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US Army Corps
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Waterways Experiment
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ENDOW USER'S GUIDE

by

F. Douglas Shields, Jr., Thomas E. Schaefer

Environmental Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199

WATER OPERATIONS TECHNICAL SUPPORT PROGRAM

December 1990

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

ENDOW (Environmental Design Of Waterways) is an expert system or knowledge-based computer program intended to aid planners and designers in learning about and selecting environmental features for stream channel alteration projects based on key project parameters and specific environmental goals. This report provides general instructions for installing and using the ENDOW system. This program aids in enviromental protection by allowing input and output for soil stabilization, levees, drainage, runoff, water erosion, erosion resistance etc. when designing for construction projects.

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Channelization	Knowledge base system	Streambank protection
Environmental design	Rivers	Streamside levee
Expert system	Rule base	Waterways

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PREFACE

This study was sponsored by the Headquarters, US Army Corps of Engineers (HQUSACE), under the Water Operations Technical Support (WOTS) Program. HQUSACE Technical Monitors for WOTS are Mr. Dave Buelow, Mr. James L. Gottesman, and Dr. John Bushman. The WOTS Program is managed under the Environmental Resources Research and Assistance Programs (ERRAP) of the Environmental Laboratory (EL), US Army Engineer Waterways Experiment Station (WES). Mr. Lewis Decell is the manager of ERRAP. Dr. A. J. Anderson was Assistant Manager, ERRAP, for the Water Operations Technical Support Program.

The report was written and prepared by Dr. F. Douglas Shields, Jr., and Mr. Thomas E. Schaefer of the Water Resources Engineering Group (WREG), Environmental Engineering Division (EED), EL. Technical reviews of the draft report were provided by Drs. P. R. Schroeder and John J. Ingram of the WREG. The report was edited for publication by Ms. Janean Shirley of the WES Information Technology Laboratory.

The work was accomplished under the direct supervision of Dr. John J. Ingram, Chief, WREG, and under the general supervision of Dr. Raymond L. Montgomery, Chief, EED; Dr. John Keeley, Assistant Chief, EL; and Dr. John Harrison, Chief, EL.

COL Larry B. Fulton, EN, was Commander and Director of WES. Dr. Robert W.Whalin was Technical Director.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
feet	0.3048	metres
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres
square miles	2.589998	square kilometres
tons (mass)	1,016.0	kilograms

ENDOW USER'S GUIDE

PART I: INTRODUCTION

Background

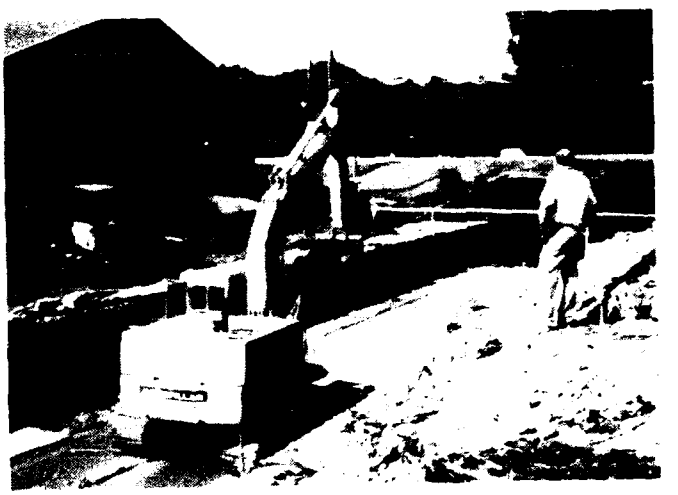
Waterway projects and environment

1. Modification of stream channels for flood control, drainage, highway and pipeline construction, or bank erosion control ("waterway projects") is widely practiced (Figure 1). Surface mines, bridge construction, and logging also frequently require channel alterations. Environmental studies of channel modification have tended to emphasize the biological and physical effects of such actions rather than to advise the engineer about design practices and procedures that are desirable from a resource protection and conservation standpoint. A body of information on environmental features for these types of projects does exist, but it is widely scattered among many types of sources.

2. Since the information about design of environmental features is "off the beaten path" and is not available in standard engineering curricula and manuals, inclusion of environmental features in stream alteration projects is often difficult. Resource agencies require or request inclusion of features unfamiliar to designers, who have difficulty locating design criteria within project time and money constraints. Furthermore, environmental scientists are not always aware of hydraulic or geotechnical constraints on environmental feature feasibility. True integration of expertise into interdisciplinary design teams is required, but sometimes does not occur in a timely fashion or at all. The ENDOW (**EN**vironmental **D**esign **O**f **W**aterways) expert system was developed to address these problems.

What are expert systems?

3. Expert systems are computer programs that replicate some of the problem-solving ability of human experts. They accept problem descriptions from users and apply logic to a knowledge base composed of rules to generate solutions. Expert systems typically function over very narrow problem domains. Application of expert systems to engineering practice is promising. Expert systems may be used to train new employees or to serve as dynamic manuals or indexes to large



a. Bed and bank protection, channel enlargement, reservoir outlet channel and road crossing

b. Flood control levees and borrow pits

Figure 1. Typical stream channel modifications (Continued)

c. Channel straightening

d. Grade-control structure

Figure 1. (Concluded)

bodies of information. The greatest benefit of expert system development, however, is the codification of a body of knowledge into rigorous, logical terms that are applied in a consistent fashion to all problems. Wolfgram, Dear, and Galbraith (1987) provide additional information on expert systems, although books such as theirs are rapidly outdated by new developments.

Purpose

4. The purpose of this report is to aid planners and designers of waterway projects in the use of ENDOW. It is envisioned that ENDOW will be used for selection of environmental features and for training new personnel. A secondary purpose of this report is to document the ENDOW system to facilitate future revision and refinements. ENDOW was developed under the Water Operations Technical Support (WOTS) Program sponsored by Headquarters, US Army Corps of Engineers in order to maintain and transfer technology developed under the Environmental and Water Quality Operational Studies conducted by the US Army Engineer Waterways Experiment Station. Mr. Lewis Decell is manager of the WOTS Program.

Scope

5. This report provides general instructions for installing and using the ENDOW system (Part II) and detailed information and examples for the streambank protection, flood control channel, and streamside levee modules, respectively (Parts III through V). Appendix A contains a list of the engineers and scientists who have contributed to the development of ENDOW.

PART II: HOW TO USE ENDOW

Before the User Begins

Take a test drive

6. Before using ENDOW to select features for a study, a plan, or a design, the user should perform two or three test runs to get a feel for system capabilities and input requirements. Example runs are provided in Parts III, IV, and V for the streambank protection, flood control channel, and streamside levee modules, respectively, and input data for test runs may be obtained directly from these sections. Alternatively, project information from a familiar study may be used as the basis for a test run. Simply typing in responses without a real-world project in mind is usually not a good way to test the system because it is often easy to generate inconsistent or self-contradictory input that way. Although ENDOW does contain a few safeguards against such inconsistency, all possible cases are not covered.

7. On the other hand, ENDOW may be tested or even actively used without an exhaustive knowledge of the project and its setting. In the first place, ENDOW does not request all possible input on every run. The internal logic is set up to minimize the number of questions asked based on previous responses. For example, if a user indicates that recreation resources are not of interest, ENDOW will not ask any more questions that apply solely to selection of recreation features. Secondly, reasonable estimates for unknown quantities are often sufficient to obtain good results, as long as the overall body of responses is consistent. Finally, for most effective use, it is suggested that ENDOW be run several times for each application using different assumptions and varying responses where appropriate. The "change and rerun" option (described in a following section) is especially useful in this regard.

Use of reaches to organize ENDOW runs

8. ENDOW often asks questions that deal with project characteristics that change as the project moves in a streamwise direction (for example, design discharge). If the project under consideration passes through different types of settings or hydrologic zones, segmenting the projects into reaches is highly advisable before applying ENDOW. ENDOW runs can then be made for each reach, and printed output can

be clearly labeled accordingly using the labels input at the beginning of each run.

Hardware Needs

9. ENDOW will run on any IBM PC, XT, AT, or compatible machine with DOS 2.0 or higher and at least 300 kilobytes (kb) of available memory. A color monitor is useful (but not necessary) because some displays are color-coded. ENDOW can be run on a hard disk or a high-density floppy disk drive. About 980 kb of storage are needed to hold the software and associated files. A printer is needed to obtain a hard copy of the output.

