HYDRAIN

INTEGRATED DRAINAGE DESIGN COMPUTER SYSTEM

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for:

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TABLE OF CONTENTS

List of Figures

Page

List of Figures (continued)

Page

List of Tables

Page

Preface

This report presents documentation for the HYDRAIN system. HYDRO, HYDRA, CDS, WSPRO and HY8 are five nonproprietary hydrology and hydraulic engineering programs incorporated in the HYDRAIN system. The HYDRAIN personal computer oriented system operates these engineering applications with programs written in the C language. The system is designed with an open architecture for expansion. HYDRAIN is sponsored as a Pooled Fund Project (PFP) of 29 State highway departments and is managed by the Federal Highway Administration (FHWA). The system is expanding with flexible lining design logic and integrated culvert analysis logic under development. Graphic output options are also under development and are available in some areas already.

Within the HYDRAIN concept, the HYDRO, HYDRA, CDS, and WSPRO allow the user to consistently input, edit and run relevant input data files and to scroll through output files. With these applications "short", one-line, and "long", multiple line, help is provided within an editor that services all applications.

HYDRAIN integrates hydraulic and hydrology programs into a unified system. The intent of the integration is to enable users to then learn basic principles of how to operate an application and file manipulation and then be able to apply the same principles to other applications and files within the system. One guiding principle is a **command land input format.** This trend in hydraulic programs is typified by HEC-2 and HYDRA. It is very pragmatic. WSPRO also adopted the command line method. Another guiding principle is a **generic input editor** that works the same for each integrated program--HYDRO, HYDRA, CDS, and WSPRO. The input file for each integrated program is a line by line command language that identifies the computation and/or provides the required data. Each line of data is preceded with a two or three-letter command. A typical command is **XS**, indicating a cross section; both WSPRO and CDS read this command. Another typical command is **PDA**, indicating the line contains the design parameters for pipe analysis (PIPE DATA); HYDRA reads this command.

A strength and a weakness of HYDRAIN is the need to know beforehand the sequence of commands that will result in making an application work. The commands are, of course, the batch input file. The user needs to know a proper sequence or know how to put one together. The sequences are termed "footprints." Given the right "footprint," an application will work; note that footprints are not necessarily unique, in that there may be several ways to get a job done. This documentation includes footprints to get users started and user support will aid in proper "footprint" design. Once a user has a library of footprints for his applications, the use of HYDRAIN should save considerable time and money. HY8 is a stand-alone interactive BASIC program that accepts inputs during processing; HY8 does not require footprints and leads the unfamiliar user through input preparation. All engineering programs but HY8 are batch oriented, and three steps are built into the process of using them: input file generation, programs execution, and output file screen review or listing. HY8 accepts inputs and generates outputs as the engineering program logic is executing.

HYDRO Program

HYDRO is a command line hydrology program. FORTRAN code for HYDRO was developed to combine existing approaches for rainfall and runoff analyses into one computerized program. Within the HYDRAIN system, it can be used independently or it can be used to generate input data for other engineering programs within the system.

HYDRO offers many hydrologic analysis options to the engineer. Each is site specific based on user inputs.

- Design Rain Using Digitized NWS Information or State-Supplied Files - Calculates the rainfall intensity for a specific return period, duration, and site.

- Design Hyetograph using Yen and Chow's method - Calculates the rain versus time plot for a return period, duration and site.

- Intensity-Duration-Frequency Curve Using Either the NWS Information or State-Supplied Files - Analyzes a specific site and creates two graphs: a plot of points for durations up to 24 hours, and a detail graph of the first two hours. Can be input to HYDRA.

- Design Flow by Rational Method - Uses a specific return period, duration and intensity to determine the peak flow for the site.

- Design Flow by USGS Regression Method - Uses USGS log-log regression equations with user-supplied parameters to determine design flow.

- Design Flow by log Pearson type III - Calculates the peak flow for given data.

- Design Hydrograph by USGS Dimensionless Hydrograph - Calculates a hydrograph to support storage routing within HYDRA or CDS.

- Maximum Observable Flood - estimates the largest flow at a site based on the envelope of all floods in a region.

HYDRA Program

HYDRA is a command line gravity pipe network hydraulics program. FORTRAN code for HYDRA previously existed and the Pooled Fund work effort included substantial improvements. HYDRA is a storm and sanitary sewer system analysis and design program. It can be used either to model an existing sewer system or to design a new system.

HYDRA generates storm flows by using either the Rational Method technique, hydrologic simulation techniques, or accepting a hydrograph generated by a HYDRO analysis. It can be used to design or analyze storm, sanitary or combined collection systems. HYDRA can handle up to 1,000 contributing drainage areas and

2,000 pipes. Additionally, HYDRA can be used for cost estimating. The Rational Method approximates the peak rate of runoff from a basin resulting from storms of a given return period. HYDRA's hydrologic simulation models the natural rainfall-runoff process. In the simulation, runoff hydrographs are generated, merged together, and routed through the collection system. Inlet limitations can be analyzed: inlet overflow can be passed down a gutter system, while inlets in sumps can store water in ponds.

In the HYDRA design process, the program will select the pipe size, slope and invert elevations given certain design criteria. Additionally, HYDRA will perform analyses on a existing system of pipes (and/or ditches). When an existing system of pipes is overloaded, HYDRA will show suggested flow removal quantities as well as an increased pipe diameter size as an alternative remedy. HYDRA includes HEC-12 inlet theory hydraulic gradeline calculations, and an ability to route flow through internal storage sites using a storage-indication method.

HYDRA requires the forming of an input file of commands to describe the sewer system. Commands for HYDRA are placed in a logical sequence usually from upper to lower elevation. Is it possible that several command sequences can produce the same result. An input file is established for a particular collection system by the engineer and then the HYDRA program is executed. To change the characteristics of the collection system, the input file can be edited.

The HYDRA program requires design criteria for the pipes: friction factor (Manning's "n"), minimum diameter, ideal depth, minimum ground cover, minimum velocity (full flow), minimum slope, and maximum diameter. The friction factor is necessary for both analysis and design, while the remaining values are needed only for design. In the case of a design, the program selects invert elevations and slope as well as the physical sizing of each link given certain design criteria, whereas in the analysis mode, pipe alignment and sizing are predetermined and the impact of proposed flows are analyzed. Design criteria can be changed for each pipe if so desired. HYDRA is not an optimization program, thus individual case studies need to be run and analyzed by the engineer.

CDS Program

CDS is a command line culvert program. The Culvert Design System provides the user with two broad options for investigating culvert characteristics. CDS can either (1) hydraulically design a culvert or (2) analyze an existing or proposed culvert. CDS has capabilities for investigating a variety of hydrograph relationships, culvert shapes, materials, and inlet types. With CDS, the engineer can request any of six culvert types: round concrete, round metal, arch concrete, arch metal, oval concrete, and concrete box. CDS routes hydrographs, considers ponding, and overtopping.

The Design option selects a culvert size and number of barrels that are compatible with engineering data, environmental constraints, and site geometry. In this option, hydraulic performance data are calculated for each new culvert system design. The Review option provides hydraulic performance data for any preselected combination of culvert type and size, inlet type, slope, and number of barrels. The initial design and analysis options may be followed by up to five

additional culvert types or flow frequencies so that a full spectrum of risk scenarios or economic considerations can be simulated at the same time.

Two possible flow scenario methods can be selected: (1) steady state or irrigation, that assumes constant flow through the culvert, or (2) dynamic, that simulates drainage flow conditions. The dynamic option can route a hydrograph through the culvert system using three hydrograph alternatives: a user input hydrograph, a hydrograph produced by the HYDRO program, or the use of an internally produced default hydrograph (simulating semi-arid, high plains conditions). Additionally, the dynamic flow scenario can accommodate upstream pond storage.

CDS will determine culvert size based on the design headwater, headwater/diameter ratio, inundation, outlet velocity, cover limitations, or any combination of these parameters. The program will automatically increase the number of barrels when the upper limit for the greatest vertical dimension is exceeded. There is a limit of six barrels for commercial size culverts and five for concrete box culverts. The program can also be used to assess flood hazards, environmental assessments of upstream pond coverage, downstream flooding, channel impact, inlet type and beveled inlet evaluations, and reservoir facilities which use a culvert type structure for the spillway. Based on these data the program will proceed to identify the flow type and the outlet conditions for velocity, Froude number, and brink depth.

WSPRO Program

WSPRO is a command line step backwater program for natural channels with an orientation to bridge construction. The Water Surface Profile Computation Model Microcomputer Program has been designed to provide a water-surface profile for six major types of open channel flow situations:

- Unconstricted flow.
- Single opening bridge.
- Bridge opening(s) with spur dikes.
- Single opening embankment overflow.
- Multiple alternatives for a single job.
- Multiple openings.

WSPRO was originally developed by the United States Geologic Survey (USGS) for the Federal Highway Administration. The model was a batch mode mainframe program, written in FORTRAN. The members of the Pooled Fund Project decided to use WSPRO as the bridge waterways analysis element of the Integrated Computerized Drainage Design System. WSPRO was downloaded to the microcomputer by the USGS and FHWA. The microcomputer version of WSPRO, is dated August 1987.

The command input file forms a logical description of the physical characteristics of a waterway. Once the user is comfortable with this method of data setup, the program provides a step backwater method for determining water surface profiles. The scheme is similar to the Corps of Engineers HEC-2 program. Both WSPRO and HEC-2 are acceptable to the Federal Emergency Management Agency. WSPRO has the advantage that it utilizes more recent approximation techniques for the backwater effects associated with bridge constrictions.

HY8 Program

HY8 is an interactive culvert analysis basic program that utilizes the FHWA analysis methods and information published by pipe manufacturers. The program includes modules to allow the user to interactively enter, save, and edit data. HY8 will compute the culvert hydraulics for circular, rectangular, elliptical, arch, and user defined geometry. Additionally, improved inlets can be specified and the user can; analyze inlet and outlet control for full and partially full culverts, analyze the tailwater in trapezoidal and coordinate defined downstream channels, analyze flow over the roadway embankment, and balance flows through multiple parallel culverts. A hydrograph can be produced and routed.

The initial logic involves calculating the inlet control and outlet control headwater elevations for the given flow. These elevations are compared and the larger of the two is used as the controlling headwater elevation. Tailwater effects are taken into consideration when calculating these elevations. If the controlling headwater elevation overtops the roadway embankment, an overtopping analysis is done in which flow is balanced between the culvert discharge and the surcharge over the roadway. A balancing technique is also used in the case of multiple barrels. If the culvert is less than full for all or part of its length open channel computations are performed.

A series of data menus, data screens, summary screens, and output screens guides the user through the program. Each menu contains several options to match the desired culvert configuration, while the data screens prompt the user for specific dimensions and coordinates. Summary screens allow the user to edit entered data or change menu selections. Output screens display the output as calculations proceed; hard copy is only obtained using the "print screen" key.

There are three main groups of data to be entered into the program: initial culvert data, downstream channel data, and roadway data. Within the program, the user is sequentially led from one group to the next. From these sets of data, the program develops culvert performance data with or without overtopping. A performance curve can be plotted on a computer with graphics capabilities. For a given flow, HY8 can design a culvert. In addition to developing performance curves, the program generates rating curves for uniform flow, velocity, and maximum shear for the downstream channel. Culvert outlet velocities, inlet control head, and outlet control head are also calculated; energy dissipator design is possible.

HYCHL and HYCULV Programs

HYCHL and HYCULV are command line, flexible channel and culvert programs that are under development. HYCHL will solve for fixed and flexible lined channels. HYCULV will integrate state-of-the-art culvert flow methods and utilize features of both CDS and HY8.

Operation

To allow the software to be used by a wide audience, HYDRAIN operates on an IBM XT/PC or equivalent microcomputer with 640 K RAM, a hard disk, and a monochrome monitor. A math coprocessor is needed. Engineering programs are in Fortran 77. The utility software and editor is in C. The HYDRO, HYDRA, CDS, and WSPRO programs have command line input with are "short" and "long" help files available through the same editor that operates any of them. HY8 has also been integrated into the HYDRAIN system and is available as an interactive BASIC culvert program.

Report Contents

The remaining section of this volume provides technical reference and user instructions for the HYDRAIN program. There are a total of 6 such volumes for HYDRAIN.

Disclaimer

FHWA, the pooled fund States and their agents have, within the limits of their resources, tested and debugged the HYDRAIN shells. The engineering programs derive from several varied sources and were adapted to HYDRAIN and also underwent testing and debugging. However, this is a very large and somewhat complicated system of logic and coded implementation and errors and omissions may yet remain in the software. Therefore, use at your own risk. Please document problems and errors and report to FHWA. User support and technical assistance will be provided to pooled fund States. Agents of these States using the system should channel their requests for support or assistance through their sponsor State.

1. Introduction

The HYDRAIN System Shell is designed to control the entire system of Pooled Fund Project (PFP) programs. The System shell supports analysis and design programs and facilitates communication (data transfer) between these programs. It also provides a basis for file and disk management as well as permitting tutorial modules. Finally, MS-DOS input, output or program files, can be reviewed within this shell.

The System Shell is written in the C language. This language is portable, and is efficient for performing input/output and controlling other programs. The system integrates existing and newly developed stormwater drainage programs to provide a modular, expandable, and comprehensive set of tools for the practicing engineer. The objective is to provide existing tools to practicing engineers in a form which will enhance their productivity.

Definitions of the following terms are useful:

- HYDRAIN System - A software package of hydraulic and hydrologic analysis programs developed under the aegis of the Pooled Fund Project.
- Engineering Program - A fundamental program or module in the HYDRAIN system that performs hydraulic or hydrologic computations. These are FORTRAN programs.
- Shell - A program "wrapped around" another program to facilitate its use. The PFP uses the C language for these shells.
- Program Shell - A shell built around one of the engineering programs (sometimes referred to as an Input Program in the documentation).
- HYDRAIN System Shell - A shell built around the entire system of engineering programs and program shells.
- Generic Editor - A program shell that provides full screen text editing capability to HYDRAIN command line engineering programs. The generic editor supplies an intermediate to high level of support (in the form of short and long help and word processing capabilities) to the user who desires to create or edit an input dataset. This editor is intended to front end any engineering programs with command line input files. A description of the generic editor is presented in Appendix A.
- Interactive Editors - This category of program shells provides semi-expert system assistance in data input/edit, range and error checking, and providing short and long help.
- Program Module - A combination of a program shell and an engineering program.

- Command Line Inputs - A line by line method of input that keys on a command as the first item in each line. The command identifies the remaining items on the line and their organization.

The engineering programs, input programs and other modules controlled by the HYDRAIN system shell are as follows:

- HYDRA - Storm Drain and Sanitary Sewer Analysis.
- WSPRO - Open Channel Water Surface Analysis.
- HYDRO - Design Event versus Return Period.
- CDSV5 - Culvert Design and Analysis System.
- HY8V3 - Version 3 of the Penn State Culvert Program.
- EQUAT - Flow Equation Program.
- Future PFP Programs - these will include:
  - HYCHL, a flexible & rigid lining channel design program.
  - HYCLV, a culvert program that combines the best of HY8V3 & CDSV5.
  - HY???, other programs desired by the HYDRAIN user community.
- Generic Editor - Inputs / Edits HYDRAIN command line data sets.
- Support System Modules.
  - DOS Shell (go back and forth to DOS without leaving HYDRAIN).
  - System Maintenance (File Housekeeping).
  - System SETUP (Change drives, directories, devices, colors).
  - System Information.
- Quit (leave HYDRAIN programs).

Currently, the HYDRA, WSPRO, HYDRO, CDSV5, and HY8V3 engineering modules, and support system modules are operational. Space has been allotted for the addition of future programs. Figure 1 illustrates the logical layout of the System Shell engineering modules.

Access to these modules is controlled by employing one of five primary options: **Input/Edit**, **Execute**, **Utilities**, **System Information**, and **Quit**. The capabilities of these options will be briefly discussed below.

The first two options, **Input/Edit** and **Execute**, provide access to a corresponding design and/or analysis program by parallel branching to the design and analysis modules. The system shell assists the user by ensuring that proper naming conventions are used and by providing on-line help upon request.

The **Utilities** option allows the user to perform many file management functions. These include the DOS equivalent activities of changing and reviewing directories as well as copying, deleting, renaming, printing or viewing files. It also allows the user, through the **DOS System Shell** option, to temporarily return to the DOS operating system. Finally, **Utilities** allows the user access to a SETUP module where screen colors, default drives and directories, or device characteristics can be changed.

The **System Information** module provides on-line help - a feature provided throughout the PFP system - for further explanation of a requested option as well as providing "how to" information and selected references.

This document reviews the capabilities of the HYDRAIN System Shell, provides a technical reference and discusses user instructions. The goal is to allow the user to understand and use the System Shell, including use of all of the modules of the Pooled Fund Project.

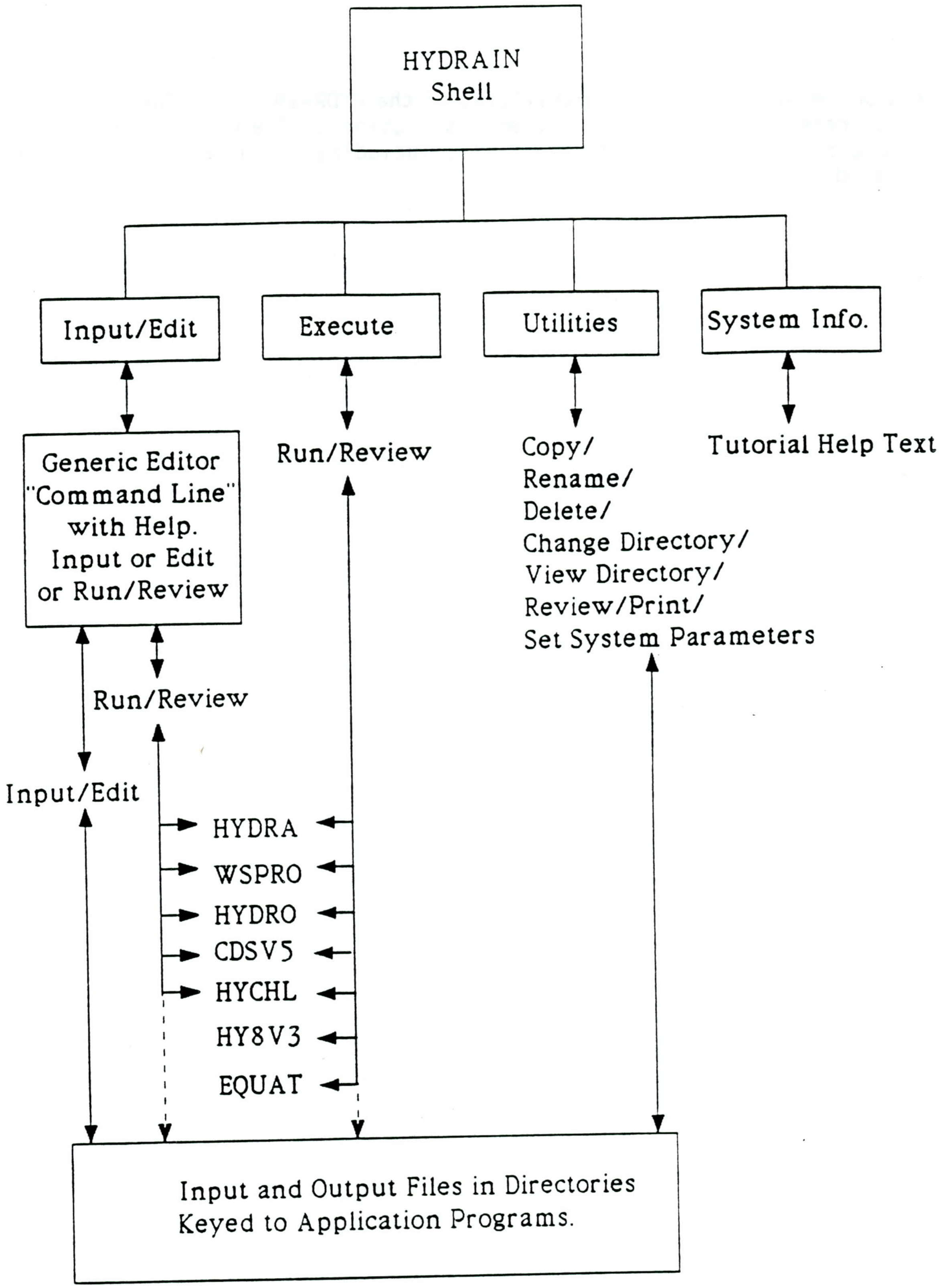

Figure 1. HYDRAIN layout.

2. Technical Reference

Summary of Features

The HYDRAIN System Shell is designed to run on MS-DOS version 3.0 (or higher) on IBM-XT/PC or compatible microcomputers. It has the following capabilities:

- Linkages to PFP Engineering Modules - There are five engineering programs: HYDRA, WSPRO, HYDRO, CDSV5, and HY8V3. Four of the five are batch programs that can use the generic editor to assist in entering/editing data. HY8V3 has internal routines that allow for the interactive input, editing, or execution of data.

- Open Architecture - This allows the number of modules and programs included in the system to grow as the user community wishes. By planning for the addition of future programs, the HYDRAIN System Shell ensures flexibility, allowing such modules to be easily "plugged in".

- Active Short Help Messages - The System Shell (as well as other program shells) has an active, one line, context sensitive, help message that appears automatically when the cursor is on each appropriate field. The help message provides the user with a short concise description of the operation of the field. When the cursor is moved to another file, the short help message is updated.

- Long Help on Request - Long help messages are available to the user at any time within the HYDRAIN system by pressing the function key <F1> (denoted as <F1> in the documentation). These messages range in length from a short paragraph to several pages.

- DOS "Shell" Capabilities - This allows the user to temporarily "leave" the HYDRAIN System Shell and enter DOS. Typing **EXIT** at the DOS prompt returns the user to the HYDRAIN main menu. An obvious use of this feature is to "leave" the System Shell to enter a word processor or text editor, or to execute a spreadsheet program such as Lotus 1-2-3. When this option is selected, HYDRAIN will remain resident in memory. For this reason it is important to always return to the System Shell (by typing **EXIT**) and leave HYDRAIN in a normal manner (through the **QUIT** option).

- Screen Capture of Inputs - The primary advantage of a shell is its ability to use the entire terminal screen as an input device.

- File Review Program - A file review program with data display capabilities is used by many modules in the system shell. The program allows the user to view all of the input, output and other files that are found in the HYDRAIN system. It allows the use of the ↑ and ↓ keys, PgUp, PgDn, Home and End keys to move vertically (ie. top to bottom) through a file, and the use of the ← and → keys to move horizontally in a file. This horizontal scrolling ability is useful for viewing documents wider than the computer's display screen. In this way, a 132 character output, such as those produced by CDSV5, can be easily reviewed.

- System Maintenance - One file module available to the user consists of system upkeep capabilities. This system maintenance module provides the user with the DOS equivalent commands of Renaming, Copying, Deleting, and Printing files. The user can either enter a filename, or choose from files contained in the HYDRAIN directories. Additionally, the Drive and Directory features allow the user to scan the files in any of the HYDRAIN or user's drives and directories.

- Ring Menus - The decision screens in the system and program shells consist of a series of fields linked by a ring menu. This means the user can select the option they wish to investigate by using the cursor keys to move to the field and striking carriage return or enter (denoted as <CR> in the documentation). In some areas of the system, the user can also choose an option by simply pressing a letter which is highlighted in the field.

File Management Structure

The overall file management structure is designed to be operated on a hard-disk drive using MS-DOS 3.0 (or higher) as the operating system.

At installation, or with the SETUP module, the user can create any file management structure that is possible on their system. A discussion of the custom directory layout is found in Appendix B of this document. If this customizing feature is not used, HYDRAIN will use the default hard disk file structure shown below in Figure 2. The "main" directory is **HYDRAIN**. This directory contains the executable and help files used by the system shell, generic editor and setup program. The main directory has a subdirectory **ITM**, that contain files shared by analysis programs. Five level one directories, designated **HYDRA**, **WSPRO**, **HYDRO**, **CDSV5**, and **HY8V3**, contain all executable files, input files, output files, and help files used by each particular analysis program. The file management structure will be transparent to the user when running the HYDRAIN package. A description of how experienced users can design alternative directory management structures is found in Appendix B.

```
- ROOT ─┐
        ├─ HYDRAIN ──── ITM  (Intermediate/Shared Files)
        ├─ HYDRA  (Storm Drains)
        ├─ WSPRO  (Bridge Waterways)
        ├─ HYDRO  (Hydrology)
        ├─ CDSV5  (Culvert 1)
        ├─ HY8V3  (Culvert 2)
        │
        └─ ETC... (other directories on the drive ...)
```

Figure 2. Default HYDRAIN directory structure.

