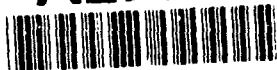


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DREDGING RESEARCH PROGRAM

CONTRACT REPORT DRP-93-3

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US Army Corps
of Engineers

GEOTECHNICAL FACTORS IN THE DREDGEABILITY OF SEDIMENTS

Report 3

GUIDANCE IN THE GEOTECHNICAL EVALUATION OF THE DREDGEABILITY OF SEDIMENTS USING GEODREDG

by

S. Joseph Spigolon

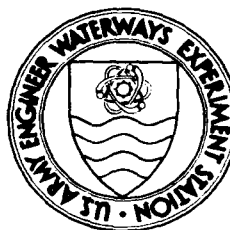
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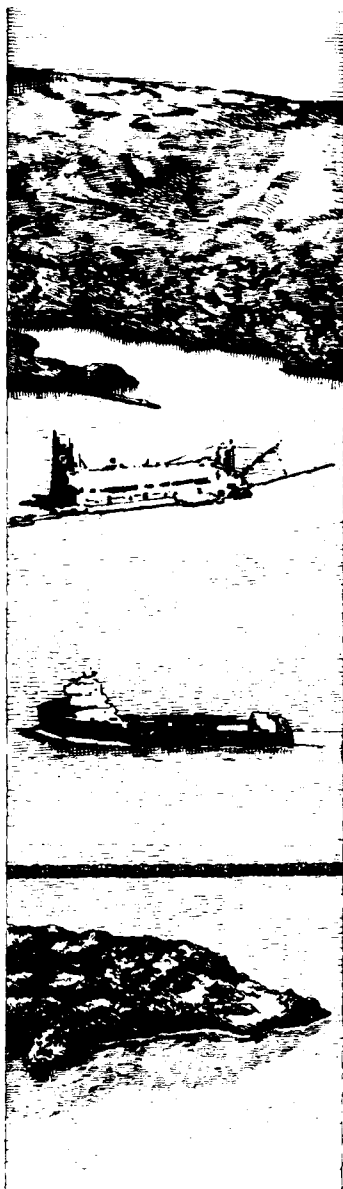
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Under Work Unit 32471

Monitored by Geotechnical Laboratory
US Army Engineer Waterways Experiment Station
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199



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The Dredging Research Program (DRP) is a seven-year program of the U.S. Army Corps of Engineers. DRP research is managed in these five technical areas:

- Area 1 - Analysis of Dredged Material Placed in Open Water**
- Area 2 - Material Properties Related to Navigation and Dredging**
- Area 3 - Dredge Plant Equipment and Systems Processes**
- Area 4 - Vessel Positioning, Survey Controls, and Dredge Monitoring Systems**
- Area 5 - Management of Dredging Projects**

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US Army Corps
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Dredging Research Program Report Summary



Geotechnical Factors in the Dredgeability of Sediments; Report 3, Guidance in the Geotechnical Evaluation of the Dredgeability of Sediments Using GEODREDG (CR DRP-93-3)

ISSUE: Geotechnical engineers, dredging estimators, and dredging contractors often do not understand each other's needs, site investigation methods, and vocabulary. Inevitable turnover in personnel means the loss of the knowledge of experienced and talented persons. These factors often lead to misinterpretation of the nature and extent of the sediments to be dredged.

Knowledge-Based Expert Systems (KBES) are computer programs that use a knowledge base of expert-derived rules for providing guidance. Rules in the knowledge base are in the form of "IF - THEN" statements that can incorporate judgement, experience, empirical rules of thumb, intuition, and other expertise as well as proven functional relationships and experimental evidence. The database of rules of a KBES is independent of the inference engine (program control); therefore, the ability to add new or expanded knowledge to the knowledge base is a major feature of a KBES.

RESEARCH: The KBES described in this report is an outgrowth of a Dredging Research Program (DRP) work unit that involves the development of geotechnical descriptors to indicate, or infer, dredgeability of sediments to be dredged. The initial knowledge bases were

based on literature surveys, personal experiences, and comments made during several workshops.

SUMMARY: GEODREDG contains prototypes of two subsystems: GEOSITE and DREDGABL. The GEOTECHNICAL SITE Investigation Methods (GEOSITE) program is for the use of engineers and geologists in the planning of a subsurface investigation for a dredging project. It provides guidance in the selection of field and laboratory tests appropriate for the estimation of site dredgeability. The Geotechnical Factors in DREDGeABILITY (DREDGABL) program provides guidance in the interpretation of geotechnical descriptors of sediments in terms of their dredgeability properties. It is intended to be used by estimators and contractors, serving as a personal geotechnical engineering consultant.

AVAILABILITY OF REPORT: The report is available through the Interlibrary Loan Service from the U.S. Army Engineer Waterways Experiment Station (WES) Library, telephone number (601) 634-2355. National Technical Information Service (NTIS) report numbers may be requested from WES Librarians.

To purchase a copy of the report, call NTIS at (703) 487-4780.

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Geotechnical Factors in the Dredgeability of Sediments

Report 3

Guidance in the Geotechnical Evaluation of the Dredgeability of Sediments Using GEODREDG

by **S. Joseph Spigolon**

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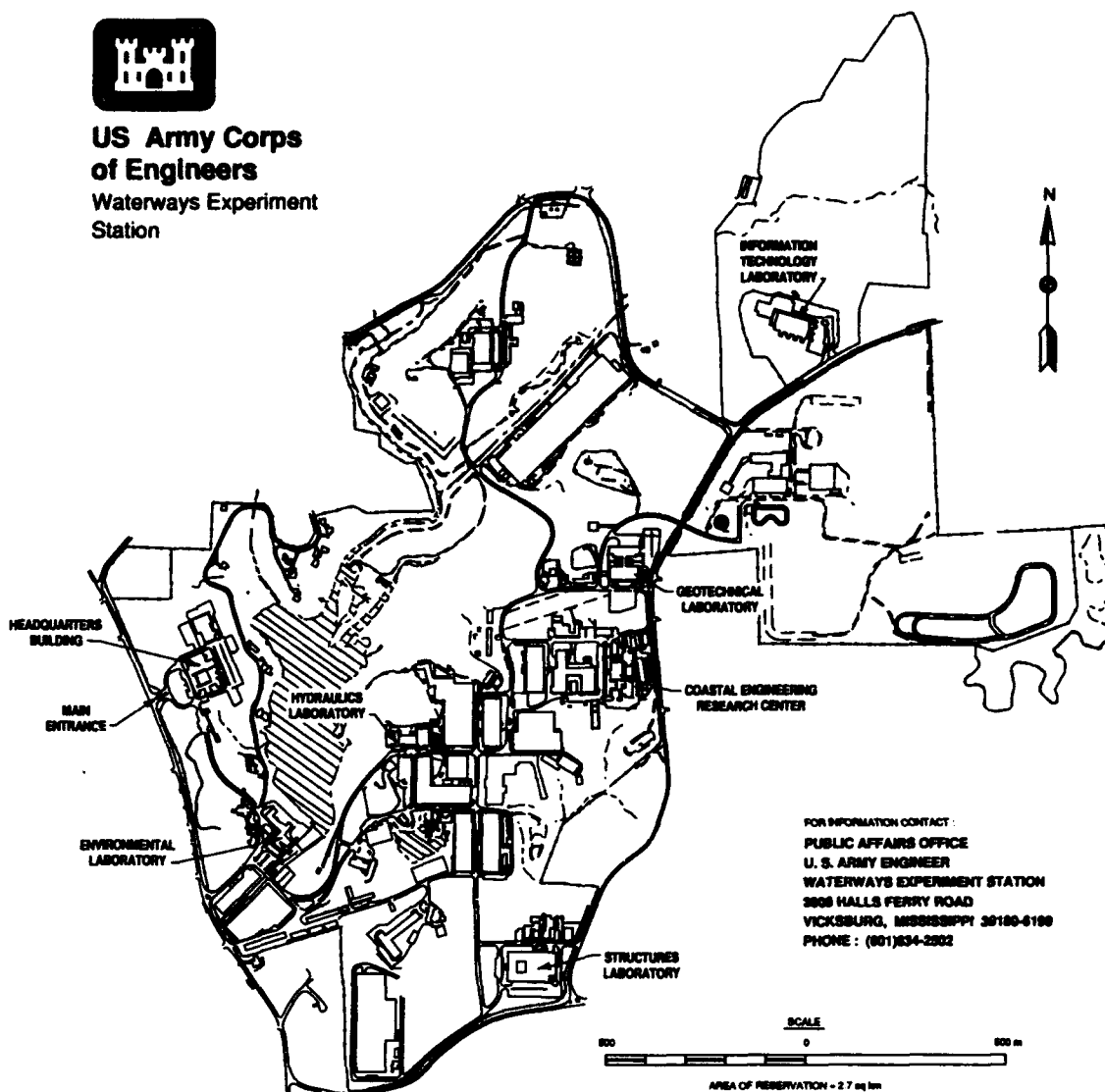
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Preface