Installation

To run on hard drive:

10. First create a directory on your hard drive in which to store all ENDOW files. Make the directory current, and copy the contents of all ENDOW diskettes into the directory. These steps may be accomplished with these commands:

```
C > cd\
C > md\endow
C > cd\endow
C > copy a:*.*
```

To run on high-density floppy disk drive:

11. Copy all files from the distribution diskettes to a high-density diskette. Specify the high-density drive as the working drive such as by the Command **A:** to make the A drive the active drive. Type **ENDOW** to run the program (See Program Operation section).

User Support

12. ENDOW was created using the "EXSYS Professional" Expert System Development Package (EXSYS Inc. 1988).

13. If you have a question about ENDOW, encounter a problem, or have a suggestion, contact:

Mr. Jerry Miller, CEWES-EE-R
US Army Engineer Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199
(601) 634-3931

Program Operation

14. **Main menu.** To start the program, type "ENDOW <return>" while in the ENDOW directory. Following an introductory title screen, the main menu appears with seven options (Figure 2). The first three options are major ENDOW modules. The help option displays an abstract of the ENDOW system and provides a list of contributors. The "Adjust screen colors" option allows the user to configure ENDOW for monochrome or color displays. ENDOW as provided to users is set up for color display, and this configuration is also satisfactory for many monochrome displays. However, if the user has trouble seeing some of the text, he can hit control-break (hold down Ctrl and Brk keys simultaneously), return to the main menu, and configure for monochrome display. Activating any module selection (either 1, 2, or 3) from the main menu will cause a short delay (a minute or so) as the module is loaded into memory; the word "WORKING" will appear at the center of the screen while the module is loaded.

15. **Run identifier.** After the module is loaded, ENDOW requests input of a run identifier (up to one line of alphanumeric characters and spaces). ENDOW stores responses to its questions and the corresponding results in an ASCII output file (end-of-run report). The run identifier will be a heading in the end-of-run report. Run identifiers may include the name of the user, the date, and the project name and reach.

16. **Dialog.** ENDOW will ask multiple-choice questions or ask the user to complete statements concerning the project of interest. ENDOW multiple-choice questions may be answered in two ways. If only one of the choices is correct, the user may either type in the number of the response or use the cursor movement keys to highlight the correct response. If the user wishes to select more than one of the choices, the corresponding numbers should be entered, separated by

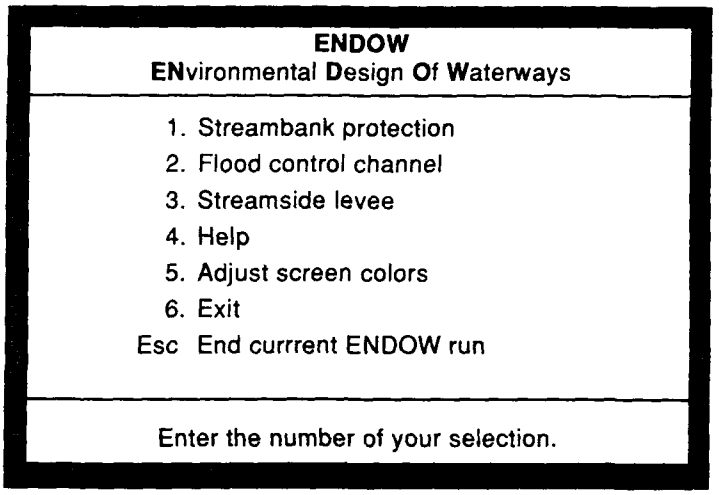


Figure 2. ENDOW main menu

spaces or commas. A message across the top of the screen alerts the user to the number of responses allowed.

17. Several menu options are available to the user during this dialog. Most of these options are accessed by responding to questions with commands listed in the menu across the bottom of the screen (Figure 3).

a. *Hypertext messages <F1>* . Definitions and explanations (Additional Information) are available whenever highlighted (or reverse highlighted) words (key words) appear on any ENDOW screen. In order to display hypertext, the user presses F1. A menu will then appear on the bottom of the screen to guide the user. If more than one highlighted word or phrase appears on the screen, the user continues pressing F1 to access the message associated with each word or phrase.

b. *Help in using the program <H>* . General explanations of how to use the program may be displayed by typing H.

c. *Help in understanding questions <?>* . Messages that provide detailed explanations are available for some (but not all) of the questions. These may be viewed by typing a question mark (?).

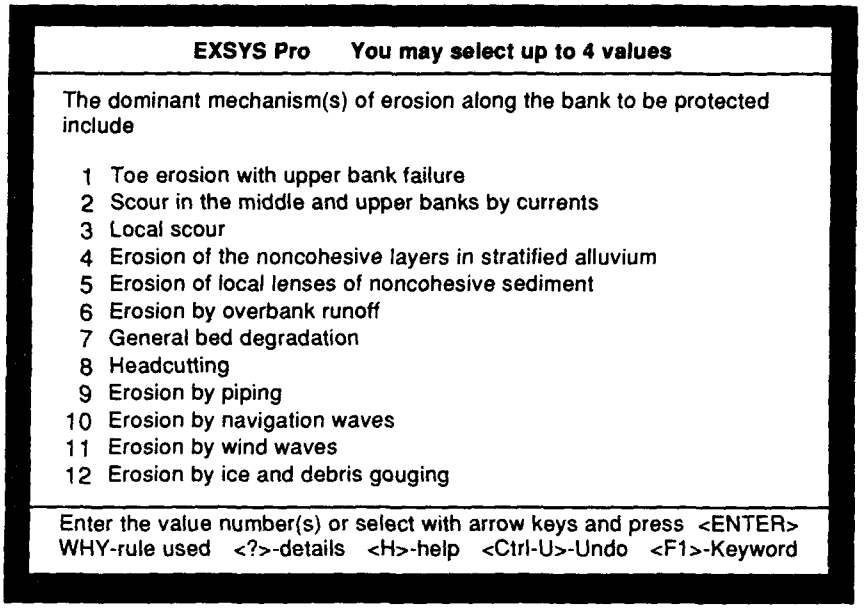


Figure 3. Typical rule display showing menu at bottom of screen

d. *Backing up <Ctrl U>* . The user may return to previous screens and change responses by pressing the Ctrl and U (U as in up) keys simultaneously. (This command will appear as a menu option after the first entry.) Because of software limitations this command will not always be available.

e. *Stopping <Ctrl-Break>* . Pressing Ctrl and Break simultaneously will terminate the run and return the user to the main menu. All input for the current run will be lost. (Note: There is no reference to this command in the menu options. The user must remember that it can be accessed by pressing the Ctrl and Break keys simultaneously.)

f. *Examining ENDOW rules-WHY.* ENDOW rules may be examined during the course of a run by typing WHY. All rules pertinent to the question being asked will be displayed. On a color display, statements known to be true will be gold in color, those known to be false will be red in color, and unknown statements will be blue in color. Although looking at the rules may be novel to a first-time user, their syntax does not make for easy reading for new

ENDOW users. However, more advanced users may find the WHY command helpful. When rules are displayed using the WHY command, a new menu appears on the bottom of the screen (Figure 4). Features of this menu include the following:

(1) *Derivation of known statements-IF line #.* Entering the line number of known statements from the IF portion of a displayed rule will cause the program to explain how it knows the statement to be true, false, or unknown. (For example, "You told me.").

(2) *Display of known data <K>* . A numbered list of known values and statements based on previous input can be viewed by entering **K**. The number of each known value may then be entered to obtain information on its derivation.

(3) *Assignment of values or scores to choices (or Environmental Features) <C>* . By entering **C** for choices (Environmental Features), all environmental features that have been assigned final values greater than or equal to a threshold value of 5 based on input

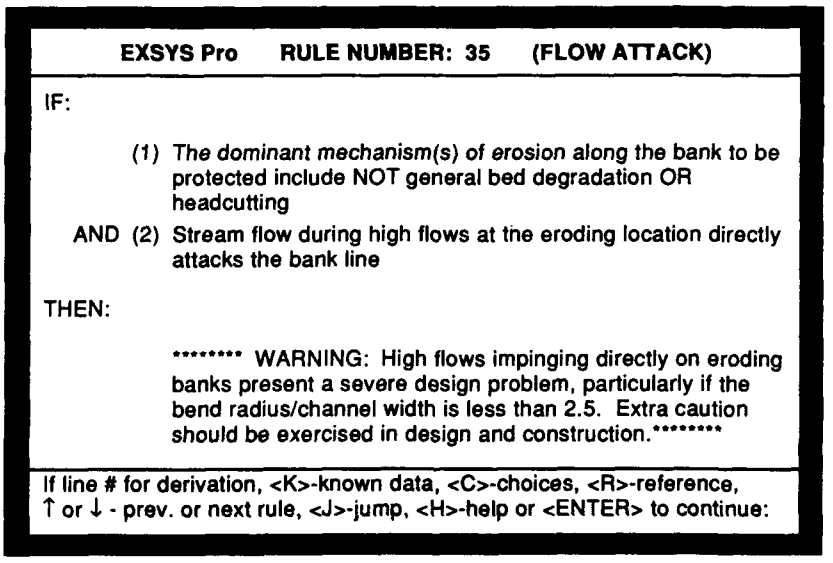


Figure 4. WHY option menu for examining ENDOW rules

to that point in the run may be viewed. Assigned values have nothing to do with probability, but are simple measures of relative feasibility on a scale of 0 to 9. Features or choices will appear only if a final value has been set based on input. All rules pertaining to a feature must be satisfied as either true or false before a final value can be established. (See the **ENDOW Results** section on page 20 for further information concerning assigned values to environmental features.)