Whether or not the default or an alternative directory structure is used, the HYDRAIN System shell uses this structure when it passes information to an input program, engineering program, or output review program. For example, when the system shell uses a "child" process to execute HYDRA, it takes the user supplied filename, appends the appropriate drives and paths, and passes this information to the program. Exactly how this is accomplished for a specific program depends on whether the "child" program performs input, output, or analysis functions.

File Naming Conventions

Standardization of input and output file extensions is used to further ensure compatibility and to prevent the passing of incorrect files.

All PFP files must follow the convention **xxxxxxxx.zzz**. The file name node or prefix (ie: xxxxxxxx) may have up to eight characters (conforming to DOS file naming conventions). An extension (ie: zzz) of up to three characters is also required.

Engineering Program File Name Extensions

To assist the programs in distinguishing the input found from different analysis programs, HYDRAIN uses some default extensions. **At the users discretion, any extension can be used instead of these defaults. The result will be that some of the helpful file finding utilities used by HYDRAIN will not function.**

- The Storm Drain and Sanitary Sewer Analysis and Design program (HYDRA) uses an **HDA** extension for inputing/editing data and executing the program.

- The Bridge Waterways (and Open Channel) Analysis program (WSPRO) uses a **WSP** extension for inputing/editing data and executing the program.

- The Hydrology program (HYDRO) uses an **HDO** extension for inputing/editing data and executing the HYDRO analysis program. As the HYDRO program has been changed to a command line format, some of the older input data sets must be converted to the new format. See the HYDRO documentation for more information on this change.

- The Culvert Design and Analysis System (CDSV5) uses a **CLV** extension for inputing/editing data and executing the CDSV5 analysis program. **Since the program has been converted to a free format command version, the older "work deck" extensions (i.e. SD, SS, CD, and FD) are no longer used and will not be recognized by HYDRAIN.** See the CDSV5 documentation for more information on this change.

Output File Name Conventions

- All output files will retain the input file name prefix (i.e. xxxxxxxx), but they will have a **LST** extension.

Other File Name Conventions

- **QT** - This extension contains the ordinates of a hydrograph (ie: flow (Q) versus time (T)). The file is generated by HYDRO and, at user option, can be incorporated into the other PFP Engineering programs (ie: into HYDRA using the **UHY** Command).

- **HYE** - This extension contains the ordinates of a hyetograph (ie: rainfall intensity (I) versus time (T)). The file is generated by HYDRO and, at user option, can be incorporated into the other PFP Engineering programs (ie: into HYDRA using the **HYE** Command).

- **IDF** - This extension contains the ordinates of an Intensity-Duration-Frequency (IDF) curve (for a duration from 5 minutes to 24 hours). The file is generated by HYDRO and, at user option, can be incorporated into HYDRA using the **RAI** Command.

- **HLP** - This extension indicates the file contains either short or long help for the different shells. There will be at least two help files for each program.

- **CNF** - This extension is used by the SETUP and INSTALL programs to hold information used by the HYDRAIN system.

- **DFN** - This extension contains the engineering shell data definitions, default values, range checks, and variable types.

- **ERR** - This extension contains any system error messages. The standard error output (if any) is captured by the system shell and may be viewed to assist in debugging.

The file convention, when combined with the file management structure discussed earlier, provides the user with a strategy and method of organizing files within the MS-DOS environment. Files would only be found within their designated directory. This avoids the confusing proliferation of many different input files within a single DOS directory. For example, if using the default directory structure, HYDRO input files will be found in the **HYDRO** input subdirectory, WSPRO executable files will be found in the **WSPRO** executable subdirectory, and so forth. Files that are used by differing programs (such as files with **IDF**, **QT**, and **HYE** extensions) are also placed in a common subdirectory, **ITM**, where they too can be easily accessed by the engineering modules.

Keyboard Usage

HYDRAIN reserves certain keys to assist the user in performing specific tasks. Generally, the meaning of each of the keys is the same. Some program specific variations occur, but usually within the context of that program. In any event, the specific meaning is provided in the appropriate documentation.

Function Keys

HYDRAIN uses two primary function keys and one secondary function key throughout the system shell and each of the program shells. The function keys currently active in the module that the user is in will be displayed on the bottom of the screen. They are used as follows:

F1 - **HELP** - strike this primary function key for additional long help. The help message corresponds to the field the cursor is on when <F1> is pressed.

F2 - **Hot Key** - this primary function key is used to "escape" or "abort" an action, or, in the case of the generic editor, to access the ring and pull-down menus.

F3 - this secondary function key is currently active only in the file delete section of the HYDRAIN System Shell (one of the Utilities). It will not be used anywhere else.

Cursor Keys

← Left arrow - moves the cursor to the left one field or space.
→ Right arrow - moves the cursor to the right one field or space.
↑ Up Arrow - moves the cursor up one line.
↓ Down Arrow - moves the cursor down one line.

Other Keys

<CR> - Enter/Carriage Return - Continue to the next screen.
Esc - Escapes or aborts an operation.
PgDn - Moves screen display forward one page.
PgUp - Moves screen display backwards one page.
Home - Moves to beginning of display.
End - Moves to end of display.
Backspace - Deletes spaces in a field one at a time.
Ctrl-End - Deletes contents of an entire field.

Minimum Equipment Configuration

Hardware

- IBM XT/PC or compatible with 640K RAM.
- 360K Floppy Diskette Drive.
- Hard Disk Drive (10MB minimum capacity).
- Math Coprocessor (8087, 82087, 83087).
- Monochrome Monitor and Adapter (24 X 80); VGA card and monitor recommended.
- Dot Matrix Printer.
- Surge/Spike Protector.

Note:

A Color Graphics Adapter (CGA) card is required to use the graphical capabilities of the HY8 program. The program can also run without a CGA card. Because of future HYDRAIN enhancement, a VGA card is recommended for all equipment.

Software

- MS-DOS (version 3.0 or higher).
- FORTRAN compiler and linker.
- "C" compiler.

Note:

The FORTRAN and C compilers are not required to run the HYDRAIN programs as supplied, but may be useful for programmers.

3. User Documentation

Installation

The following is a description of the procedure to be performed in order to successfully install the HYDRAIN system onto a microcomputer. The Install program itself is quite descriptive and the user is prompted for all necessary information. The user will notice that, at the bottom right corner of virtually every screen, the message "To continue, press any key" is displayed. This ensures that the user has sufficient time to read all of the information presented on the screen.

Begin by placing the Install diskette into the A drive. (If the system on which HYDRAIN is being installed does not have a color monitor type "MSHERC" and press <CR> before proceeding). Type "Install" and press <CR> to begin the program.

The first screen displayed provides the user with vital information about his system: the DOS version detected, the presence of a math coprocessor, and the graphics card detected. In the case that the DOS version is less than 3.0, the Install program will automatically terminate. Similarly, if the system does not have a math coprocessor, the program will terminate. It is recommended that, if the latter occurs, a math coprocessor be purchased and installed on the machine.

If none of the aforementioned factors are present to prevent the Install program from running, the prompt "To continue, press any key" is displayed and the user should continue.

The next screen asks the user to choose the disk drive from which HYDRAIN will be run. The HYDRAIN system requires 2.75 MB of disk space, therefore, it is important to choose a drive with sufficient free space. To aid the user in making a selection, the screen displays the amount of free space available on all of the hard disks. If a drive is selected which has insufficient space, the program will terminate and offer the user the opportunity to clear space on the disk. If a feasible drive is selected, the message "To continue, press any key" will appear.

After selecting a disk drive, the user is asked to choose if the default or user defined HYDRAIN directory structure will be used. Recall that the directory structure specifies where executable, input, output, and help files are found when using the HYDRAIN system. During installation, these directory structures are created, and the appropriate executable, data, and help files are copied from the diskettes to the structures. (The input and output files are created by the user, and so none of these types files are copied). If the user has no specific layout in mind, it is recommended that "Default" be selected.

If the "Default" option is chosen, the next screen will either show the program creating the new directories, or, it will tell the user that an older version of HYDRAIN exists. If the latter is the case, choosing "Yes" will allow the user to leave the Install program to back-up or remove the old files.

Choosing "No" will result in a screen which gives explanations as to what (if any) new directories have been created.

In order to specify manually where the HYDRAIN programs will be located, move to "User Defined" and press <CR> (or simply press "U"). Again, press any key to continue. The screen depicted in Figure 3 is then displayed.

** User Defined Hydrain Paths **

Using the menu at the right, the user should select each of the seven Hydrain path categories. Upon selecting an option, the user will be prompted for information needed to build a valid path; namely the drive & directory for the executable files, the help files, & depending on the option, the input & output files. After entering all the relevant information, continue the installation by using the LEAVE option. See documentation for more information

HYDRAIN
ITM FILES
HYDRA
WSPRO
HYDRO
CDSV5
HY8V3
Leave

Enter Path Information for Hydrain Files

Figure 3. User defined path menu

From this sub-menu, the paths are set for HYDRAIN, as well as for all of its sub-programs. To select an option, move the cursor and press <CR>, or, type the letter which is highlighted for the desired option.

The screen which is displayed when the HYDRAIN option is selected lets the user tell the program where to find the HYDRAIN executable and help files. To change the path, move the cursor to the appropriate field and enter the new drive and directory. To exit the HYDRAIN option and return to the "Path Information" sub-menu shown above, press <Esc>. This process applies for all of the other programs listed in the sub-menu shown in the figure above. It is important to note, however, that some of the programs may require the user to enter the appropriate directory for input and output files as well.

After all of the directories have been set, move the cursor to "Leave" and press <CR> (or simply press "L") to continue with the install process.

Upon leaving the portion of the Install program wherein the user sets the correct directories, the program will load the information from the first diskette onto the selected drive. The block in the center of the screen tells the user exactly what procedure is being carried out. There will only be two files, **HYDRAIN.EXE** and **EDIT.EXE** copied from this first diskette.

After all of the information from diskette 1 is copied, the following prompt is displayed:

Insert 'HYDRA Program' disk (2 of 9) into disk drive

Insert the correct diskette and press <CR>. If the correct disk IS NOT inserted, the program will continue to prompt the user for the correct diskette. After the second distribution disk is properly inserted, the program will then copy all of the information from diskette 2 to the directory which was specified for HYDRA. When the copy is complete, the following prompt will appear for the next diskette:

Insert 'WSPRO Program' disk (3 of 9) into disk drive

Insert disk 3 and press <CR>. This time, the program will copy all of the information from the diskette to the directory which was specified for WSPRO. Follow the same procedure for the remaining diskettes until all nine have been copied onto the computer.

After the files have been copied to their respective directories, the installation program creates three files, **HYDRAIN.CNF**, **PFPHY8.BAT**, and **DRIVE.DAT**. These files contain information developed by the installation program, based on the users responses at the prompts. This file creation process is transparent to the user. Upon completion of this file creation, HYDRAIN is now installed on the computer. The installation program will terminate, leaving the user in the HYDRAIN main directory. The HYDRAIN system is ready to be used.

This concludes the installation procedure. The next section discusses how to use the features in the HYDRAIN System Shell.

Note: Versions of HYDRAIN installed prior to the version 3.0 release modified the **AUTOEXEC.BAT** and **CONFIG.SYS** files. These modifications were a series of DOS statements that added HYDRAIN drive and path information to the environment (using SET commands). HYDRAIN Version 3.0 no longer needs these statements in order to execute. It is suggested that these older statements be removed at the users leisure.

Using the HYDRAIN System Shell

To enter the HYDRAIN system, change the directory and type "Hydrain" as follows:

C> CD HYDRAIN and press <CR>
C> HYDRAIN and press <CR>

where <CR> denotes enter/carriage return. This notation for carriage return will be used throughout the documentation.

The first HYDRAIN System Shell screen, depicted below in Figure 4, will appear on the monitor. This screen provides introductory program information. At the top of the screen is the program title and current version (the version number is important for assisting in user support questions). These are followed by a listing of the 29 sponsoring states in the Pooled Fund. Finally, the name, address, and telephone number of the prime contractor, GKY & Associates, is provided in case user support is required. This first screen will always appear. Press any key to continue.

HYDRAIN - DRAINAGE DESIGN SYSTEM
Version 3.0

Sponsored by the Pooled Fund Project States:

Alabama	Arizona	Arkansas	California	Colorado
Connecticut	Florida	Idaho	Illinois	Iowa
Kansas	Louisiana	Maryland	Minnesota	Mississippi
Montana	New Jersey	New York	N Carolina	Oklahoma
Oregon	Pennsylvania	S Carolina	Texas	Utah
Vermont	Virginia	Washington	Wyoming	

in cooperation with Federal Highway Administration

developed by:
GKY & Associates, Inc., Springfield, VA.
(703-642-5080)

To continue, press any key.

Figure 4. HYDRAIN system shell initial screen.

The second screen contains a statement dealing with the responsibilities of the user and the FHWA. Again, any key can be pressed to continue.

The next screen is the HYDRAIN Main Menu, illustrated below in Figure 5. The Main (or primary) Menu is the principle decision node for the entire HYDRAIN system. This means that to reach any module in the HYDRAIN system, the user must begin with this menu.

```
Friday December 1, 1989                                HYDRAIN Version 3.0
Input or edit data for HYDRA, WSPRO, HYDRO, CDSV5, HYCHL
      Input/Edit    Execute    Utilities    System Info    Quit

  - Program Type -

       HYDRA
       WSPRO
       HYDRO
       CDSV5
       HYCHL

                         Main Menu
                      F1-HELP  F2-Return
```

Figure 5. HYDRAIN main menu.

There are five options available in this menu, the first four of which have sub-menus associated with them. The five main menu options and their functions are listed below:

- **Input/Edit** - Create or edit new and existing input files using either the generic or interactive editor.
- **Execute** - Run a program.
- **Utilities** - Make DOS changes, view files, change Setup.
- **System Info** - Access long help for selected HYDRAIN topics.
- **Quit** - Leave the HYDRAIN system and return to MS-DOS.

The main menu, as well as several other menus in the HYDRAIN system shell, is a "ring menu". Ring menus enable the user to move in either the left or right directions using the arrow keys. The "ring" means that moving the cursor "right" of the **QUIT** option moves it back to the **INPUT/EDIT** option. Similarly, moving "left" of **INPUT/EDIT** places the cursor back at **QUIT**.

Options within the four sub-menus just mentioned are presented in the form of **pull-down** menus which enable the user to move in either the up or down directions using the arrow keys. The advantage of pull-down menus as compared to clearing the screen to display options is that the user is able to see all of the selections they have made to get to the sub-menu they are in. That is, the user is able to follow a progression from entering the system to the most detailed sub-menu. Movement within the sub-menus is accomplished using the arrow, <Home>, and <End> keys. Home moves the cursor to the top of the pull-down menu, while End moves the cursor to the last selection in a menu.

There are two ways by which the user might select an option from a menu:

- Use the arrow keys to move the cursor (actually a highlight bar) to the desired option. Press <CR> to select an option. This method may be employed in every menu in the HYDRAIN system.

- If a letter in an option in any given HYDRAIN menu or sub-menu is **highlighted**, pressing that letter will invoke the associated option. For example, notice that the "E" in Execute is highlighted in the main menu. Pressing **E** will select the Execute command. It is equivalent to manually moving the cursor to **Execute** and striking <CR>.

Two forms of **Help** are available throughout the HYDRAIN system. Help is designed to provide the user with brief but detailed information regarding commands, functions, and operations of the given program. Active (short) help is constantly displayed at the top of the screen for the command on which the cursor is positioned. In addition, more detailed long help is available for many command options by pressing <F1>. Once in the long help screen, the text can be scrolled using the ↓, ↑, <PgUp>, and <PgDn> cursor keys. Pressing <Esc> will return control to the HYDRAIN System Shell.

The ensuing sections investigate the options available through the HYDRAIN System Shell. The first group of options is found in the Input/Edit menu.

Input/Edit

Selecting the Input/Edit function results in the user being presented with a pull-down menu. This menu, shown earlier in Figure 5, currently has five program options from which to choose. These options are: HYDRA, WSPRO, HYDRO, CDSV5, and HYCHL. For this (and all other) pull-down menu, a program is selected by using the arrow keys to move the cursor to the desired program. Once the cursor is in the correct position, pressing <CR> will effect the selection. As mentioned earlier in this document, **HYCHL**, the flexible and rigid lining channel design program is currently under development and is not active at this time.

Regardless of which program is selected, the user is presented with a choice of the generic or interactive editor. Figure 6 depicts the screen that illustrates these two choices. The generic editor allows the user almost complete freedom to edit command line input files. Use of this editor assumes that the user has a basic working knowledge of the generic editor program and its requirements; details on the generic editor are found in Appendix A. The more specific instructions, in the appendix, take the user through the editing process in a step-by-step manner. Specifications and proper use of the editor are also provided in that area of the documentation.

To make a selection, move the cursor to the desired field and press <CR>, or, press **G** for generic or **I** for interactive. **As it is still under development, currently, none of the HYDRAIN programs can access an interactive editor.** Should the user select this option, they will be given a message to this effect.

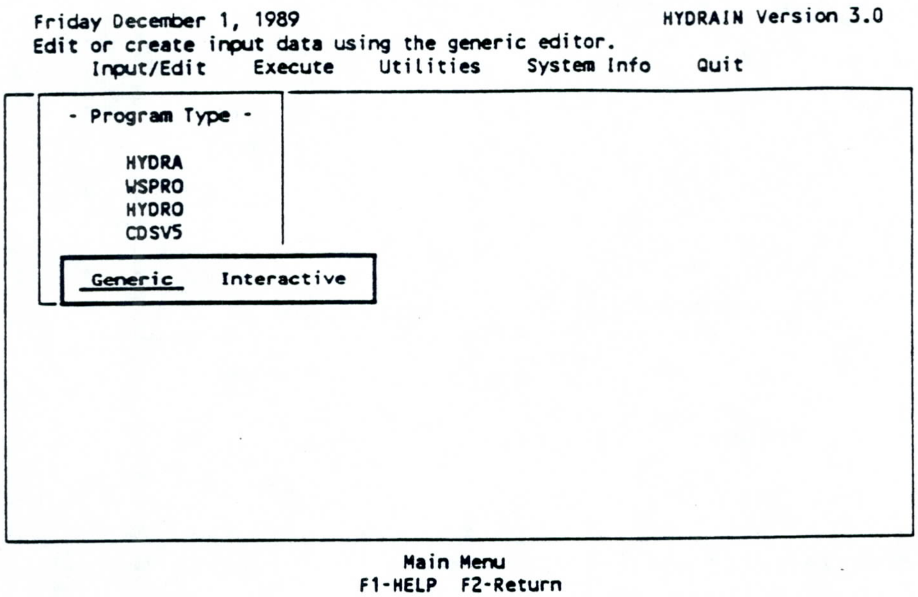

Figure 6. Generic or interactive editor choice screen

The next screen, displayed in Figure 7, asks the user to select a file to be edited (or created). The bottom of the screen shows the path of the input files of the program selected. It also displays the number of bytes free on the disk being used. Only those files having the default extension (.HDA, .WSP, .HDO, or .CLV) that is appropriate for the program selected are displayed.

To create a new file (or use a file that does not use the default extension), move the cursor to **[..EDIT..]** and press <CR>. The cursor will move to the "File:" field. The user should type the name of the file and press <CR> **twice** to begin editing. (The first <CR> places the users newly entered name into the "File:" field). After pressing <CR> the second time, the user is placed into the generic editor (or the interactive editor, when it becomes available). If the user has not yet decided on a name, simply pressing <CR> once (leaving the "File:" field blank), will enter the editor without a filename. At the appropriate time, a filename can be added within the editor. Refer to the editor documentation for instructions on this and other aspects of the editors usage.

```
Friday December 1, 1989                                    HYDRAIN Version 3.0
Edit or create input data using the generic editor.
    Input/Edit    Execute    Utilities    System Info    Quit

                       Select File to be Edited

                  File: __________
           ________________________________________________
      [..EDIT..]    EXAMPLE1.HDA  EXAMPLE2.HDA  ROUTE95.HDA
      OCEAN-RD.HDA

              C:\HYDRAIN\HYDRA\*.hda    Bytes Free: 25000000.

                              Main Menu
                          F1-HELP  F2-Return
```

Figure 7. File selection screen.

To select a file from those already existing, move the cursor and press <CR>. The file name selected will be moved to the field next to "File:" as shown in Figure 8. To begin editing, press <CR>.

```
Friday December 1, 1989                                    HYDRAIN Version 3.0

    Input/Edit    Execute    Utilities    System Info    Quit

                       Select File to be Edited

                  File: EXAMPLE2.HDA
           ________________________________________________
      [..EDIT..]    EXAMPLE1.HDA  EXAMPLE2.HDA  ROUTE95.HDA
      OCEAN-RD.HDA

              C:\HYDRAIN\HYDRA\*.hda    Bytes Free: 25000000.

                              Main Menu
                          F1-HELP  F2-Return
```

Figure 8. Select file in the "File:" field.

Should the user wish to change his file name selection, at the "File:" field, they may type the name of the file desired (with the proper three-letter extension) and press <CR>. This newly entered file name will be sent to the appropriate editor.

The user is never required to use the default HYDRAIN extensions, but, as will become evident with continued use of HYDRAIN, to do so makes operations such as this much easier.

The user may return to the HYDRAIN main menu at any time by pressing <Esc> or <F2>. This conclude the description of the Input/Edit option.

Execute

There are six programs from which to choose in the Execute sub-menu shown in Figure 9. (The last program, HYCHL, is not yet active). The programs can be categorized as being from one of two categories; batch or interactive execution. These concepts are discussed below:

- HYDRA, WSPRO, HYDRO, and CDSV5 are known as **BATCH** programs (this is not to confused with a DOS Batch file). This means that they assume that any data they use to solve a problem already exists and is in a separate input data file. The program executes. The results calculated by the program are placed in a separate output file. This approach is similar to how mainframe programs process information.

- HY8V3 and EQUAT are **INTERACTIVE** programs. That is, they combine data entry and program execution together. For example, HY8V3 will collect data, calculate intermediate output, collect more data and calculate more information, and so on until the problem has been completed. The user is an element of the process. Choosing either of the interactive programs will cause HYDRAIN to directly invoke the interaction execution process.

Figure 10 depicts the screen displayed after selecting any of the batch programs. The user must select a file to be run. The selection is made in exactly the same manner as was described earlier in the Input/Edit section. The user may choose an already existing file from those displayed by moving the cursor and pressing <CR> twice (the first <CR> selects the file, while the second <CR> executes the engineering program), or, they might enter a filename by selecting the **[..EDIT..]** option. The only reason the user might use the **[..EDIT..]** option would be to run a file which has a different extension than the one for the program. For example, HYDRA program files will most often have the **.HDA** extension. If, however, a HYDRA file has a .DAT extension, the **[..EDIT..]** option would be used to select that file. Because of the nature of the HYDRAIN file management module, these non-default extension files will not appear as available selections, even though they may exist on the correct input drive and path.

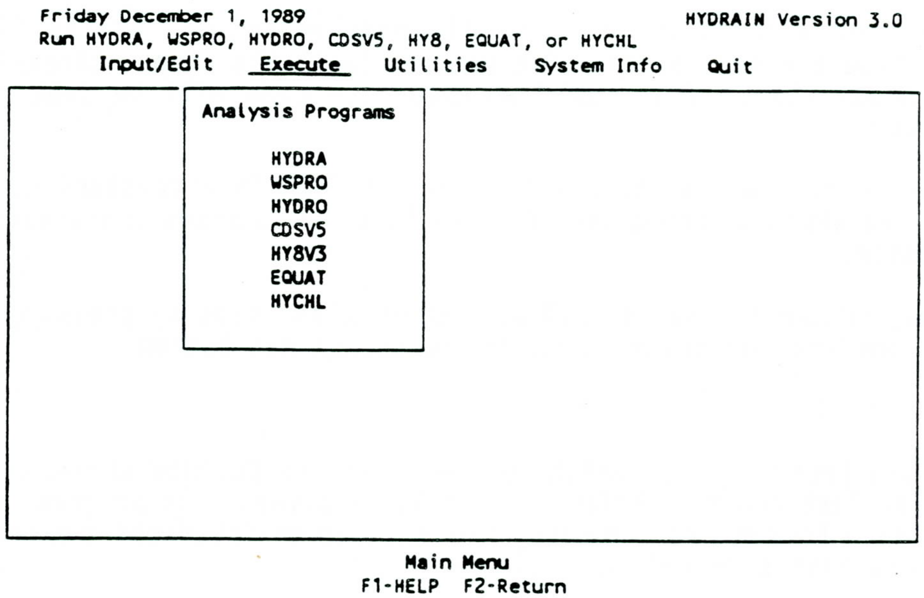

Figure 9. "Execute" option pull-down menu.