This report was prepared under Contract No. DACW39-91-C-0040, dated 31 May 1991, for the U.S. Army Engineer Waterways Experiment Station (WES) under Dredging Research Program (DRP) Technical Area 2, Work Unit No. 32471, "Descriptors for Bottom Sediments to be Dredged." The DRP is sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE). Technical Monitor for Technical Area 2 was Mr. Barry W. Holliday; Chief Technical Monitor was Mr. Robert H. Campbell.

This report was written by Dr. S. Joseph Spigolon, Engineering Consultant, Coos Bay, OR, and Dr. Reda M. Bakeer, Associate Professor, Department of Civil and Environmental Engineering, Tulane University, New Orleans, LA, under the supervision of Dr. Jack Fowler, Principal Investigator, Soil Mechanics Branch (SMB), Soil and Rock Mechanics Division (S&RMD), Geotechnical Laboratory (GL), WES, Mr. W. Milton Myers, Chief, SMB, GL; Dr. Don C. Banks, Chief, S&RMD, GL; and Dr. W. F. Marcuson III, Chief, GL. Dr. Banks was also the Manager for Technical Area 2, "Material Properties Related to Navigation and Dredging," of the DRP. Mr. E. Clark McNair, Jr., and Dr. Lyndell Z. Hales were Manager and Assistant Manager, respectively, of the DRP, Coastal Engineering Research Center (CERC), WES. Dr. James R. Houston and Mr. Charles C. Calhoun, Jr., were Director and Assistant Director, respectively, of CERC, which oversees the DRP.

During the publication of this report, Dr. Robert W. Whalin was Director of WES. COL Bruce K. Howard, EN, was Commander.

For further information concerning this report, contact Dr. Jack Fowler, (601) 634-2703, or Mr. E. Clark McNair, Jr., (601) 634-2070.

Summary

Geotechnical engineers investigate and describe dredging sites using their own methods and terminology. Government estimators and dredging contractors use that information in preparing plans and estimates. The two groups often do not understand each other's needs, methodology, and vocabulary. Inevitable turnover in personnel means the loss of the knowledge of experienced and talented persons. These factors often lead to misinterpretation of the nature and extent of the sediments to be dredged, resulting in higher bid prices because of unknown or unclear risk and in unnecessary claims for changed conditions. Therefore, there is a need for retaining expert knowledge for the guidance and training of inexperienced personnel and for peer consultation among the experienced persons.

The work described in this report is part of the Dredging Research Program (DRP) at the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS. Work unit No. 32471, a part of Technical Area 2, "Material Properties Related to Navigation and Dredging," involves the development of geotechnical descriptors to indicate, or infer, dredgeability of sediments to be dredged.

Knowledge-Based Expert Systems (KBES) are computer programs for problems that require expertise for the solution of problems in a field. Conventional programs generally use a fixed algorithm to solve numerical problems; therefore, they are easily modified during use. A KBES uses a knowledge base of expertly derived rules for its solutions. The knowledge base contains a database of expert facts and opinions. The rule statements are in the form of "IF - THEN" statements that answer the types of questions a typical user will ask. The rules can incorporate judgement, experience, empirical rules of thumb, intuition, and other expertise as well as proven functional relationships and experimental evidence. The database of rules of a KBES is independent of the inference engine (program control); therefore, the ability to add new or expanded knowledge to the knowledge base is a major feature of a KBES.

The proposed WES DRP dredging expert system is called GEODREDG (GEOtechnical Factors in DREDGing). It uses a commercial relational database management system, Microsoft FoxPro, which can operate within both the DOS and the Microsoft Windows environments on PC-DOS or MS-DOS personal computers. The only input needed is numbers and

mouse-pointer selection from menus. This should greatly facilitate the use of the system by non-typists. At present, GEODREDG has been developed as a prototype system and is based on previous work done in the DRP work unit. GEODREDG contains prototypes of two subsystems: GEOSITE and DREDGABL. Each subsystem is menu-driven, and provides guidance for decision making in each topic area. Extensive "explanation" screens, containing text and figures, are readily available during any session for explaining the rationale for any recommendation.

The GEOTEchnical SITE investigation Methods (GEOSITE) program is for the use of engineers and geologists in the planning of a subsurface investigation for a dredging project. It provides guidance in the selection of field and laboratory tests appropriate for the estimation of site dredgeability. Guidance is provided in the areas of:

- a. Selection of a suitable sampling method.
- b. Testing for in situ strength.
- c. Testing for in situ density.
- d. Boring (or test pit) methods and work platforms.
- e. Appropriate materials properties identification tests.

The Geotechnical Factors in DREDGeABiLity (DREDGABL) program provides guidance in the interpretation of geotechnical Unified Soil Classification System (USCS) descriptors of sediments in terms of their dredgeability properties. It is intended to be used by estimators and contractors, serving as a personal geotechnical engineering consultant. All guidance, at present, is given in relative terms, in the same manner that a human consultant would.

A third program, not part of the present study, is described. The GEOTEchnical Soil CLASSification (GEOCLASS) program guides the user in the appropriate procedures for identifying, describing, and classifying soils in the field and the laboratory. The program provides for storage of the data in a standardized database, using a limited menu of standardized terms, for future interpretation and graphical presentation.

1 Introduction

Geotechnical engineers typically plan and conduct the subsurface investigation of a proposed dredging site. They describe the physical properties of the sediments that appear to be present within the dredging prism and provide the geotechnical information to all interested parties. Dredging operations personnel, whether the government's or owner's estimator or planner or the contractor's staff, use the furnished geotechnical information in their estimating and planning.

The geotechnical engineers, when planning and executing their site investigation, may not be fully aware of the type of information the dredgers need about the sediments to be dredged. Turnovers in personnel or changes in assignments mean that geotechnical engineers with little experience in dredging can become involved in the subsurface investigation and the testing of sediments for dredging projects. The dredging-related knowledge of the more experienced geotechnical engineers is often not adequately transferred and is usually lost on retirement or position change.

The dredgers often do not fully understand the geotechnical information in the manner that it has been presented, and its limitations, and the expertise of those that do understand is also lost through turnover or retirement. Geotechnical engineering descriptions do not indicate "dredgeability" properties directly — any more than they indicate foundation or earthwork behavior properties directly. All require analysis and interpretation. This leads to possible misinterpretation of sediment-related risks, with resulting higher bid costs, and is often a cause of costly claims.

There is, then, a continuing need for the guidance and training of those persons lacking knowledge and experience in the dredgeability analysis of geotechnical data. For this reason, it is desirable to retain the expertise of capable persons involved in dredging-related fields and to make their expertise available for use by less experienced workers. Also, knowledgeable and experienced personnel can derive considerable benefit from consultation with their peers for review and as a cross-check on their own work. One highly useful manner for retaining this knowledge and making it available to prospective users is by means of a computerized knowledge-based expert system.

Background

The expert system computer programs described herein were developed in response to the needs of a work unit of the U.S. Army Corps of Engineers Dredging Research Program (DRP). The DRP is being conducted by the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS. The objective of Work Unit 32471 is the development of standard dredging-related geotechnical descriptors to indicate, or infer, the dredgeability of sediments. Previous reports in the work unit, and publications resulting from this work, consisted of literature reviews to:

- a. Establish the needed type and form of geotechnical descriptors to indicate, or infer, the dredgeability of sediments (Spigolon and Fowler 1988, 1989; Spigolon 1993a).
- b. Define a geotechnical site investigation strategy for dredging projects that would provide the necessary geotechnical descriptors (Spigolon and Fowler 1990; Spigolon 1993b).