(4) *Rule References <R>* . If a rule is based on a particular reference, the reference option will appear. The user can type **R** to view the reference for that rule.

(5) *Looking at other rules* ↑ *or* ↓ *and <J>* . The up and down cursor movement keys allow the user to scroll through the rule base one rule at a time. Typing **J** allows the user to jump to any rule, but the user must supply a rule number.

Environmental goals

18. Immediately after asking for a run identifier, all three ENDOW modules request the user to identify one or more environmental goals. Users should not think of this question as a statement of formal project objectives, but rather as a statement of their interests specific to the current run. The linkage between environmental goals and features imbedded in the ENDOW rule base is shown in Figures 5 through 7. If a user identifies more than one environmental goal (say, cultural resources and aquatic habitat for a levee's module run) then ENDOW will identify features that meet either goal. Identified objectives will then be screened based on user responses to additional questions dealing with engineering and institutional constraints. In contrast to the environmental goals, the additional constraint questions are exclusive rather than inclusive. Features must meet all identified constraints and address at least one of the user-specified environmental goals to be listed in the end-of-run report.

19. The streambank protection module offers a choice of three environmental goals, while the flood control and levees modules offer choices of four and five goals respectively (Figure 8a, b, and c). All

three modules contain visual resource, aquatic habitat, and riparian or wetland habitat goals. Recreation is included for the flood control channel and levees modules and cultural resources is included for the levee module because of the availability of information about features to address these goals.

ENDOW Streambank Protection Module: Environmental Goals

Bank Protection Method	Environmental Goals		
	Visual Resources	Aquatic Habitat	Riparian or Wetland Habitat
Flow diversions and slope drains	Yes	No	Yes
Drop inlet storm drains	Yes	No	Yes
Cobble or gravel armor	Yes	Yes	No
Iowa vanes	Yes	No	Yes
Gabions	Yes	Yes	No
Cobble revetment	Yes	Yes	No
Cellular concrete block revetment	Yes	No	No
Covering riprap with soil and grass or ground cover	Yes	No	No
Live cribwalls	Yes	No	Yes
Bank shaping and establishment of woody vegetation	Yes	No	Yes
Brush mattresses	Yes	No	Yes
Geotextiles and vegetation	Yes	No	Yes
Clay blankets with vegetation	Yes	No	Yes
Rock toe protection with vegetative treatment of upper banks	Yes	Yes	Yes
Riprap with live stakes	Yes	Yes	Yes
Window revetment	No	Yes	Yes
Tree retards, pendants, and revetments	No	Yes	No
Hard points, jetties, and earth core dikes with vegetation	No	Yes	Yes
Bank shaping and establishment of grass or ground cover	Yes	No	No
Jack fields	No	No	Yes

Figure 5. Environmental goals and streambank protection methods

Endow Flood Control Channel Module: Environmental Goals

Environmental Feature	Environmental Goals			
	Visual Resources	Recreation	Aquatic Habitat	Riparian or Wetland Habitat
Preservation and creation of wetlands	No	No	No	Yes
Meandering alignments	Yes	No	Yes	No
Special treatments to color or texture concrete surfaces	Yes	No	No	No
Mounding excavated material to create topographic diversity	Yes	No	No	No
Preservation and development of riparian terrestrial habitat	No	No	No	Yes
Greentree reservoirs	No	No	No	Yes
Single-bank modification	Yes	No	Yes	Yes
Fishways	No	No	Yes	No
Water level control structures	Yes	Yes	Yes	No
Low-flow channels	Yes	Yes	Yes	No
Selective clearing and snagging	Yes	Yes	Yes	Yes
Pools and riffles	Yes	No	Yes	No
Maintenance of hydraulic connections between the stream channel and cutoff bendways	Yes	No	Yes	No
Impoundment of cutoff bendways to form lakes	Yes	Yes	Yes	Yes
Instream habitat structures	No	No	Yes	No
Gravel or stone armor	Yes	No	Yes	No
Two-stage channel	Yes	Yes	Yes	No
Recreational boatways	No	Yes	No	No

Figure 6. Environmental goals and flood control channel environmental features

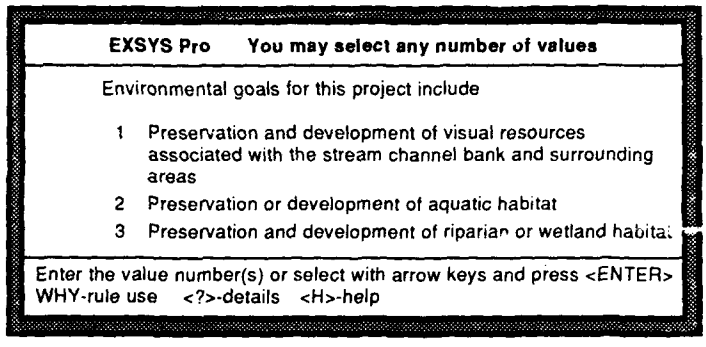
ENDOW results

20. **Suggested environmental features.** At the conclusion of the dialog, ENDOW will display results and warning messages or notes, if any warnings or notes are issued (Figure 9). During the run, ENDOW calculates a score or feasibility value between 0 and 9 for each environmental feature in the knowledge base. Only features assigned scores of 5 or greater are listed on the results screen. Scores are shown on the

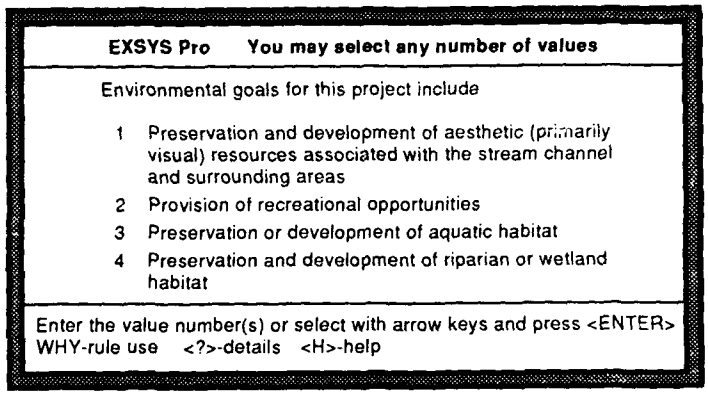
ENDOW Streamside Levee Module: Environmental Goals

Environmental Feature	Environmental Goals				
	Visual Resources	Recreation	Aquatic Habitat	Riparian or Wetland Habitat	Cultural Resources
Overbuilt levee embankments	Yes	No	No	Yes	No
Overdesigned drainage ditches	No	No	No	Yes	No
Alignment of levee to avoid ecologically sensitive areas	No	No	Yes	Yes	No
Alignment of levee to avoid cultural sites	No	No	No	No	Yes
Relocation of historic structures	No	No	No	No	Yes
Tree preservation	Yes	No	No	Yes	No
Design of borrow pits for waterfowl	No	No	No	Yes	No
Design of borrow pits for visual effects	Yes	No	No	No	No
Textured or colored finishes for floodwalls	Yes	No	No	No	No
Floodwalls with folding or removable sections	Yes	Yes	No	No	No
Use of dry interior drainage collection ponds for recreation	No	Yes	No	No	No
Design of interior drainage collection ponds for visual effects	Yes	No	No	No	No
Design of interior drainage collection ponds for waterfowl	No	No	No	Yes	No
Placement of brush piles for wildlife	No	No	No	Yes	No
Design of interior drainage collection ponds for water-based recreation	No	Yes	No	No	No
Creation of islands in borrow pits	Yes	No	No	Yes	No
Containerized plantings on levee embankments	Yes	No	No	Yes	No
Design of borrow pits for wildlife	No	No	No	Yes	No
Design of borrow pits for fishing	No	Yes	Yes	No	No
Design of borrow pits for recreation	No	Yes	No	No	No
Burial of cultural resources sites under the levee embankment or berm	No	No	No	No	Yes
Creation of islands in interior drainage collection ponds	Yes	Yes	No	Yes	No

