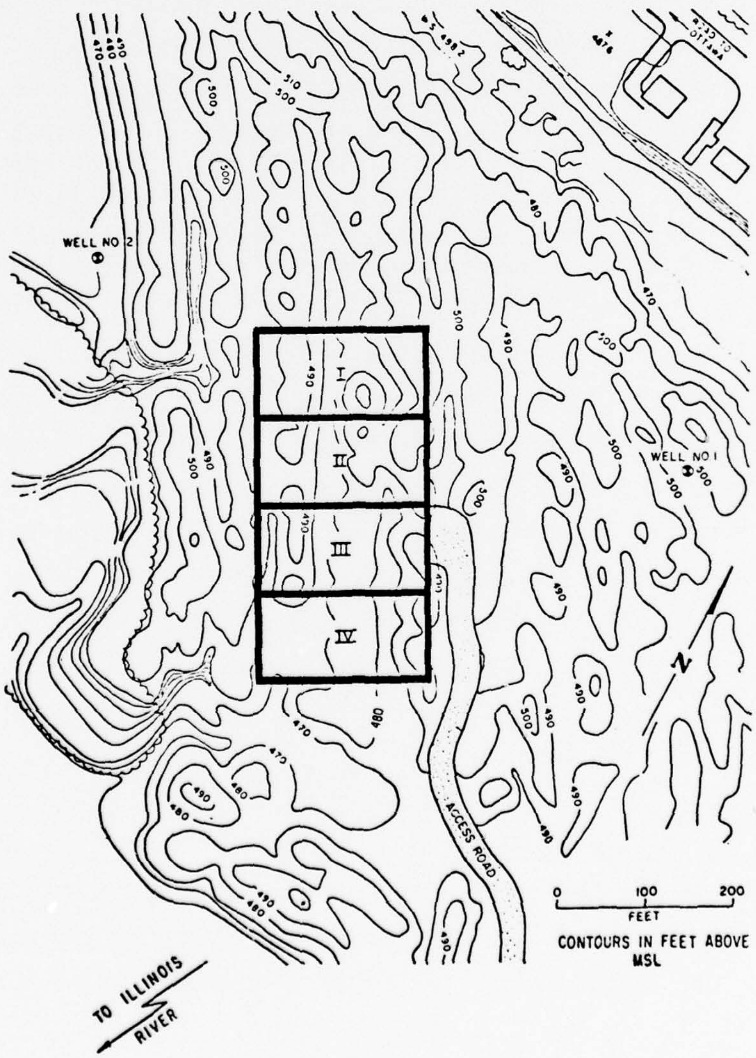

Figure B5. Initial site topography, groundwater observation wells, and test plots (superimposed)