Objective of the Report

Knowledge-Based Expert Systems (KBES) are computer programs capable of providing the necessary vehicle for: (a) recording the accumulated knowledge and experiences of experts in a field in a knowledge base, and (b) providing for a readily available interaction between the user and the knowledge base. The objective of the prototype Knowledge-Based Expert System (KBES) presented in this report is to provide access to the recorded expertise and guidance from experts in their respective fields for the use of:

- a. Geotechnical engineers in the planning and execution of a subsurface investigation for a dredging project.
- b. Dredging estimators and planners for interpreting geotechnical site investigation data in terms of dredgeability.

A prototype KBES system, called: "GEOtechnical Factors in DREDGing (GEODREDG)", is shown in Figure 1. GEODREDG is intended to address the needs of the dredging industry for guidance in describing the physical properties of sediments and assessing their dredgeability. Two of the programs, GEOSITE and DREDGABL, are described in this report. The third, GEOCLASS, is being developed separately but is an integral part of the GEODREDG system.

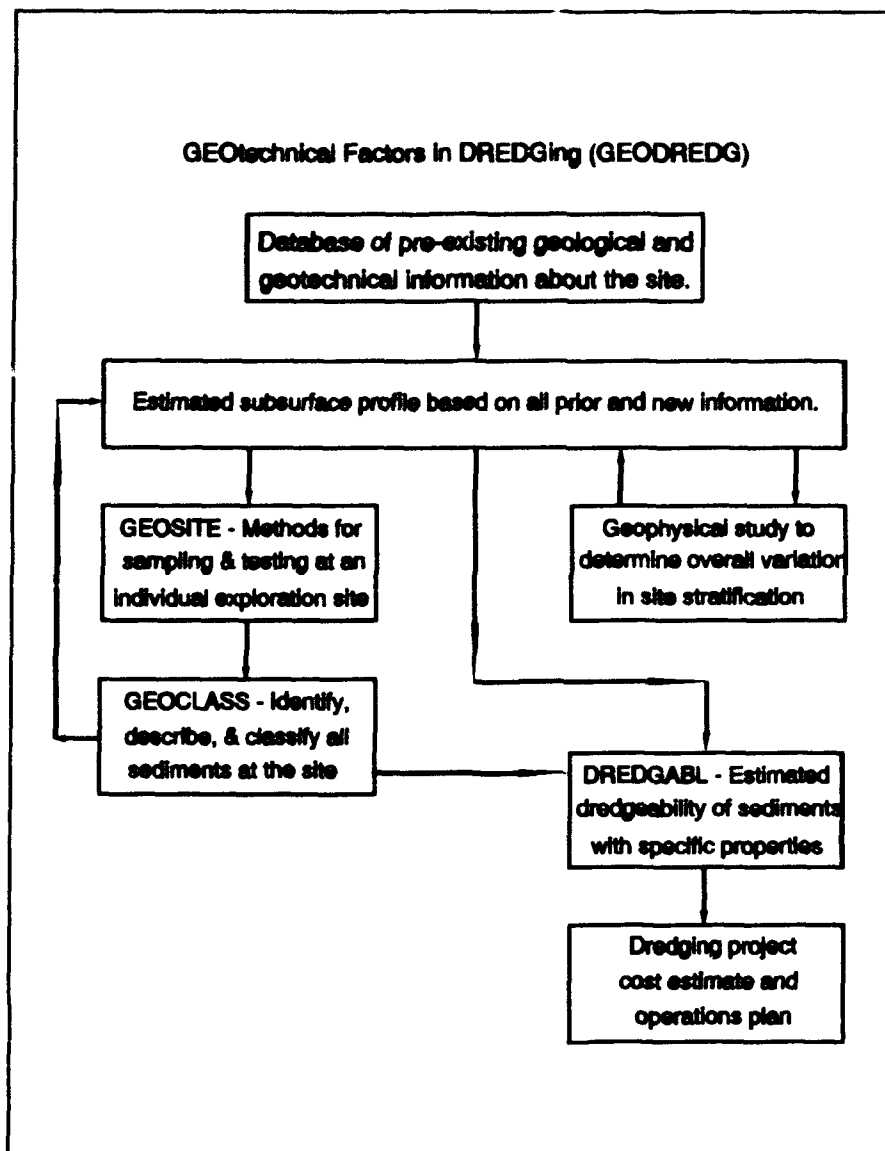


Figure 1. The GEODREDG expert system modules

The total system shown in Figure 1 works as follows:

- a. It is assumed that some prior information, geological and perhaps geotechnical, exists about a proposed dredging site. This may be augmented, as appropriate, with geophysical exploration data. The pre-existing information is used to develop a preliminary estimate of the subsurface geotechnical profile (Spigolon 1993b).
- b. Based on all the pre-existing geotechnical information about the site, a site exploration strategy is developed, including the number and locations of the exploration sites.

- c. The GEOSITE program is used to select suitable sampling and testing methods, a suitable sample/test access method, and a work platform for each site.
- d. At each exploration site, the GEOCLASS program is used to identify, describe, and classify the samples retrieved. GEOCLASS is also used during sample review and boring log preparation.
- e. After completion of the site exploration program, a complete set of boring logs is prepared, containing suitable sample descriptions and classifications.
- f. During the planning of a dredging project, the DREDGABL program is used to provide guidance in the dredgeability properties of each of the sediment types encountered during the site investigation.

Scope of the Report

This report presents and discusses the two prototype and interrelated KBES programs that have been developed as part of the overall GEODREDG system:

- a. **GEOTECHNICAL SITE Investigation Methods (GEOSITE)** — guidance for geotechnical engineers and engineering geologists in the selection of methods and equipment for the sampling and strength testing, field and laboratory, of sediments to obtain the information necessary for evaluation of the dredgeability of the sediments.
- b. **Geotechnical Factors in DREDGeABiLity (DREDGAEL)** — guidance in the interpretation of geotechnical properties data for estimating the dredgeability of sediments. Intended to serve the planner or estimator as a personal geotechnical engineering and dredging expert consultant.

A third program in the GEODREDG system, **GEOTECHNICAL SOIL CLASSIFICATION (GEOCLASS)**, is being developed separately and is not discussed in detail in this report. Its objective is to provide guidance in the field and laboratory identification, description, and classification of soil sediments in a consistent manner using a consistent language. The program also provides for analyzing and recording the data in a standardized project database that can be accessed directly by boring log and other graphic data presentation programs.

It is expected that the prototype modules of GEODREDG will be field evaluated and, if necessary, modified in future versions. Because of the knowledge-based expert system concept, there really is no terminal point for the programs. The knowledge base(s) and the explanation system for

each module can, and probably will, increase with time as more and more experts add their knowledge to the system.

Knowledge Acquisition

There are two primary tasks in the building of a KBES. The first is accomplished by persons with expertise in computerized knowledge-based expert systems, who are called *knowledge engineering experts*. The second is accomplished by *domain experts*, the contributors to the knowledge base. In this case, it refers to geotechnical engineers knowledgeable and experienced in dredging operations, simply referred to as the *geotechnical engineering experts*. In the ideal knowledge base, there are multiple experts who either reinforce each other or present valid alternate solutions to problems.

The present prototype programs, GEOSITE and DREDGABL, were developed with the combined expertise of the authors. Dr. Reda Bakeer, Associate Professor, Department of Civil and Environmental Engineering, Tulane University, New Orleans, LA, was the *knowledge engineer*. Dr. S. Joseph Spigolon, Engineering Consultant, SJS Corporation, Coos Bay, OR, served as the initial *geotechnical engineering expert*. Dr. Bakeer is also a geotechnical engineer and was able to bring that knowledge to the system as a check on all of the rules. The rules developed for the GEOSITE and DREDGABL modules represent expertise that was developed through the authors' personal experiences and extensive literature reviews and, therefore, reflect their personal biases. It is most desirable that the present rules be critically reviewed by other domain experts including geotechnical, coastal, and dredging engineers as well as electronic and instrumentation experts. The KBES should then be expanded or modified, as needed.