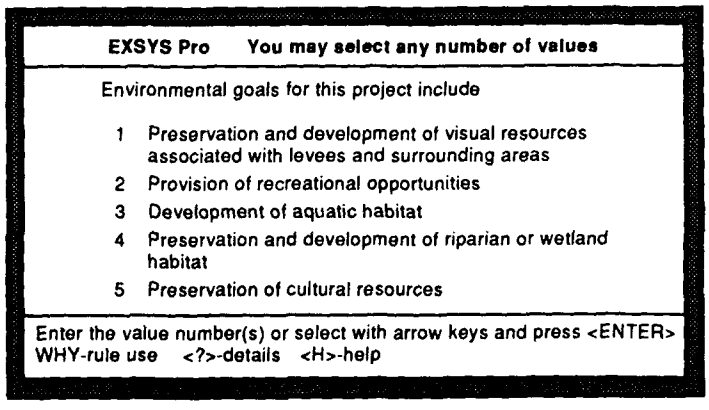
Figure 7. Environmental goals and streamside levee environmental features



a. Streambank protection module



b. Flood control channels module



c. Streamside levee module

Figure 8. ENDOW environmental goal selection menus

results screen under the heading "VALUE." These values have nothing to do with probability, but are simply measures of relative feasibility. A feature with a score of 9 is highly recommended. Caution should be used when implementing features with scores between 5 and 8. Features assigned scores less than 5 are not recommended.

21. **Additional information.** Hypertext messages are available for each feature listed on the results screen. These messages include a description of the environmental feature and a bibliography for more information. Some messages also include a list of projects where the feature has been employed and rough cost information. The hypertext for each module is contained in a file with an .SCR extension that is included with the software. For example, hypertext for the channels module is in the file CHANNELS.SCR. These .SCR files may be printed using the DOS print command or imported to a word processor for further editing or inclusion in a longer document. Hypertext words and phrases are set off in .SCR files with double arrows or carets (^^).

22. A menu of options is provided across the bottom of the results screen (Figure 9). However, if the user wishes to save a detailed report of the run for printing later, he proceeds to the next step by selecting **D** (Done) from the menu. The user will then be allowed to return to the results screen after saving the report to an ASCII file that may be printed later using the DOS print command, or imported to a word processor for editing or inclusion in a longer document. Options from the results screen include:

a. *Finding out how a conclusion was reached line <#>* . When a line number from the results screen is entered, ENDOW will display an explanation. When line numbers for selected features are entered, ENDOW displays all rules used to determine the feasibility value (score).

b. *Printing a report <R> and <D>* . An end-of-run report listing selected input, suggested environmental features, and any warnings or notes will be printed if R is entered (Is the printer on?). The report may be saved to an ASCII disk file by selecting D and proceeding to the next screen as described above. Example reports are included in the example descriptions presented in Parts III-V.

c. *Changing responses and rerunning <C>* . Multiple runs using different assumptions are recommended, especially if

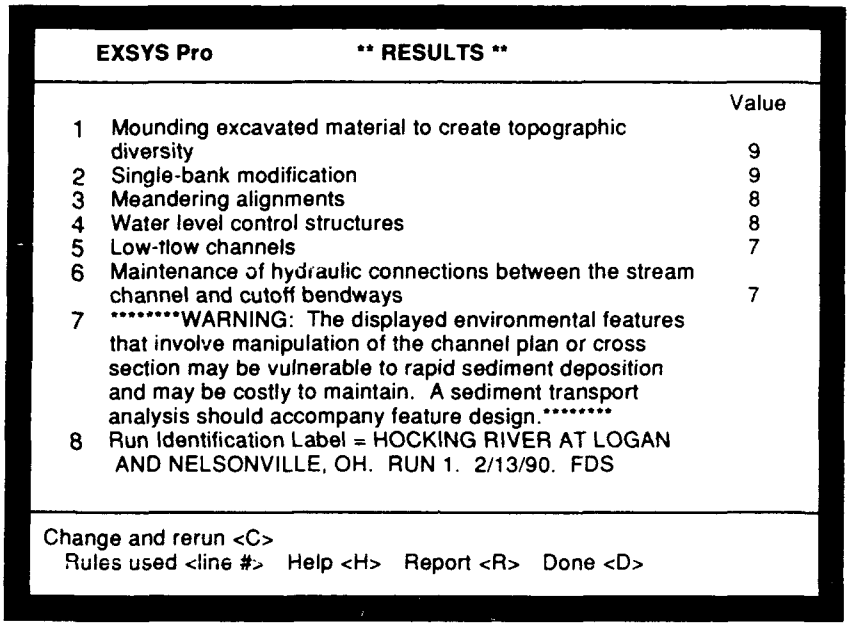


Figure 9. Typical results display, flood control channels module

some of the inputs requested by ENDOW are known only approximately. A separate report can be generated and saved for each run by selecting D from the results screen the first time it appears, saving the report file, and then selecting "Change and Rerun" when ENDOW asks what you want to do next. The user will be asked if he wishes to store the current results (scores or feasibility values) for comparison with the new results. Replying Y will cause the results screen after the rerun to tabulate both sets of feasibility values. This facility is a good way to evaluate the impact of a given assumption on ENDOW output. Choices from the change and rerun screen menu (Figure 10) include:

(1) *Changing input line #*. Each input from the latest run appears on the change and rerun screen(s) as a numbered statement; the user enters the number he wishs to change and the appropriate question(s) will be asked again.

(2) *Return to original data <O>* . The user may return to his original input by selecting **O**.

(3) *Rerun <R>* . After input is edited, the user presses **R** to rerun. ENDOW may ask additional questions necessitated by the revised input.

Note: Some versions of ENDOW may display error messages (for example, "OUT OF MEMORY") when the change and rerun opton is used from within the channels module. If this happens, the user should reboot his computer and initiate an entirely new run. On the results page, the user should press "Done <D>," answer the results with "no," answer the what to do next question with "change and rerun, then on the results page, press "change and rerun <C>."

EXSYS Pro **** CHANGE INPUT DATA ****

1 Environmental goals for this project include preservation and development of aesthetic (primarily visual) resources associated with the stream channel and surrounding areas AND provision of recreational opportunities AND preservation or development of aquatic habitat
2 The existing riparian corridor has trees on one or both sides of the proposed channel right-of-way AND available right-of-way wide enough to allow for excavation of a wide flood control channel AND flat enough topography to allow a shallow (2-6 ft or 0.6-1.8 m) impoundment near the channel AND site characteristics (soil, topography, acreage, adjacent land use) suitable for wildlife habitat
3 The existing stream reach in question contains one or more significant meanders
4 Estimated or approximate channel characteristic values are unknown or not available
5 The bed of the constructed channel will be composed primarily of gravel or cobble

** MORE DATA **

Enter number of line to change, <O> for original data, <R> to run the data, <H> for help

Figure 10. CHANGE and RERUN option menu

PART III: STREAMBANK PROTECTION MODULE

Introduction

23. The ENDOW streambank protection module is a set of rules that assist a user in learning about and selecting bank protection methods that meet engineering criteria and address stated environmental goals. ENDOW selects candidate bank protection methods from a list of 20 alternative techniques (see left side of Figure 5). If none of the 20 techniques address the selected environmental goals and meet the engineering constraints for the site in question, ENDOW will suggest reconsideration of input and rerunning. Text screens that include bibliographies are available for each bank protection method. The text screens are in the ASCII file BANKS.SCR on the ENDOW disks. Photos and drawings of many of the bank protection methods can be found in Henderson and Shields (1984).

Erosion Mechanisms

24. The success or failure of a bank protection device is highly dependent on the type of erosion occurring. Some bank protection methods are effective in counteracting one type of erosion but are likely to fail if another erosion mechanism is at work. Therefore the primary or dominant mechanisms of bank erosion must be identified before an effective method of streambank erosion control can be selected. The ENDOW bank protection module asks the user to select at least one and as many as four primary bank erosion mechanisms for the site in question (Figure 11).