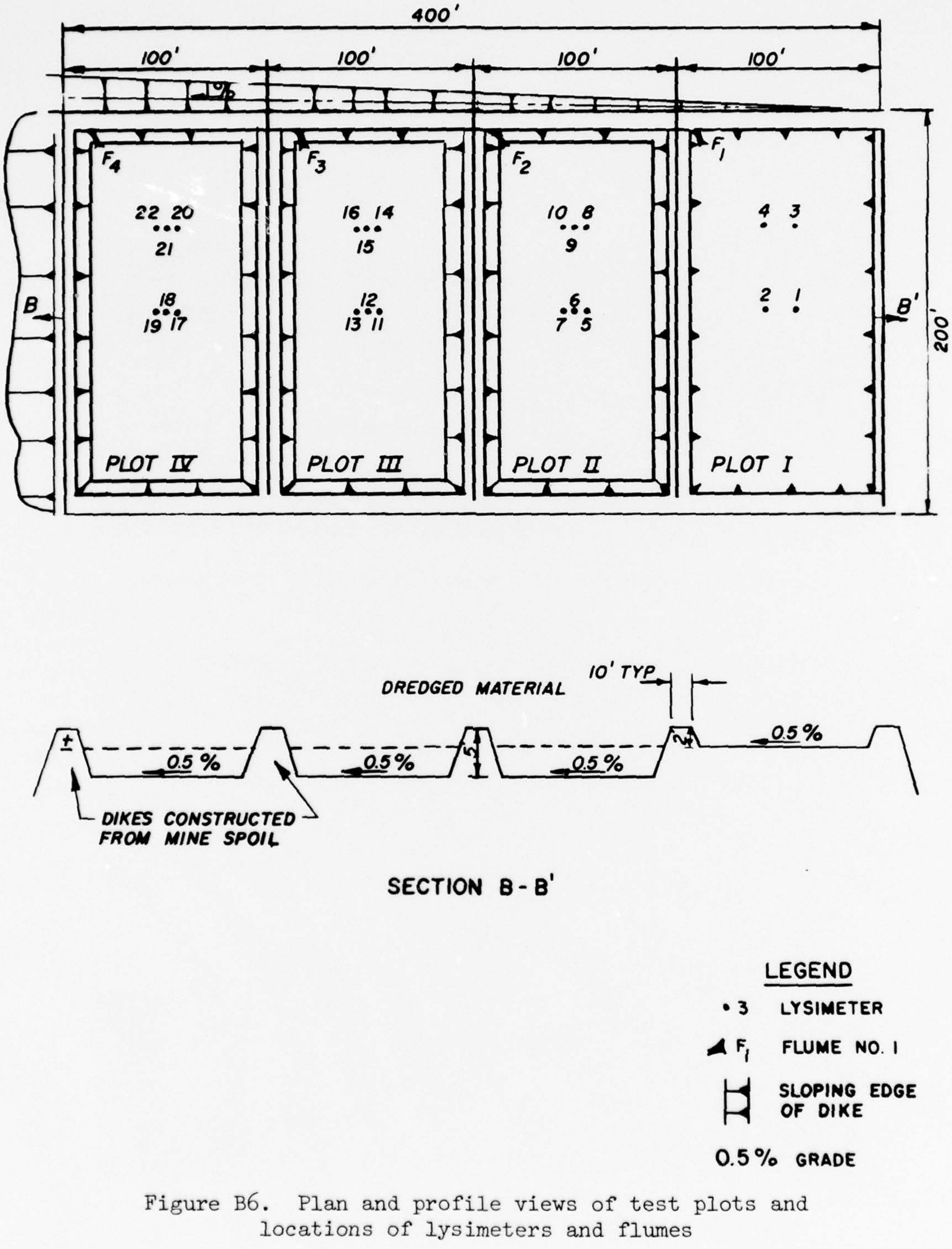

Figure B6. Plan and profile views of test plots and locations of lysimeters and flumes

Figure B7. Stockpiling dredged material in borrow area

Figure B8. Loading dredged material at borrow area to the seemingly more economical barge movement mode because of simplicity, economy, and timeliness. The dredged material was placed directly on plots 2, 3, and 4. A dozer then spread the material to the specified depth of 3 ft (Figure B9), and the finished surface was graded to the southwest corner of each plot at a grade of approximately 0.5 percent with a front end loader.

13. The finished surface was scarified to a depth of 3 in. with the teeth of the bucket of a front end loader in preparation for broadcast seeding (Figure B10).

Seeding

14. The seed mixture and application rate listed in Table B3 were used on each plot.

15. After seeding, wheat straw mulch was placed at a rate of 2 tons/acre and sprayed with an asphalt emulsion as a binder. Figure B11 shows the plots after the plants had grown to about the 8-in. height on the three dredged material sites (right-hand plots); however, the seed mixture did not establish a plant cover on the surface mine spoil plot (left-hand plot).

Water Quality Monitoring

Objective

16. The objective of the water quality study is to monitor the migration of the chemical compounds and elements present in the dredged material and the mine spoil as listed below. This is to be accomplished by monitoring the soil water present in the test plots, runoff from each test plot, and local groundwater. The chemical parameters to be analyzed are pH, acidity, alkalinity, total phosphorus, orthophosphate, total Kjeldahl nitrogen, ammonia-nitrogen, nitrate-nitrite, chloride, cyanide, sulfate, sulfide, silica, calcium, magnesium, sodium, potassium, strontium, aluminum, cadmium, chromium, copper, iron, mercury, manganese, nickel, lead, and zinc.

Monitoring devices

17. To determine the downward migration of chemical constituents in the leachate, pressure-vacuum soil water samplers were installed in

Figure B9. Spreading dredged material on plots

Figure B10. Plot 4 scarified and prepared for seeding

Table B3

Seed Mixture and Application Rate

Seed Mixture	Application Rate lb/acre
Kentucky bluegrass (*Poa pratensis*)	15
Kentucky 31 tall fescue (*Festaca arundinacea*)	20
Lincoln smooth brome (*Bromus inerimis*)	15
Blackwell switchgrass (*Panicum virgatum*)	20
Birdsfoot trefoil (Empire) (*Lotus corniculatus*)	15
Perennial ryegrass (*Lolium perenne*)	15
	100