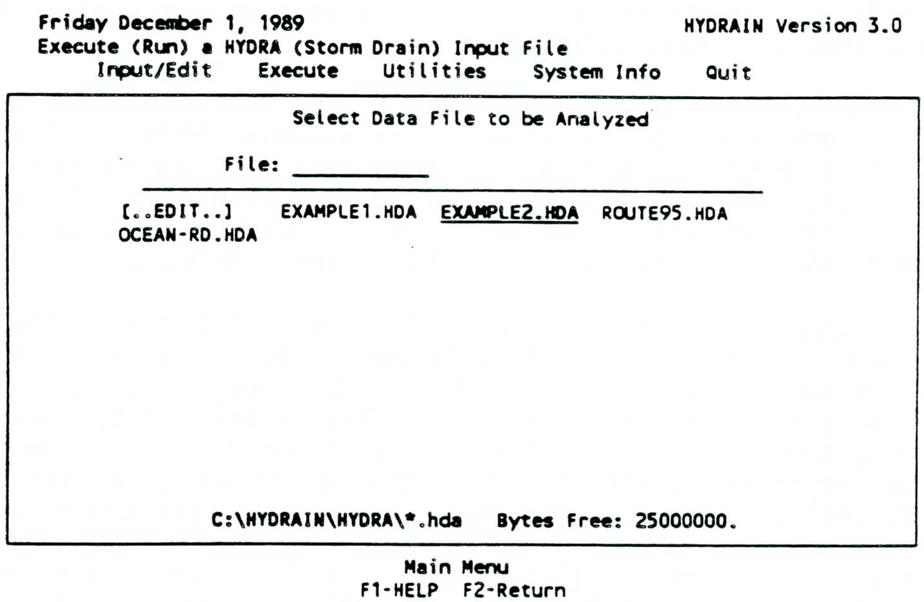

Figure 10. Selection of data file to be analyzed.

After a file is selected, the program is run and the output will be displayed. Again, pressing <Esc> or <F2> will return the screen to the HYDRAIN main menu.

Utilities

The Utilities sub-menu, shown in Figure 11, provides the user with ten options on the pull-down menu. The first six: copy, rename, delete, change directory, change drive, and view directory enable the user to easily perform maintenance functions. The DOS system shell option enables the user to enter the DOS system without leaving the HYDRAIN system shell. The final two options: review and print, allow file manipulation. The last option invokes the SETUP program. Select any of these options by moving the cursor and pressing <CR>. Pressing <Esc> or <F2> at any time will return the user to the HYDRAIN main menu. Each of these pull-down menu options will be discussed in detail in the following section.

```
Friday December 1, 1989                              HYDRAIN Version 3.0
DOS commands, File operations, HYDRAIN setup
     Input/Edit    Execute    Utilities    System Info    Quit

                         DOS Functions
                       ----------------
                             Copy
                            Rename
                            Delete
                       Change Directory
                         Change Drive
                        View Directory
                       DOS System Shell

                       ---- Files ----
                            Review
                            Print

                       ----------------
                            SETUP

                          Main Menu
                      F1-HELP  F2-Return
```

Figure 11. "Utilities" option pull-down menu.

Copy

The **Copy** function is used to copy a file located on the current drive and directory to a file found at any location. After selecting this option, the screen in Figure 12 is displayed.

The wildcard filename, "*.*", is provided as the default file name. It is global in that, by DOS convention, "*.*" applies to all files present in a directory. The reason this is done is to allow the user to view an entire directory (achieved by simply striking <CR> at the wildcard), or to apply the wildcard concept so that only certain files would be listed. For example, to copy only the executable files, the user could enter "***.EXE**" at the prompt. Another example would be to enter "**H*.***" to copy only those file that begin with an "**H**".

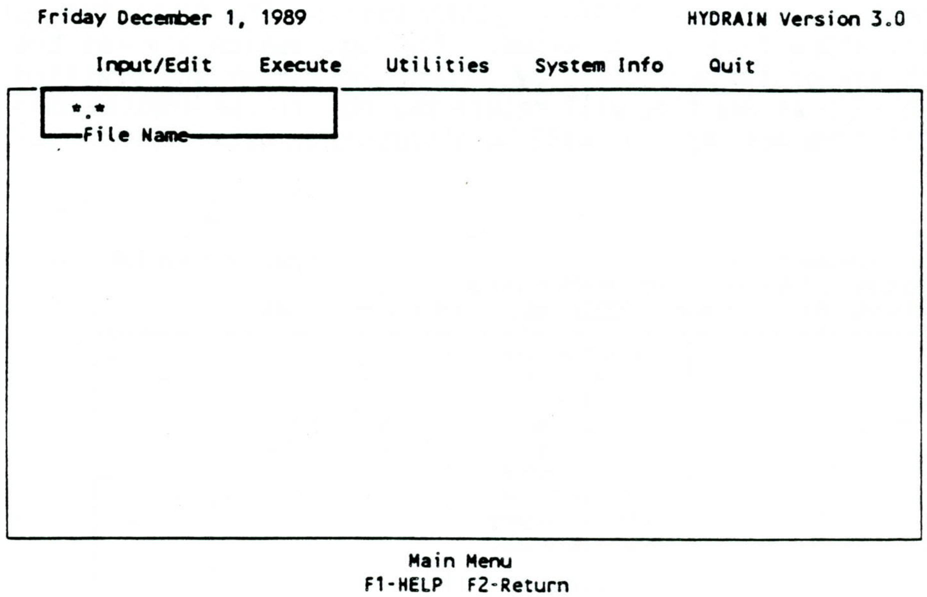

Figure 12. File selection screen.

Press <CR> to view a listing of all of the files in the current drive and directory. When presented with the list of files, such as the one in Figure 13, choose the Source File by moving the cursor and pressing <CR>. Should there be more files than can "fit" on the screen, the cursor keys can be used to scroll files into view. In this example, the file **KROLAK.LTR** has been selected.

The "Destination File:" field is now highlighted and the user should type the filename to which the copied file should go. When this information is entered, press <CR> twice to execute the copy and return to the main menu. (The first <CR> indicates to the program that a change in the default setting in the field is taking place. In essence, the user is changing the contents of the field from a blank to a filename. The second <CR> simply starts the copying process.). The file will be copied into the default directory. To change to a new drive, path, or filename, simply retype them when entering the desired filename and pressing <CR> twice. (Note: **[.RET MENU.]** will always return the user to the HYDRAIN main menu.). Alternatively, the user can return to the HYDRAIN main menu by pressing <Esc> or <F2>.

```
Friday December 1, 1989                                  HYDRAIN Version 3.0

     Input/Edit     Execute     Utilities     System Info     Quit

  Source File:                              Destination File:
  C:\HYDRAIN\____KROLAK.LTR                 C:\HYDRAIN\__________________

    [.RET MENU.]       EDIT.EXE        HELP.EXE        PFPHY8.BAT
    HYDRAIN.EXE        HYDRO.HLP       WSPROI.HLP      WSPRO.HLP
    SETUP.EXE          HDRN1.HLP       HDRN2.HLP       HDRN3.HLP
    HDRN4.HLP          HDRN5.HLP       HDRN6.HLP       HDRN7.HLP
    HDRN8.HLP          HDRN9.HLP       HDRN10.HLP      HDRN11.HLP
    HYDRAIN.CNF        HDN.ERR         SETUP1.HLP      SETUP2.HLP
    SETUP3.HLP         SETUP4.HLP      SETUP5.HLP      SETUP6.HLP
    SETUP7.HLP         WINDEF          READ.ME         FAKE.EXE
    KROLAK.LTR         NOTREAL.FIL     HYDRAIN.LTR     ZATZ.MEM
    HC12.EXE           HC15.EXE        TBOX.EXE

                         HYDRAIN File Select
                          F1-HELP  F2-Return
```

Figure 13. Selecting files in the copy option.

Rename

The **Rename** function allows the user to rename any file in the current drive and directory. After selecting this option, the screen in Figure 12 is again displayed. Once again, the user can select the default (considering all available files), or by using the wild card, select files which have certain names or characters. In either case, press <CR> to view the listing of available files. Once again, a screen similar to the one depicted in Figure 13 will appear. Select a file to be renamed by moving the cursor and pressing <CR>. Then type the new name of the file (with three-letter extension) and press <CR> twice to enact the command. As before, the new name can be changed by reentering it before <CR> is hit for the second time. Press <Esc> or <F2> to return to the HYDRAIN main menu.

Delete

The **Delete** function allows the user to delete one or more files from the current drive and directory. The screen in Figure 12 is displayed once again after choosing this option, and the listing of available files is given on the next screen. To select a file to be deleted, move the cursor to the file and press <CR>. Selected files are marked with two asterisks: "**". The mark may be removed by moving the cursor to the file and pressing <CR> again. More than one file may be marked for deletion at any time. Figure 14 shows a file listing with several files marked for deletion. To delete the files, press F3. This is the only usage of F3 in the entire HYDRAIN system. The intent being to give the user ample opportunity to change his mind before deleting a group of files.

```
Friday December 1, 1989                                        HYDRAIN Version 3.0

      Input/Edit     Execute     Utilities     System Info     Quit

                         Select File(s) to be Erased

     [.RET MENU.]       ROUTE1.LST         IST95.RPT          SCOUR.RPT
     FILE1 **           FILE2              FILE3              FILE4
     FILE5 **           FILE6              FILE7              FILE8
     FILE9              FILE10             KROLAK.LTR **      TRB.RPT
     REPORT1            REPORT2            READ.ME            ERROR.CNF **
     CULVERT.DAT **     FISHPSGE.MEM       CLVRT2.DAT **      CLVRT3.OUT **
     CULVERT.OUT **     SCOUR1.DAT         SCOUR1.LST         SCOUR2.INP
     SCOUR2.LST         BADFILE.DAT **     ERRFILE.DAT **     IST95A.CDS
     IST95B.CDS         IST95C.CDS         BADFL2.OUT **      OOPS **
     HYDRAIN.CNF        EQUAT.EXE          EQUAT.DAT          HYDRAIN.EXE
     HDN.ERR **         EXAMPLE3.HDA **    EXAMPLE2.HDA **    EDIT.EXE
     MEMO.HDA           HELP.EXE           GROCERY.LST        PFPHY8.BAT
     SETUP.EXE          SETUP1.HLP         SETUP2.HLP         SETUP3.HLP
     BADFL3.DAT **      T.DAT **           SETUP4.HLP         SETUP5.HLP
     SETUP6.HLP         SETUP7.HLP         HDRN1.HLP          HDRN2.HLP

                             HYDRAIN File Select
         RET-Select File(s)     F2-ESC     F3-Delete Selected File(s)
```

Figure 14. Selecting files to be deleted.

The result of striking F3 will be a re-listing of the files on the current drive and directory **without** those files that have been deleted. This re-listing of files is illustrated in Figure 15. As stated earlier, the fact that a file

```
Friday December 1, 1989                                        HYDRAIN Version 3.0

      Input/Edit     Execute     Utilities     System Info     Quit

                         Select File(s) to be Erased

     [.RET MENU.]       ROUTE1.LST         IST95.RPT          SCOUR.RPT
     FILE2              FILE3              FILE4              FILE6
     FILE7              FILE8              FILE9              FILE10
     TRB.RPT            REPORT1            REPORT2            READ.ME
     FISHPSGE.MEM       SCOUR1.DAT         SCOUR1.LST         SCOUR2.INP
     SCOUR2.LST         IST95A.CDS         IST95B.CDS         IST95C.CDS
     HYDRAIN.CNF        EQUAT.EXE          EQUAT.DAT          HYDRAIN.EXE
     EDIT.EXE           MEMO.HDA           HELP.EXE           GROCERY.LST
     PFPHY8.BAT         SETUP.EXE          SETUP1.HLP         SETUP2.HLP
     SETUP3.HLP         SETUP4.HLP         SETUP5.HLP         SETUP6.HLP
     SETUP7.HLP         HDRN1.HLP          HDRN2.HLP          HDRN3.HLP
     HDRN4.HLP          HDRN5.HLP          HDRN6.HLP          HDRN7.HLP
     HDRN8.HLP          HDRN9.HLP          HDRN10.HLP         HDRN11.HLP
     MISSEDME.HA        ALSO.BAD           REPORT3            REPORT4
     LAST.FIL

                             HYDRAIN File Select
         RET-Select File(s)     F2-ESC     F3-Delete Selected File(s)
```

Figure 15. Result of file deletion.

is not shown on the screen does not necessarily mean that it is not in the directory. If the screen appears full, use the cursor keys to scroll through the list of files to see if any more are present. Notice that in Figure 15, there are files present in the directory that were not visible in Figure 14. These files could have been seen by scrolling down. To return to the HYDRAIN main menu, press <Esc> or <F2>, or select the **[.RET MENU.]** option.

Change Directory

The **Change Directory** option allows the user to change the directory which is to be used as a default throughout the use of the system shell. The screen in Figure 16 is displayed after selecting this option. The current default directory is listed at the bottom of the screen. To change the default, move the cursor to **[.PREV DIR.]** and press <CR> or move to one of the listed sub-directories and press <CR>. If Figure 16 reflected the default HYDRAIN directory structure, selecting **[.PREV DIR.]** would take the user to the root directory. The next screen would list all of the first level directories available on the current drive. Select a directory by moving the cursor and pressing <CR>. (Note: **[.RET MENU.]** will return the user to the HYDRAIN main menu.) Also, pressing <Esc> or <F2> at any time will return the user to the HYDRAIN main menu. **Note:** there may be more directories than are immediately shown on the screen. In this case, simply use the cursor keys to scroll down until all available directories are in view.

```
Friday December 1, 1989                              HYDRAIN Version 3.0
Change the default directory to any other on the current drive
     Input/Edit    Execute    Utilities    System Info    Quit

                  Select Directory for HYDRAIN Access

         [.RET MENU.]  [.PREV DIR.]     HYDRA       WSPRO
         HYDRO         CDSV5            HY8V3       ITM

                     Current Directory: C:\HYDRAIN

                        F1-HELP  F2-Return
```

Figure 16. Directory screen.

Change Drive

The **Change Drive** option lets the user change the default disk drive. Figure 17 illustrates the screen that appears after selecting this option. The current default drive is displayed at the bottom of the screen. To change the drive, move the cursor and press <CR>. The display at the bottom of the screen will change accordingly.

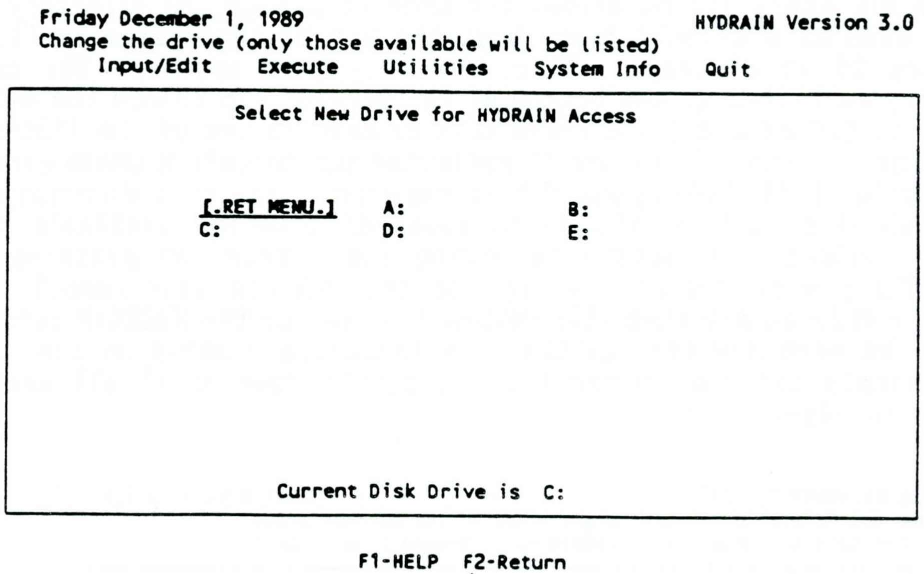

Figure 17. Current drives on user's system.

After the desired drive is selected, move to **[.RET MENU.]** and press <CR> to return to the HYDRAIN main menu. Using the <F2> or <Esc> keys will automatically return the user to the HYDRAIN main menu.

View Directory

The **VIEW DIRECTORY** option allows the user to view a listing of all of the files on the current drive and directory. After selecting this option, the screen in Figure 10 will appear once again. Press <CR> to view the directory, or use the wildcard feature to view any part of a directory. An example directory is shown in Figure 18. All pertinent information about the files and the directory is given. Use the arrow, <PgUp>, and <PgDn> keys to view additional files. The list of files shown are in no particular order, so if a expected file is not seen, scroll down the list until it is found. Notice that the current date and time are displayed in this screen. This is the current time and date of the system. To return to the main menu, press <Esc> or <F2>.

Friday December 1, 1989 HYDRAIN Version 3.0

Input/Edit Execute Utilities System Info Quit

Files	Bytes	Date	Time
EDIT.EXE	139251	12-01-89	9:00a
HDRN10.HLP	568	12-01-89	9:00a
HDRN2.HLP	2884	12-01-89	9:00a
SETUP.EXE	100685	12-01-89	9:39a
WINDEF	92	12-01-89	10:47a
HDRN3.HLP	4438	12-01-89	9:00a
HDRN5.HLP	796	12-01-89	9:00a
HDRN4.HLP	3813	12-01-89	9:00a
SETUP2.HLP	1148	12-01-89	9:00a
EQUAT.EXE	119296	12-01-89	9:00a
HELP.EXE	25070	12-01-89	9:00a
EQUAT.DAT	27162	12-01-89	9:00a
READ.ME	2500	12-01-89	9:00a
PFPHY8.BAT	162	12-01-89	10:22a
HYDRAIN.EXE	98674	12-01-89	9:00a
HDRN1.HLP	3108	12-01-89	9:00a

Current Working Directory:
C:\HYDRAIN

Search Criteria: *.*

75 Files Use 1500000 bytes.

Total of 25000000 bytes free.

Fri Dec 01 11:00:00 1989

F1-HELP F2-Return

Figure 18. Files found on default directory.

DOS System Shell

The **DOS SYSTEM SHELL** option allows the user to enter DOS while keeping the system shell resident in memory. It was recognized by users of earlier versions of the HYDRAIN system that sometimes the need arises for the HYDRAIN user to temporarily go to DOS, possibly to use a word processor or a spreadsheet. To use the DOS System Shell, move the cursor and press <CR>. The user will be placed into DOS with the screen resembling that seen below.

```
The IBM Personal Computer DOS
Version 3.10 (C)Copyright International Business Machines Corp 1981, 1985
             (C)Copyright Microsoft Corp 1981, 1985

Type EXIT to return to HYDRAIN.
C>
```

Operate normally within DOS and type "**EXIT**" to return to HYDRAIN. It is important that the user types "**EXIT**" and does not reenter HYDRAIN "normally" or forget that they were in HYDRAIN and move onto other applications. To assist in the prevention of this occurrence, the DOS prompt has been temporarily altered to remind the user that, although they are using DOS, they are still active in HYDRAIN.

Review

The **Review** option allows the user to look at the contents of any file on the current drive and directory. After choosing Review, the screen in Figure 10 will appear once more. Press <CR> to continue. The next screen will again be a listing of all of the files in the specified directory. Choose the file to be viewed by moving the cursor and pressing <CR>. When the contents of the file are displayed use the arrow, <PgUp>, and <PgDn> keys to view the text. Wide text can be viewed by right and left scrolling using the arrow keys. To exit and return to the HYDRAIN main menu, press <Esc> or <F2>.

Print

The **Print** option allows the user to obtain a printout of the contents of a selected file. To print a file, follow the same procedure as for **Review**. The only difference is that the contents of the file are printed rather than displayed on the screen. Before attempting to print a file, be sure that the printer settings in the SETUP section are correct, otherwise, the program will "blow up". For instance, if the printer default in Setup is set on "Text" and there is no printer connected to the terminal, HYDRAIN will attempt to send data to this non-existent device. The result is a program failure.

Setup

The **SETUP** option executes the Setup program which allows the user to change system defaults such as colors and devices. The Setup menu, shown in Figure 19, has six options (including QUIT). These options may be accessed by moving the cursor and pressing <CR>, or by pressing the letter which is highlighted in the desired option. Pressing Q while in the Setup main menu will return the program to the HYDRAIN main menu. Any changes made and saved in SETUP will be transferred to the HYDRAIN system shell. The full capabilities of the Setup option are discussed in Appendix C.

```
Change the graphics display (CGA, EGA, etc.) to a different default value.
    Input/Edit    Execute    Utilities    System Info    Quit

                  Set Graphics Display Type
                  Define HYDRAIN Screen Colors
                  Set HYDRAIN Drives & Directories
                  Set Port Information
                  Other Device Options
                  Quit

                  DOS System Shell

                  ---- Files ----
                       Review
                       Print

                  ----------------
                       SETUP
```

Figure 19. Setup main menu.

System info

The SYSTEM INFO sub-menu, shown in Figure 20, provides the user with six options. Any of the options provides the user with an on-line tutorial focusing on the subject which was chosen. Each of these may be selected by moving the cursor and striking <CR>. The purpose of the System Info feature is to provide additional long help on a variety of topics in HYDRAIN. To move within the help, use the arrow, <PgUp>, and <PgDn> keys. To leave the help and return to the HYDRAIN main menu, press <Esc> or <F2>.

```
Friday December 1, 1989                              HYDRAIN Version 3.0
Long Help files for selected topics in HYDRAIN
     Input/Edit    Execute    Utilities    System Info    Quit

                                         On-Line Tutorials

                                              General
                                            Primary Menu
                                            Keyboard Use
                                             File names
                                             References
                                               Setup

                          Main Menu
                     F1-HELP  F2-Return
```

Figure 20. "System Info" option pull-down menu.

Quit

The QUIT option allows the user to leave the HYDRAIN program. To leave the HYDRAIN System Shell, return to the Main Menu, move the cursor to the QUIT option and press <CR> (or press Q). The user will be placed into DOS.

Summary of operations

Entry to engineering programs is via the HYDRAIN System shell. Other operations are listed in Table 1.

Table 1. HYDRAIN system operations.

Engineering Program	Input* Generation	Editing Input Data	Run* Control	Input and Output Review and Print
HYDRA	Generic Editor or Text Editor**	Generic Editor or Text Editor	HYDRAIN Shell or Generic Editor	HYDRAIN Shell or Generic Editor
WSPRO	Generic Editor or Text Editor**	Generic Editor or Text Editor	HYDRAIN Shell or Generic Editor	HYDRAIN Shell or Generic Editor
HYDRO	Generic Editor or Text Editor**	Generic Editor or Text Editor	HYDRAIN Shell or Generic Editor	HYDRAIN Shell or Generic Editor
CDSV5	Generic Editor or Text Editor**	Generic Editor or Text Editor	HYDRAIN Shell or Generic Editor	HYDRAIN Shell or Generic Editor
HY8V3	HY8V3 Program	HY8V3 Program	HY8V3 Program	HY8V3 Program and HYDRAIN Shell
EQUAT	EQUAT Program	EQUAT Program	EQUAT Program	Print screens during program processing

*All programs except HY8V3 and EQUAT use batch file operations. HY8V3 and EQUAT secure data from the user as they are processing.

**Note - indicates that either a text editor, word processor or line editor could be used in the specified operation.

APPENDIX A

THE GENERIC EDITOR

The generic editor provides the HYDRAIN user with a simple method of changing existing data and adding new data to program input files for programs which have command line inputs. The editor itself is a full-screen editor with each line having two fields. The first field has space for three characters and is the location in which the user enters the Command ID for a line of data. The cursor is moved to field two using the right arrow key. Field two is the location of the input data associated with a given Command ID and consists of a maximum of 72 characters.

In addition to its basic editing capabilities, the generic editor relies on the usage of two function keys. The <F1> key allows the user to access Help while the <F2> key accesses special editing and word processing tools. These two function keys act as on/off switches. Pressing the key once activates the function, while pressing it a second time deactivates the function, returning the screen to edit mode. In addition to the <F1> and <F2> keys, there are numerous other keys which are active in the generic editor. Table 2 provides a listing of these keys and their functions.

Table 2
Active Keys and Their Functions

Key	Function
F1 ("Help Key")	Access long help.
F2 ("Hot Key")	Access pull-down menus of editing options.
Ctrl End	Delete a line.
Carriage Return <CR>	Insert a line. Move to the next line.
Esc	Return to HYDRAIN main menu.
Arrow keys	Move the cursor throughout the document.
PgUp	View the previous screen of data.
PgDn	View the next screen of data.
Ctrl PgUp	Move to the top of the document.
Ctrl PgDn	Move to the bottom of the document.
Ins	Switch between Insert and Replace modes.
Home	Move to beginning of the field, of the line, of the screen, and then of the file.
End	Move to the end of the field, of the line, of the screen, and then of the file.
Backspace	Move back one space (or field in certain cases)

Throughout this section, the user will be asked to choose, select, and highlight various items. When asked to perform such a task, the arrow keys should be used to move the highlight bar to the appropriate option. To make the selection, press the carriage return (henceforth denoted as <CR>).