Identifying erosion mechanisms

25. Usually a hydraulic engineer, geomorphologist, or geotechnical specialist with experience in the project region can identify primary erosion mechanisms with information gathered from site inspections, maps, aerial photographs, and hydrologic records. A description of each of the mechanisms is available on hypertext screens, which may be accessed by pressing F1 as described in PART II. ENDOW may be expanded in the future to provide additional assistance in identifying primary erosion mechanisms.

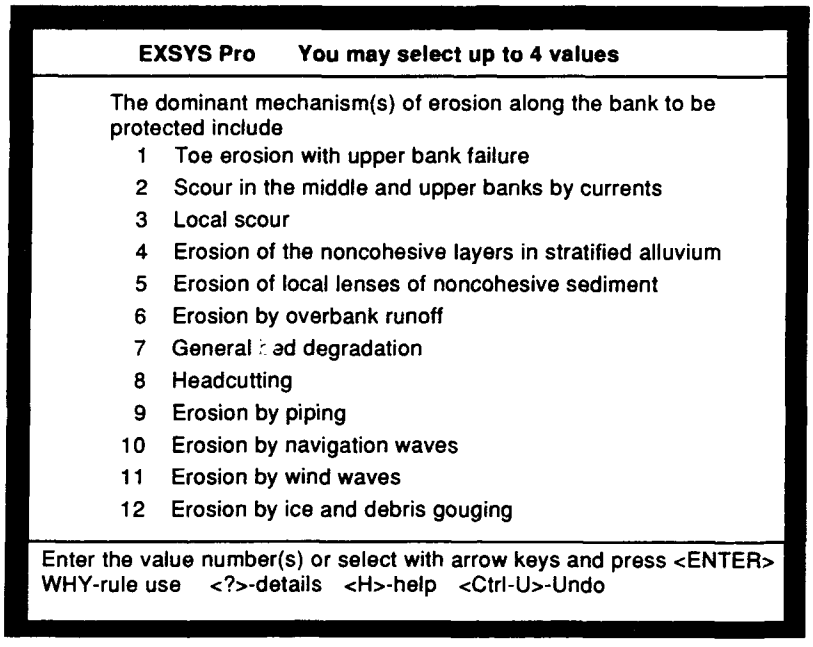


Figure 11. Erosion mechanisms menu

How ENDOW uses erosion mechanisms

26. In order for a bank protection method to be recommended by ENDOW, it must provide protection against all of the specified erosion mechanisms. For example, if the user specifies that ice and debris gouging and toe erosion with upper bank failure are primary mechanisms, then ENDOW will eliminate windrow revetment from further consideration even though it will counteract the latter mechanism. This strategy is opposite to the one used for evaluating bank protection methods on the basis of environmental goals—a method will be retained if it addresses any of the specified goals. The linkage between bank protection methods and erosion mechanisms contained in the ENDOW rules is shown in Figure 12. Note that none of the bank protection methods are suitable for addressing problems caused by headcutting and only one method is suitable for general bed degradation. Grade control or bed stabilization is usually needed for bank stability when these processes are at work unless they are extremely gradual.

Endow Streambank Protection Module: Erosion Mechanisms

Bank Protection Method	Erosion Mechanisms											
	Toe Erosion With Upper Bank Failure	Scour in the Middle and Upper Banks by Currents	Local Scour	Erosion of the Noncohesive Layers in Stratified Alluvium	Erosion of Local Lenses of Noncohesive Sediment	Erosion by Overbank Runoff	General Bed Degradation	Headcutting	Erosion by Piping	Erosion by Navigation Waves	Erosion by Wind Waves	Erosion by Ice and Debris Gouging
Flow diversions and slope drains	No	No	No	No	No	Yes	No	No	Yes	No	No	No
Drop inlet storm drains	No	No	No	No	No	Yes	No	No	Yes	No	No	No
Cobble or gravel armor	No	No	Yes	No	No	No	Yes	No	No	No	No	No
Iowa vanes	Yes	No	Yes	No	No	No	No	No	No	No	No	No
Gabions	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	No
Cobble revetment	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes
Cellular block concrete revetment	No	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	No
Covering riprap with soil and grass or ground cover	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes
Live cribwalls	No	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	No
Brush mattresses	No	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	No
Bank shaping and establishment of woody vegetation	No	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	No
Geotextiles and vegetation	No	No	Yes	Yes	Yes	No	No	No	No	No	No	No
Clay blankets with vegetation	No	Yes	No	Yes	Yes	No	No	No	No	No	No	No
Rock toe protection with vegetative treatment of upper banks	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	No
Hard points, jetties, and earth core dikes with vegetation	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No
Riprap with live stakes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes
Window revetment	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No
Tree retards, pendants, and revetments	No	Yes	No	No	No	No	No	No	No	No	No	No
Bank shaping and establishment of grass or ground cover	No	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No
Jack fields	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No

Figure 12. Streambank erosion mechanisms and streambank protection methods

Other Considerations

27. In addition to environmental goals and erosion mechanisms, ENDOW screens the list of 20 bank protection methods for potential feasibility based on several other factors. For example, the 11 methods involving use of live vegetation will be eliminated if average annual rainfall is less than 30 in.* This may be overconservative in some cases; successful applications of vegetative techniques can be made in areas of low rainfall if plant materials are carefully selected and handled and if they receive sufficient water (naturally or by irrigation) during establishment. Erosion rates, current velocities, availability of construction materials, and existing riparian vegetation form the basis of some of the other qualifiers. ENDOW does not ask for information it does not need; i.e, questions dealing with the feasibility of bank protection alternatives that have already been eliminated will not be asked.

A word about the examples in this guide

28. This guide contains two examples for each of the ENDOW modules. Existing projects have been used for all but one example, and an effort has been made to make the input data as realistic as possible. However, the sole purpose of the example sections is to illustrate the use of ENDOW. In a few instances, input values were estimated or assumed. Input and output from these example runs should not be applied to a real-world project.

Example 1: Sacramento River above Sacramento, CA

Description

29. The project is in a rural area about 1 mile upstream of the Interstate Highway 5 bridge, and about 12 miles northwest of downtown Sacramento (Figure 13). Although bank protection structures are viewed by recreational boaters and by some residents along the opposite bank, aesthetics is not a major consideration. Riparian habitat, however, is at a premium as it comprises less than 5 percent of the area it covered prior to European settlement. Studies of avifauna have also

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 4.

Figure 13. Sacramento River just upstream from Sacramento, CA

shown that the thin strip of riparian vegetation affects species richness on adjacent agricultural lands. The river supports sizable sport and commercial fisheries including warmwater and anadromous species. The river is an important spawning area for white sturgeon, shad, and striped bass; therefore, aquatic habitat preservation and development are important.

30. Floodplain soils consist primarily of clays with some interbedded noncohesive strata. No headcutting, piping, or erosion by overbank runoff is obvious in the project reach, but some general bed degradation has occurred. Bank failure is typically due to toe erosion and upper bank failure. Bank failures tend to be characterized by collapse of large sections of bank during floods. The eroding bank is on the outside of a very gradual bend, and secondary currents are likely involved in toe erosion. Navigation waves and debris gouging occur, but are not major erosion causes. The average rate of bank retreat at the site in question is 3 ft/year. Additional erosion cannot be tolerated because a flood control levee is threatened.

31. Bank-full discharge is about 60,000 cfs, and mean velocity at this discharge is about 3.4 fps. Channel top width is 540 ft. There are

no large bars or sediment deposits in the channel, and suspended sediment concentrations are about 150 mg/L. Average annual rainfall is 17 in.

32. Most existing bank protection works are quarry-run stone riprap revetments. Cobble revetments have been used in the past, and a few stone spur dikes have also been built.

Input data

33. Input for an ENDOW run was extracted from the above description. The statements below list the input in the order it was provided to ENDOW:

a. Environmental goals for this project include preservation or development of aquatic habitat and preservation and development of riparian or wetland habitat.

b. The dominant mechanism(s) of erosion along the bank to be protected include toe erosion with upper bank failure and erosion of the noncohesive layers in stratified alluvium.

c. Construction materials available at reasonable cost include stream cobble suitable for building revetment, stone suitable for riprap, and stone suitable for gabions.

d. Mean annual precipitation is less than or equal to 30 in. (762 mm).

e. The existing bankline or riparian corridor is severely restricted by levees, streamside structures, or cultivation.

f. Structures placed in the channel would interfere with navigation or be hazardous to recreational users.

g. Stream flow during high flows at the eroding location is essentially parallel to the bank.