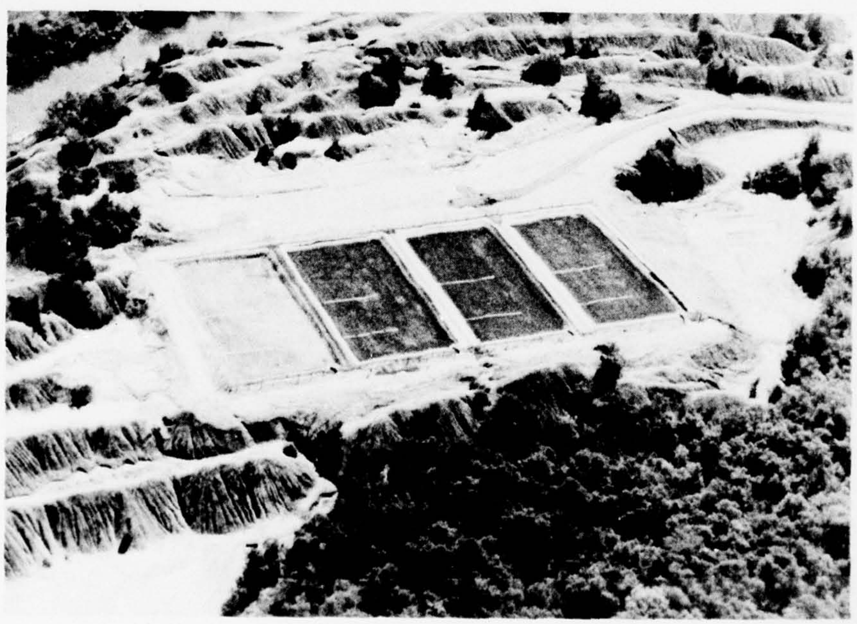

Figure B11. Aerial photograph of demonstration plots and adjacent surface mine spoil ridges the dredged material, lime layer (dredged material-mine spoil interface), and the mine spoil (Figure B12). A Parshall flume was installed in the corner of each plot to record the amount of runoff and collect runoff samples for chemical analysis. Groundwater samples are being collected from two observation wells installed by the Corps of Engineers.

Figure B12. Installing a pressure-vacuum lysimeter for collection of soil water

Dredged Material Characteristics

18. Composite samples of the dredged material were collected from plots 2, 3, and 4 to determine its classification according to the Unified Soil Classification System (Table B4). The dredged material is a silt with intermixed fine sand and high-plasticity clays.

Chemical analyses

19. Samples of dredged material crust were collected from the containment area in the fall of 1976 and analyzed for various chemical compounds and metals as listed previously in Table B2. After the

Table B4

Physical Characteristics of Placed Dredged Material

Ottawa, Ill.

Sample Number	Unified Soil Classification Group Symbol*	Liquid Limit	Plastic Limit	Plasticity Index	Percent Passing U. S. Standard Sieve No. 400 (0.4 mm)
DM P2-1	MH	54.0	31.0	23.0	80
DM P2-2	MH	54.0	30.0	24.0	80
DM P3-1	MH	51.0	28.0	23.0	95
DM P3-2	MH	50.0	29.0	21.0	95
DM P4-1	MH	53.0	31.0	22.0	90
DM P4-2	MH	57.0	31.0	26.0	90

* Typical name of group symbol; MH - silt, fine, sandy; samples collected on 21 October 1977.

reclamation site was established, samples of dredged material were collected from plots 2, 3, and 4 and analyzed for similar parameters (Table B5).

20. Analyses of the chemical data from the dredged material crust and the dredged material in place at the site show that Cr, Fe, Zn, Mn, and Pb are near or slightly exceed the upper range of constituents that can be expected in dredged material (see Table 7 of the main text). In the dredged material crust, Cd, Zn, and Pb are close to or exceed the toxic metal levels recommended for use in agriculture for "domestic sludge" (see Table 8 of the main text). However, in the dredged material samples from the plots, only Cd approached the toxic level.

Mine Spoil Characteristics

Physical analyses

21. Before site preparation began, four wells were drilled at the demonstration site. The cores were characterized by physical analyses as listed previously in Table B1. The foundation material at the site consists of clay shales and clays of high plasticity. The potential for contaminating the groundwater with dredged material leachate is negligible because of the low permeability of the 30-ft layer of mine spoil overlying the closest aquifer.

Chemical analyses

22. Composite samples of mine spoil were collected from plots 1, 2, 3, and 4 and analyzed for various chemical parameters (Table B6). As expected (Table B7), the pH was very low (3.6 to 4.1) due to the formation of acid from iron disulfides. The salt content was variable but at a level that would restrict the growth of salt sensitive plants.