The F1 Key

Though the generic editor supplies the user with continuous short help, more detailed help is available through the program's long help capabilities. The <F1> key may be depressed at any time to access long help information. While in the edit mode, as shown in Figure 21, pressing <F1> produces a matrix of command ID's as shown in Figure 22.

```
F2 - | Select    Search    Modify    Block  | F1 - Help  | Rep
Row #| File:               Prog: HYDRA - Version 3.0
   1 ___ ________________________________________________





Desc | No Help Available
```

HYDRAIN Generic Editor

Figure 21. Edit Mode

The cursor is automatically placed on the last Command ID which had been entered. To select that command, simply press <CR>. To select a different Command ID, move the cursor and press <CR>. Notice that as the cursor is moved through the matrix of commands, the short help description changes to the highlighted command.

After making a selection, the long help for that command will be displayed. Figures 22 and 23 illustrate the long help menu and a sample long help entry. Once in the help screen, the arrow keys allow the user to scroll through files that are larger than the screen display. To move more quickly through the long help, use the Pg Up, Pg Dn, Home, and End keys.

```
F2 - ¦ Select     Search     Modify     Block   ¦ F1 - Help   ¦ Rep
Row #¦ File:                 Prog: HYDRA - Version 3.0
    1  JOB
            - Command List -
   BAS BEN CHA CRI CST DEL DIR DIV ECF EFF
   END EXC FIL FLO GET GPC GUT HGL HOL HYD
   HYE INF INL IPU JOB LOA LOS LPC MAP NEW
   PAV PCF PCO PDA PEA PIP PNC PON PUM PUT
   RAI REC REM RES RET SAF SAN SDI STE STO
   SST SUN SUR SWI TRA TSL TWE UHY UNP HLP

Desc ¦ Up to 50 alphanumeric characters describing your job.
```

HYDRAIN Generic Editor

Figure 22. Sample Long Help Menu

```
F2 - ¦ Select     Search     Modify     Block   ¦ F1 - Help   ¦ Rep
Row #¦ File:                 Prog: HYDRA - Version 3.0
    1  JOB
        COMMAND JOB - JOB title

        Purpose:  Initiates job and enters job title.

        Structure:
            JOB  jobtitle

              jobtitle    - up to 50 alphanumeric characters
                            describing your job.

        Note:  This must be the first command and there may be only
               one JOB in any command file.  It allows you to "load" a
Desc ¦ Up to 50 alphanumeric characters describing your job.
```

HYDRAIN Generic Editor

Figure 23. Sample Long Help Entry

The program is returned to the edit mode while long help is in use by pressing <Esc> or <F1>.

The F2 Key

While in the edit mode, depressing the <F2> key allows the user to view several pull-down menus of editing options. The four menus, titled **Select**, **Search**, **Modify**, and **Block** are shown in Figures 24, 25, 26, and 27 respectively.

Movement across the banner ring menu of down the associated pull-down menus is accomplished using the arrow keys. In addition, the <Home> and <End> keys may be used to move within any pull-down menu. Pressing the <Home> key will highlight the menu title, while the <End> key will move the highlight bar to the final entry in the pull-down menu. In order to return to the edit mode, press <Esc> or <F2>.

Long help is also available for the editing options listed under <F2>. By depressing the <F1> key, help is displayed for the options in the banner ring menu (select, search, modify, and block features).

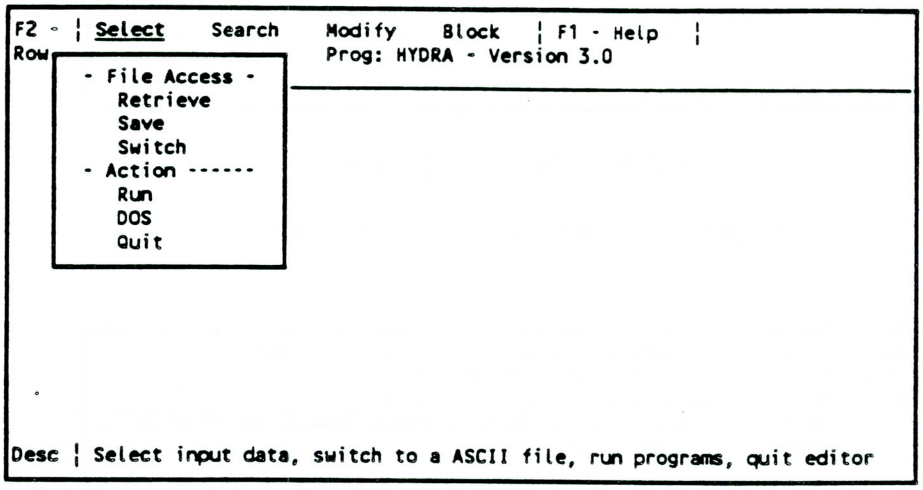

Figure 24. Select Menu

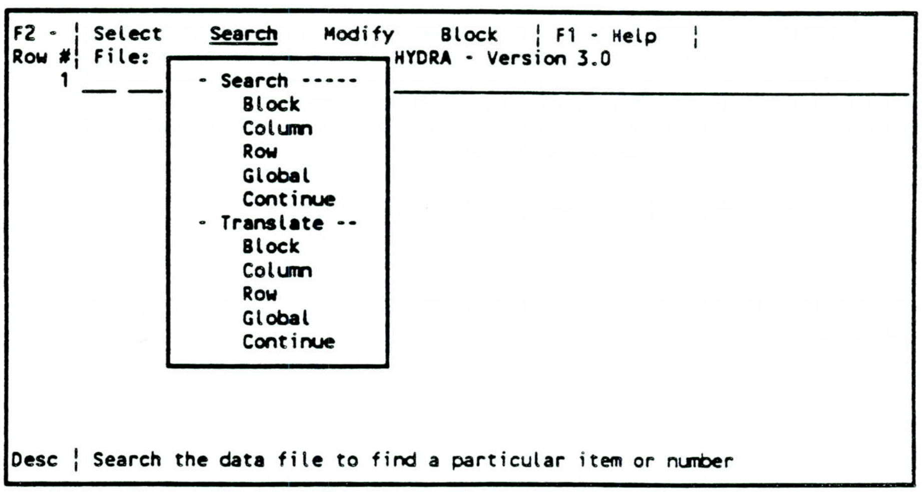

Figure 25. Search Menu

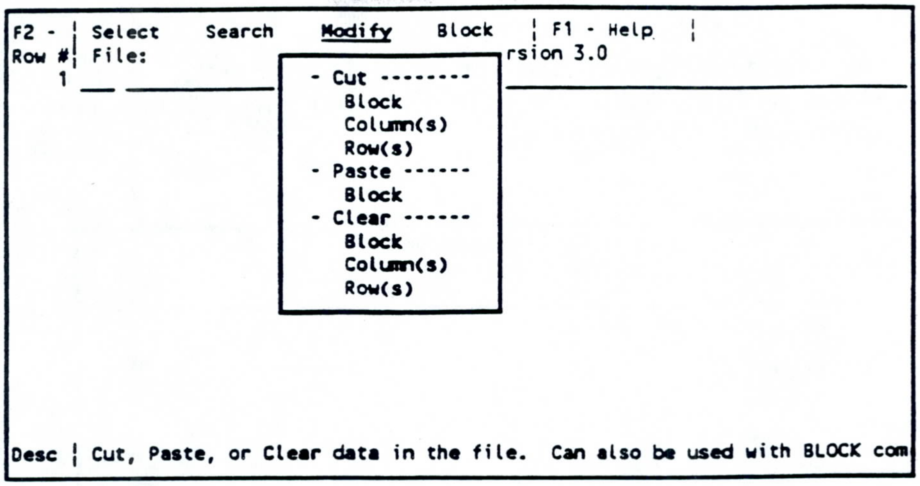

Figure 26. Modify Menu

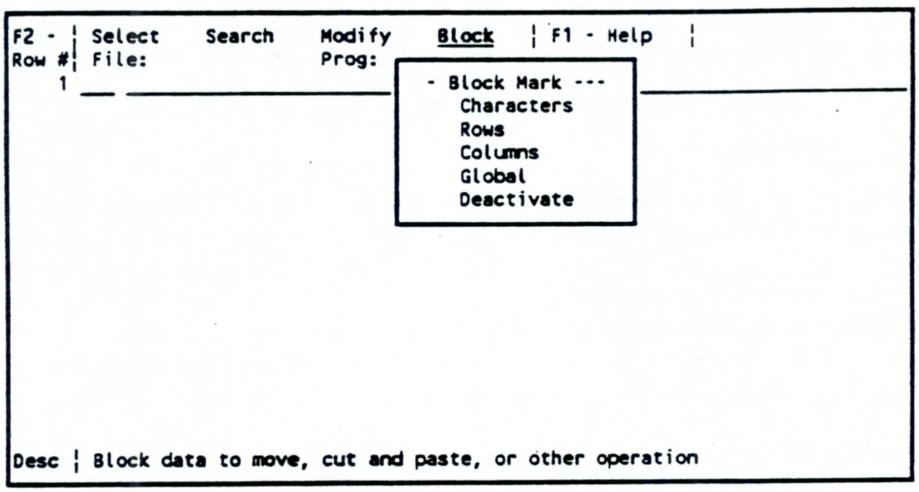

Figure 27. Block Menu

Basic File Management

The next section introduces several of the basic file management procedures which will be used. These procedures include **Retrieving** a file, **Saving** a file, and **Quitting** the editor. Each of these procedures will be explained in detail within this documentation.

Retrieving a File

After entering the generic editor, the user is presented with headers and a blank field as shown in Figure 28. If data is being entered as a new file, the user may begin typing the data on row 1.

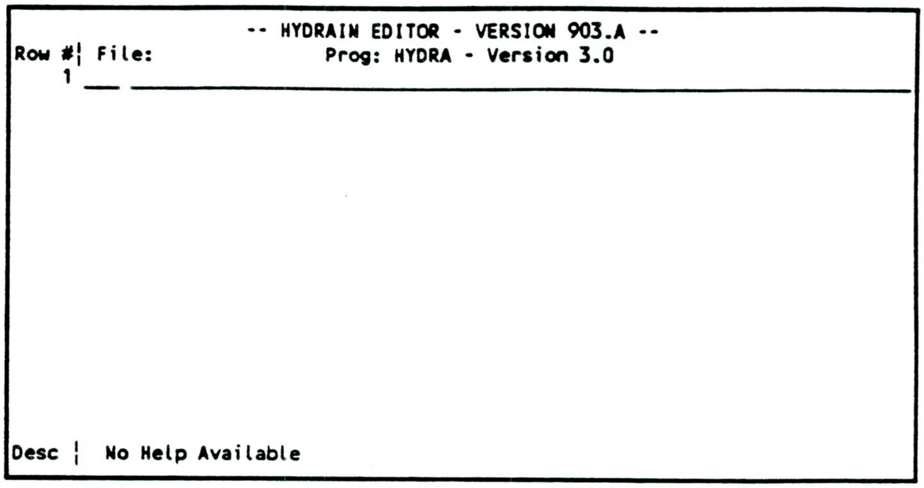

Figure 28. Blank editing screen

In the case that the user wants to edit an existing file, such a file may be retrieved in one of two ways. While in the HYDRAIN system shell, the user may enter the name of the program to be edited on the "filename screen" which is displayed just after selecting the generic editor. This method of file selection is discussed in detail in the HYDRAIN system shell documentation. If, however, the user wants to edit an existing file which has not been retrieved from the HYDRAIN system shell, the following procedure is used to retrieve it:

a. **Press <F2>** to view the Select menu in Figure 24.
b. **Select "Retrieve"**. The screen in Figure 29 will be displayed.
c. If the current directory, as indicated, is incorrect, enter the **correct directory** (Note: there must be a backslash (\) before and after the directory name).
d. **Using the down arrow, move the highlight bar** to the desired file and Press <CR>. **Or, type the filename** (with extension) in the space next to "Current File:".

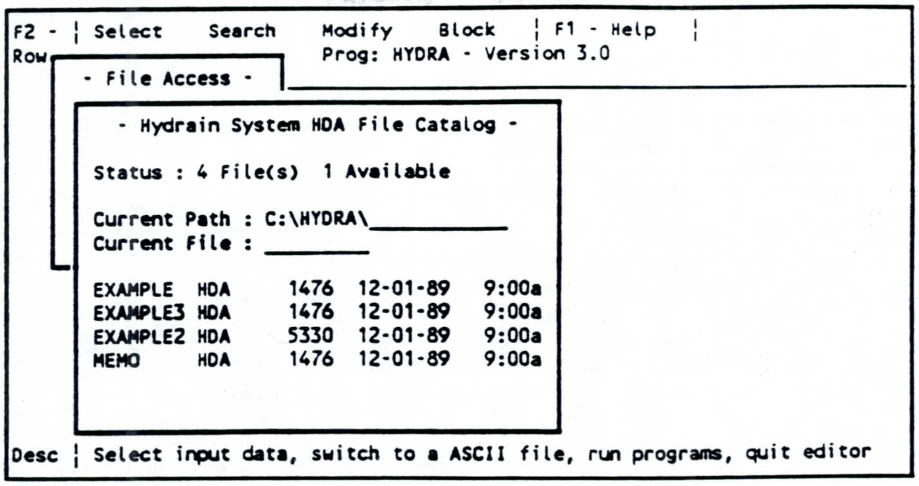

Figure 29. Retrieve Sub-Menu

e. An inset "Warning" screen will appear as shown in Figure 30. To retrieve the file and overwrite any text which is on the screen, select "Continue . . .". Or, to cancel the retrieval and return to the Select menu, choose "Abandon . . .".

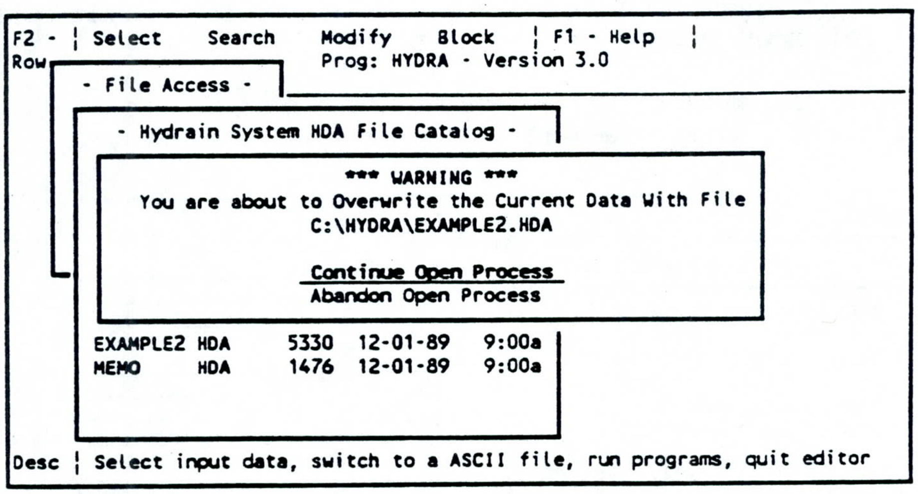

Figure 30. Retrieve "Warning" Screen

f. When the text is retrieved and appears on the screen, press <Esc> or <F2> to remove the menu.

The result of the retrieval procedure is a screen which resembles the one in Figure 31.

```
F2 - | Select     Search     Modify     Block     | F1 - Help    |
Row #| File: EXAMPLE2.HDA  Prog: HYDRA - Version 3.0
   1 JOB _EXAMPLE_FIVE:_HYDROGRAPHIC_SIMULATION_AND_DESIGN
   2 SWI _3
   3 PDA _.013_12_5_4_2.5_.001
   4 PCO _12_46_15_51_18_57_21_63_24_69_27_74_3_80_33_86_36_97_42_109_48_126_
   5 ___ _143_60_160_66_177_72_206_84_297
   6 CST _1.5_1.5_0_0_0_.5_6.21_1_0_1.52_1.05_.6_1.56_1.52_0
   7 EXC _5_.72_25_1.13
   8 TSL _0_.25_10_.25
   9 STE _2
  10 HYE _0.0_3.51_7.03_10.54_9.03_7.53_6.02_4.52_3.01_1.51
  11 UNP _.15_.5_.1_.1_4.0_1.5_.07_45_.03_24_48
  12 PAV _.013_.1_.05_.2_.5_30_.4
  13 NEW _FEEDER_1
  14 HYD _.52_49_.025_.77_2.2
  15 GUT _500_940_932.5_.013_0_2_0_10_20
  16 INL _1_1_4_26_0.0_1_0_0_0_0_0_1
Desc | Initiates JOB and enters JOB title.
```

Figure 31. Sample file accessed through the Retrieve function

Saving a File

Before quitting the generic editor, always be sure that all data files have been saved. The following procedure is used to save a file:

a. **Press** <F2> and move to the Select menu shown in Figure 24.
b. **Select "Save"**. The screen in Figure 32 will be displayed.

```
F2 - | Select     Search     Modify     Block     | F1 - Help    |
Row                   A  Prog: HYDRA - Version 3.0
   - File Access -    _HYDROGRAPHIC_SIMULATION_AND_DESIGN

      - Hydrain System HDA File Catalog -
                                             _80_33_86_36_97_42_109_48_126_
      Status : 4 File(s)   1 Available   +w
                                             6_1.56_1.52_0
      Current Path : C:\HYDRA\
      Current File : EXAMPLE2_

  10  EXAMPLE   HDA      1476  12-01-89   9:00a
  11  EXAMPLE3  HDA      1476  12-01-89   9:00a
  12  EXAMPLE2  HDA      5330  12-01-89   9:00a
  13  MEMO      HDA      1476  12-01-89   9:00a
  14
  15
  16
Desc | Select input data, switch to a ASCII file, run programs, quit editor
```

Figure 32. Save Sub-Menu

c. If necessary, change the path and directory in which the file will be saved.
d. Using the down arrow, move the highlight bar to the desired file and press <CR>. Or, type the filename (an extension will be assigned automatically) in the space next to "Current File:".
e. If the file being saved is new, it is automatically saved and the user is returned to the Select menu. If the file had already existed, the "Warning" screen shown in Figure 33 will appear. Choose "Continue . . ." to overwrite the existing file or, choose "Abandon . . ." to cancel the save process and return to the Select menu.

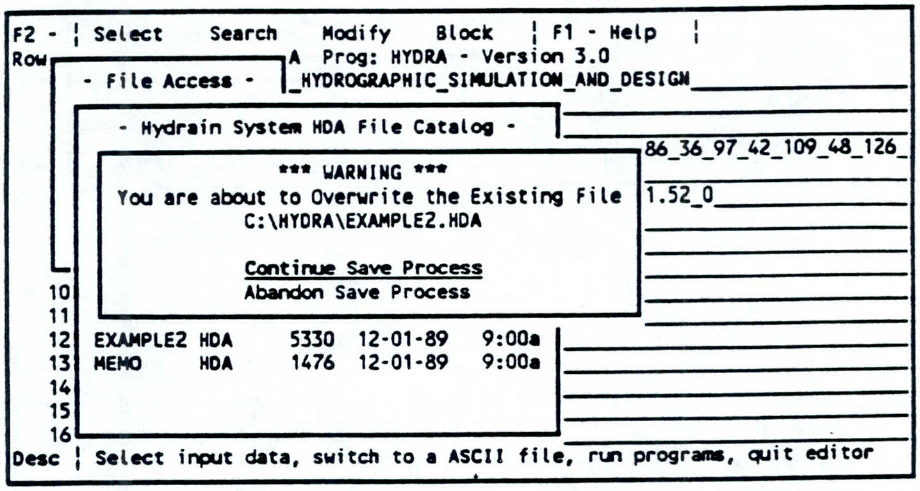

Figure 33. Save "Warning" Screen

In addition, it should be noted that an input file will automatically be saved if it is run. Therefore, running a program results in the input file overwriting the previously existing data file.

Quitting the Generic Editor

After all editing is completed and all files are saved, the user may leave the generic editor. To quit the editor, press <F2> and select "QUIT" in the Select menu. If all files to which changes were made have been saved, the HYDRAIN main menu will appear. If changes were made and the files aren't saved, the warning screen in Figure 34 will appear. If the choice is made to continue with the exit, all changes will be lost. If the user chooses to abandon the exit, the program will return to the Select menu and the user should then save the file(s). Once the file has been saved, the user may safely leave the generic editor and return to HYDRAIN.

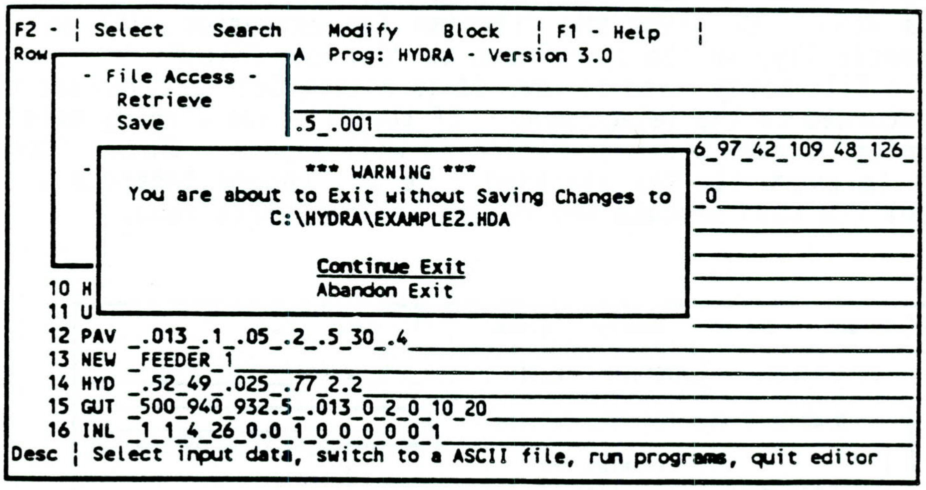

Figure 34. Exit "Warning" Screen

Editing

As previously mentioned, the data entered in the generic editor occupies only two fields. The first field can accommodate three characters, although three are not always used. The only way to move to field two is to press the right arrow. Do not press <CR> as this will result in the addition of another row. While in field two, notice that the active help provides parameter specific help, based on the Command ID which was entered in the first field. Parameter specific means that the program prompts the user by stating which piece of data should be entered at any given location. After the data for a row has been completely entered, press <CR> to return to field one of the next row.

The <Home> and <End> keys, which were briefly mentioned in Table 2, deserve further discussion. Depending on the location of the cursor, pressing the <Home> key moves the cursor to the beginning of a field, the beginning of a row, the top left-hand corner of the screen, or the first character in a file. Similarly, the <End> key moves the cursor to the end of a field, the end of a row, the lower right-hand corner of the screen, or the last space in a file. Table 3 details the functions of the <Home> and <End> keys.

In order to change existing data or add data to an existing file, use the <Ins> key to choose the insert or replace mode. Upon entering the generic editor, the program will insert data. If the user wishes to switch to replace, so that data will be overwritten, press the <Ins> key. Notice that there will be a message in the upper-right corner of the screen (either Ins or Rep) which indicates the current status of the program. Using the arrow, <PgUp>, <PgDn>, <Home>, and <End> keys, move the cursor to the desired location and edit as in any other word processor.

Table 3
Functions of the Home and End Keys

Cursor Location	Key (# of Times Pressed)	Final Cursor Location
Field 1	Home (1)	Beginning of Field 1
	Home (2)	Top left of screen
	Home (3)	First character in file
Field 2	Home (1)	Beginning of Field 2
	Home (2)	Beginning of Field 1
	Home (3)	Top left of screen
	Home (4)	First character in file
Field 1	End (1)	End of Field 1
	End (2)	End of Field 2
	End (3)	Bottom right of screen
	End (4)	Last space in file
Field 2	End (1)	End of Field 2
	End (2)	Bottom right of screen
	End (3)	Last space in file

HYDRA Example

The remainder of this section presents an example editing problem designed to familiarize the new user with the basic operations of the generic editor. The instructions which follow are a step-by-step walk through of the editing process. After the example, additional features of the editor are discussed.