Organization of the Remainder of the Report

Chapter 2 contains a discussion of knowledge-based expert systems. It discusses the choice of a commercial software package for the GEODREDG expert system. Chapter 3 summarizes the geotechnical properties needed to define, or infer, the dredgeability properties of sediments, and the relationships between the two sets of properties. Chapter 4 presents details of the GEOSITE and DREDGABL modules. Chapter 5 contains a summary of the report and presents suggestions for further work on this KBES. Minutes of a GEODREDG workshop held on November 21-22, 1991 in New Orleans, LA, are presented in Appendix A.

2 Knowledge-Based Expert Systems

A KBES is a computer program for the type of problem that requires expertise in a field or discipline for its solution. Conventional programs generally use algorithmic (repetitive) procedures in a pre-defined sequence for processing data that are primarily numerical. The information (knowledge) and the method of controlling it are integrated; this inhibits mid-run changes in procedure. A KBES uses expertly derived rules for its solutions; the rules can incorporate and process judgement, experience, empirical rules of thumb, intuition, and other expertise as well as proven functional relationships and experimental evidence. The knowledge base contains a database of facts and "IF - THEN" rule statements that include all of the "IF" questions a typical user is expected to ask and all of the "THEN" solutions. The control system (inference engine) is independent of the knowledge base. An independent explanation facility, consisting of a series of individually accessible texts on relevant topics, is used to explain the rationale for the rules. The separate knowledge base and explanation facility may be edited and modified without changing the other components of the program.

The choice of the name — Knowledge-Based Expert System — derives from a combination of two sources of knowledge (Mullarkey 1987). A true expert system records the expertise and judgement capacity of human experts, based on their remembered experiences, fuzzy reasoning, and ill-defined logic. This includes information and procedures that are valuable but are often intuitive and incapable of rigorous or experimental proof. A Knowledge-Based System uses so-called "textbook" knowledge, that which has been compiled and is capable of verification by mathematical rigor, by experimental evidence, or by common acceptance and use by the practitioners of a field.

Using a Knowledge-Based Expert System

The components of a typical KBES are:

- a. Knowledge base — contains the facts and expert-derived rules associated with the domain (subject matter) of the KBES.
- b. User interface — provides for input of problem information as IF statements and for the output of THEN solutions.
- c. Context — contains the information about the problem currently being solved, i.e., the parameters of the problem and information generated by the KBES during solution of the problem.
- d. Inference mechanism — uses the context of the problem to search the knowledge base for a solution, or solutions, to the problem.
- e. Explanation facility — provides the user with information about the reasoning process and how a solution was reached.
- f. Knowledge acquisition facility — an editor providing for creation and modification of the knowledge base.

During a consultation, the KBES searches the knowledge base through a chain of "IF - THEN" rule statements. The "IF" questions are posed in a series of screens in the user interface. The path through the matrix of rules is not pre-determined; rather, the path depends on the specific IF questions and on the generated THEN replies which lead to the next IF statement. The net effect is one of having an expert in a field answering the IF questions with a THEN reply, each presumably leading the user to the next IF question until the solution is reached. The logic of the IF statements may be modified by using such modifiers as AND, OR, or NOT, and the arguments may be either English words or phrases or numbers. The solution(s) are then displayed by the user interface.

Choice of an Expert System Shell for GEODREDG

A general purpose programming language can be, and has been, used to build a problem-solving system. Examples of such languages are PROLOG, C, LISP, and FORTRAN. The development of a KBES is greatly facilitated by the use of an expert system shell (development framework). Several of the most commonly used commercial expert system shells were evaluated for use in GEODREDG. The criteria used for the final selection of the GEODREDG system were:

- a. Hardware compatibility — with the PC-DOS type of personal computer machines.
- b. Implementation language — natural English words.
- c. Convenient environment — including user interface and explanation facilities.
- d. External interface — with databases (dBase III PLUS and compatibles) and with spreadsheets (Lotus 1-2-3 and compatibles).
- e. Reasonable initial cost and low cost for unlimited run-time versions; stability of vendor and continued availability of user help support.

Both GEOSITE and DREDGABL use a forward-chaining, or data-driven, problem-solving strategy. The knowledge representation is rule-based, each rule consisting of a number of IF <antecedents> . . . THEN <conclusion> statements. One rule exists for each of the total, finite number of options in the antecedents.

In the present version of DREDGABL, there are 1,035 unique sets of options. Ideally, each unique set of antecedent options leads to a single conclusion. DREDGABL reaches 27 different conclusions for each unique set of antecedents, for a total of 27,945 possible conclusions. Inferencing can, therefore, be done as a standard database search, using the antecedents (IF statements) as search filters to find the conclusion records (THEN statements) that satisfy all of the unique query requirements. By using 27 conclusion fields for each record, the total number of records to be searched is reduced to the 1,035 possible sets of antecedents, greatly increasing the search speed of the system.

The system chosen for use in the GEODREDG system was the Microsoft FoxPro Relational Database Management System, although any other database management system would probably do as well. All of the necessary facilities for implementing a KBES are available in Microsoft FoxPro, including user interface screens, control programs (inference engine), context storage as memory variables, a spreadsheet-derived database of rules, and an explanation (help) text access system. Once the antecedents (IF statements) are established, the search of the knowledge base (database) is very rapid. The knowledge bases were developed in spreadsheet format and converted to dBase III Plus format, which is supported by FoxPro. Therefore, the control programs, the explanation texts, and the knowledge base may be operated by other, compatible database programs.

There are two other important advantages of Microsoft FoxPro. One is the capability of using the same program in either a DOS or a Windows environment; only the screen format changes because Windows uses a graphical display. The other advantage is the availability of a run-only

distribution version. The distribution version can be used for an unlimited number of applications at a single, modest fee beyond the cost of the original developer's version.

Both versions of GEOSITE and of DREDGABL (DOS and Windows) support either keyboard tab-arrow key selections or mouse input. This practically eliminates the need for the user to type words for data input or for consultations. This should greatly facilitate the use of the system by non-typists. When running under the Windows environment, the GEODREDG programs provide for graphical displays in the explanation facility, which will permit line drawings, sketches, and even photographs to be used to enhance the texts.

3 Dredgeability of Sediments

The relationship between the engineering properties of sediments, as determined by geotechnical engineers, and the dredgeability of the sediments in terms useful to dredgers has been presented in a previous report (Spigolon 1993a). A summary is presented here for completeness of this report. Dredgeability is defined as the facility with which an underwater soil sediment or rock can be excavated, removed, transported, and deposited with respect to known or assumed equipment, methods, and in situ material characteristics. There are several independent variables that affect dredgeability (Bray 1979):

- a. Equipment type and rated capacity.
- b. Physical properties of the soil or rock.
- c. Geometry of the site.
- d. Cycle factors.
- e. Management and crew efficiency.
- f. Equipment breakdowns.
- g. External delay factors.

The computer programs discussed in this report are concerned only with the effect of the physical properties of the soil or rock, as represented by their geotechnical properties, on the dredgeability of the sediments. It must be recognized that the total evaluation of dredgeability, in terms of production rate or of fuel consumption, must include the other, non-geotechnical factors.

The process of dredging an underwater sediment typically occurs in four stages:

- a. *Stage 1: Dislodgement* — loosening or excavation of material from its location at or below the bottom.

- b. Stage 2: Removal** — movement of the excavated material from the bottom up to the pump or transport system.
- c. Stage 3: Transport** — movement of the material from the excavation/removal site to the disposal site.
- d. Stage 4: Disposal** — discharge and possible placement of the material on a land or into a water disposal area.

Dredging equipment uses one, or a combination, of hydraulic, pneumatic, or mechanical systems. The mechanisms useful for accomplishing the four stages of dredging are dependent on the characteristics of the sediment to be dredged. The dredging mechanisms in common use are listed in Table 1. The mechanisms used by common types of dredging equipment are listed in Table 2. The generic types of dredging equipment are those listed in the dredging fleet issue of *World Dredging, Mining and Construction* (WDMC 1993).