ENDOW output

34. ENDOW found that the following features were potentially feasible for the Sacramento River.

a. *Gabions.*

Figure 14. Little Blue River, Independence, MO

b. *Cobble revetment* was found to be potentially feasible. No warnings were issued.

Example 2: Little Blue River Near Independence, MO

Description

35. The Little Blue River (Figure 14) is a right-bank tributary of the Missouri River, joining the main stem about 20 miles downstream from Kansas City, MO. The drainage basin, which has an area of 224 square miles, is primarily rural. However, urbanization is gradually occurring due to expansion of the Kansas City metropolitan area. Mean daily discharges measured over a 30-year period range from 0 to 17,000 cfs and average 133 cfs. Bed slope is about 3 ft/mile. Mean velocity at bank-full flow is about 9 fps. Mean suspended sediment load for a 10-yr period of record is 426 tons/day. Average suspended sediment load consists of 6 percent sand, 51 percent silt, and 43 percent clay (US Army Corps of Engineers 1981, Appendix H).

36. The eroding location is within a reach that was straightened and enlarged as part of a Corps flood control project (US Army Engineer

District, Kansas City 1972). Parks and public use areas are nearby. The banks are composed of sandy silts to lean clays; the bed is sandy, silty clay. Erosion locations are characterized by the presence of deposits of erodible soils and turbulence during high flows (US Army Corps of Engineers 1981, Appendix H).

Input data

37. The following statements contain answers to questions posed by the ENDOW streambank protection module:

a. Environmental goals for this project include preservation and development of visual resources associated with the stream channel bank and surrounding areas and preservation and development of riparian or wetland habitat.

b. The dominant mechanisms of erosion along the bank to be protected include scour in the middle and upper banks by currents, local scour, and erosion of local lenses of non-cohesive sediment.

c. Construction materials available at reasonable cost include stone suitable for riprap and stone suitable for gabions.

d. Mean annual precipitation is more than 30 in. (762 mm).

e. Mean annual flood discharge is less than 10,000 cfs (283 m^3/sec).

f. Mean flow velocity at bank-full discharge is 5-10 ft/sec (1.5-3 m/sec).

g. Brush suitable for cutting and live staking (e.g., willow) is available locally.

h. The existing bankline or riparian corridor is not heavily vegetated with trees nor is it severely restricted by levees, streamside structures, or cultivation (answer none of the above to this question).

i. Stream flow during high flows at the eroding location is essentially parallel to the bank.

ENDOW output

38. ENDOW found that the following features were potentially feasible for the Little Blue River:

a. *Gabions.*

b. *Cellular concrete block revetment.*

c. *Covering riprap with soil and grass or ground cover.*

d. *Live cribwalls.*

e. *Brush mattresses.*

f. *Bank shaping and establishment of woody vegetation.*

g. *Rock toe protection with vegetative treatment of upper banks.*

h. *Riprap with live stakes.*

39. ENDOW rules do not account for effects of different bank protection methods on conveyance. Since the eroding bank is located in a flood control channel, some of the suggested techniques (such as riprap with live stakes) may not be feasible due to adverse effects on conveyance. Effects on conveyance should be considered prior to implementation.

PART IV: FLOOD CONTROL CHANNEL MODULE

Introduction

40. The ENDOW flood control channel module is a set of rules that assist a user in learning about and selecting structural features for inclusion in stream channel alteration projects that meet engineering criteria and address stated environmental goals. ENDOW selects these features from the list of 18 alternatives on the left side of Figure 6. If none of the 18 alternatives address the selected environmental goals and meet the engineering constraints for the site in question, ENDOW will suggest reconsideration of input and rerunning. Text screens that include bibliographies and existing projects related to the subject environmental feature are available for each of the 18 features. The text screens are in the ASCII file CHANNELS.SCR on the ENDOW disks. Photographs and figures of many of the environmental features are found in Shields (1982) and Nunnally and Shields (1985).

Channel Stability Check

41. Modified stream channels sometimes experience instability; in other words, they rapidly erode their beds or banks. Channel instability is often extremely detrimental to environmental resources. If the user has enough information, the flood control channel module will perform a rough check on the stability of the constructed channel. The stability check is attempted regardless of the environmental goals. However, if the user specifies that the constructed channel will not have a movable bed (e.g., it will be paved or excavated into rock), ENDOW assumes that the channel will be stable.

42. The ENDOW stability check is a "quick and dirty" procedure designed to identify the most extreme stability problems. If a problem is indicated, ENDOW includes a warning message in the final report that recommends a sediment transport analysis of the proposed channel by experienced hydraulic engineers. The ENDOW check will not identify all potential problems because the underlying equations are mostly empirical relationships that fit data sets with considerable scatter. Furthermore, problems caused by deposition in the constructed channel

(rather than by erosion) are not identified. It is possible that a situation flagged by ENDOW as a stability problem may not be one.

43. A flowchart of the ENDOW stability check is presented in Figure 15. Six equations are considered; five of these are checks of the slope of the constructed channel. A warning is issued if the constructed channel slope exceeds a critical value computed from equations based on discharge, bed material size, and channel width and depth. Selection of the equations used is based on bed sediment size and the available information. If the user assumes or estimates values for input to the stability check, he may use the change and rerun option (described in Part II) to check the sensitivity of the stability check to his assumption.

44. Literature references for each stability check are provided in Figure 15. The critical values for slope are based on observations of many natural streams and canals. Relationships that are based on bed material grain size as well as discharge are generally superior to those based on discharge alone. Channels that have slopes exceeding the critical value tend to have braided planforms (high sediment load, shifting mid-channel bars) rather than straight or meandering planforms.

45. The only stability check equation that is not a check of constructed channel slope checks velocity. If the mean velocity in the constructed channel exceeds 10 fps at bank-full discharge, and if the channel bed is expected to be sand, then a warning is issued (Warning 2, Figure 15). Mean velocity is computed from the continuity equation $V = Q/A$.

Example 1: Hocking River at Logan and Nelsonville, OH

Description

46. The Hocking River in southeastern Ohio flows in a sinuous channel about 90 ft wide with wooded banks (Figure 16). The channel meanders through small towns and forms in a steep-walled valley with heavily wooded slopes. A large borrow pit lake is located between a bend in the channel and a highway. The proposed project involves widening the channel to about 200 ft for approximately 2.7 miles. The upstream drainage area is about 580 square miles. The design event is the 100-yr flood (30,000 cfs). Mean discharge is 580 cfs, and bank-full