Begin by entering the generic editor and pressing any key to prepare the screen for editing. This example creates a new file, therefore, the editing field will be blank. Before beginning to enter data, be sure that the program is in **Insert** mode. In order to check, refer to the upper right-hand corner of the screen where there will be either an **Ins** or an **Rep** indicating Insert and Replace, respectively. In order to change from one to the other, simply depress the <Ins> key. Note that the program defaults to the Insert mode when initially entering the program. The data to be used in this example is reproduced in Figure 35 (Note: the row numbers shown are merely for reference to this text. When data is entered in the generic editor, a row number is <u>not</u> entered.)

```
JOB EXAMPLE FIVE: HYDROGRAPHIC SIMULATION AND ANALYSIS
SWI 3
PDA .013 12 5 4 2.5 .001
PCO 12 46 15 51 18 57 21 63 24 69 27 74 30 80 33 86 36 97
    42 109 48 126 54 143 60 160 66 177 72 206 84 297
CST 1.5 1.5 0 0 0 .5 6.21 1 0 1.52 1.05 .6 1.56 1.52 0
EXC 5 .72 25 1.13
TSL 0 .25 10 .25
STE 2
HYE 0.0 3.51 7.03 10.54 9.03 7.53 6.02 4.52 3.01 1.51
UNP .15 .5 .1 .1 4.0 1.5 .07 45 .03 24 48
PAV .013 .1 .05 .2 .5 30 .4
NEW FEEDER 1
HYD .52 49 .025 .77 2.2
GUT 500 940 932.5 .013 0 2 0 10 20
INL 1 1 4 26 0.0 1 0 0 0 0 0 1
PIP 88 940 931.6 935 930 -6
HOL 1
NEW FEEDER 2
HYD 50.5 49 .025 .77 2.2
GUT 500 940 932.5 .013 50 3 40 0 0 0 1
INL 2 7 0 0 0.8 0 0 1.5 0 0 0 1
PIP 88 940 931.6
HOL 2
NEW FEEDER 3
HYD 20.5 49 0.025 0.77 2.2
GUT 500 940 932.5 .013 0 5 0 50 30 0
INL 3 9 0 0 0.9 1 20 0 0 0 0 1
HYD 5.5 49 .025 .77 2.2
GUT 500 940 932.5 .013 30 5 0 30 0 0 0
INL 4 5 0 29 0 0 0 0 0 0 0 1
EFF 1 100 10 90 500 50 1000 25
PIP 88 932.5 924.1
HOL 4
NEW LEFT-SIDE MAIN
GET 29
GUT 500 940 932.5 .013 25 0 25 0 0 0 1
INL 5 6 3 0 0.3 6
PIP 500 931.6 924.1
HOL 5
NEW RIGHT-SIDE MAIN
REC 2
HYD 15.5 49 .025 .77 2.2
GUT 500 940 932.5 .013 0 5 0 50 40 0 0
INL 6 7 0 30 0.5 0 0 0.5 10 0 0 1
PIP 500 931.6 924.1
HOL 6
NEW OUTFALL PIPE
REC 1
REC 4
REC 5
```

```
52  REC 6
53  GET 30
54  GUT 500 931.6 924.1 .013 50 3 40 0 0 0
55  HYD 20.5 49 0.025 0.77 2.2
56  GUT 1000 900 895 0.016 30 2 30 0 0 1
57  INL 8 9 0 31 0.1 6 20 0 0 0 0 1
58  HYD 20.5 49 0.025 0.77 2.2
59  GUT 500 931.6 924.1 .013 0 0 50
60  INL 9 5 0 0 0 0 0 0 0 0 0 1
61  EFF 1 100 10 90 500 50 1000 25
62  PIP 50 924.1 920 0 0 0 0 1 1
63  HOL 9
64  NEW OUTFALL CHANNEL
65  REC 9
66  CHA 1000 914.0 912.0 .034 1 4 1
67  END
```

Figure 35. Data for HYDRA Example

First, type the three-letter command ID "JOB". Notice that upon completion of entering the ID, the active help for that command is automatically displayed. In order to move to field two, press the right arrow. Proceed by typing the remainder of the data associated with the "JOB" ID. From the parameter short help, it becomes clear that the associated parameter with the JOB command is an alphanumeric description. The screen should now look like the one presented in Figure 36. Press <CR> to move to row two. This procedure is followed for all data entry using the generic editor.

```
F2 -  | Select    Search    Modify    Block    | F1 - Help    | Ins
Row # | File:               Prog: HYDRA - Version 3.0
     1 JOB EXAMPLE_FIVE:_HYDROGRAPHIC_SIMULATION_AND_DESIGN________________

Desc | Up to 50 alphanumeric characters describing your job.
```

HYDRAIN Generic Editor

Figure 36. Edit mode with one row of code entered

Continue by entering the data in rows two and three in similar fashion. Notice that the data in row four (beginning with "PCO") is split over two consecutive rows. In cases such as this, the editor's special "wraparound" feature is utilized. First, check to be sure the editor is in insert mode. If it isn't, press the <Ins> key to put it into insert mode. Begin entering the data as in any other row. Continue typing from the end of the first row into the second row of data. When the cursor reaches the right margin, it will automatically be pushed to the beginning of field two on the next row. Field one will default to the previous command ID. After finishing the data for the "PCO" ID, press <CR> and continue as before, The screen should resemble that which is shown in Figure 37.

```
F2 -  | Select    Search    Modify    Block   | F1 - Help   | Rep
Row # | File: EXAMPLE2.HDA       Prog: HYDRA - Version 3.0
    1 JOB EXAMPLE_FIVE:_HYDROGRAPHIC_SIMULATION_AND_DESIGN_______________
    2 SWI 3__________________________________________________________
    3 PDA .013_12_5_4_2.5_.001_______________________________________
    4 PCO 12_46_15_51_18_57_21_63_24_69_27_74_3_80_33_86_36_97_42_109_48_126__
    5 ___ 143_60_160_66_177_72_206_84_297____________________________







Desc | Initiates JOB and enters JOB title.
```

HYDRAIN Generic Editor

· Figure 37. Example illustrating "Wraparound" feature

Upon reaching row 17, which reads "HOL 1", another of the editor's features may be used to speed the data entry process. Notice that rows 19-24 are very similar to rows 13-18. Rather than retype many of the same numbers, use the editor's block/cut and paste feature. The following steps will copy rows 13-18 to rows 19-24:

a. Position the cursor over "N" in "New" in row 13.
b. Press <F2> to access the pull-down menus.
c. Move the cursor to the Modify menu using the arrow keys.
d. Choose "Rows" in the "Cut" section of the Modify menu by moving the cursor and pressing <CR>.
e. When the "Cut Rows from Sheet" screen shown in Figure 38 is displayed, change "Number of rows to cut" to 5.

```
F2 - | Select   Search   Modify   Block   | F1 - Help  |
Row #| File: EXAMPLE2.HDA  Prog: HYDRA - Version 3.0
   1 JOB _EXAMPLE_FIVE:_HYDROGRAPHIC_SIMULATION_AND_DESIGN________________
   2 SWI _3____________________________________________________________
   3 PDA  +-----------------------------------+___________________________
   4 PCO  |     - Cut Rows from Sheet -       |3_80_33_86_36_97_42_109_48_126_
   5 ___  |                                   |___________________________
   6 CST  | Proceed with cut ? -------  Yes   |.6_1.56_1.52_0_____________
   7 EXC  |                             No    |___________________________
   8 TSL  | Number of rows to cut ----  ____1 |___________________________
   9 STE  | Cut starting at row ------  ____1 |___________________________
  10 HYE  +-----------------------------------+.52_3.01_1.51______________
  11 UNP _.15_.5_.1_.1_4.0_1.5_.07_45_.03_24_48__________________________
  12 PAV _.013_.1_.05_.2_.5_30_.4_______________________________________
  13 NEW _FEEDER_1______________________________________________________
  14 HYD _.52_49_.025_.77_2.2___________________________________________
  15 GUT _500_940_932.5_.013_0_2_0_10_20________________________________
  16 INL _1_1_4_26_0.0_1_0_0_0_0_0_1____________________________________
Desc | Cut, Paste, or Clear data in the file.  Can also be used with BLOCK com
```

Figure 38. Cut Rows Sub-Menu

f. **Change "Cut starting at row" to 13.**
g. **Move the cursor to "Yes" and press** <CR>.
h. **Press** <F2> again to access the pull-down menus.
i. Due to the fact that cutting a section erases it, the section needs to be replaced. **Paste the block** back into its original position. Using the arrow keys, move to "Block" in the "Paste" section of the Modify menu. Press <CR> to paste the block.
j. When the Paste Block screen is displayed as shown in Figure 39, move the cursor to "Insert" and press <CR>.

```
F2 - | Select   Search   Modify   Block   | F1 - Help  |
Row #| File: EXAMPLE2.HDA  Prog: HYDRA - Version 3.0
   1 JOB _EXAMPLE_FIVE:_HYDROGRAPHIC_SIMULATION_AND_DESIGN________________
   2 SWI _3____________________________________________________________
   3 PDA _.013_12_5_4_2.5_.001__________________________________________
   4 PCO  +-----------------------------------------+3_86_36_97_42_109_48_126_
   5 ___  |            - Paste Block -              |_______________________
   6 CST  |                                         |6_1.52_0_______________
   7 EXC  | Proceed with paste ? -----  Yes         |_______________________
   8 TSL  |                             No          |_______________________
   9 STE  | Paste block will ---------  Insert      |_______________________
  10 HYE  |                           < Overwrite > |.52_3.01_1.51__________
  11 UNP  | Start paste at row -------  _____1      |_______________________
  12 PAV  | Start paste at column ----  _____0      |_______________________
  13 NEW  +-----------------------------------------+_______________________
  14 HYD _.52_49_.025_.77_2.2___________________________________________
  15 GUT _500_940_932.5_.013_0_2_0_10_20________________________________
  16 INL _1_1_4_26_0.0_1_0_0_0_0_0_1____________________________________
Desc | Cut, Paste, or Clear data in the file.  Can also be used with BLOCK com
```

Figure 39. Paste Block Screen

k. With row 13 now highlighted. **Move the cursor to "Yes"** in the Paste Block menu and press <CR>.
l. **Repeat** steps 8, 9, and 10 to insert the rows a second time (Note: this process may be repeated as many times as desired).
m. **Press <Esc> or <F2>** to resume editing.

Changes can now be made to rows 19-24 using the insert/replace key. Place the editor in replace and change the 1 in row 19 to 2. In Row 20 change the .52 to 50.5. Next, change the values in rows 21 and 22 to read as they do in Figure 35. In row 23 remove all values after 931.6 by moving the cursor to the value 935 and pressing the space bar repeatedly until the remainder of the data on that row is deleted. Finally, change the number 1 in row 24 to 2.

Though the process just described might seem to be a bit slow at first, it will become much quicker with experience.

Moving to row 25, continue entering data as before until all of the text has been entered. The next step is to save the file. **Press <F2> and choose "Save"** in the Select menu. Change the path and directory if necessary. Since this is a new file, enter a name (the extension .HDA is automatically added unless another is specified) and press <CR>. The file is saved, after which pressing <Esc> or <F2> will return the program to edit mode.

Additional Features

The user should now be comfortable with the basic operations of the generic editor. There are, however, numerous other capabilities built into the system. These are addressed in the sections which follow.

Select Menu

Within the Select menu, there are six functions which are presented under two sub-headings. The "File Access" sub-heading has three functions which allow the user to execute basic file management procedures. The "Action" sub-heading has three functions, each of which allows the user to execute a specified procedure.

File Access

There are three options in the File Access section of the Select menu shown in Figure 24. The first two, **"Retrieve"** and **"Save"**, have already been discussed in detail. The third is the **"Switch"** option. "Switch" allows the user to bring a new file onto the screen while keeping the original file open. The screen will clear when the "Switch" option is utilized and the new file will be displayed. The original file is then stored in the program's memory so that it can be quickly and easily retrieved. This feature is especially useful for copying or moving a block of text from one file into another through use of the cut/paste option.

To utilize the "Switch" option, **select "Switch"** and proceed as before to retrieve another file. The screen that appears when the switch is made consists of a single field. Any file may be retrieved into the second input screen. To switch back to the original file, select "Switch" again. In this manner, the user may move between the two files. Additionally, any text that is blocked in one document can be transferred to the other document. Upon completion of editing using the "Switch" option, each file must be saved separately. Selecting "Quit" before saving any files which have been changed will result in the changes being lost.

Action

The action section of the Select menu has three functions. They are: **Run**, DOS, and **Quit**. "Quit" has already been discussed, so this section focuses on "Run" and "DOS". The "Run" option allows the user to run the program which is displayed on-screen. It is important to note, however, that the "Run" command is only active when the editor is invoked from the HYDRAIN program. As previously mentioned, a program should have first been saved before it can be run. In addition, running the program will automatically save the input file. The third option, "DOS", allows the user to return to MS-DOS without actually leaving the editor. Figure 40 shows the screen which will appear when the "DOS" option is used. To exit DOS and return to the editor, type **EXIT** at the DOS prompt. In order to use either of these options, highlight the one desired and press <CR>.

```
The IBM Personal Computer DOS
Version 3.10 (C)Copyright International Business Machines Corp 1981, 1985
             (C)Copyright Microsoft Corp 1981, 1985


Type "EXIT" to return to HYDRAIN
C>
```

Figure 40. DOS prompt accessed from the Generic Editor

Block Menu

The Block function is used throughout the generic editor to support a variety of editing tasks. These tasks include: cut/paste, search, clear, and translate. Each of these tasks are presented in detail in the sections which follow. Furthermore, the block function allows the user to specify the exact area of the text where the task is to be performed. There are five options available in the Block menu. The first three, **"Characters"**, **"Rows"**, and **"Columns"**, allow the user to block one or more of the chosen item. To use any of these options, select it and use the arrow keys to highlight the block area. When the desired area is highlighted, press <CR> to mark it. The **"Global"** option automatically blocks the entire document. Finally, the **"Deactivate"** option removes the block notation from all blocked areas and returns it to standard text.

Modify Menu

Cut

There are three options in the "Cut" section of the Modify menu. The user is able to cut a block of one or more columns, and one or more rows. The "Cut" command deletes the specified portion of the text, but keeps it in memory for a short period of time. In order to cut text which has been blocked, select "Block". There is no further prompt, so the block is immediately deleted.

In order to cut one or more rows, select "Row(s)". An inset screen titled "Cut Rows from Sheet" will appear. This screen is shown in Figure 38. Move to the field for "Number of rows to cut" and enter the desired number. Then, specify the row at which the cut should start. Note that the default row is the row the cursor was in and the default number of rows is one. The area to be cut is now highlighted. To execute the cut, select "Yes". Selecting "No" will abort the process and return the program to the Modify menu. In addition, pressing <Esc> or <F2> at any time will return the screen to edit mode.

In order to cut one or more columns from the text, select "Columns" and follow the procedure described for cutting rows.

Paste

The paste function, which was utilized in the Hydra example, adds to the text a section which has been cut. This section can be a block, rows, or columns. After selecting "Paste", the Paste Block menu shown in Figure 38 will appear and the program will automatically highlight as much text as was previously cut. For instance, if four rows had been cut, four rows would be highlighted, beginning at the location of the cursor.

Several choices are then made. First, choose whether the new text is to be inserted or is to overwrite existing text. As mentioned, a section of the text is highlighted on the screen. If "overwrite" is selected, that section is where the new text will be displayed. If "insert" is chosen, the new text will be added above the highlighted area in the case of rows, and left of the highlighted area for columns. If the text to be pasted is a block, it will be inserted above the position of the cursor for rows and left of the cursor for columns.

The second choice depends on whether rows or columns are being pasted. For rows, the user specifies the row and column at which the paste is to begin. Keep in mind that for "overwrite", the new text will replace the old text beginning at the specified row number, while for "insert", the new text will go above the specified row. For columns, the choices are the same as those for rows, with one addition; the user specifies the character at which the paste should start. "Overwrite" works in the same manner as for rows, while "Insert" will add the column(s) to the left of the highlighted text.

After the paste is completed, select "Deactivate" in the Block menu (by moving the cursor and pressing <CR>) to remove the block notation.

Clear

The "Clear" section of the Modify menu also has three options. For each of these options, **block**, **column(s)**, and **row(s)**, the text in the specified (highlighted) area is erased. The block, columns, or rows remain in the text but are blank (contain no characters). If the "Block" option is chosen, all text in any area marked as a block is erased. If columns or rows are being cleared, the user specifies the number to clear and the starting location. This information is entered on the screen displayed in Figure 41. To execute the "Clear" command, select "Yes". Figure 42 shows a cleared row (Row 0). Once again, pressing <Esc> or <F2> will return the program to edit mode while selecting "No" will display the Modify menu.

```
F2 - ¦ Select    Search    Modify    Block   ¦ F1 - Help   ¦
Row #¦ File: EXAMPLE2.HDA  Prog: HYDRA - Version 3.0
   1 JOB _EXAMPLE_FIVE:_HYDROGRAPHIC_SIMULATION_AND_DESIGN________
   2 SWI _3___________________________________________________
   3 PDA  ┌──────────────────────────────────┐________________
   4 PCO  │    - Clear Rows from Sheet -     │3_80_33_86_36_97_42_109_48_126_
   5 ___  │                                  │________________
   6 CST  │ Proceed with clear ? -----  Yes  │.6_1.56_1.52_0__
   7 EXC  │                             No   │________________
   8 TSL  │ Number of rows to clear -- _____1│________________
   9 STE  │ Clear starting at row ---- _____1│________________
  10 HYE  └──────────────────────────────────┘.52_3.01_1.51___
  11 UNP _.15_.5_.1_.1_4.0_1.5_.07_45_.03_24_48_______________
  12 PAV _.013_.1_.05_.2_.5_30_.4_____________________________
  13 NEW _FEEDER_1____________________________________________
  14 HYD _.52_49_.025_.77_2.2_________________________________
  15 GUT _500_940_932.5_.013_0_2_0_10_20______________________
  16 INL _1_1_4_26_0.0_1_0_0_0_0_0_1__________________________
Desc ¦ Cut, Paste, or Clear data in the file.  Can also be used with BLOCK com
```

Figure 41. Clear Rows Sub-Menu

Search Menu

Searc2h

The "Search" section of the Search menu has five available options. The first four options specify the range of a search while the fifth executes the command. Begin by selecting the range to be searched (**block**, **row(s)**, **column(s)**, **global**). Note that the "Block" option is not available unless there is already text which is marked as a block. Similarly, the "Continue" option is not made available until the search operation has already been performed. Each selection displays a screen similar to that shown in Figure 43. In the field next to "Pattern to Match", enter the string of characters to be located. Next, select "Floating" for "Pattern Position". Finally, choose "Yes" to begin the search. Choosing "No" will return the program to the Search menu.

```
F2 - | Select     Search     Modify     Block    | F1 - Help    |
Row #| File: EXAMPLE2.HDA  Prog: HYDRA - Version 3.0
   1 ___
   2 SWI _3
   3 PDA _.013_12_5_4_2.5_.001
   4 PCO _12_46_15_51_18_57_21_63_24_69_27_74_3_80_33_86_36_97_42_109_48_126_
   5 ___ _143_60_160_66_177_72_206_84_297
   6 CST _1.5_1.5_0_0_0_.5_6.21_1_0_1.52_1.05_.6_1.56_1.52_0
   7 EXC _5_.72_25_1.13
   8 TSL _0_.25_10_.25
   9 STE _2
  10 HYE _0.0_3.51_7.03_10.54_9.03_7.53_6.02_4.52_3.01_1.51
  11 UNP _.15_.5_.1_.1_4.0_1.5_.07_45_.03_24_48
  12 PAV _.013_.1_.05_.2_.5_30_.4
  13 NEW _FEEDER_1
  14 HYD _.52_49_.025_.77_2.2
  15 GUT _500_940_932.5_.013_0_2_0_10_20
  16 INL _1_1_4_26_0.0_1_0_0_0_0_0_1
Desc |  No Help Available
```

Figure 42. Sample screen with Row 1 cleared

```
F2 - | Select     Search     Modify     Block    | F1 - Help    |
Row #| File: EXAMPLE2.HDA  Prog: HYDRA - Version 3.0
   1 JOB _EXAMPLE_FIVE:_HYDROGRAPHIC_SIMULATION_AND_DESIGN
   2 SWI _3
   3 PDA
   4 PCO   - Search Column For Matching Pattern -  _33_86_36_97_42_109_48_126_
   5 ___
   6 CST   Pattern to match ------   __________    .56_1.52_0
   7 EXC   Proceed with search ? -    Yes
   8 TSL                              No
   9 STE   Pattern position is ---    Anchored
  10 HYE                            < Floating >   .01_1.51
  11 UNP
  12 PAV _.013_.1_.05_.2_.5_30_.4
  13 NEW _FEEDER_1
  14 HYD _.52_49_.025_.77_2.2
  15 GUT _500_940_932.5_.013_0_2_0_10_20
  16 INL _1_1_4_26_0.0_1_0_0_0_0_0_1
Desc | Search the data file to find a particular item or number
```

Figure 43. Search Column Sub-Menu

The program then highlights the first instance in which the desired pattern is found. There may, however, be more matches. To check for additional matches, choose **"Continue"** in the "Search" section of the Search menu. Selecting "Continue" will result in the next instance in which a match occurs being highlighted. This procedure may be repeated as many times as desired until the end of the file is reached.

Translate

The "Translate" section of the Search menu has the same five options as the "Search" section. Once again, however, the "Block" and "Continue" options are not always available. The purpose of the translate function is to search for a given pattern and then automatically replace or amend it. The translate screen, illustrated in Figure 44, requires the same information as search. In addition, the user must enter the new pattern which will replace or be added to the old one. This string is entered in the "Translate to pattern" field. Also, the user must specify whether the new pattern is to overwrite the old one or be inserted after it. Again, choosing "Yes" executes the translate command, while choosing "No" returns the program to the Search menu.

```
F2 - | Select   Search   Modify   Block  | F1 - Help  |
Row #| File: EXAMPLE2.HDA  Prog: HYDRA - Version 3.0
   1 JOB _EXAMPLE_FIVE:_HYDROGRAPHIC_SIMULATION_AND_DESIGN
   2 SWI _3
   3 PDA
   4 PCO   - Translate Pattern Within Column -        _86_36_97_42_109_48_126_
   5
   6 CST   Pattern to match ---------   ________      _1.52_0
   7 EXC   Translate to pattern -----   ________
   8 TSL   Proceed with translate ? -   Yes
   9 STE                                No
  10 HYE   Pattern position is ------   Anchored      _1.51
  11 UNP                              < Floating >
  12 PAV   Translate pattern will --- < Insert   >
  13 NEW                                Overwrite
  14 HYD
  15 GUT _500_940_932.5_.013_0_2_0_10_20
  16 INL _1_1_4_26_0.0_1_0_0_0_0_0_1
Desc | Search the data file to find a particular item or number
```

Figure 44. Translate Within Column Sub-Menu

Whenever the program locates the pattern to be translated, it asks the user whether or not that occurrence should be translated. This prompt screen is shown in Figure 45.

```
F2 - | Select   Search   Modify   Block  | F1 - Help  | Rep
Row #| File: EXAMPLE2.HDA  Prog: HYDRA - Version 3.0
   1 JOB _EXAMPLE_FIVE:_HYDROGRAPHIC_SIMULATION_AND_DESIGN
   2 SWI _3
   3 PDA _.013_12_5_4_2.5_.001
   4 PCO _12_46_15_51_18_57_21_63_24_69_27_74_3_80_33_86_36_97_42_109_48_126_
   5       143_60_160_66_177_72_206_84_297
   6 CST _1.5_1.5_0_0_0_.5_6.21_1_0_1.52_1.05_.6_1.56_1.52_0
   7 EXC
   8 TSL  - Translate Occurrence -
   9 STE           Yes
  10 HYE           No             3_6.02_4.52_3.01_1.51
  11 UNP           Global         .03_24_48
  12 PAV           Quit
  13 NEW
  14 HYD _.52_49_.025_.77_2.2
  15 GUT _500_940_932.5_.013_0_2_0_10_20
  16 INL _1_1_4_26_0.0_1_0_0_0_0_0_1
Desc| Search the data file to find a particular item or number
```

Figure 45. Translate Occurence prompt

Choosing "Yes" will perform the translation and move on to the next occurrence. Selecting "No" will move to the next occurrence without changing the previous instance. The "Global" option will automatically translate all of the matches and will return to the Search menu. "Quit" will abandon the translate procedure and return to the Search menu. The final option in the Search menu, "Continue", allows the user to continue the most recent translate procedure, even if the Search menu has been exited and normal editing has been resumed.

APPENDIX B

HYDRAIN DIRECTORY STRUCTURE

The standard HYDRAIN disk and directory layout is intended to place a series of directories on a single hard disk drive. With the exception of the Intermediate/Shared files path, this arrangement insures that every program or file is one level from the root directory. The directory names are chosen to reflect the contents therein. For example, in the default layout, the HYDRA directory contains the executable, input, output, and help files associated with the HYDRA storm drain program.

This organization is advantageous if the user decides later to run the programs batch. There is no other linkages between the directories through the HYDRAIN system shell. Additionally, by placing the entire HYDRAIN system on a single hard disk, the installation program can check that disk for sufficient space BEFORE copying the HYDRAIN files. (This prevents a partial installation from occurring).

However, from the system shell's perspective, there is more than a single path required for each of the programs. In reality, each of the programs, HYDRAIN, HYDRA, WSPRO, HYDRO, CDSV5, and HY8V3, have at least two, and, in the case of HY8V3, possibly up to ELEVEN distinct directories! For example, the four batch engineering programs have "separate" directories for input, output, executable, and help files. The standard (or default) layout simplifies things by using the same directory "name" for all the elements used in a particular program. This results in the simplified directory structure, depicted earlier in Figure 2.