Lime layer

23. Crushed agricultural limestone was applied at rates of 5 and 7.5 tons/acre on plots 3 and 4, respectively. Samples of the mine spoil-lime layer were collected and analyzed for various chemical parameters (Table B8). Incorporation of the limestone into the mine spoil increased not only the concentration of Ca and Mg, but also the

Table B5

Chemical Analysis of Placed Dredged Material

Ottawa, Ill., 21 October 1977

Plot No.	Ca (mg/kg)	Cd (mg/kg)	Cr (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Pb (mg/kg)	Mg (mg/kg)	Ni (mg/kg)	K (mg/kg)	Na (mg/kg)	Zn (mg/kg)	Mn (mg/kg)
2	49,500	12.5	169	108	42,400	507	25,800	57.3	17,900	4970	1190	538
3	58,900	13.6	168	128	42,400	514	30,100	51.4	18,100	4470	1120	532
4	52,100	12.9	160	103	40,800	500	26,100	51.0	17,900	2690	1060	536

Plot No.	TKN (mg/kg)	TP (mg/kg)	NH_3-N (mg/kg)	SO_4 (mg/kg)	Cl (mg/kg)	CN (mg/kg)	Hg (mg/kg)	pH	NO_3NO_2 (mg/kg)	$S^{=}$ (mg/k)	CONDUC (μmhos/cm)
2	1620	4730	65	3610	720	2.3	0.786	7.0	23.2	<10	2530
3	1610	5180	20	3770	140	1.9	1.38	7.1	18.8	<10	2530
4	1740	5060	20	3940	140	2.2	0.621	7.1	18.2	<10	2530

Table B6

Procedures Used in Chemical Analyses of Dredged Material and Surface Mine Spoil

Parameter	Description	Units	Detection Limit	Reference
pH	Determined with a glass electrode pH meter on a 1:1 soil-to-water suspension	--	0.01	Bear[44]
Chloride	Potentiometric determination of chloride using a titration assembly	mg/kg	10	Black[24]
Electrical conductivity	Measured with a conductivity bridge using a 2:1 water-to-soil solution	μmho/cm	7.0	Bear[44]
Mercury	Manual cold vapor technique	mg/kg	0.025	EPA[45]
Metals	Nitric, perchloric, and hydrofluoric acid digest and analyzed on an atomic absorption spectrophotometer	mg/kg	0.002	Black[24]
Sulfate	Oxidation of organic sulfur to sulfate and retained upon ignition of a mixture of soil and sodium bicarbonate	mg/kg	0.1	Black[24]
Cyanide	Conversion to sodium salts and absorbance measured at 620 mμ	mg/kg	0.02	EPA[46]
Sulfide	Distillation under acidic conditions to form zinc sulfides add methylene blue and determine concentration with spectrophotometer	mg/kg	1.0	EPA[46]
Total nitrogen	Determination by titration of ammonia released by distillation from sample previously digested with sulfuric acid	mg/kg	0.02	EPA[46]
Total phosphorus	Determined colorimetrically with vandomolybdate on a soil-acid (HNO_3-$HCPO_4$) digest	mg/kg	5.0	EPA[46]
Nitrate-nitrite	Ultaviolet colorimetric determination	mg/kg	0.01	EPA[46]

Table B7

Chemical Analysis of Mine Spoil, Ottawa, Ill.

Plot No.	Date Sampled	Ca (mg/kg)	Cd (mg/kg)	Cr (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Pb (mg/kg)	Mg (mg/kg)	Ni (mg/kg)	K (mg/kg)	Na (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	TKN (mg/kg)	TP (mg/kg)
1	21 Oct 77	1160	<0.010	91.4	28.2	35,800	41.8	4640	43.4	29,400	6790	88.3	212	570	582
2	28 Sep 77	1200	<0.010	90.0	27.8	38,600	38.2	4110	44.0	31,100	6810	78.8	266	670	630
3	28 Sep 77	2390	<0.010	86.2	28.2	36,500	42.8	5970	50.9	33,800	6770	100.0	272	670	629
4	27 Sep 77	1450	<0.010	84.3	26.8	37,100	42.8	4890	42.0	31,900	6590	86.9	232	670	598

Plot No.	Dated Sampled	NH_3-N (mg/kg)	SO_4 (mg/kg)	Cl (mg/kg)	CN (mg/kg)	Hg (mg/kg)	pH	NO_3NO_2 (mg/kg)	S= (mg/kg)	CONDUC (μmhos/cm)
1	21 Oct 77	<10	18,500	20	<0.4	<0.025	3.6	10.6	<10	3370
2	28 Sep 77	18	16,800	<10	<0.4	<0.025	3.6	6.40	<10	3060
3	28 Sep 77	18	18,700	<10	<0.4	0.028	4.1	3.24	<10	4810
4	27 Sep 77	<10	15,400	<10	<0.4	0.116	3.8	7.58	<10	2970

Table B8

Chemical Analysis of Mine Spoil-Lime Layer,

Ottawa, Ill., Parameters

Plot No.	Date Collected	Ca (mg/kg)	Cd (mg/kg)	Cr (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Pb (mg/kg)
3	29 Sep 77	3290	0.380	83.9	25.0	34,100	39.3
4	28 Sep 77	4020	0.200	90.0	23.6	33,400	49.5