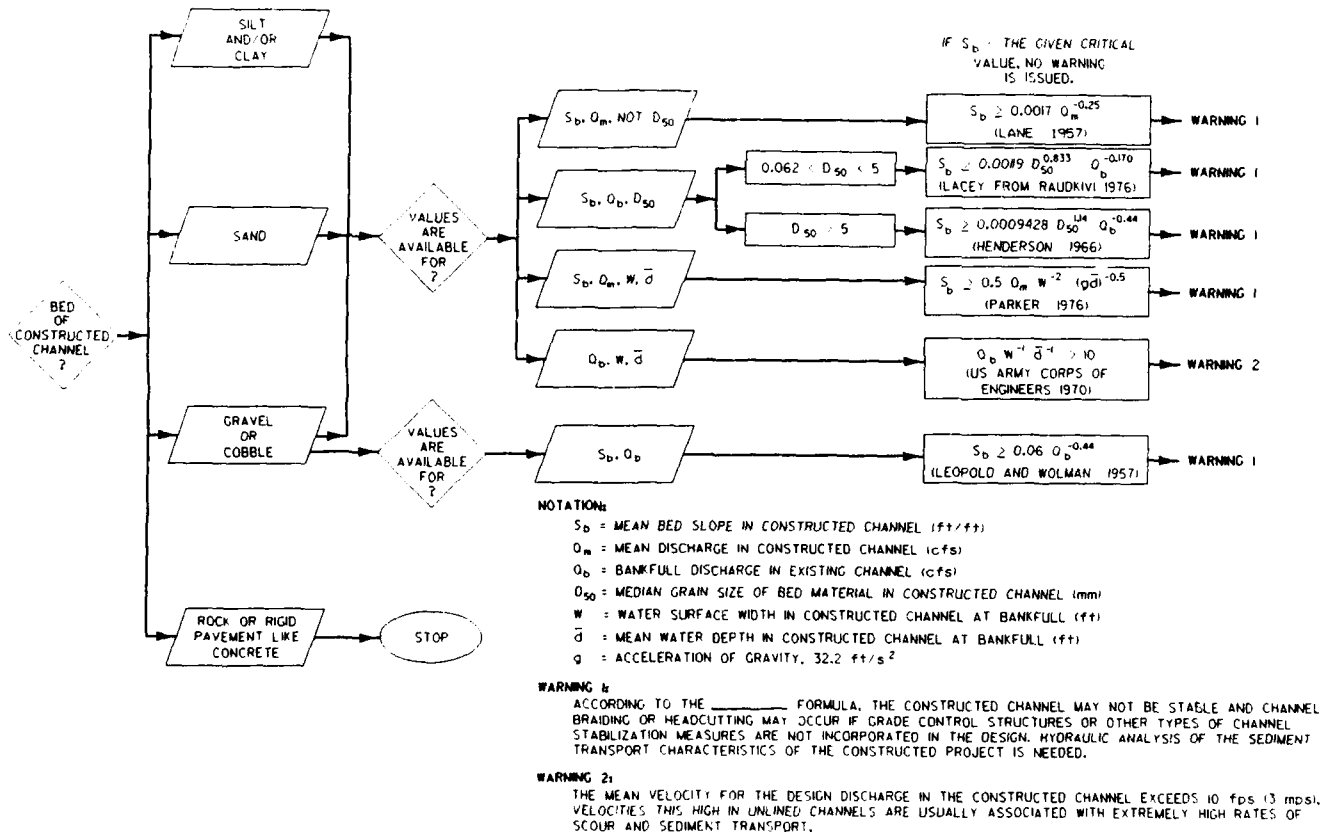


Figure 15. ENDOW stability check, flood control channel module

Figure 16. Hocking River in southeastern Ohio

discharge is about 2,000 cfs. Mean bed slope of the new channel will be 0.0002 (US Army Engineer District, Huntington 1987).

47. The bed is composed of gravel and coarse sand. Median bed particle size is expected to be 30 mm. Another channel project on the same stream, but downstream from this site (at Athens) has experienced rapid sediment deposition and has required frequent maintenance (six times in 10 years). However, three major tributaries flow into the Hocking River between Nelsonville and Athens, and the bed sediments grow noticeably finer below these confluences. A low-head water supply dam just upstream of Logan trapped very little sediment during its 20 years of existence.

Input data

48. Input data for an ENDOW run based on this project were as follows:

    a. Environmental goals for this project include preservation and development of aesthetic (primarily visual) resources associated with the stream channel and surrounding areas, provision of recreational opportunities, and preservation or development of aquatic habitat.

    b. Water quality in the constructed channel is expected to be suitable for recreational boating or canoeing and suitable to support a viable fishery.

c. The existing stream contains one or more significant meanders.

d. The bed of the constructed channel will be composed primarily of gravel or cobble.

e. The existing riparian corridor has

(1) Trees on one or both sides of the proposed channel right-of-way.

(2) Available right-of-way wide enough to allow for excavation of a wide flood control channel.

(3) Flat enough topography to allow a shallow (2-6 ft) impoundment near the channel.

(4) Site characteristics (soil, topography, acreage, adjacent land use) suitable for wildlife habitat.

f. The constructed channel will be at least partially inundated at all times except during severe droughts.

g. The constructed channel will have no barriers to fish movement up and down the channel.

h. Enlarged portions of the existing channel (for example, at a bridge crossing where the channel was widened when the bridge was built) are characterized by: little deposition and low sediment removal maintenance requirements.

i. The design discharge is greater than the 2-year discharge.

j. The design discharge for the constructed channel is more than 10,000 cfs.

k. The thalweg elevations of cutoff bends will be generally lower than expected low-flow stages in the constructed channel, and the bends will hold water even at low flow.

l. The constructed channel will not contain a boatway.

m. Estimated or approximate channel characteristic values are available for design slope in the constructed channel, mean discharge, bank-full discharge in the existing channel prior to enlargement, and median grain size [D_{50}] of the bed material in the constructed channel.

n. Median grain size of bed material in the new channel is 30 mm.

o. The design slope of the new channel is .0002.

p. The bank-full discharge of the existing channel (usually an event with return interval of 1 to 2 years) is 2,000 cfs.

q. Mean daily discharge in the constructed channel is 580 cfs.

r. The average concentration of suspended bed material in the main channel after cutoff construction is expected to be less than 50 ppm (mg/l).

s. ENDOW can compute projected sediment deposition volumes for a cutoff bend left connected to the main channel at its upstream end. Projections of the volume of sediment deposited in any one of the cutoff bends are not of interest at this time.

ENDOW output

49. ENDOW identified the following features for further study and possible inclusion in the proposed project:

a. *Mounding excavated material to create topographic diversity.*

b. *Single-bank modification.*

c. *Water level control structures.*

d. *Maintenance of hydraulic connections between the stream channel and cutoff bendways.*

e. *Two-stage channel.*

f. *Meandering alignments.*

g. *Low-flow channels.*

50. Problems with sediment deposition in the flood control channel downstream at Athens may or may not indicate a potential problem for this project. The impact of changing assumptions on ENDOW results was assessed with a second run similar to the first but with the answer to the statement:

"Enlarged portions of the existing channel....are characterized by:"

changed to

"little deposition and low sediment removal maintenance requirements,"

to

"sediment deposition in the widened portion of the channel and/or frequent sediment removal maintenance requirements."

51. The seven environmental features identified at the end of the first run were again listed, but water-level control structures, low-flow channels, maintenance of hydraulic connections between the stream channel and cutoff bendways, and two-stage channels received lower scores than originally. Furthermore, a warning was added to the final report: "The displayed environmental features that involve manipulation of the channel plan or cross section may be vulnerable to rapid sediment deposition and may be costly to maintain. A sediment transport analysis should accompany feature design." Identical results occur when the question about sediment removal is answered "don't know." For some versions, see the note on page 22, "Changing responses and rerunning."

Example 2: Twentymile Creek, Northeast Mississippi

Description

52. Twentymile Creek drains a 174-square-mile rural watershed and is tributary to the East Fork of the Tombigbee River. Crops and pasture cover the valley floor with isolated patches of brush and woods between fields and on the hillsides. Available evidence suggests that the stream had a meandering channel with an average bed slope of about 0.0002, an average width of 70 ft, and a depth of 8 ft at the turn of the century. Bank-full discharge was about 1,500 cfs. Historical sediment data are not available, but recent observations indicate that the bed is composed of fine sand with a D_{50} of 0.2 mm. Local interests straightened the channel between 1910 and 1930 to improve drainage, and Federal agencies may have further modified the channel between 1936 and 1940 (Shields et al. 1990).

53. In 1966 the Corps completed a flood control channel project on Twentymile Creek consisting of channel enlargement between RM 9.1 and the mouth, and clearing and snagging between RM 9.1 and RM 11.7. Design discharge for the enlarged channel was 3,200 to 3,700 cfs; design slope was about 0.0004. A period of extreme channel instability followed the 1966 project. Channel bed degradation and channel enlargement occurred from about RM 5.5 to RM 20 (Figure 17). Sediments that eroded from upstream reaches and tributaries were deposited in the reach

Figure 17. RM 11.7, Twentymile Creek, Mississippi, showing channel instability

between RM 5.5 and the mouth (Shields et al. 1990). The channel instability was severe enough that corrective measures (grade control structures and bank protection) were authorized and installed in the early 1980s. A 1989 study (Shields et al. 1990) found minimal aquatic habitat resources except in the scour holes below the grade control structures.

Input data

54. This example is based on Twentymile Creek conditions prior to the 1966 project. Could use of ENDOW have averted some of the problems that occurred? The statements below are in the order they were provided to ENDOW.

a. Environmental goals for this project include preservation or development of aquatic habitat and preservation and development of riparian or wetland habitat.

b. The existing riparian corridor has

   (1) Available right-of-way wide enough to allow for excavation of a wide flood control channel.

   (2) Flat enough topography to allow a shallow (2-6 ft or 0.6-1.8 m) impoundment near the channel.

(3) Site characteristics (soil, topography, acreage, adjacent land use) suitable for wildlife habitat.

(4) Site characteristics (flat topography, relatively impermeable soils, high groundwater table, and non-conflicting adjacent land uses) suitable for wetlands development.