Overriding this standard configuration is most easily implemented during the installation procedure. While installing the program, should the "User Defined" option be selected, the program will allow the user to change the standard paths before creating any paths or copying any files.

Before installation begins, it is strongly recommended that the user should plan on defining:

- two HYDRAIN paths (executable and help),
- one Intermediate/shared file path,
- four HYDRA paths (executable, input, output, and help files),
- four WSPRO paths (executable, input, output, and help files),
- four HYDRO paths (executable, input, output, and help files),
- four CDSV5 paths (executable, input, output, and help files),
- eleven HY8V3 paths (not including the path where PFPHY8.BAT will reside.

The user may decide to place these thirty paths in thirty different areas, or to make the layout very simple, place all files on a single directory.

One advantage of the user defined layout is that, since the user is overriding the standard layout, the constraint that all directories be maintained on the same drive is NO LONGER REQUIRED. Of course, a caveat associated with this capability is that the user takes his chances on there being adequate disk space when the program starts to copy the files.

The user can also define the layout after installation by using a text editor to edit the contents of the **HYDRAIN.CNF** and **DRIVE.DAT** files. These files are created at installation and are used by the HYDRAIN system shell and HY8V3, respectively. Since this will also involve potentially copying 2.75 MB worth of files all over creation, this option should be attempted only by experienced DOS users. It will not be discussed here.

In conclusion, version 3.0 of the HYDRAIN system provides the user with a remarkable amount of flexibility in determining the directory and drive layout. It should be understood CLEARLY that only the default layout will be given total support should a file management error be uncovered. In other words, should you NOT use the default or standard layout with the system, the developers of HYDRAIN can provide no guarantees that the system will always run smoothly.

APPENDIX C

SETUP PROGRAM

The **SETUP** program is invoked from within the HYDRAIN System Shell. It allows the user to establish settings that inform the software of the appropriate drives, directories, and colors. The menus in Setup are ring menus, and options may be selected by moving the cursor to the desired selection and pressing carriage return <CR>. In addition, options may be selected in many of the Setup menus by pressing the letter which is highlighted in the desired option.

Upon entering Setup, the user will first view the Setup main menu shown in Figure 46.

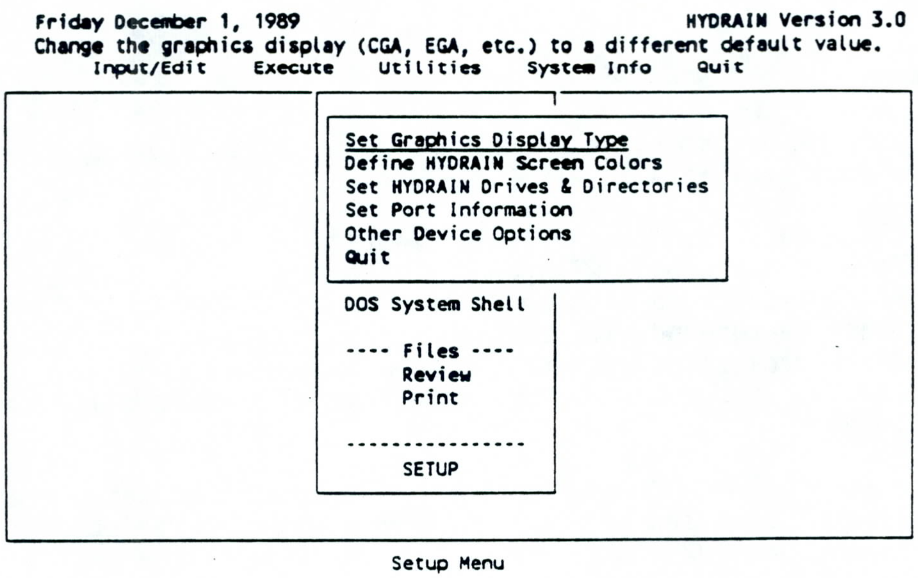

Figure 46. Setup Main Menu

There are five options (excluding QUIT) from which to choose:

- Set Graphics Display Type
- Define HYDRAIN Screen Colors
- Set HYDRAIN Drives and Directories
- Set Port Information
- Other Device Options

Each of these five options will be discussed in detail in this documentation. Either of the two methods described above may be used to select one of these options. For the benefit of the user, active (short) help is displayed at the top of the screen, and long help is available by pressing <F1>. Within the long help, the **PgUp**, **PgDn**, **Home**, and **End** keys are all active. The PgUp and PgDn keys move the display one page backward or one page forward, respectively. Furthermore, the Home key moves the display to the top of the Help file, while the End key moves the display to the bottom of the file. To exit the long help, press **<Esc>**.

Graphics Display Type

The **SET GRAPHICS DISPLAY TYPE** option allows the user to set the program's graphics mode. If the system is being run on a computer with a color monitor, the user is prompted to specify Low or High Resolution as the setting. To choose, move the cursor to the desired choice and press <CR>. If the monitor is Hercules Monochrome, there is no choice available. The setting is automatically set at High Resolution. To exit the Graphics Display Option, press **<Esc>**.

Screen Colors

Monochrome

Since the Hercules and monochrome monitors do not have color options, there are only FIVE options available to alter the screen appearance:

- Black background with regular lettering.
- Reverse background with black lettering.
- Black background with bold lettering.
- Black background with text underline.
- Black background with text bolded and underlined.
- Reverse background with bold text (Monochrome EGA and VGA only).

The sixth option is only available if an EGA or VGA monitor is being used. The last four options should be used to distinguish menu items for selection. Their use allows the user to move the block, bold, or underline to the desired option for selection.

Color Monitor

Within the Define HYDRAIN Screen Colors menu, the color monitor allows for hundreds of possible color combinations. The user can experiment with the different color combinations (through use of the display and sample long help) until one is found which is both practical and aesthetically pleasing.

Setting the Screen Colors

Choosing the **DEFINE HYDRAIN SCREEN COLORS** option takes the user to the screen shown in Figure 47. The Screen Colors sub-menu has seven available options. Choose the item for which the colors are to be changed by moving the cursor and pressing <CR> or by pressing the highlighted letter in the desired option. Regardless of which option is chosen, the screen in Figure 48 is displayed. The choices for screen colors are used to affect monochrome screen shading and contrast.

The screen in Figure 48 contains a matrix of available color combinations from which the user may choose if a color monitor is being used. If a monochrome or Hercules monitor is being used, the screen in Figure 49 will be displayed. When an item from the menu is chosen and the cursor is moved within the screen colors matrix, the corrsponding part of the current display is changed. If the option **Frame Colors** is chosen, moving the cursor in the matrix will change the background color of the display. Similarly, the highlight bar on "Input/Edit" and "Menu Cursor" will change if the **Menu Cursor** option is selected. Manipulating **the Menu Color** option will affect the color of the entire display,

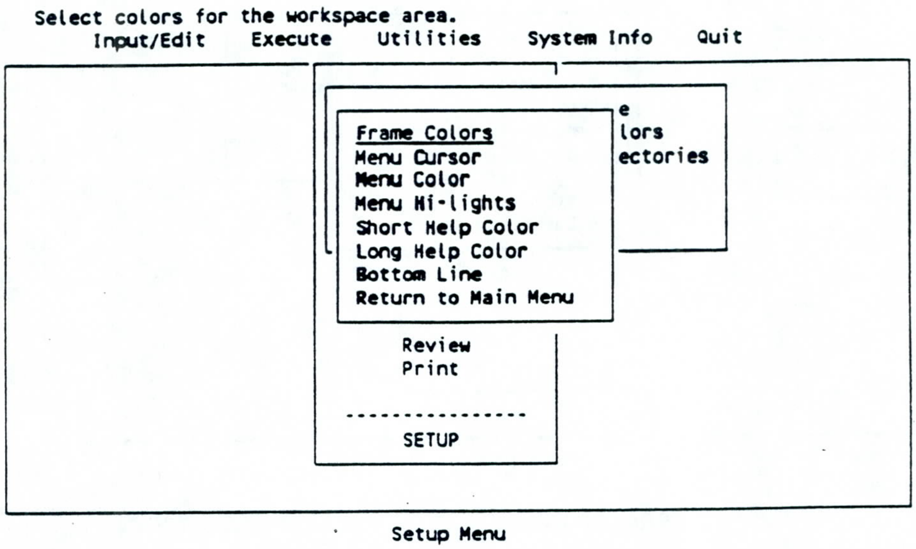

Figure 47. "Define HYDRAIN Screen Colors" Sub-Menu

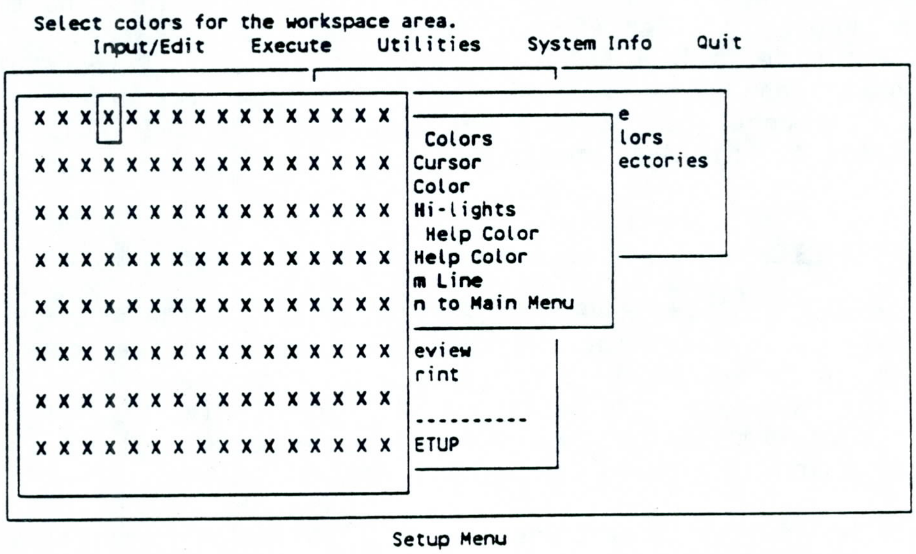

Figure 48. Color monitor Color Selection "X" matrix

while selecting **Menu Hi-lights** will change the first letter in each menu selection. Choosing **Short Help Color** and moving the cursor will affect the color of the short help at the top of the display. The **Long Help Color** option will allow the user to manipulate the color of the text in the sample "Help Screen", while choosing **Bottom Line** will allow the user to alter the color of the F1 and F2 footers at the bottom of the screen.

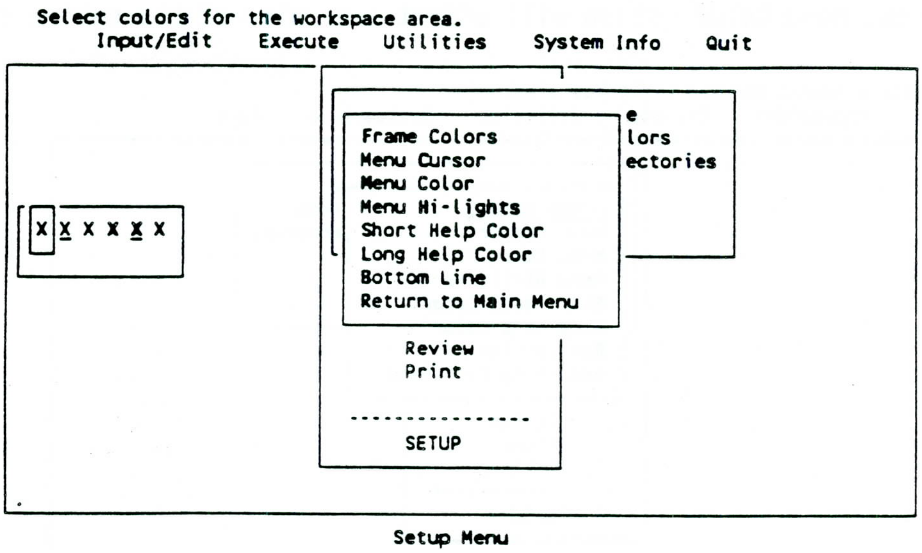

Figure 49. Monochrome Color Selection "X" matrix

In order to make changes, move the cursor through the "X" matrix to the desired location and press <CR> to return to the Screen Colors sub-menu. The user may then choose to alter various other parts of the screen. When all changes have been made, select **RETURN TO MAIN MENU** from the Screen Colors sub-menu. The program should now be in the Setup main menu. In order to save the changes which have been made, select **QUIT** and refer to the "Quitting Setup" section at the end of this documentation.

Drives and Directories

The option **SET HYDRAIN DRIVES & DIRECTORIES** allows the user to indicate where input and output files for the various HYDRAIN programs can be found. After selecting the Drives and Directories option, the screen in Figure 50 will appear. From this sub-menu, the paths are set for HYDRAIN, as well as for all of its sub-programs. To select an option, move the cursor and press <CR>, or, type the letter which is highlighted for the desired option.

The screen which is displayed when the HYDRAIN option is selected is shown in Figure 51. This screen lets the user tell the program where to find the HYDRAIN executable and help files. To change the path, move the cursor to the appropriate field and enter the new drive and directory. It is important to note that changing the drive and/or directory does not automatically switch files from the old drive/directory to the new one. It is the responsibility of the user to insure that the files for which the program will be searching are moved or copied to the new directory. To exit the HYDRAIN option and return to the Drives and Directories menu, press <Esc>.

```
Friday December 1, 1989                              HYDRAIN Version 3.0

        Input/Edit   Execute   Utilities   System Info   Quit

                    Set Path for HYDRAIN     rs
                    Set Path for HYDRO       tories
                    Set Path for HYDRA
                    Set Path for WSPRO
                    Set Path for CDS
                    Set Path for HY8
                    Intermediate Path
                    Quit

                        Review
                        Print

                      ----------------
                        SETUP

                            Setup Menu
```

Figure 50. "Set HYDRAIN Drives and Directories" Sub-Menu

```
Friday December 1, 1989                              HYDRAIN Version 3.0

        Input/Edit   Execute   Utilities   System Info   Quit

  Path for HYDRAIN shell to find HYDRAIN   C:\HYDRAIN
  Path where HYDRAIN HELP files are stored C:\HYDRAIN

                  FILE/PATH Information for HYDRAIN
                       Press ESC Key to Exit
                    Intermediate Path
                    Quit

                        Review
                        Print

                      ----------------
                        SETUP

                            Setup Menu
```

Figure 51. HYDRAIN Path input screen

If the option for **HYDRO**, **HYDRA**, **WSPRO**, **CDS**, or **HY8** is selected, a screen similar to the one in Figure 52 is displayed. The only difference is that wherever the word HYDRO appears, the appropriate program name will be substituted. In these screens, there are four lines which may require user input. The first asks the user to specify where the program's executable file is located. Second, the user may specify where the program's input files can be found. Third, the destination to which the output files should be directed may be entered. Finally, the user specifies where the help files for the given program are located. The current settings are displayed and can be changed by moving the cursor to the desired field, typing the new drive and directory, and pressing <CR>.

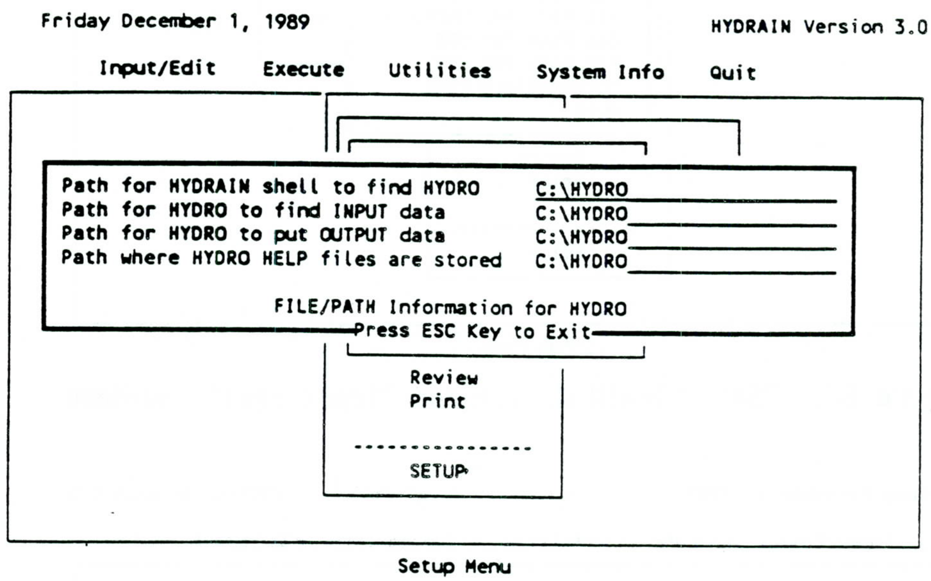

Figure 52. Program path input screen

Selecting the **INTERMEDIATE PATH** option results in the screen displayed in Figure 53. Once again, the preassigned drive and directory are displayed and may be changed as needed. This intermediate path defines the directory to which output to be used in other programs may be sent. By sending output to the specified directory, it will be readily available for retrieval into another program. For example, if the output from a given program is in the form of a hydrograph, the data describing the hydrograph might be sent, via the intermediate path, to a new file. This data might then be retrieved directly into a program which requires the input of a hydrograph. Use of the Intermediate Path option saves the user a great deal of time.

Finally, selecting **QUIT** will return the user to the Setup main menu.

Port Information

Choosing the **SET PORT INFORMATION** option enables the user to define all printing devices with which the HYDRAIN program might be used. The screen shown in Figure 54 displays the current information and enables the user to make any necessary changes. Due to the nature of the current HYDRAIN system, only the parallel port devices need to be specified.

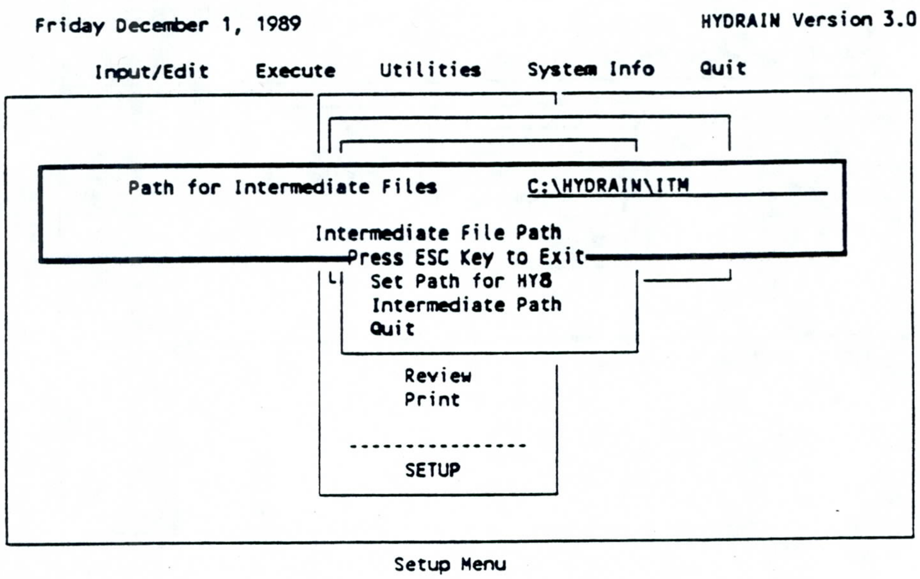

Figure 53. Intermediate path input screen

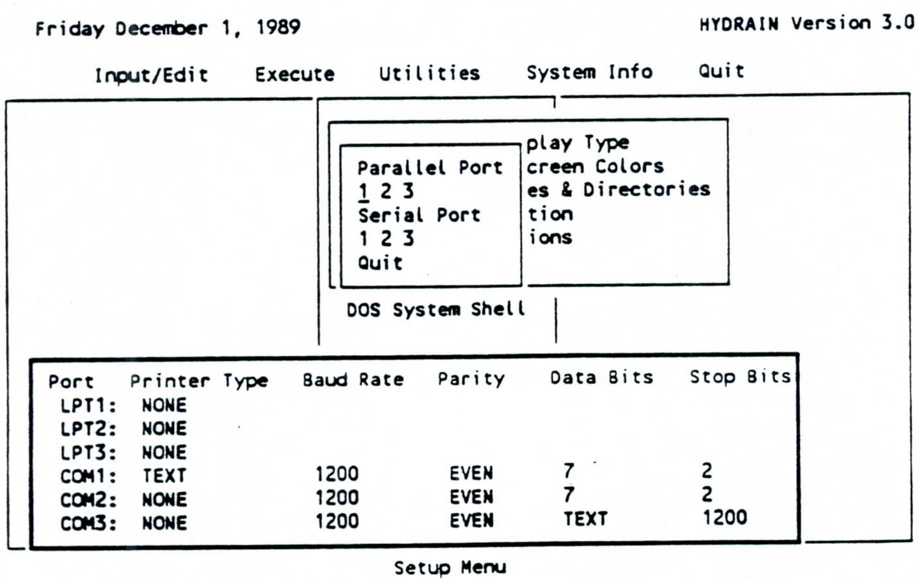

Figure 54. "Set Port Information" Sub-Menu

Select the port number under "Parallel Port" by moving the cursor and pressing <CR>. Another inset screen will be displayed as shown in Figure 55. Choose "Printer Device" for a text printer, "Graphics Device" for a printer with graphics capabilities, and "None" if there is no device at that port. Choose by moving the cursor and pressing <CR> or by typing the highlighted letter in the option chosen. Next, choose "Quit" to return to the screen displayed in Figure 54.

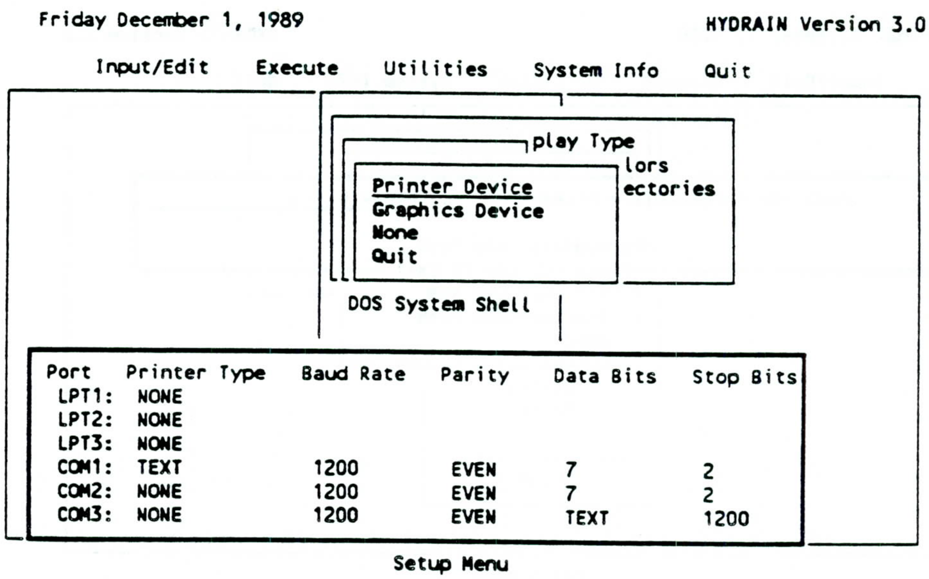

Figure 55. Input screen for changing printer definition

The "Serial Port" options are not used with current version of HYDRAIN, but may become useful in the future.

After all desired changes have been made, select "Quit" to return to the Setup main menu.

Device Options

The **OTHER DEVICE OPTIONS** selection is not operative in the current version of HYDRAIN. It is to be made available at a later date.

Quitting Setup

After all changes have been made, the user should leave the Setup program. Before exiting, however, it is important to be sure that all changes are saved. By selecting **QUIT**, the user will be prompted with the screen shown in Figure 56.

The **KEEP** option will save the changes and return to the HYDRAIN main menu while **STAY** will bring the user back to the Setup menu. Finally, choosing **RETURN** will bring the user to the HYDRAIN main menu without saving any changes.

```
Friday December 1, 1989                                  HYDRAIN Version 3.0
Keep the results of SETUP changes and return to HYDRAIN.
     Input/Edit    Execute    Utilities    System Info    Quit

                                 ics Display Type
                          Keep   DRAIN Screen Colors
                          Stay   IN Drives & Directories
                          Return Information
                                 ice Options
                         Quit

                         DOS System Shell

                         ---- Files ----
                              Review
                              Print

                         ----------------
                              SETUP

                              Setup Menu    Leave the configuration utility.
```

Figure 56. "Keep" prompt displayed when leaving Setup

APPENDIX D

Running HYDRAIN Program from DOS
Basic Instructions

Introduction

The analysis (or engineering) programs that comprise the HYDRAIN system can be accessed in two methods: from the HYDRAIN system shell, or from simply running them in DOS, without any ancillary programs. The following material discusses how to proceed with the HYDRAIN programs using the second method.