Plot No.	Date Collected	Mg (mg/kg)	Ni (mg/kg)	K (mg/kg)	Na (mg/kg)	Zn (mg/kg)	Mn (mg/kg)
3	29 Sep 77	5840	41.9	29,100	6620	80.4	253
4	28 Sep 77	7290	40.3	30,700	6430	78.6	538

Plot No.	Date Collected	TKN (mg/kg)	TP (mg/kg)	NH_3-N (mg/kg)	SO_4 (mg/kg)	Cl (mg/kg)	CN (mg/kg)
3	29 Sep 77	610	552	10	19,100	10	<0.4
4	28 Sep 77	580	560	10	16,800	<10	<0.4

Plot No.	Date Collected	(mg/kg)	pH	NO_3NO_2 (mg/kg)	S (mg/kg)	CONDUC (µmhos/cm)
3	29 Sep 77	0.074	5.5	8.18	<10	4210
4	28 Sep 77	0.064	5.8	4.52	<10	5050

concentration of Cd. This was probably due to the presence of Cd in the limestone.

24. The water quality monitoring of this demonstration area is continuing under Work Unit 4C05 by Argonne National Laboratory (see Appendix A). Sufficient data has not yet been collected to draw conclusions on runoff or leachate water quality. A vegetative cover quickly established on the dredged material covered plots, and these plots will continue to be monitored.

25. Results of Work Units 4C04, Area Strip Mine Reclamation Using Dredged Material: A Field Demonstration, and 4C05, Water Quality Analysis of Leachates, will be published in separate technical reports. The report of Work Unit 4C04 will discuss project development, specific problems, and the feasibility of using dredged material for strip mine reclamation. The report of Work Unit 4C05 will elaborate on long- and short-term problems of water quality in runoff and groundwater from strip mine areas reclaimed by dredged material.

APPENDIX C: POTENTIAL VEGETATIVE COVERS FOR LAND IMPROVEMENT PROJECTS

Potential vegetative covers for land improvement projects using dredged material are presented in two tables. Table C1 presents grass species and their characteristics as related to vegetation. Table C2 presents legumes and their suitability for revegetation. Commonly used trees and shrubs are presented in Table C3.

Table C1

Characteristics of Commonly Used Grasses[a] for Revegetation Purposes (from EPA[39])

Common name	Botanical name	Season: Cool	Season: Warm	Season: Dry (not droughty)	Site suitability: Well drained	Site suitability: Moderately well drained	Site suitability: Somewhat poorly drained	Site suitability: Poorly drained	Growth habit[b]	pH range[c]	Use suitability: Erodible areas	Use suitability: Waterways and channels	Use suitability: Agriculture[d]	Remarks
Bahiagrass	*Paspalum notatum*		X	X	X	X			P	4.5-7.5	X	X	X	Tall, extensive root system. Maintained at low cost once established. *Able to withstand a large range of soil conditions.* Scarify seed.
Barley	*Hordeum vulgare*	X			X	X			A	5.5-7.8	X		X	Cool season annual. Provides winter cover.
Bermuda grass	*Cynodon dactylon*		X	X	X	X	X		P	4.5-7.5	X	X	X	Does best at a pH of 5.5 and above. Grows best on well drained soils, but not on waterlogged or tight soils. Propagated vegetatively by planting runners or crowns.
Bluegrass, Canada	*Poa compressa*	X		X	X	X			P	4.5-7.5	X		X	Does well on acid, droughty, or soils too low in nutrients to support good stands of Kentucky bluegrass.
Bluegrass, Kentucky	*Poa pratensis*	X			X	X	X		P	5.5-7.0	X	X	X	Shallow rooted; best adapted to well drained soils of limestone origin.
Bluestem, big	*Andropogon gerardi*		X		X	X	X		P	5.0-7.5	X		X	Strong, deep rooted, and short underground stems. Effective in controlling erosion.
Bluestem, little	*Andropogon scoparius*		X		X	X			P	6.0-8.0	X		X	Dense root system; grows in a clump to 3 feet tall. More drought tolerant than big bluestem. Good surface protection.
Bromegrass, field	*Bromus arvensis*	X			X	X	X		A	6.0-7.0	X		X	Good winter cover plant. Extensive fibrous root system. Rapid growth and easy to establish.
Bromegrass, smooth	*Bromus inermis*	X		X	X	X	X		P	5.5-8.0	X	X	X	Tall, sod forming, drought and heat tolerant. Cover seed lightly.
Buffalograss	*Buchloe dactyloides*		X			X	X		P	6.5-8.0	X		X	Drought tolerant. W[illegible] alkaline soils but not sandy ones. Will regenerate if overgrazed.
Canarygrass, reed	*Phalaris arundinacea*	X		X	X	X	X	X	P	5.0-7.5	X	X	X	Excellent for wet areas, ditches, waterways, gullies. Can emerge through 6 to 8 inches of sediment.
Deertongue	*Panicum clandestinum*		X	X	X	X	X	X	P	3.8-5.0	X	X		Very acid tolerant; drought resistant. Adapted to low fertility soils. Volunteers in many areas. Seed not available.
Fescue, creeping red	*Festuca rubra*	X		X	X	X	X		P	5.0-7.5	X	X	X	Grows in cold weather. Remains green during summer. Good seeder. Wide adaptation. Slow to establish.
Fescue, tall	*Festuca arundinacea*	X			X	X	X		P	5.0-8.0	X	X	X	Does well on acid and wet soils of sandstone and shale origin. Drought resistant. Ideal for lining channels. Good fall and winter pasture plant.
Grama, blue	*Bouteloua gracilis*		X	X	X	X	X		P	6.0-8.5	X			More drought resistant than sideoats grama. Sod forming. Extensive root system. Poor seed availability.
Grama, sideoats	*Bouteloua curtipendula*		X		X	X			P	6.0-7.5	X		X	Bunch forming; rarely forms a sod. May be replaced by blue grama in dry areas. Feed value about the same as big bluestem. Helps control wind erosion.
Indian grass	*Sorghastrum nutans*		X			X	X		P	5.5-7.5	X		X	Provides quick ground cover. Rhizomatous, tall. Seed available.
Lovegrass, sand	*Eragrostis trichodes*		X		X				P	6.0-7.5	X		X	A bunchgrass of medium height. Adaptable to sandy sites. Good for grazing. Fair seed availability.
Lovegrass weeping	*Eragrostis curvula*		X	X	X	X	X		P	4.5-8.0	X			Bunchgrass, rapid early growth. Grows well on infertile soils. Good root system. Low palatability. Short-lived in Northeast.