Although the configuration of the equipment and the stage of dredging can be communicated reliably between geotechnical engineers and dredgers, the expected dredgeability character of the sediment to be dredged is not directly evident, or directly inferred, from the engineering descriptions. Based on the mechanisms discussed in Tables 1 and 2, the dredgeability properties of soil and rock sediments are:

- a. Excavation Stage:** Significant properties are suctionability, erodability (scourability), cuttability, friability, rock hardness, scoopability, and underwater slope instability (flowability).
- b. Removal and Transport Stages:** Significant properties are pumpability (affected by rheologic properties of slurry), abrasiveness in a pipeline, stickiness (affects clay balling), sedimentation rate in a hopper, and bulking.
- c. Deposition Stage:** Significant properties are dumpability (friability and stickiness), sedimentation rate in a disposal area, amount of bulking, and compactability.

The geotechnical engineering characteristics of a sediment needed for the evaluation of its dredgeability properties are:

- a.** In situ consistency of cohesive soils, compactness of granular soils, or degree of cementation of cemented soils or rock.
- b.** Grain size distribution, including median size, maximum size, uniformity, and amount of fines.
- c.** For granular materials, the shape and hardness of the grains.
- d.** For cohesive soils, the plasticity of the -40 screen fraction.

Table 1
Dredging Mechanisms

Excavation Mechanisms	
Plain Suction	Suction is applied to a pipe inserted into extremely soft soil. External pressure causes the soil to enter the pipe as a soft mass at nearly 100% of in situ volume, i.e., with no excess water.
Hydraulic Erosion	The flow of a high velocity, high volume water stream across the surface of a clean granular material causes scour due to cavitation or impingement, which lifts and pushes the grains into the water stream. Due to the high volume of water required, the resulting slurry contains much less than 100% of in situ volume, i.e., low solids content.
Mechanical Dislodgement - Cutting	If soil/rock is not easily eroded, i.e., dense granular, friable (easily crumbled or pulverized), or cohesive, then cutting it with a rotating or fixed blade or ripping it with plows or knives moves the soil/rock particles into a suction water stream to form a low solids content slurry.
Mechanical Dislodgement - Scooping	In space-restricted areas or locations where hydraulic excavation is not feasible, scooping of the soil/rock may be done with a bucket, shovel, or clamshell.
Removal Mechanisms	
Hydraulic Pipeline	A suction pipeline is used to move the soft mass or the hydraulic slurry from the excavation area at the bottom to the pumping system.
Mechanical Containers	A bucket, scoop, shovel, clamshell, bucket ladder, bucketwheel, or other container is used to move the material from the bottom to the surface; often this is the same device used for excavation.
Transport Mechanisms	
Hydraulic Pipeline	The particles, clumps of material, or clay balls, are pumped in a pipeline as a hydraulic slurry.
Mechanical Containers	The material is moved in the hold of a hopper ship, a barge (self-propelled or towed), or a land-based device such as a truck or conveyor belt.
Disposal Mechanisms	
Hydraulic Pipeline	The pipeline slurry is directly discharged into a land or water disposal area.
Mechanical Devices	Materials are discharged from mechanical containers by: bottom discharge from hopper ship or barge; direct dumping from the transport unit; mechanical removal using a scraper, bucket, clamshell, or high pressure water stream.

Table 2
Characteristics of Dredging Equipment

Dredge Type	Excavation Method	Removal Method	Transport Method	Disposal Method
Suction Dredges				
Trailing Suction Hopper	Plain suction Hydraulic erosion Mechanical dislodgement	Hydraulic suction	Sedimentation in vessel hopper; vessel moves to disposal site	Bottom dump or side discharge from hopper ship or barge
Suction Hopper	Plain suction Hydraulic erosion	Hydraulic suction	Soil settles in vessel hopper; vessel moves to disposal site	Bottom dump or side discharge from hopper ship or barge
Cutter Suction	Mechanical dislodgement (rotary cutter)	Hydraulic suction	Pipeline as a slurry	On land or in water site as a slurry
Suction	Plain suction	Hydraulic suction	Pipeline as a slurry	On land or in water site as a slurry
Suction Dustpan	Plain suction Erosion using water jets	Hydraulic suction	Pipeline as a slurry	On land or in water site as a slurry
Bucket Wheel Suction	Mechanical dislodgement (cutting by buckets)	Hydraulic suction	Pipeline as a slurry; settles in a hopper	On land or in water site as a slurry
Mechanical (Bucket-type) Dredges				
Bucket Ladder	Mechanical dislodgement (cutting by buckets)	Series of buckets	Barge	Bottom dump or using scraper
Floating Grab/Clamshell	Mechanical dislodgement (cutting by clamshell)	Clamshell bucket	Barge or land-based belt or trucks	Bottom dump or using scraper
Bucket Dipper	Mechanical dislodgement (cutting by dipper bucket)	Dipper bucket	Barge or land-based belt or trucks	Bottom dump or using scraper
Grab Hopper	Mechanical dislodgement (cutting by clamshell)	Clamshell bucket	Soil settles in vessel hopper; vessel moves to disposal site	Bottom dump or side discharge from hopper ship or barge
Bucket Backhoe	Mechanical dislodgement (cutting by backhoe)	Backhoe bucket	Barge or land-based belt or trucks	Bottom dump or using scraper

e. Presence and amount of organic matter and shells.

The in situ strength characteristics of the sediment determine the dredgeability during the excavation (dislodgement) stage. Suctionability depends on the extreme softness of a cohesive soil. Erodability functions best in a clean sand or fine gravel. Cuttability is directly related to shear strength and friability, as is scoopability and slope instability.

The appropriate field or laboratory tests for establishment of the in situ strength depend on the grain material characteristics. The strength of cohesive soils and of organic soils is dependent primarily on in situ density, stress history, and plasticity, which reflect the clay content and clay mineralogy. The shear strength of granular soils depends primarily on relative compactness, grain size distribution, and grain shape. The strength of intact rock depends on mineralogy and on the degree of induration.

After dislodgement the in situ structure is thoroughly disturbed and only the grain material properties are of concern: grain size distribution, plasticity (reflecting clay amount and type), grain shape and hardness, and the amount of organics, shells, and debris. Not all material characteristics affect every stage of dredging in every type of equipment. Entry into the fluid stream as a slurry depends on friability which, in turn, is a function of plasticity. Clay balling in a pipeline is also a function of plasticity. Pumpability depends on the median size. Grain size distribution affects the settlement rate in a hopper and in the disposal area. Dumpability is a function of stickiness, which is a function of plasticity. Abrasiveness, bulking, and compactability are all related to the grain size distribution and plasticity. Organic content and shell content affect removal and transport.

4 The Prototype GEODREDG Modules

The KBES programs described in this report are prototypes, i.e., they are the models from which the final versions of the programs will be developed. The form and contents were evaluated in a workshop held at Tulane University, New Orleans, LA, on November 21-22, 1991. The workshop was sponsored by the DRP and the Geotechnical Laboratory, WES. The minutes of the workshop are presented in Appendix A.

The present form of the two modules of GEODREDG, consisting of GEOSITE and DREDGABL, was modified to conform to the recommendations made by the workshop attendees. After some further modifications and improvements, listed in Chapter 5 of this report, it is expected that the GEODREDG modules will be submitted to several groups within the Corps of Engineers for field testing prior to issuance as a usable product.

GEOTECHNICAL SITE Investigation Methods (GEOSITE)

GEOSITE is intended to be used by persons familiar with basic geotechnical site investigation and testing methods, such as a Corps of Engineers civil engineer or a geologist assigned to a geotechnical engineering group. GEOSITE may also be used by dredging contractors; in this case, it is expected they would use a private geotechnical firm who also would have someone familiar with basic site investigation and testing methods. The system is not intended to be a primary teaching tool, although it could serve as a reference or as a refresher for experienced persons or as an aid in training inexperienced personnel. It would take much more than this program has to offer to teach geotechnical engineering testing methods to anyone without the necessary background.

The first step in any geotechnical site investigation is the assembly and evaluation of all prior information about the proposed dredging site. This information is used to develop a tentative geotechnical subsurface profile.