(5) Very few or no small lakes.

c. Water quality in the constructed channel is expected to be suitable for recreational boating or canoeing and suitable to support a viable fishery.

d. The existing stream reach in question is straight or only slightly curving.

e. The existing stream is straight or only slightly curving due to previous channel alterations.

f. Estimated or approximate channel characteristic values are available for design slope in the constructed channel, mean discharge, discharge in the existing channel prior to enlargement, and median grain size [D_{50}] of the bed material in the constructed channel.

g. The design slope of the new channel is 0.0004.

h. If shallow impoundments were created for use as green-tree reservoirs, they would have flooding and draining requirements compatible with the flood control channel hydrograph.

i. The bed of the constructed channel will be composed primarily of sand.

j. The constructed channel will be at least partially inundated at all times except during severe droughts.

k. The constructed channel will have no barriers to fish movement up and down the channel.

l. Enlarged portions of the existing channel (for example, at a bridge crossing where the channel was widened when the bridge was built) are characterized by little deposition and low sediment removal maintenance requirements.

m. The design discharge for the constructed channel is less than 10,000 cfs (280 cm).

n. Median grain size of bed material in the new channel is 0.2 mm.

o. The bank-full discharge of the existing channel (usually an event with a return interval of 1 to 2 years) is 1,500 cfs.

p. Mean daily discharge in the constructed channel is 35 cfs.

ENDOW output

55. ENDOW suggested the following environmental features for further consideration and possible inclusion in the project in order to address stated environmental goals of aquatic and riparian habitat preservation and development:

a. *Preservation and creation of wetlands.*

b. *Preservation and development of riparian terrestrial habitat.*

c. *Green-tree reservoirs.*

d. *Water level control structures.*

e. *Gravel or stone armor.*

f. *Meandering alignments.*

g. *Low-flow channels.*

h. *Two-stage channels.*

i. *Instream habitat structures.*

56. ENDOW output also included an advisory warning regarding channel instability:

> *According to the Lacey formula the constructed channel may not be stable and channel braiding or headcutting may occur if grade control structures or other types of channel stabilization measures are not incorporated in the design. An additional hydraulic analysis of the sediment transport characteristics of the constructed project is needed.*

This warning resulted from execution of the stability check rules illustrated in the flowchart in Figure 15.

PART V: STREAMSIDE LEVEE MODULE

Introduction

57. The ENDOW levee module is a set of rules that assists a user in learning about and selecting structural features for inclusion in stream channel alteration projects that meet engineering criteria and address stated environmental goals. ENDOW selects these features from the list of 22 alternatives on the left side of Figure 7. If none of the 22 alternatives address the selected environmental goals and meet the engineering constraints for the site in question, ENDOW will suggest reconsideration of input and rerunning. Text screens that include bibliographies and example applications are available for each environmental feature. The text screens are in the ASCII file LEVEES.SCR on the ENDOW disks. Hynson et al. (1985) contains illustrations of many of the features.

58. Eleven of the 22 features deal with structural elements of borrow pits or interior drainage collection ponds. These small water bodies can be developed to provide habitat, recreation, or visual resources. However, public investment in special features for these areas may be unwise or against certain policies if they are entirely under private landowner control. Accordingly, ENDOW rules eliminate these features from further consideration if they are under private control. However, extenuating site-specific circumstances may allow implementation of some features on private property, so users may wish to vary their responses to questions about pit and pond ownership using the change and rerun option described in Part II.

Example 1: Souris River at Minot, ND

Description

59. A local flood protection project was constructed by the Corps of Engineers on the Souris River at Minot, in north central North Dakota in the late 1970s. The project consisted of channel realignment (cutoffs), channel enlargement, and about 3.4 miles of low, earthen flanking levees. Two-thirds of the levee embankment (by length) is less than 5 ft high. Basic levee sections had side slopes of 1V:2.5H or 1V:3H and top widths of 10 ft. In some cases existing levees constructed during emergency conditions in 1970 were reshaped or incorporated

into the new levees. Borrow pits were generally not needed, as sufficient material for new levee construction was provided by channel excavation and reshaping existing levees. Design discharge for the flood control project was about 5,000 cfs.

60. Minot is a medium-sized city in a community with a population of about 60,000. The project right-of-way passes through the urban center, but also traverses residential areas, a golf course, and a few wooded parcels. Wooded areas along the stream provide contrast to the surrounding treeless, gently rolling prairie. Waterfowl are common in the project area during warmer months.

Input data

61. The following input represents conditions prior to construction of the Corps project. Input was based on information gleaned from various documents (US Army Engineer District, St. Paul, 1972 and 1973; Nunnally and Shields 1985). In some cases, responses were based on reasonable assumptions.

a. Environmental goals for this project include preservation and development of visual resources associated with levees and surrounding areas, provision of recreational opportunities, and preservation and development of riparian or wetland habitat.

b. Overbuilding the levee embankment is practical.

c. Sufficient right-of-way to overdesign drainage ditches is not available.

d. The proposed levee right-of-way contains trees with outstanding visual or biological habitat value.

e. Alternative levee alignments are practical.

f. Streamside levee borrow pits will be entirely under private landowner control. (Note: Since the project will not include borrow pits, this response was given to avoid consideration of borrow pit features.)

g. The levee will be located in:

   (1) A waterfowl breeding area or a waterfowl flyway.

   (2) An urban area, park, or other highly accessible location used for recreation.

(3) A highly visible area.

h. Floodwalls will not be included in this project.

i. Levee interior drainage collection ponds will be public domain or covered by easement to allow fish and wildlife habitat or dry recreational area development and management.

j. Interior drainage collection ponds can be designed to hold water for short periods only.

k. Terrestrial habitat or habitat for small mammals and ground-dwelling birds is scarce in the project area.

l. Brush to develop wildlife habitat is available locally.

ENDOW output

62. ENDOW selected five features for consideration and possible inclusion in the Souris River levee:

a. *Overbuilt levee embankments.*

b. *Alignment of levee to avoid ecologically sensitive areas.*

c. *Use of dry interior drainage collection ponds for recreation.*

d. *Placement of brush piles for wildlife.*

e. *Containerized plantings on levee embankment.*

Additional information, including a short bibliography and lists of projects where these features have been employed, is available for each feature. Additional information may be accessed by pressing F1 while viewing the final results screen.

Example 2: Hypothetical Stream in the Southwestern US

Description

63. A local flood protection project including 6.2 miles of earthen levee and 0.8 mile of concrete floodwall is proposed for the reach of Dry Creek that passes through the center of Arid, a city of 100,000. The 100-year floodplain is only partially developed, and several stands of mature riparian trees and cultural resources sites occur along the

stream. Several alternative levee alignments are under consideration. Overbuilding the levee embankment, at least for part of its length, may be feasible. Borrow areas will be located along the river side of the levee and will remain in public ownership after the project. Interior drainage ponding areas will be of minimal size and are not available for environmental management.

64. Local sponsors have expressed interest in cost-sharing recreation developments. They are planning a park area in connection with the project. Much of the project is visible from streets and bridges downtown.

Input data

65. The following input represents conditions prior to construction of the Corps project.

a. Environmental goals for this project include preservation and development of visual resources associated with levees and surrounding areas, preservation and development of riparian or wetland habitat, and preservation of cultural resources.

b. Overbuilding the levee embankment is practical.

c. Sufficient right-of-way to overdesign drainage ditches is available.

d. The proposed levee right-of-way contains trees with outstanding visual or biological habitat value.

e. Alternative levee alignments are practical.

f. The proposed levee right-of-way contains significant subsurface cultural resources.

g. Streamside levee borrow pits will be public domain or covered by easement to allow fish and wildlife habitat development and management.

h. The levee will be located in or near an urban area, park, or other highly accessible location used for recreation and located within highly visible areas.

i. Levee borrow pits will hold water permanently and are located on the waterside of the levee but will not experience flooding by the leveed stream more than 60 days annually, on average.

j. Floodwalls will be included in this project.

k. Levee interior drainage collection ponds will be under private landowner control.

l. Terrestrial habitat or habitat for small mammals and ground-dwelling birds is scarce in the project area.

m. Brush to develop wildlife habitat is available locally.

n. Borrow areas will be large enough to leave unexcavated areas.

o. Borrow pit dimensions will include maximum depths greater than 3 ft (1 m).

ENDOW output

66. ENDOW identified the following features as potentially feasible for the streamside levee project under consideration:

a. *Overbuilt levee embankments.*

b. *Overdesigned drainage ditches.*

c. *Alignment of levee to avoid ecologically sensitive areas.*

d. *Design of borrow pits for visual effects.*

e. *Textured or colored finishes for floodwalls.*

f. *Floodwalls with folding or removable sections.*

g. *Placement of brush piles for wildlife.*

h. *Creation of islands in borrow pits.*

i. *Containerized plantings on levee embankment.*

j. *Design of borrow pits for wildlife.*

k. *Burial of cultural resources sites under the levee embankment or berm.*

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