(Continued)

Table C1 (Concluded)

Common name	Botanical name	Season: Cool	Season: Warm	Season: Dry (not droughty)	Site suitability: Well drained	Site suitability: Moderately well drained	Site suitability: Somewhat poorly drained	Site suitability: Poorly drained	Growth habit[b]	pH range[c]	Use suitability: Erodible areas	Use suitability: Waterways and channels	Use suitability: Agriculture[d]	Remarks
Millet, foxtail	*Setaria italica*		X	X	X	X			A	4.5-7.0	X		X	Requires warm weather during the growing season. Cannot tolerate drought. *Good seedbed preparation important.*
Oats	*Avena sativa*	X		X	X				A	5.5-7.0	X		X	Bunch forming. Winter cover. Requires nitrogen for good growth.
Oatgrass, tall	*Arrhenatherum elatius*	X		X	X				P	5.0-7.5	X		X	Short-lived perennial bunchgrass, matures early in the spring. Less heat tolerant than orchardgrass except in Northeast. *Good on sandy and shallow shale sites.*
Orchardgrass	*Dactylis glomerata*	X		X	X	X	X		P	5.0-7.5	X		X	Tall-growing bunchgrass. Matures early. Good fertilizer response. More summer growth than timothy or bromegrass.
Redtop	*Agrostis alba*	X		X	X	X	X	X	P	4.0-7.5	X	X	X	Tolerant of a wide range of soil fertility, pH, and moisture conditions. Can withstand drought; good for wet conditions. Spreads by rhizomes.
Rye, winter	*Secale cereale*	X		X	X	X			A	5.5-7.5	X		X	Winter hardy. Good root system. Survives on coarse, sandy spoil. Temporary cover.
Ryegrass, annual	*Lolium multiflorum*	X			X	X	X		A	5.5-7.5	X		X	Excellent for temporary cover. Can be established under dry and unfavorable conditions. Quick germination; rapid seedling growth.
Ryegrass, perennial	*Lolium perenne*	X			X	X	X		P	5.5-7.5	X		X	Short-lived perennial bunchgrass. *More resistant than weeping love or tall oatgrass.*
Sandreed, prairie	*Calamovilfa longifolia*		X	X	X				P	6.0-8.0	X			Tall, drought tolerant. Can be used on sandy sites. Rhizomatous. Seed availability poor.
Sudangrass	*Sorghum sudanense*		X	X	X	X	X		A	5.5-7.5	X		X	Summer annual for temporary cover. Drought tolerant. Good feed value. Cannot withstand cool, wet soils.
Switchgrass	*Panicum virgatum*		X		X	X	X		P	5.0-7.5	X	X	X	Withstands eroded, *acid and low fertility soils.* Kanlow and Blackwell varieties most often used. Rhizomatous. Seed available. Drainageways, terrace outlets.
Timothy	*Phleum pratense*	X			X	X	X	X	P	4.5-8.0	X		X	Stands are maintained perennially by vegetative reproduction. Shallow, fibrous root system. Usually sown in a mixture with alfalfa and clover.
Wheat, winter	*Triticum aestivum*	X		X	X	X	X		A	5.0-7.0	X		X	Requires nutrients. Poor growth in sandy and poorly drained soils. Use for temporary cover.
Wheatgrass, tall	*Agropyron elongatum*	X		X	X	X	X	X	P	6.0-8.0	X	X	X	Good for wet, alkaline areas. Tolerant of saline conditions. Sod forming. Easy to establish.
Wheatgrass, western	*Agropyron smithii*	X		X	X	X	X	X	P	4.5-7.0	X	X	X	Sod forming, spreads rapidly, slow germination. Valuable for erosion control. Drought resistant.