Engineering Programs

There are five engineering programs currently in the HYDRAIN system, HYDRO (HEC-19 Hydrology), HYDRA (Storm Drain Analysis and Design), WSPRO (Water Surface Profiles and Bridge Constriction Analysis), CDSV5 (Culvert Design and Analysis) and HY8V3 (Culvert Analysis). The first four programs consist of a single executable file. The last engineering program, HY8V3, consists of several executable files linked together by a DOS Batch file. The five programs are seen below:

Engineering Program	File Size	Creation Date	Creation Time	Program Description
HYDRA.EXE	165808	12-01-89	9:00a	HYDRA executable program
WSPRO.EXE	226596	12-01-89	9:00a	WSPRO executable program
HYDRO.EXE	122666	12-01-89	9:00a	HYDRO executable program
CDSV5.EXE	173054	12-01-89	9:00a	CDSV5 executable program
HY8V3.BAT	128	12-01-89	9:00a	HY8V3 DOS Batch file

HYDRA, WSPRO, HYDRO, and CDSV5 are known as BATCH programs (this is not to be confused with a DOS Batch file, mentioned above). This means that they assume that any data they use to solve a problem already exists and is in a separate input data file. The program executes. The results calculated by the program are placed in a separate output file. This approach is similar to how mainframes programs process information.

HY8V3 is an INTERACTIVE program. That is, it combines data entry and program execution together. For example, HY8V3 will collect data, calculate intermediate output, collect more data and calculate more information, and so on until the problem has been completed. The user is an element of the process.

Placing The Programs On Your System

If the HYDRAIN system has already been installed on the computer, the user can skip this section. In this context, installed means that the INSTALL program has been executed; thus automatically creating HYDRAIN and supporting directories, determining the computer's capabilities, and copying relevant files from the nine systems disks onto the user selected hard disk drive. If this is the case, proceed to the "Running HYDRAIN Programs"section.

If HYDRAIN has not already been Installed on the computer, several steps will need to be completed in order to successfully execute the programs. In the case of HYDRA, WSPRO, HYDRO, and CDSV5, this is a relatively simple matter of copying files. For HY8V3, it involves more of an effort and will not be discussed here. The best approach for installing HY8V3 involves either using the INSTALL program or other programs already developed for this purpose.

Begin by creating a directory on the hard disk (for this example we will call this directory "HYDRN"). At the DOS prompt type:

C> MD HYDRN<CR>

Next change to that directory by typing "CD HYDRN" and striking <CR>. The user is now in an empty directory called "HYDRN". Note that, if desired, a user could just as easily place each program on a separate floppy diskette.

Now begin to copy the files from the distribution disks to the hard disk directory as follows:

1. Copy HYDRA.EXE from disk 2 to HYDRA.EXE on the HYDRN directory;

   COPY A:\HYDRA.EXE<CR>

2. Copy WSPRO.EXE from disk 3 to WSPRO.EXE on the HYDRN directory;

   COPY A:\WSPRO.EXE<CR>

3. Copy HYDRO.EXE from disk 4 to HYDRO.EXE on the HYDRN directory;

   COPY A:\HYDRO.EXE<CR>

4. Copy CDSV5.EXE from disk 5 to CDSV5.EXE on the HYDRN directory;

   COPY A:\CDSV5.EXE<CR>

This concludes this section of the instructions.

Generating Input Files

Prior to running a program under DOS, an input file must be created. The versions of HYDRA, WSPRO, HYDRO, & CDSV5 that are provided need command line input files with the definitions given in the documentation or appropriate HELP files. These formats must be adhered to if the input file is created with a word processor, such as WORDPERFECT, with an editor, such as NORTON, or with a line editor, such as EDLIN. If the file is created with the HYDRAIN generic editor, the format is predetermined.

Running HYDRAIN Programs

HYDRA - To run PFP-HYDRA without the shell, at the DOS prompt type "HYDRA" and strike <CR>. Several blank lines will scroll across the screen. A message prompting the user for the input data file will appear. When it does, enter this file name and once again strike the <CR> key. In this example, the file name is called "ROUTE1.HDA." The next message will ask the user for the output file. Type in this name and hit <CR> (for this example, it will be called "ROUTE1.LST"). Finally, if there are any intermediate files on a different drive, provide that information at the third prompt. Since this example assumes that there are no intermediate files used in ROUTE1.HDA, simply press <CR>.

```
C>HYDRA<CR>

  - spaces -

  Enter the name of the data file: ROUTE1.HDA<CR>
  Enter the name of the output file: ROUTE1.LST<CR>
  Enter the name of the drive and path
  containing intermediate files - Press
  <CR> key if none or to use default
  drive and path:<CR>
```

An alternative is to type the executable file, input data file, output file and intermediate drive on the same line. This causes the program to function in the same manner as above, but without prompting the user for the files.

```
C>HYDRA ROUTE1.HDA ROUTE1.LST<CR>
```

WSPRO - To run WSPRO (sometimes called HY7) without the shell, at the DOS prompt type "WSPRO" and strike <CR>. Similar to HYDRA, a message prompting the user for the input data file will appear. When it does, enter this file name and strike the <CR> key. In this example, the data file name is called "ROUTE1.WSP." The next message will ask the user for the output file. Type in this name and hit <CR> (for this example, it will be called "ROUTE1.LST").

```
C>WSPRO<CR>
  Enter the name of the data file: ROUTE1.WSP<CR>
  Enter the name of the output file: ROUTE1.LST<CR>
```

An alternative is to type the executable file, input data file, and output file on the same line. This causes the program to function in the same manner, but without prompting the user for the files.

```
C>WSPRO ROUTE1.WSP ROUTE1.LST<CR>
```

HYDRO - To run HYDRO without the shell, at the DOS prompt type "HYDRO" and strike <CR>. A message prompting the user for the input data file will appear. When it does, enter this file name and once again strike <CR>. In this example, the file name is called "ROUTE1.HDO."

```
C>HYDRO<CR>
  Enter the name of the data file: ROUTE1.HDO<CR>
  Enter the name of the output file: ROUTE1.LST<CR>
  Enter the name of the drive and path
  containing intermediate files - Press
  <CR> key if none or to use default
  drive and path:<CR>
```

An alternative is to type the executable file and the input data file on the same line. This causes the program to function in the same manner, but without prompting the user for the data file.

```
C>HYDRO ROUTE1.HDO ROUTE1.LST<CR>
```

CDSV5 - To run CDSV5 without the shell, at the DOS prompt type "CDSV5" and strike <CR>. A message prompting the user for the input data file will appear. When it does, enter this file name and strike the <CR> key. In this example, the data file name is called "ROUTE1.CLV." The next message will ask the user for the output file. Type in this name and hit <CR> (for this example, it will be called "ROUTE1.LST").

```
C>CDS<CR>
  Enter the name of the data file: ROUTE1.CLV<CR>
  Enter the name of the output file: ROUTE1.LST<CR>
  Enter the name of the drive and path
  containing intermediate files - Press
  <CR> key if none or to use default
  drive and path:<CR>
```

An alternative is to type the executable file, input data file and output file. This causes the program to function in the same manner, but without prompting the user for the files.

```
C>CDS ROUTE1.CVT ROUTE1.LST<CR>
```

HY8V3 - To run HY8V3 without the shell, at the DOS prompt type "HY8V3" and strike <CR>. Since HY8V3 is Interactive, the user will be prompted for subsequent actions by the program itself.

APPENDIX E

READ ME File

HYDRAIN Programs and Support Files

Nine 360K diskettes are included with HYDRAIN and they can be categorized into two major groups: programs and support files. The programs are the executable files which govern the flow of HYDRAIN and perform the engineering analyses. The support files provide data and help messages to the programs as needed. The following is a complete listing of HYDRAIN computer files with a description of each file, and the location of the file if using the standard file management structure:

Executable Programs:

Program		Description
HYDRAIN.EXE	-	system shell
HYDRO.EXE	-	HYDRO engineering program
CDSV5.EXE	-	CDS engineering program
HYDRA.EXE	-	HYDRA engineering program
WSPRO.EXE	-	WSPRO engineering program
EDIT.EXE	-	Generic Editor program
SETUP.EXE	-	Setup program
HELP.EXE	-	
EQUAT.EXE	-	Hydro equation module program

TITLE.EXE
CULVERT.EXE
BRUN45.EXE
CULV2.EXE
HYD.EXE
TWATER.EXE
MULT.EXE
ROUTE.EXE

— HY8 Culvert Analysis Program executable programs

Support files:

READ.ME	-	overview documentation for HYDRAIN (this document)
HYDRA.HLP	-	HYDRA input program long and short help
HYDRAI.HLP	-	HYDRA help index file
EQUAT.DAT		Equation module support file
EQUAT.I1	-	Equation module support file
EQUAT.DD	-	Equation module support file
HYDRN*.HLP	-	system shell long help (18 files)
HYDRO.HLP	-	HYDRO input program long and short help
HYDROI.HLP	-	HYDRO help index file
CDSV5.HLP	-	CDS input program long and short help

CDSV5I.HLP	-	CDS help index file
WSPRO.HLP	-	WSPRO input program long and short help
WSPROI.HLP	-	WSPRO help index file
SETUP*.HLP	-	SETUP program long help (7 files)
CULVERT.HLP	-	
MULT.HLP	-	
CULV2.HLP	-	
ELPC*.DAT	-	(2 files)
LSHPA.DAT	-	
LSLPA.DAT	-	
SPSA.DAT	-	
PAC*.DAT	-	(7 files)

The System Shell

The system shell is a managerial program that presents option and help menus to lead a user through HYDRAIN. Therefore, new users need not possess advanced microcomputer skills and can begin using HYDRAIN productively almost immediately. (Furthermore, once in the system shell, the user is provided with continuous "short" help and may access "long" help by pressing <F1>.

The system shell is initiated from its resident subdirectory by typing HYDRAIN and <CR>. The opening screens will then be displayed. The first screen displays the sponsors of HYDRAIN and the second displays a disclaimer. Press any key twice to access the main menu.

The next screen to be displayed is the HYDRAIN main menu.

Main Menu

The HYDRAIN main menu allows the user to choose between the following options:

- **Input/Edit** - Create or edit new and existing input files using either the generic or interactive editor.
- **Execute** - Run a program.
- **Utilities** - Make DOS changes, view files, change Setup.
- **System Info** - Access long help for selected HYDRAIN topics.
- **Quit** - Leave the HYDRAIN system and return to MS-DOS.

Two means of selecting an option are available to the user. The first is to use the cursor keys to move to the desired menu option and strike <CR>. Notice that a line of "active" help provides the user with a short description of each option. Another method for selecting an option is to simply strike the first letter of the desired menu item (e.g. to choose Execute, simply strike "E"). Selection of any option other than QUIT results in a pull-down menu being displayed.

Information on the various aspects of the system shell is found in the SYSTEM INFO option. The information includes menu descriptions, function key descriptions, file naming conventions, a PFP bibliography, and other useful information.

Function Sub-Menus

Once an option has been selected, and the associated pull-down menu is displayed, the user should select one of the available options from the sub-menu. In order to select an option from a pull-down menu, use the cursor keys to move to the desired menu item and strike <CR>. Notice that a line of "active" help provides the user with a short description of each option.

Selecting Input/Edit or Execute will result in a pull-down menu which lists the engineering programs available to the user. The user should select a program and proceed with the desired operation. Selecting Utilities will provide the user with a choice of ten options available for file maintenance. Finally, selecting System Info provides the user with a choice of five topics on which further long help is available.

Keyboard Usage

HYDRAIN includes a series of specially defined function keys which are used throughout the system shell. They are used as follows:

F1 - Access long help.
F2 - Access pull-down menus.

Cursor Keys

Left arrow - moves the cursor to the left one space or field.
Right arrow - moves the cursor to the right one space or field.
Up Arrow - moves the cursor up one line.
Down Arrow - moves the cursor down one line.

Other Keys

<CR> - Enter/Carriage Return - Continue to the next option.
Esc - Return to HYDRAIN main menu.
Home - Moves to the top of a menu.
End - Moves to the bottom of a menu.
Backspace - Deletes spaces in a field one at a time.

Engineering Programs

HYDRO (Hydrology)

HYDRO is the hydrology component of the HYDRAIN system. This program was developed as part of the Pooled Fund effort to combine existing approaches for rainfall and runoff analyses into one computerized program. Within the HYDRAIN system, HYDRO can be used either alone or in coordinated drainage design studies, providing hydrological information so that other programs can analyze culverts, constructed and natural channels, storm sewers, bridge constrictions and other situations where flooding and flood mitigation are important. The HYDRO analysis program provides rainfall/flow inputs for other system elements (bridge, pipes, culverts) to act upon. The output includes a hydrograph, rainfall frequency/duration/intensity curves, and a triangular hyetograph.

The Hydro input program main menu allows the user to choose between the following options:

- o RETRIEVE data from an existing input dataset (worksheet). If an input dataset is being created, the user does not need to use this option, but can simply go to the EDIT option.

- o EDIT and Enter design rainfall or design flow input data. This is the option that will be used to access the hydrological analysis selections and to execute the input datasets.

- o STORE data into a worksheet file. If the user forgets to save the data before leaving the input program, it is automatically saved in a file called LASTIME.HDO that can be retrieved the next time the user enters the program.

- o QUIT the Hydro input program and return to the HYDRAIN System Shell. Save all data in a file called LASTIME.HDO.

To select an option, use the cursor keys to move to desired menu item (or field) and strike <CR>. Notice that a line of "active" help provides the user with a short description of each option. Another method for selecting an option is to simply strike the highlighted letter of the menu item you wish to select, for example, to choose the Retrieve option, strike the R key

Each of these choices results in another menu with choices specific to the option chosen. At any time, the user may press the <F1> key to access the full screen help.

Design Rainfall

There are two design rainfall options. The first option is used to determine rainfall intensities. The second option builds an IDF curve. Both options use an unique rainfall intensity database (RAIN.PFP) that contains rainfall values for the contiguous United States to perform calculations. The first option also allows the user to input their own duration and/or rainfall intensity values. Brief summaries of the options follow:

o Rainfall Intensity Determination

The rain option calculates the rainfall intensity (inches/hour) for a desired return period and a duration (assumed to be time of concentration in hours) at a site. Additionally, this option can use Yen and Chow's Method to create a triangular hyetograph (intensity-vs-time) for the site. If desired, users can input their own duration (time of concentration) and/or intensity.

o Intensity-Duration-Frequency Curve

The second design rainfall option creates an intensity duration frequency (IDF) curve for the desired site and return period. The duration ranges from 5 minutes up to 24 hours. The frequency (return period) ranges from 2 to 100 years. A plotting routine puts these IDF ordinates on a graph where the y-axis is intensity (inches/hour) and the x-axis is duration (hours). Two graphs are created: one plots all points for durations up to 24 hours; the second details the first 2 hours of the first curve.

Because this option uses the rainfall intensity database, the site must be in the continental United States. The IDF option does not allow the user to input a rainfall intensity.

When the rainfall database is used, and a return period of less than 2 years is entered, the program will set the return period equal to 2. A warning message is not generated when this occurs, but the change in return period is reflected in the title of the IDF curve. If a return period greater than 100 is entered, HYDRO sets the value to 100.

Design Flow

There are four design flow options. These are: rational method, user developed equations, log Pearson type III analysis, and user supplied design flow. These options can produce input to other HYDRAIN programs.

o Rational Method

This option uses the rational method equation (Q = CiA) to calculate the peak flow (in ft^3/s) at a site. The rainfall intensity is calculated for a specific return period and duration (time of concentration) using a unique rainfall database (RAIN.PFP), or it can entered by the user. The area variable is developed using seven land use conditions as subareas. Default runoff coefficients are provided (or can be replaced at the Users option). A unit hydrograph can be developed using Constant's modification of Snyder's method.

o User Developed Equations

This option allows the user to develop their own site specific and general peak flow equations (or use USGS 3 and 7 Parameter Regression Equations). The user inputs the equation in its algebraic form. For example:

Q25 = SLOPE * AREA ** 0.147 + INTENSITY * DURATION ...)

The user would only need to enter the equations once. A unit hydrograph can be developed using the resulting calculated peak flows.

o Log Pearson Type III

This option uses log Pearson type III analysis with USGS gauge station data to calculate the peak flow (in ft^3/s) at a site. A unit hydrograph can be developed using Constant's hydrograph method. The gauge station data must be provided by the user. Several sources of this information are provided in the HYDRAIN System Shell resources help screen.

NOTE The log Pearson type III analysis is designed for 30 or more records; however, the program has been run successfully with as few as 7.

o Design Hydrograph

This option develops a unit hydrograph for a given flow across a specific site. The option uses the USGS Urban Dimensionless hydrograph to create the unit hydrograph.

The hydrology program (HYDRO) uses an .HDO extension for inputing / editing data and executing the program. If no extension is added by the user, the System Shell will automatically append the correct extension.

HYDRO also provides rainfall/flow data for other system elements including hydrographs, rainfall intensity/duration/frequency curves, and hyetographs. The filename extensions for the above output are as follows:

" .QT " = This extension contains the ordinates of a hydrograph (ie: flow (Q) vs. time (T)). If desired, this file can be incorporated into the other engineering programs (i.e.: into CDS using the XXXX.CD. work deck, and into HYDRA using the "UHY" Command).

" .HYE " = This extension contains the ordinates of a hyetograph (ie: rainfall intensity (I) vs. time (T)). If desired, this file can be incorporated into HYDRA using the "HYE" command.

" .IDF " = This extension contains the ordinates of an Intensity-Duration-Frequency (IDF) curve (for a duration from 5 minutes to 24 hours). If desired, this file can be incorporated into HYDRA using the "RAI" command.

CDSV5 (Culvert Design System)

The Culvert Design System (CDSV5) can design a culvert or review an existing or proposed culvert. It investigates hydrograph relationships, culvert shapes, materials, and inlet types. Data may be obtained to allow manual plotting of culvert performance curves. CDS can generate a hydrograph, determine culvert size, and identify the flow type, outlet conditions for velocity, Froude number, and brink depth. The system provides four distinct types of analysis that can be classified into two broad options: design and review.

The "design option" selects a culvert size and number of barrels compatible with the engineering data, environmental constraints, and site geometry. With this option, the user can request that CDS consider any or all of the following culvert types: round concrete, round metal, arch concrete, arch metal, oval concrete (horizontal placement only), and concrete box. There is an upper limit of six barrels for commercial culverts or five for concrete box culverts.

The user must select one of two methods of design: irrigation design or drainage design. The irrigation design method ignores any upstream pond storage and selects a culvert capable of passing the peak discharge. Irrigation ditches in western States operate for long periods at full or near full capacity, thereby precluding any available pond storage. The drainage design method uses any temporary upstream pond storage by routing a hydrograph through the site.

Provision has been made in the design option for the user to obtain data for manually plotting a culvert performance curve. This is accomplished by the user identifying the design discharge and five other performance discharges deemed suitable to define a performance curve. With these discharges, the system will first size a culvert using the design option and then review this design culvert size using the five performance discharges. This satisfies FHWA requirements for a culvert performance curve and assists in making a flood hazard assessment provided the basic flood (100-year event) is one of the five performance discharges. It is not necessary to input the five performance discharges in order to secure a culvert design, however.

The "review option" provides hydraulic performance data for a specific culvert identified by the user. In this option, the user identifies the culvert type (in accordance with those listed above), size, inlet type, slope, and number of barrels.

The review option uses the same equations as the design option. Again, users must indicate whether the specific culvert is to be reviewed using the irrigation design method or the drainage design method.

The review can also be used to obtain a culvert performance curve for a predetermined culvert size and geometry. With this option, the program reviews the specified culvert size, type, and geometry using the discharges provided (six maximum).

CDS provides the user with a choice of two hydrograph alternatives in either the design or review options. The first alternative allows the user to input up to six hydrographs for a given discharge; these may be generated in HYDRO. Each of the six discharges that can be input to the system also require input of their own unique hydrograph. The second alternative is where the user does not elect to input a hydrograph. With the second alternative, the system generates a hydrograph internally based on the State of Wyoming's flood studies. These studies are for semiarid regions having watersheds ranging from 0 to about 15 square miles. In Wyoming's snowmelt regions, urbanized watersheds and any watersheds greater than 15 square miles, it is necessary to input a hydrograph for the design to be valid. (An alternative in Wyoming's snowmelt region would be to specify the irrigation design option as snowmelt hydrographs tend to have relatively long duration hydrographs.)

Data should be gathered prior to data entry and analysis activities. Typical data needs depend upon the work deck combination and include:

- Channel cross-section.
- Friction factor.
- Desired culvert type.

- Culvert length and slope.
- Channel slope.
- Road profile.
- Height of overtopping.
- Storage versus stage.
- Design flow.
- Hydrograph (from HYDRO).

HYDRA (Storm and Sanitary Sewers)

HYDRA can be used to analyze a predescribed or existing sewer system or to create a preliminary design for a new one. In the design made it can also be used to estimate construction costs including the following categories: bedding, area, excavation, pipe zone, backfill, and surface restoration.

HYDRA can analyze sanitary, storm, or combined sewers. If the user is designing/analyzing a storm sewer, HYDRA has the capability of generating flow using hydrographic simulation, or if the contributing land segment is a small, urban watershed, the rational method. The method of flow generation is strictly up to the user.

HYDRA operates in two basic modes: design and/or analysis. In the design mode, HYDRA accepts design data (such as friction factor, pipe length, land use characteristics, etc.), generates a design flow, and suggests a system capable of handling the given flow. The output includes such information as recommended pipe diameter, slope, depth of pipe, invert elevations, minimum cover, quantity and velocity of flow, and the estimated total cost of placing the pipe.

The analysis mode input is very similar to that of the design mode. The major difference is that the known characteristics of an existing system are entered instead of generic design criteria. HYDRA then calculates whether or not the system can accommodate the specified flow. If not, HYDRA suggests the necessary pipe size to correct the problem. Whether performing a design or an analysis, HYDRA is capable of handling a system of virtually any practical size.

HYDRA uses an ".HDA" extension for inputing / editing data and executing the program. The extension is automatically appended by the program shell and should not be added by the user. HYDRA output file names have the input file name prefix and the ".LST" extension.

WSPRO (Water Surface Profiles)

The Water Surface Profile Computation Model Microcomputer Program has been designed to provide a water-surface profile for six major types of open channel flow situations:

- Unconstricted flow.
- Single-opening bridge.

- Single-opening bridge with spur dikes.

- Single-opening embankment overflow.

- Multiple alternatives for a single job.

- Multiple openings.

WSPRO was originally developed by the United States Geologic Survey (USGS) for the Federal Highway Administration. The original model was a batch mode mainframe program, written in FORTRAN. The members of the Pooled Fund Project decided to use WSPRO as the bridge waterways analysis element of the Integrated Computerized Drainage Design System. WSPRO was downloaded to the microcomputer by the USGS and FHWA. The microcomputer version of WSPRO, is dated August 1988.

The input file forms a logical description of the physical characteristics of a waterway. Once the user is comfortable with this method of data setup, the program will provide a simple method for determining water surface profiles. The scheme is similar to the Corps of Engineers HEC-2 program. Both WSPRO and HEC-2 are acceptable to the Federal Emergency Management Agency. WSPRO has the advantage that it utilizes more recent approximations for the backwater effects associated with bridge constrictions.

The Bridge Waterway (and Open Channel) Analysis program (WSPRO) uses an ".WSP" extension for inputing / editing data and executing the program.

HY8V3 Program

HY8 Version 3.0 was developed by Pennsylvania State University in cooperation with the Bridge Division (HNG-31). The HY8 software is sponsored by the Rural Technical Assistance Program (RTAP) of the National Highway Institute under Project 18B administered by the Pennsylvania Department of Transportation.

The software automates the design methods described in HDS No. 5, "Hydraulic Design of Highway Culverts" dated September 1985, FHWA-IP-85-15; HEC No. 14, "Hydraulic Design of Energy Dissipators for Culverts and Channels" dated September 1984; and HEC No. 19, "Hydrology" dated October 1984, FHWA-IP-84-15. These publications are available from the Government Printing Office, Washington, DC 20402, from NTIS, 5285 Port Royal Rd, Springfield, VA 22161, and from the McTrans Center, 512 Weil Hall, Gainesville, FL 32611.

The software has been structured to be self-contained and requires no users' manual. This facilitates its use by roadway design squads. However, the knowledgeable hydraulic engineer will also find the software package useful because it contains advanced features.

The software is designed to be self-explanatory. Help screens have been added to the Culvert Design and Energy Dissipator programs. However, some screens such as plots, do not tell you what your next action should be. In these cases, pressing enter will normally take you to the next screen or continue operation.

Some of the features such as improved inlets, hydrograph generation, routing, and design of energy dissipator require an experienced user who is familiar with these design methods. These options can be used by others, but uneconomical, hydraulically inadequate, or unpractical designs may result.