Sources of prior information include a review of existing geological and geotechnical data from the vicinity of the project site and may include a geophysical survey of the site. The number and location of exploration sites are selected, based on a number of factors, including site variability (Spigolon 1993a). Therefore, at any exploration point where a pit or boring will be made, a general idea of the sediment profile already exists in the mind of the evaluator, even if it is erroneous. The sediment types expected to be present at any dredging project exploration point include one or more of those shown in Table 3.

Table 3 Characteristics of Basic Sediment Types	
Highly Organic Soils	Peat, humus, and swamp soils are typical. Typically have a spongy consistency, a high water content, and are dark brown to black color, although the color alone is not an indicator. Usually have an organic odor in a fresh sample or in wet sample that has been heated. Have a fibrous to amorphous texture and often contain vegetable matter (sticks, leaves, etc.).
Cohesive Soil	By definition in the United Soil Classification System (USCS), any soil with 50% or more by weight passing the No. 200 screen ($D_{50} < 74$ microns) is a "fine-grained soil." Cohesive fines (silt and clay) dominate engineering behavior. The presence of as little as 20 to 40% passing the No. 200 screen is sufficient for a granular soil to behave as a cohesive soil. Has sufficient density to have unconfined shear strength, i.e., will retain the shape of a container. Little or no grain-grain contact; shear strength derives from density, stress history, and amount and type of clay. The "cohesiveness" of the clay prevents the soil from densifying with vibration. Exhibits plasticity, cohesiveness, and dry strength.
Cohesionless Soil	By USCS definition, more than 50% by weight of a "coarse-grained" soil is retained on the No. 200 screen ($d_{50} > 74$ microns). Maximum size is 76 mm (3 in.). Grain-to-grain contact dominates the engineering behavior. Shear strength derives from relative density, grain angularity, and lack of fines. Clean granular soils (few or no plastic fines) will densify with vibration and will not stand unconfined if dry. Exhibits moderate to high friability.
Cobbles & Boulders	Individual grains between 76 mm (3 in.) and 305 mm (12 in.) are cobbles and those over 305 mm in diameter are boulders. May be rounded from movement in a stream or may be angular rock fragments, either natural or as the result of ripping or blasting of solid rock. Usually dense and shear strength derives almost entirely from grain-to-grain contact.
Cemented Soil and Shale	Rock-like soils cemented with iron oxide, lime, silica, or magnesia or highly compressed clays (shale); have compressive strength below that of massive, hard rock; when cut or ripped, usually fragment into small particles.
Rock or Coral	Rock is massive, solid (non-granular), inorganic mineral matter with an unconfined compressive strength exceeding 10,000 lb/sq in. Coral consists of living calcareous organisms usually formed into a massive offshore reef. Hard rock and coral require blasting to break the mass into particles that can be removed by normal dredging equipment. Softer rock and coral capable of being easily cut or ripped into small fragments.

The consultation process of GEOSITE starts with the assumption that the stratification is moderately well known. It is reasonable to require this assumption; this demands that every effort be made to assemble and evaluate the pre-existing information and to use geophysical surveys wherever they are feasible. The choice of specific primary sediment types from the expected profile causes GEOSITE to limit its consultation process only to those topics that apply to the chosen sediment types and to exclude all others. If the profile expectation is found to be wrong in the field, then a return to the program for reevaluation with the updated information will be necessary. Three separate objectives are permitted:

- a. Complete site investigation, including sampling, strength testing, and laboratory materials tests.
- b. Limited site investigation (measuring in situ density only).
- c. Limited site investigation (locating a rock surface only).

In the first step, GEOSITE presents all sediment sampling methods that are appropriate to the specific sediment type. They are recommended without ranking and the superiority of one method over another, if it exists, is discussed in the "explanation/help" texts. Second, the user chooses one of the sampling methods, and GEOSITE displays all of the strength testing methods, field or laboratory, that are appropriate for that sediment type and sampler. Third, for the chosen combination of sediment type, sampler, and strength test device, GEOSITE advises on the suitability of various methods for accessing the sampling/testing depth. The suitability and need for a fixed or a floating platform is then presented. At any time, the user may back up and select another route of sediment type, sampler, and testing device.

The rule formats used for the successively implemented rules in the prototype version of GEOSITE are:

- a. Guidance on suitable sampler types:

IF the sediment type is:

THEN the suitable sampler types are:

- b. Guidance on suitable strength testing devices:

IF the sediment type is:

AND the sampler type is:

THEN the suitable strength testing devices are:

c. Guidance on methods for accessing sampling and/or testing depth:

IF the sediment type is:
AND the sampler type is:
AND the strength testing devices are:
THEN the suitability of various methods of accessing the
sampling/testing depth is:

d. Guidance on the suitability of work platforms:

IF the sampler type is:
AND the strength testing device is:
AND the method of accessing sampling/testing depth is:
THEN the suitability of various work platforms is:

e. Guidance on suitable material properties tests:

IF the sediment type is:
THEN the suitability of various materials properties tests, field
and/or laboratory, is:

Geotechnical Factors in DREDGeABlity (DREDGABL)

DREDGABL is planned to serve as an interpreter of sample test and observation data for estimators and planners, whether Corps of Engineers or contractor, in terms of dredgeability. It can also demonstrate to the geotechnical engineers and geologists involved in a dredging project site investigation what the important sediment properties are for dredgeability evaluation. Only the direct effect of soil type and character on dredgeability is considered, separate from all other factors that affect dredging productivity discussed in Chapter 3 above, such as equipment characteristics, water depth, weather, tides, traffic, personnel problems, equipment maintenance, and so forth.

It is assumed by DREDGABL that the geotechnical description of the sediment to be dredged is given in project documents in the Unified Soil Classification System (USCS) format (USAEWES 1960, ASTM 1992). The USCS description may be supplemented with other needed information

such as compactness or consistency data. DREDGABL prompts the user for the geotechnical data needed for evaluation of dredgeability.

After entry of the appropriate geotechnical data, DREDGABL evaluates the data for each of the dredgeability properties listed in Chapter 3 and displays the results, along with the rationale for each evaluation. DREDGABL provides guidance on the dredgeability properties of a sediment of specific properties for all of the dredge types shown in Table 2.

The rules for evaluation used in DREDGABL are in the following form (NOTE: the following are used as appropriate to the sediment type):

- IF primary sediment description is BOULDERS OR COBBLES:
- OR primary sediment description is CEMENTED SOIL OR SHALE:
- OR primary sediment description is ROCK OR CORAL:
- OR primary sediment description is FLUID MUD:

- IF primary sediment description is GRAVEL:
- OR primary sediment description is SAND:
- AND main name and USCS classification are:
- AND in situ compactness of the cohesionless soil is:
- AND gradation fineness is:
- AND grain angularity is:

- IF primary sediment description is INORGANIC FINE-GRAINED SOIL:
- OR primary sediment description is ORGANIC FINE-GRAINED SOIL:
- AND main name and USCS classification are:
- AND in situ consistency of cohesive soil is:
- OR liquidity index is:
- AND plasticity index is:

THEN estimated relative suctionability is:

THEN estimated relative erodability (scourability) is:

THEN estimated relative cuttability is:

THEN estimated relative scoopability (diggability) is:

THEN estimated relative flowability (underwater slope instability) is:

THEN estimated relative pumpability is:

THEN estimated relative pipeline abrasiveness is:

THEN estimated relative clay balling potential is:

THEN estimated relative stickiness is:

THEN estimated relative sedimentation rate in a hopper is:

THEN estimated relative bulking factor in a hopper is:

THEN estimated relative sedimentation rate in a disposal area is:

THEN estimated relative bulking factor in a land disposal area is:

THEN estimated relative mechanical compactability is:

The rules for evaluation operate internally in the program to consider all of that sample's properties that affect each of the specific dredgeability mechanisms. Wherever possible, the rationale for the guidance is given along with the expert opinion. Care is taken in the explanation texts to differentiate between factual information and the expert's interpretation of the facts.

GEOTEchnical Properties DATAbase (GEOCLASS)

Although not developed for the specific objectives of this report on GEODREDG, the GEOCLASS program can be an integral part of the sequence from site investigation, to soil description and classification recording, to dredgeability evaluation. Therefore, the following description is given for completeness.