[a] Grasses should be planted in combination with legumes. Seeding rates, time, and varieties should be based on local recommendations.

[b] P = perennial; A = annual.

[c] Many species survive and grow at lower pH; however, optimum growth occurs within these ranges.

[d] Hay, pasture, green manure, winter cover, and nurse crops are primary agricultural uses.

Note.—Prepared in cooperation with Soil Conservation Service plant material specialists and State conservationists.

Table C2

Characteristics of Commonly Used Legumes[a] for Revegetation Purposes (from EPA[39])

Common name	Scientific name	Season			Site suitability				Growth habit[b]	pH range[c]	Use suitability			Remarks
		Cool	Warm	Dry	Well drained	Moderately well drained	Somewhat poorly drained	Poorly drained			Erodible areas	Waterways and channels	Agriculture[d]	
Alfalfa	*Medicago sativa*	X		X	X	X			P	6.5-7.5	X		X	Requires high fertility and good drainage.
Clover, Alsike	*Trifolium hybridum*	X			X	X	X	X	P	5.0-7.5	X		X	Good for seeps and other wet areas. Dies after 2 years.
Clover, red	*Trifolium pratense*	X			X	X			P	6.0-7.0	X		X	Should be seeded in early spring.
Clover, white	*Trifolium repens*	X			X	X	X		P	6.0-7.0	X		X	Stand thickness decreases after several years.
Flatpea	*Lathyrus sylvestris*	X		X	X	X	X		P	5.0-6.0	X			Seed is toxic to grazing animals. Good cover.
Lespedeza, common	*Lespedeza striata*		X		X	X			A	5.0-6.0	X			Low growing, wildlifelike seed. Kobe variety most often used. Acid tolerant.
Lespedeza, Korean	*Lespedeza stipulacea*		X	X	X	X	X		A	5.0-7.0	X			Less tolerant of acid soils than common lespedeza.
Lespedeza, sericea	*Lespedeza cuneata*		X	X	X	X	X		P	5.0-7.0	X	X		Woody, drought tolerant, seed should be scarified. Bunchlike growth.
Milkvetch, cicer	*Astragalus cicer*			X	X	X	X		P	5.0-6.0	X		X	Drought tolerant. Low growing. No major diseases. Hard seed coat.
Sweetclover, white	*Melilotus alba*	X		X	X	X			B	6.0-8.0	X		X	Requires high-pH spoil. Tall growing. Produces higher yields. Less reliable seed production.
Sweetclover, yellow	*Melilotus officinalis*	X		X	X	X			B	6.0-8.0	X		X	Requires high-pH spoil. Tall growing. Can be established better than white sweetclover in dry conditions.
Trefoil, birdsfoot	*Lotus corniculatus*	X		X	X	X	X		P	5.0-7.5	X		X	Survives at low pH. Inoculate with special bacteria. Plant with a grass.
Vetch, crown	*Coronilla varia*	X		X	X	X			P	5.5-7.5	X		X	Excellent for erosion control. Drought tolerant. Winter hardy.
Vetch, hairy	*Vicia villosa*	X		X	X	X			A	5.0-7.5	X		X	Adapted to light sandy soils as well as heavier ones. Used most often as a winter cover crop.

[a]Legumes should be inoculated. Use four times normal rate when hydroseeding.

[b]A = annual; B = biennial; P = perennial.

[c]Many species survive and grow at lower pH; however, optimum growth occurs within these ranges.

[d]Hay, pasture, green manure.

Note.–Prepared in cooperation with Soil Conservation Service plant material specialists and State conservationists.