The objective of the GEOCLASS program is to guide the user in obtaining and recording the appropriate dredging-related test data and observations in a standardized database. A complete database record is developed

and maintained of every sample type, field strength test, visual-manual observation, and laboratory test made of each sample. Only a limited number of acceptable descriptors are permitted for each property. The program makes all necessary calculations, checks for internal consistency of the data, and develops a word description of the sample and a classification according to the USCS.

A database system has been developed by WES for Corps-wide use as part of the Computer Applications to Geotechnical Engineering (CAGE) program (CAGE CADD Support Task Group 1991). The system as presently constituted contains three interrelated programs:

- a. Boring Log Database System - a collection of routines for data entry, editing, and reporting of boring log information.
- b. Boring Log Plotting Program - this program uses the database to generate Computer Aided Design and Drafting (CADD) design files for display of the boring logs.
- c. Cell Library and Matrix Menu - for ease of generating geotechnical boring logs using the CADD Standards Manual, EM 1110-1-1807.

GEOCLASS is the dredging project equivalent to the Boring Log Database System and, insofar as possible, the field headings of the Boring Log Database System have been used by GEOCLASS. In practice, those fields unique to dredging may be contained in one or more separate GEOCLASS databases. At the present time, GEOCLASS consists only of database storage with limited retrieval capability. The data in the database are not attached to a specific report form; therefore, the user has complete freedom to create customized reports. Future versions of GEOCLASS are expected to coordinate even more closely with the Boring Log Database System or its successors and to support use by the Boring Log Plotting Program.

With the aid of "explanation screens" a sample is first identified by simple manipulation as being one of the types described in Table 3. The program then prompts for information pertinent to that sediment type. The user selects from a menu of acceptable choices for each geotechnical property. In this manner, only a limited number of acceptable terms are available for each of the usual geotechnical descriptors (Spigolon 1993a) and consistency of terminology is maintained.

Sample test/observation data may result from one of several sources:

- a. Simple visual/manual manipulation in the field.
- b. Field compactness/consistency tests.
- c. Office or laboratory review tests — formal Visual-Manual (ASTM D2488) tests of cohesive soils and other simple, visual-manual tests.

- d. Standardized formal laboratory tests.**
- e. Visual comparison with another sample whose characteristics are known.**

The data for each individual sample are entered into the database at any one of three times and locations; this information may be modified at later times as needed:

- a. At the field sampling and testing site; this is the same type and form of information now maintained in the field boring log.**
- b. During the office/laboratory review of the logs and samples, preparatory to assigning laboratory tests.**
- c. Following completion of laboratory tests on selected samples.**

The GEOCLASS computer database is meant to take the place of many of the paper records now being maintained. If all samples in all borings (or pits) on a project are recorded in similar fashion, the data for developing formal boring logs and a subsurface profile will be present in electronic storage, ready for manipulation. The information in this form may even be supplied to all concerned, owner and prospective contractor, in the form of a diskette.

The GEOCLASS module is expected to be used by:

- a. Corps of Engineers soils technicians with some geotechnical training.**
- b. Relatively inexperienced civil engineers or geologists.**
- c. Experienced geotechnical engineers or geologists who will use this module primarily as an electronic data recording system.**

This program can also serve as a training device for inexperienced persons and as a review and cross-checking device for experienced persons. The more experienced people will be able to bypass some of the more elementary input screens. The elementary levels are aided by explanation/help screens.

5 Summary and Proposed Future Work

Summary

There exists a need for retaining the expert knowledge of persons proficient in the application of geotechnical information to the evaluation of dredgeability of sediments. This knowledge is useful in the guidance and training of inexperienced personnel and for peer consultation among experienced persons.

KBES are computer programs for problems whose solution requires expertise in a field. Conventional programs use a generally fixed algorithm to solve numerical problems. A KBES uses a knowledge base of expertly derived rules for its solutions. The knowledge base contains a database of facts and "IF - THEN" rule statements that answer the types of questions a typical user will ask. The rules can incorporate judgement, experience, empirical rules of thumb, intuition, and other expertise as well as proven functional relationships and experimental evidence. The ability to add new or expanded knowledge to the knowledge base is a major feature of a KBES.

The proposed WES DRP dredging expert system is called GEODREDG (GEOTEchnical factors in DREDGing). It uses a commercial relational database management system, Microsoft FoxPro, version 2.5, operating within both the DOS and the Microsoft Windows environments on PC-DOS or MS-DOS personal computers. The only input needed is numbers and mouse-pointer selection from menus. This should greatly facilitate the use of the system by non-typists. At present, GEODREDG is in the prototype stage and is based on previous work done in the DRP work unit. GEODREDG presently contains prototypes of two subsystems: GEOSITE and DREDGABL.

The GEOSITE (GEOTEchnical SITE investigation methods) subsystem is for the use of engineers and geologists in the planning of a subsurface investigation for a dredging project. It provides guidance in the selection

of field and laboratory tests appropriate for the estimation of site dredgeability.

The DREDGABL (Geotechnical Factors of DREDGeABiLity) subsystem provides guidance in the interpretation of geotechnical descriptors of sediments, contained in the project database, in terms of their dredgeability properties. It is intended to be used by estimators and contractors.

Although not formally included in this report, the GEOCLASS (GEOtechnical soil CLASSification) subsystem is used for recording geotechnical site investigation data in a database using consistent format, terminology, and methods of data analysis. Test data and observations are entered at the field site, in the office, and in the laboratory.

Recommendations for Further Work on GEODREDG

The programs described above are in the prototype stage. The needs and the basic philosophy of each of the subsystems have been established. Each module is in a working state. However, a number of modifications will make them more useful, more user-friendly, and more efficient. The next stage in the continued development of GEODREDG will be a field trial by a select few users. It is strongly suggested that the following be added to the various modules prior to the field trials.

The explanation/help screens for GEOSITE will be greatly improved by the addition of graphics to illustrate the methodologies discussed in the program. At present the module lists all appropriate sampling and test methods for a given sediment type. GEOSITE must eventually give guidance on a site investigation strategy that is based on maximum information for minimum cost. Therefore, a provision should be made for cost comparison between appropriate sample/test methods, possibly by use of a formal decision making strategy.

As suggested by the participants in the workshop (Appendix A), the present DREDGABL module has been modified to permit dredgeability guidance for specific, generic types of equipment. As productivity data become available from other studies, this information can be included in the explanation/help facility texts to provide further guidance. Expansion of, and the addition of graphics to, the explanation/help screens will improve their readability and user-friendliness.

It was strongly suggested during the workshop (Appendix A) that a glossary or lexicon be added. The glossary may be added as a stand-alone module or the definitions of dredging terms may be introduced throughout the explanation/help screens of the existing modules.

GEOCLASS presently uses a dBase III PLUS type of database structure. This corresponds closely to a concept used in the present WES CAGE-CADD Boring Log Program (CAGE CADD Support Task Group 1991). Furthermore, dBase III PLUS does not adequately provide guidance in analysis of data in the manner done by expert system shells. Calculation capabilities are limited. GEOCLASS can benefit greatly by adoption of a Microsoft FoxPro format, which will permit use of the same program in either the DOS or Microsoft Windows environment. This will then permit coordination with GEOSITE and DREDGABL. The addition of explanation/help screens with graphics will enhance the usefulness of the program. Data cross-checking for internal consistency, to inhibit input of wrong data, can be easily added.

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Appendix A

Minutes of Workshop

MEMORANDUM

TO: Dr. Jack Fowler, CEWES-GS-S

FROM: S. J. Spigolon

SUBJ: Workshop on KBES for Dredgeability¹

DATE: November 29, 1991

A workshop was held on November 21 and 22, 1991, at Tulane University, New Orleans, Louisiana, as part of a work unit of the USAE Waterways Experiment Station (WES) Dredging Research Program (DRP). Its objective was the study and appraisal of the prototype Knowledge-Based Expert System (KBES) for dredging projects developed by Drs. S. J. Spigolon and Reda Bakeer under contract with WES. Sponsor of the workshop was Dr. Jack Fowler, Geotechnical Laboratory, WES, the principal investigator of the work unit.