Table C3

Commonly Used Trees and Shrubs (from EPA[39])

Common name	Scientific name	Remarks
Shrubs:		
Amur honeysuckle	*Lonicera maacki podocarpa*	Good for wildlife. Shows more vigor and adaptability as plants mature.
Bristly locust	*Robinia fertilis*	Extreme vigor. Thicket former. Good erosion control. Rizomatous, 5-7 ft tall. Excellent on flat areas and outslopes.
Autumn-olive	*Elaeagnus umbellata*	Nitrogen-fixing nonlegume. Good for wildlife. Excellent fruit crops. Wide adaptation. Up to 15 ft tall.
Bicolor lespedeza	*Lespedeza bicolor*	Can be established from planting and direct seeding. Ineffective as a ground cover for erosion control.
Indigo bush	*Amorpha fruticosa*	Has high survival on acid spoil. Leguminous. Not palatable to livestock. Thicket former. Slow spreader. 8-12 ft tall.
Japanese fleeceflower	*Polygonum cuspidatum*	Grows well on many sites, especially moist areas. Excellent leaf litter and canopy protection. pH range of 3.5 to 7.0.
Silky dogwood	*Cornus amomum*	Grows best on neutral spoil pH. Can withstand pH range of 4.5 to 7.0. Some value as wildlife food and cover plants. Poor surface protection.
Tatarian honeysuckle	*Lonicera tatarica siberica*	Upright shrub, forms clumps. Does well on well-drained soils. Up to 12 ft tall. Takes 2 years for good cover.
Trees, conifers:		
Virginia pine	*Pinus virginiana*	Tolerant of acid spoil. Use for esthetics and where other species will not survive. Slow development. Good for wildlife.
Pitch pine	*Pinus rigida*	Deep rooted and very acid tolerant. Can survive fire injury. Deer like small seedlings. Plant in bands or blocks.
Loblolly pine	*Pinus taeda*	Very promising species, rapid early growth. Marketable timber products. Can survive pH 4.0 to 7.5. Susceptible to ice and snow damage.
Scotch pine	*Pinus sylvestris*	Good for Christmas trees if managed properly. Can be planted on all slopes and tolerates pH of 4.0 to 7.5.
Shortleaf pine	*Pinus echinata*	Some insect problems. Will sprout freely if cut or fire killed when young. Good marketable timber.
White pine	*Pinus strobus*	May be used for Christmas trees. Has poor initial growth but improves with time. Plant in bands or blocks.
Austrian pine	*Pinus nigra*	Can be planted on all slopes. Plant in bands or blocks. When planted near black locust, deer cause browse damage.
Japanese larch	*Larix leptolepis*	Should be planted on unleveled and noncompacted spoil. Provides good litter.
Red pine	*Pinus resinosa*	Sawfly damage in some areas. Plant on all slopes. Light ground cover.
Rocky Mountain juniper	*Juniperus scopulorum*	Has shown good survival on Kansas spoil materials. Compact growth varieties have from silver to purple colors.
Eastern red cedar	*Juniperus virginiana*	Tall, narrow growth. Best on dry, sandy soils. Good with black locust. pH 5.0 to 8.0.
Mugho pine	*Pinus mugo mughus*	Survives on acid spoil. Develops slowly. Low growing. Good cover for wildlife.
Trees, hardwoods:		
Black locust	*Robinia pseudoacacia*	Can be direct seeded. Wide range of adaptation. Rapid growth; good leaf litter. Use mixed plantings. Dominant stem clones preferred.
Bur oak	*Quercus macrocarpa*	Better survival with seedling transplants than acorns. Light to heavy ground cover.
Cottonwood	*Populus deltoides*	A desirable species for large-scale planting. Good cover and rapid growth. Pure stands should be planted.
European black alder	*Alnus glutinosa*	Rapid growing. Wide adaptation. Nitrogen fixing, nonlegume. Can survive pH 3.5 to 7.5. Adapted to all slopes.
Green ash	*Fraxinus pennsylvanica*	Very promising species. Use on all slopes and graded banks with compact loams and clays. Plant in hardwood mixture.
Hybrid poplar	*Populus spp.*	Rapid growth. Good survival at low pH. Marketable timber after 20 years. Cannot withstand grass competition. Good for screening.
Red oak	*Quercus rubra*	Makes slow initial growth. Good survival, plant on upper and lower slopes only. Can grow from pH 4.0 to 7.5.
European white birch	*Betula pendulata*	Makes rapid growth on mine spoil. Poor leaf litter and surface coverage.
Sycamore	*Platanus occidentalis*	One of the most desirable species for planting. Poor ground cover. Volunteer trees grow faster than planted ones.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Spaine, Patricia A

Guidance for land improvement using dredged material / [by Patricia A. Spaine, José L. Llopis, and Eugene R. Perrier]. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1979.

85, [34] p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; DS-78-21)

Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C.

References: p. 82-85.

1. Dredged material. 2. Dredged material disposal. 3. Land development. 4. Land management. 5. Land use. I. Llopis, José L., joint author. II. Perrier, Eugene R., joint author. III. United States. Army. Corps of Engineers. IV. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; DS-78-21.

TA7.W34 no.DS-78-21