In attendance, by invitation, were:

Reda Bakeer	Tulane University
Greg Breerwood	USAE District, New Orleans
Sandra Curtis	USAE District, Vicksburg
Larry DeMent	USAE District, New Orleans

¹ Editor's note: Several GEODREDG workshops have been held in geographically diverse locations (i.e., Seattle, WA; Jacksonville, FL; Galveston, TX; Mobile, AL) in addition to New Orleans, LA. Comments and opinions in appraisal of the KBES from those meetings were considered in the final draft of this report.

Jack Fowler	USAE Waterways Experiment Station
Jay L. Joseph	USAE District, New Orleans
Joseph Moon	Great Lakes Dredge and Dock
Tom Murphy	USAE District, New Orleans
Milton Myers	USAE Waterways Experiment Station
S. Joseph Spigolon	SJS Corporation
Ancil Taylor	Bean Dredging Corporation
Russ Tillman	USAE Waterways Experiment Station
Tom M. Turner	Turner Consulting, Inc.
Tom Verna	Headquarters, USACE

Welcoming statements were made by Jack Fowler. He summarized the background of the DRP and of the work unit titled "Geotechnical Descriptors for Bottom Sediments to be Dredged." Fowler also described possible future extensions of the work unit.

S. Joseph Spigolon described the present work being accomplished on the descriptor work unit. A KBES called GEODREDG (originally named DREDGCON) at this time contains three modules:

- a. GEOSITE (originally named DREDSITE): a KBES whose purpose is to guide planners of a site investigation for dredging projects in the selection of suitable field test methods, sampling methods, field density test methods, laboratory tests, hole advancement methods, and testing platforms for a variety of sediments.
- b. GEOCLASS (originally named GEOPROP): a database management program for recording geotechnical site investigation data from (a) field sediment description, (b) office review of all samples and field test data, and (c) laboratory tests of selected samples. The program prompts for all requisite information for the specific sediment type. All pertinent calculations are made.
- c. DREDGABL (originally named GEODREDG): a KBES for guidance of planners and estimators of dredging projects in the interpretation of geotechnical data - from the project GEODATA database or from boring log information. Relative dredgeability is presented for all sediment types and properties for all dredging mechanisms during excavation, removal, transport, and disposal.

The KBES modules contain extensive explanation and/or help screens to assist the user in understanding the terminology and methodology of the geotechnical engineering guidance.

Reda Bakeer presented the computer-based aspects of the KBES. The system selected requires an MS-DOS or PC-DOS operating system with at least an AT-style machine or equal, a hard disk, and at least 640k RAM. Microsoft Windows was chosen as the basic operating environment because of its usefulness, availability, simplicity, and graphical interface. It is intended that the user should not need typing ability to operate any of the KBES modules. Windows permits the use of a mouse to choose options on the screen. The KBES chosen was LEVEL5. This is a complete shell that is relatively simple to program, has an unlimited-distribution run only version, and has many graphical features when used in the Windows environment. Bakeer demonstrated Windows and the LEVEL5 system to the attendees using a series of slides and hands-on operation of individual computers in the Tulane University Civil Engineering computer laboratory.

The afternoon was devoted to extensive, module-by-module, screen-by-screen, discussion of the various features, strengths, and weaknesses of the three modules by all attendees.

In the late afternoon, the attendees were asked to present personal observations about the prototype system and its three modules. First came a discussion of names for the programs. Acronym names must fit into the eight character limitation of MS-DOS; changes were proposed as shown above.

The attendees were unanimous in indicating approval of the total KBES program as it is being applied to the problem at hand and to the type and arrangement of the three sub-modules. They felt that the site investigation planning module (GEOSITE) was a definite benefit to both the Corps and to the dredging contractors in guidance in planning and executing a suitable geotechnical site investigation and in understanding the methods used, with their strengths and limitations.

The database module (GEOCLASS) was viewed by all attendees as a valuable product and the attendees expressed the desire that it, or a similar database, be adopted as standard for use in the dredging industry. The consistency of file formats and of geotechnical terminology, and the utility of a database were of primary interest. Spigolon indicated the desirability of converting GEOCLASS from dBase III PLUS format to LEVEL5 format - the ability to add explanation/help screens and the greater user-friendliness.

DREDGABL, the dredgeability module, was deemed useful by all Corps geotechnical personnel present. At least one contractor representative felt that the Corps should stick to presenting the geotechnical data in a readily understood and consistent format, such as in GEOCLASS, but should not attempt to interpret that data for them. Spigolon explained that

this module was primarily for the use of government estimators and planners - equivalent to having a geotechnical engineer nearby, ready to interpret the data in dredging terms. After reflection, the other contractor representative admitted that he would appreciate the interpretation of geotechnical data in the form shown in DREDGABL because it gave interpretations and explanations but not equipment-specific performance. Both contractors felt that was their business.

The workshop reconvened on Friday morning at the Tulane location. Constructive advice and encouragement were given by Tom Turner and others for further development of the three modules along the lines of the prototype.

In summary, the attendees were in general agreement that the three modules were worthwhile and should be continued and expanded. Although some dredging contractors have the capability, real or imagined, of interpreting geotechnical information in terms of dredgeability, even they can benefit from the insight the modules present. The government estimators can certainly benefit from the guidance given by the DREDGABL module and the GEOSITE and GEOCLASS modules should produce appropriate data in a consistent and readily available manner.

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13. ABSTRACT (Maximum 200 words) Geotechnical engineers investigate and describe dredging sites using their own methods and terminology. Government estimators and dredging contractors use that information in preparing plans and estimates. The two groups often do not understand each other's needs, methodology, and vocabulary. Inevitable turnover in personnel means the loss of the knowledge of experienced and talented persons. These factors often lead to misinterpretation of the nature and extent of the sediments to be dredged, resulting in higher bid prices because of unknown or unclear risk and in unnecessary claims for changed conditions. Therefore, there is a need for retaining expert knowledge for the guidance and training of inexperienced personnel and for peer consultation among the experienced persons. The work described in this report is part of the Dredging Research Program (DRP) at the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS. The specific work unit involves the development of geotechnical descriptors to indicate, or infer, dredgeability of sediments to be dredged. Knowledge-Based Expert Systems (KBES) are computer programs for problems that require expertise in a field for solution. Conventional programs use a generally fixed algorithm to solve numerical problems. A (Continued)				
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KBES uses a knowledge base of expertly derived rules for its solutions. The knowledge base contains a database of facts and "IF - THEN" rule statements that answers the types of questions a typical user will ask.

The rules can incorporate judgement, experience, empirical rules of thumb, intuition, and other expertise as well as proven functional relationships and experimental evidence. The ability to add new or expanded knowledge to the knowledge base is a major feature of a KBES.

The proposed WES DRP knowledge-based dredging expert system is called GEODREDG (GEOtechnical Factors in DREDGing). It uses a commercial relational database management system, Microsoft FoxPro, operating within either the DOS or the Microsoft Windows environment on PC-DOS or MS-DOS personal computers. The FoxPro programs satisfy all requirements for an expert system program — knowledge base, user interface, context, inference engine, and explanation facility are all included. The only input needed is numbers and mouse-pointer selection from menus. This should greatly facilitate the use of the system by non-typists. GEODREDG is in the prototype stage and is based on previous work done in the DRP work unit. GEODREDG contains prototypes of two subsystems: GEOSITE and DREDGABL. A third system, GEOCLASS, is described as part of GEODREDG even though it is not included in the present study.

The GEOSITE (GEOtechnical SITE Investigation Methods) subsystem is for the use of engineers and geologists in the selection of subsurface investigation methods and equipment for a dredging project. It provides guidance in the selection of sampling methods and the field and laboratory strength tests appropriate for the estimation of site dredgeability for a given sediment type.

The DREDGABL (Geotechnical factors in DREDGeABiLity) subsystem provides guidance in the interpretation of geotechnical descriptors of sediments, contained in the project database, in terms of their dredgeability properties. It is intended to be used by estimators and contractors.

The GEOCLASS (GEOtechnical Soil CLASSification) subsystem, although not part of this study, may be used for recording geotechnical site investigation data in a database using consistent format, terminology, and methods of data analysis. Test data and observations are entered at the field site, in the office, and in the laboratory.