Software Features

PROCEDURES - FHWA HDS No. 5, Hydraulic Design of Highway Culverts; FHWA HEC No. 14, Hydraulic Design of Energy Dissipators for Culverts and Channels; and HEC 19, Hydrology, are the references for the procedures used in the software package.

APPROACH - Programs analyze or review user selected variables. This approach is chosen so that the user is not constrained by the design philosophy of the software and can easily compare alternatives.

SHAPES - Circular, box, elliptical, and pipe-arch with constant "n" and user defined shape , arch, low-profile arch, high-profile arch and metal boxes with different "n" for top and bottom. Execution of user defined shape, arch, low-profile arch, high-profile arch and metal boxes is considerably slower than other shapes.

INLETS - The user selects inlet edge condition from a menu which is consistent with the selected shape. An inlet depression may be provided. If a circular or box shape is selected, the user may select either a circular or rectangular side-tapered inlet or a slope-tapered inlet.

NUMBER - The user may choose any number of barrels with the same site, shape, inlet, and "n" or up to 6 independent culverts. In both cases the culverts share the same headwater pool, tailwater pool, and roadway.

SITE DATA - The station and elevation of the culvert inverts can be entered or will be calculated if embankment slope and toe DATA are entered.

DISCHARGE - User chooses maximum discharge for 11 point performance (rating) curve. The minimum discharge default is 0, but can be changed. Design discharge is one of points in the rating curve.

TAILWATER - The user can input a rectangular, trapezoidal, triangular channel, 15 cross-section points for irregular channel, 11 rating curve points, or a constant tailwater elevation. A rating curve can be displayed.

MINIMIZATION- ROUTINE — This new feature in HY8 allows the designer to enter an allowable headwater elevation which wiill be used to adjust the culvert size. The program will increase or decrease the culvert size until it computes a controlling headwater elevation lower than the defined allowable headwater for the design discharge. Several hydraulic parameters such as the controlling headwater elevation, inlet and outlet control elevation, culvert flow velocity, channel flow velocity, culvert flow depth, channel flow depth, and normal and critical depth will be recomputed when the minimization routine is activated. This routine is activated by selecting letter M from the options shown in the Summary Table screen. Only one culvert size can be minimized at a time.

OVERTOPPING - If a roadway profile cross-section is provided, flow over the roadway weir will be balanced with the flow through the culverts.

OUTPUT - A performance table is provided which contains for each discharge: headwater and tailwater elevation, inlet and outlet control headwater depths, crest control, throat control and face control elevations, and outlet velocity. The user can choose to view the inlet and outlet control curves and computational error table. A print-out of the analysis in a report format can be selected.

ROUTING AND HYDROGRAPH - A culvert file and an inflow hydrograph file name may be provided with upstream topographic data and the software will provide both a table and a plot of the outflow hydrograph. If a hydrograph file is not available, it can be created if rainfall data is known.

ENERGY DISSIPATOR - This program is now part of HY8 Version 3.0. It follows the design procedures presented in HEC No. 14, Hydraulic Design of Energy Dissipators for Culverts and Channels. Hydraulic parameters computed in the culvert design program are imported into this program. Therefore, a culvert file has to be created in order to use the energy dissipator program. The following categories of energy dissipators are available:

1) Internal Energy Dissipators:
   - Increased Resistance
   - Tumbling Flow

   These dissipators are only available for Box or Circular culverts only.

2) External Energy Dissipators:
   A) Drop Structures
      - Box Drop-Structure
      - Straight Drop-Structure

B) Stilling Basin:
- USBR Type 2 Basin
- USBR Type 3 Basin
- USBR Type 4 Basin
- S.A.F. Basin

C) At-Streambed-Level Structures
- CSU Basin
- Riprap Basin
- Contra Costa
- USBR Type 6

Restrictions and special limitations on these dissipators are presented in a table format for each dissipator category in The screen.

FILES - Data files which are keyed to the MS-DOS name provided by the user are stored under the appropriate extension supplied by the software. The user has to create the subdirectories specified on SETUP.EXE so that the data files can be stored and retrieved by the software. The subdirectories specified on SETUP.EXE will be stored in DRIVE.DAT which should reside in the same directory as the *.EXE files.

EDITING CULVERT DESIGN FILES - Existing file data are loaded to a data summary screen and can be edited or run. If a change is desired, the user selects the data to revise: site, culvert, discharge, tailwater, or overtopping. The existing data are then displayed in the data entry screens and can be edited.

```
******************************************************************************
* Users who have older versions of HY8 should not attempt to run old data   *
* sets with this release. These old data sets will not correspond and       *
* will not be read by the current version.                                   *
******************************************************************************
```

We hope that you find this software to be a very useful tool for designing culverts. We would appreciate receiving your written comments on any errors identified in the software. Please send them to one of the following addresses:

Bridge Division, HNG - 31
Federal Highway Administration
400 Seventh St., SW, Room 3113
Washington, D.C. 20590

-OR-

GKY and Associates, Inc.
5411-E Backlick Rd.
Springfield, VA 22151

HYDRAIN - INTEGRATED DRAINAGE DESIGN COMPUTER SYSTEM

VOLUME II. HYDRO - HYDROLOGY

by:

GKY and Associates, Inc.
5411-E Backlick Road
Springfield, VA 22151
(703)642-5080

for:

Structures Division, HNR-10
Federal Highway Administration

Under Contract #DTFH61-88-C-00083

February 1990

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TABLE OF CONTENTS

TABLE OF CONTENTS
(continued)

Page

List of Figures

List of Tables

Preface

This report presents documentation for the HYDRAIN system. HYDRO, HYDRA, CDS, WSPRO and HY8 are five nonproprietary hydrology and hydraulic engineering programs incorporated in the HYDRAIN system. The HYDRAIN personal computer oriented system operates these engineering applications with programs written in the C language. The system is designed with an open architecture for expansion. HYDRAIN is sponsored as a Pooled Fund Project (PFP) of 29 State highway departments and is managed by the Federal Highway Administration (FHWA). The system is expanding with flexible lining design logic and integrated culvert analysis logic under development. Graphic output options are also under development and are available in some areas already.

Within the HYDRAIN concept, the HYDRO, HYDRA, CDS, and WSPRO allow the user to consistently input, edit and run relevant input data files and to scroll through output files. With these applications "short", one-line, and "long", multiple line, help is provided within an editor that services all applications.

HYDRAIN integrates hydraulic and hydrology programs into a unified system. The intent of the integration is to enable users to then learn basic principles of how to operate an application and file manipulation and then be able to apply the same principles to other applications and files within the system. One guiding principle is a **command land input format**. This trend in hydraulic programs is typified by HEC-2 and HYDRA. It is very pragmatic. WSPRO also adopted the command line method. Another guiding principle is a **generic input** editor that works the same for each integrated program--HYDRO, HYDRA, CDS, and WSPRO. The input file for each integrated program is a line by line command language that identifies the computation and/or provides the required data. Each line of data is preceded with a two or three-letter command. A typical command is **XS**, indicating a cross section; both WSPRO and CDS read this command. Another typical command is **PDA**, indicating the line contains the design parameters for pipe analysis (PIPE DATA); HYDRA reads this command.

A strength and a weakness of HYDRAIN is the need to know beforehand the sequence of commands that will result in making an application work. The commands are, of course, the batch input file. The user needs to know a proper sequence or know how to put one together. The sequences are termed "footprints." Given the right "footprint," an application will work; note that footprints are not necessarily unique, in that there may be several ways to get a job done. This documentation includes footprints to get users started and user support will aid in proper "footprint" design. Once a user has a library of footprints for his applications, the use of HYDRAIN should save considerable time and money. HY8 is a stand-alone interactive BASIC program that accepts inputs during processing; HY8 does not require footprints and leads the unfamiliar user through input preparation. All engineering programs but HY8 are batch oriented, and three steps are built into the process of using them: input file generation, programs execution, and output file screen review or listing. HY8 accepts inputs and generates outputs as the engineering program logic is executing.

HYDRO Program

HYDRO is a command line hydrology program. FORTRAN code for HYDRO was developed to combine existing approaches for rainfall and runoff analyses into one computerized program. Within the HYDRAIN system, it can be used independently or it can be used to generate input data for other engineering programs within the system.

HYDRO offers many hydrologic analysis options to the engineer. Each is site specific based on user inputs.

- Design Rain Using Digitized NWS Information or State-Supplied Files - Calculates the rainfall intensity for a specific return period, duration, and site.
- Design Hyetograph using Yen and Chow's method - Calculates the rain versus time plot for a return period, duration and site.
- Intensity-Duration-Frequency Curve Using Either the NWS Information or State-Supplied Files - Analyzes a specific site and creates two graphs: a plot of points for durations up to 24 hours, and a detail graph of the first two hours. Can be input to HYDRA.
- Design Flow by Rational Method - Uses a specific return period, duration and intensity to determine the peak flow for the site.
- Design Flow by USGS Regression Method - Uses USGS log-log regression equations with user-supplied parameters to determine design flow.
- Design Flow by log Pearson type III - Calculates the peak flow for given data.
- Design Hydrograph by USGS Dimensionless Hydrograph - Calculates a hydrograph to support storage routing within HYDRA or CDS.
- Maximum Observable Flood - estimates the largest flow at a site based on the envelope of all floods in a region.

PFP-HYDRA Program

HYDRA is a command line gravity pipe network hydraulics program. FORTRAN code for HYDRA previously existed and the Pooled Fund work effort included substantial improvements. HYDRA is a storm and sanitary sewer system analysis and design program. It can be used either to model an existing sewer system or to design a new system.

HYDRA generates storm flows by using either the Rational Method technique, hydrologic simulation techniques, or accepting a hydrograph generated by a HYDRO analysis. It can be used to design or analyze storm, sanitary or combined collection systems. HYDRA can handle up to 1,000 contributing drainage areas and 2,000 pipes. Additionally, HYDRA can be used for cost estimating. The Rational

Method approximates the peak rate of runoff from a basin resulting from storms of a given return period. HYDRA's hydrologic simulation models the natural rainfall-runoff process. In the simulation, runoff hydrographs are generated, merged together, and routed through the collection system. Inlet limitations can be analyzed: inlet overflow can be passed down a gutter system, while inlets in sumps can store water in ponds.

In the HYDRA design process, the program will select the pipe size, slope and invert elevations given certain design criteria. Additionally, HYDRA will perform analyses on a existing system of pipes (and/or ditches). When an existing system of pipes is overloaded, HYDRA will show suggested flow removal quantities as well as an increased pipe diameter size as an alternative remedy. HYDRA includes HEC-12 inlet theory hydraulic gradeline calculations, and an ability to route flow through internal storage sites using a storage-indication method.

HYDRA requires the forming of an input file of commands to describe the sewer system. Commands for HYDRA are placed in a logical sequence usually from upper to lower elevation. Is it possible that several command sequences can produce the same result. An input file is established for a particular collection system by the engineer and then the HYDRA program is executed. To change the characteristics of the collection system, the input file can be edited.

The HYDRA program requires design criteria for the pipes: friction factor (Manning's "n"), minimum diameter, ideal depth, minimum ground cover, minimum velocity (full flow), minimum slope, and maximum diameter. The friction factor is necessary for both analysis and design, while the remaining values are needed only for design. In the case of a design, the program selects invert elevations and slope as well as the physical sizing of each link given certain design criteria, whereas in the analysis mode, pipe alignment and sizing are predetermined and the impact of proposed flows are analyzed. Design criteria can be changed for each pipe if so desired. HYDRA is not an optimization program, thus individual case studies need to be run and analyzed by the engineer.

CDS Program

CDS is a command line culvert program. The Culvert Design System provides the user with two broad options for investigating culvert characteristics. CDS can either (1) hydraulically design a culvert or (2) analyze an existing or proposed culvert. CDS has capabilities for investigating a variety of hydrograph relationships, culvert shapes, materials, and inlet types. With CDS, the engineer can request any of six culvert types: round concrete, round metal, arch concrete, arch metal, oval concrete, and concrete box. CDS routes hydrographs, considers ponding, and overtopping.

The Design option selects a culvert size and number of barrels that are compatible with engineering data, environmental constraints, and site geometry. In this option, hydraulic performance data are calculated for each new culvert system design. The Review option provides hydraulic performance data for any preselected combination of culvert type and size, inlet type, slope, and number

of barrels. The initial design and analysis options may be followed by up to five additional culvert types or flow frequencies so that a full spectrum of risk scenarios or economic considerations can be simulated at the same time.

Two possible flow scenario methods can be selected: (1) steady state or irrigation, that assumes constant flow through the culvert, or (2) dynamic, that simulates drainage flow conditions. The dynamic option can route a hydrograph through the culvert system using three hydrograph alternatives: a user input hydrograph, a hydrograph produced by the HYDRO program, or the use of an internally produced default hydrograph (simulating semi-arid, high plains conditions). Additionally, the dynamic flow scenario can accommodate upstream pond storage.

CDS will determine culvert size based on the design headwater, headwater/diameter ratio, inundation, outlet velocity, cover limitations, or any combination of these parameters. The program will automatically increase the number of barrels when the upper limit for the greatest vertical dimension is exceeded. There is a limit of six barrels for commercial size culverts and five for concrete box culverts. The program can also be used to assess flood hazards, environmental assessments of upstream pond coverage, downstream flooding, channel impact, inlet type and beveled inlet evaluations, and reservoir facilities which use a culvert type structure for the spillway. Based on these data the program will proceed to identify the flow type and the outlet conditions for velocity, Froude number, and brink depth.

WSPRO Program

WSPRO is a command line step backwater program for natural channels with an orientation to bridge construction. The Water Surface Profile Computation Model Microcomputer Program has been designed to provide a water-surface profile for six major types of open channel flow situations:

- Unconstricted flow.
- Single opening bridge.
- Bridge opening(s) with spur dikes.
- Single opening embankment overflow.
- Multiple alternatives for a single job.
- Multiple openings.

WSPRO was originally developed by the United States Geologic Survey (USGS) for the Federal Highway Administration. The model was a batch mode mainframe program, written in FORTRAN. The members of the Pooled Fund Project decided to use WSPRO as the bridge waterways analysis element of the Integrated Computerized Drainage Design System. WSPRO was downloaded to the microcomputer by the USGS and FHWA. The microcomputer version of WSPRO, is dated August 1987.

The command input file forms a logical description of the physical characteristics of a waterway. Once the user is comfortable with this method of data setup, the program provides a step backwater method for determining water surface profiles. The scheme is similar to the Corps of Engineers HEC-2 program. Both WSPRO and HEC-2 are acceptable to the Federal Emergency Management Agency. WSPRO has the advantage that it utilizes more recent approximation techniques for the backwater effects associated with bridge constrictions.

HY8 Program

HY8 is an interactive culvert analysis basic program that utilizes the FHWA analysis methods and information published by pipe manufacturers. The program includes modules to allow the user to interactively enter, save, and edit data. HY8 will compute the culvert hydraulics for circular, rectangular, elliptical, arch, and user defined geometry. Additionally, improved inlets can be specified and the user can; analyze inlet and outlet control for full and partially full culverts, analyze the tailwater in trapezoidal and coordinate defined downstream channels, analyze flow over the roadway embankment, and balance flows through multiple parallel culverts. A hydrograph can be produced and routed.

The initial logic involves calculating the inlet control and outlet control headwater elevations for the given flow. These elevations are compared and the larger of the two is used as the controlling headwater elevation. Tailwater effects are taken into consideration when calculating these elevations. If the controlling headwater elevation overtops the roadway embankment, an overtopping analysis is done in which flow is balanced between the culvert discharge and the surcharge over the roadway. A balancing technique is also used in the case of multiple barrels. If the culvert is less than full for all or part of its length open channel computations are performed.

A series of data menus, data screens, summary screens, and output screens guides the user through the program. Each menu contains several options to match the desired culvert configuration, while the data screens prompt the user for specific dimensions and coordinates. Summary screens allow the user to edit entered data or change menu selections. Output screens display the output as calculations proceed; hard copy is only obtained using the "print screen" key.

There are three main groups of data to be entered into the program: initial culvert data, downstream channel data, and roadway data. Within the program, the user is sequentially led from one group to the next. From these sets of data, the program develops culvert performance data with or without overtopping. A performance curve can be plotted on a computer with graphics capabilities. For a given flow, HY8 can design a culvert. In addition to developing performance curves, the program generates rating curves for uniform flow, velocity, and maximum shear for the downstream channel. Culvert outlet velocities, inlet control head, and outlet control head are also calculated; energy dissipator design is possible.

HYCHL and HYCULV Programs

HYCHL and HYCULV are command line, flexible channel and culvert programs that are under development. HYCHL will solve for fixed and flexible lined channels. HYCULV will integrate state-of-the-art culvert flow methods and utilize features of both CDS and HY8.

Operation

To allow the software to be used by a wide audience, HYDRAIN operates on an IBM XT/PC or equivalent microcomputer with 640 K RAM, a hard disk, and a monochrome monitor. A math coprocessor is needed. Engineering programs are in Fortran 77. The utility software and editor is in C. The HYDRO, HYDRA, CDS, and WSPRO programs have command line input with are "short" and "long" help files available through the same editor that operates any of them. HY8 has also been integrated into the HYDRAIN system and is available as an interactive BASIC culvert program.

Report Contents

The remaining section of this volume provides technical reference and user instructions for the HYDRO program. There are a total of 6 such volumes for HYDRAIN.

Disclaimer

FHWA, the pooled fund States and their agents have, within the limits of their resources, tested and debugged the HYDRAIN shells. The engineering programs derive from several varied sources and were adapted to HYDRAIN and also underwent testing and debugging. However, this is a very large and somewhat complicated system of logic and coded implementation and errors and omissions may yet remain in the software. Therefore, use at your own risk. Please document problems and errors and report to FHWA. User support and technical assistance will be provided to pooled fund States. Agents of these States using the system should channel their requests for support or assistance through their sponsor State.

1. Introduction

This document introduces the computer program HYDRO. HYDRO is a hydrology analysis program developed for the Pooled Fund Project (PFP) and was written in FORTRAN. It is based on the Federal Highway Administration (FHWA) Highway Engineering Circular 19, HYDROLOGY, and as such, is an effort to combine existing approaches for rainfall and runoff analyses into one system.[1] HYDRO generates point estimates or a single design event. It is not a continuous simulation model. HYDRO uses the probabilistic distribution of natural events such as rainfall or stream flow, as a controlling variable. HYDRO should be considered as a computer based subset of Highway Engineering Circular (HEC) 19, with some areas of HEC-12 also included.[2] This documentation will attempt to explain the concepts and theories used within HYDRO, although the user should refer to HEC-19 and other listed references for detailed explanations.

The documentation is divided into three sections: System operation, technical operation, and Users application. The first section, system operation, provides insight into the capabilities and hydrological aspects covered in the program. The technical operation section provides data on how the system operation is achieved. Specifically, it provides the user with all equations and methodologies used by HYDRO when performing a hydrologic analysis. The last chapter demonstrates how to apply the program, particularly as it pertains to the HYDRAIN microcomputer package. The user is led through a sample session using the HYDRO Input Program. A complete listing of the sample problem is found in an appendix.

HYDRO is a tool that allows the highway drainage engineer to quickly make analyses of hydrologic problems. It is designed to be one of several programs within the PFP, and therefore its output can be used by other programs as input. HYDRO can also be used as a stand-alone system. The program was written using structured programming techniques that allow system modularity and open architecture for expandability.

2. System Overview

HYDRO capabilities are divided into three major hydrological scenarios: rainfall analysis, Intensity-Duration-Frequency (IDF) curve generation, and flow (runoff or stream flow) analysis. Rainfall analysis allows the user to investigate what will be categorized as steady-state (rainfall intensity) and dynamic (hyetograph) rainfall conditions. Both the rainfall analysis and IDF curve generation are a function of frequency, geographic location, and duration of the storm event. The third scenario, flow, permits the user to investigate several methods for determining peak flow. This peak flow can be the result of either runoff or gauged stream flow. As with the rainfall scenario, both steady-state (peak flow) and dynamic (hydrograph) flow conditions can be considered. The basic types of analysis available through use of HYDRO are shown in Figure 1.

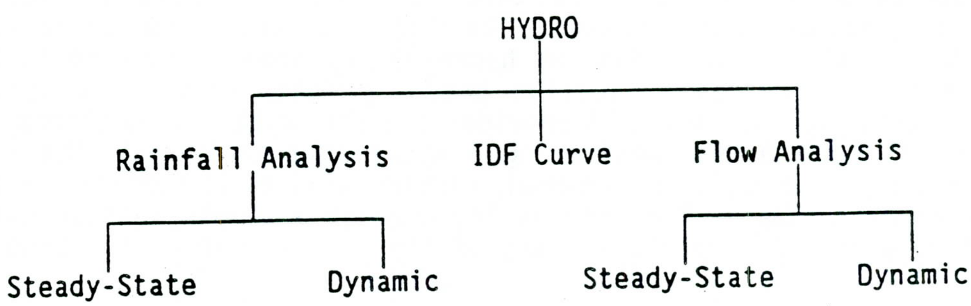


Figure 1. HYDRO flow chart.

Rainfall and IDF Curve Generation

HYDRO can internally calculate rainfall intensities for any site in the continental United States. This rainfall intensity is a single peak rainfall; or it can be used to create a hyetograph (a plot of rainfall intensity versus time). A site specific IDF curve can also be estimated.

Rainfall Databases

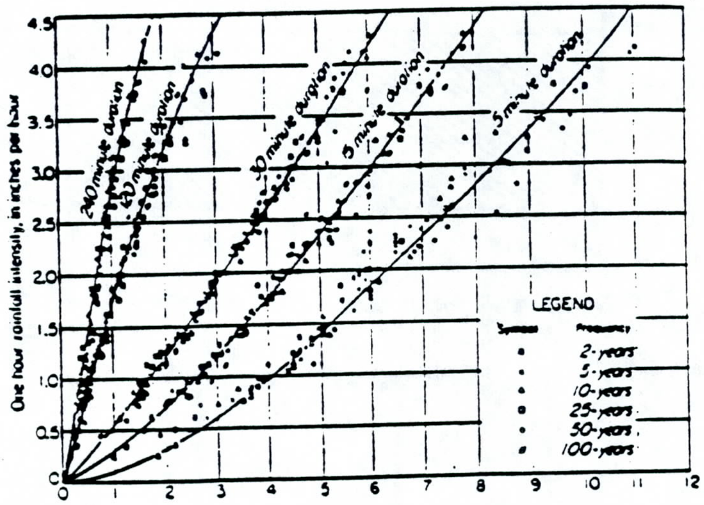
Rainfall intensities are generated from values provided in either the default, Pooled Fund database (RAIN.PFP) or a State-supplied database. The option to access a State-supplied database was added to HYDRO at the request of the California Department of Transportation (CALTRANS). This option addresses the problem experienced by users in California and other western States: the Pooled Fund database is too coarse for regions where the climate varies greatly over short distances due to the presence of mountain ranges or other topographic features.

The default database consists of the 1- hour rain durations for 2- and 100-year return periods for a total of 5597 latitude/longitude coordinate pairs. The database was developed from two sources; the National Weather Service (NWS) technical memorandum, HYDRO-35 and the National Oceanic and Atmospheric Administration (NOAA) Atlas 2 documents.[3,4] The resolution of the data is as follows: 30 minutes for the eastern and midwest States covered by the HYDRO-35 document, 20 minutes for the eleven western States covered by the NOAA Atlas 2, and 10 minutes for parts of Southern California.

The State-supplied database must provide the intensities of 1-hour storms for six return periods selected by the State as well as the log-log ratios of short duration storms to long duration storms. Intensities can be generated using any statistical method accepted by the State. Database format must conform to that specified in an appendix, which is the format of the database utilized by the CALTRANS program, IDF.

Peak Intensity

The manner in which HYDRO determines a rainfall intensity from the default database follows. A weighted rainfall intensity average of the points surrounding a user supplied latitude and longitude is computed. A rainfall intensity is calculated for a desired frequency and duration using two steps. In the first step, the rainfall is adjusted to the user supplied frequency or return period using NWS regression equations.[3] This yields a 1-hour rainfall corresponding to the user defined frequency. The second step adjusts the duration of the storm event (if necessary). HYDRO assumes that the storm duration is equal to the time of concentration (t_c) of the watershed in question.[2] The methods for determining time of concentration are: Soil Conservation Service (SCS) curve number or the kinematic wave for overland t_c; SCS grassy waterway, Manning's formula or HEC-12 triangular gutter for channel t_c; or user supplied for combined t_c. These will be discussed in more detail later. Finally, the 1-hour rainfall intensity is adjusted to a rainfall intensity associated with the duration using NWS and GKY regression equations.[3,5] The GKY regression equations are based on Figure 2 shown below.



Rainfall intensity for durations indicated by parameter, in inches per hour

Figure 2. Rainfall intensity relationships.[6]

In this manner, any rainfall with a frequency between 2- and 100-years and duration between 5 minutes and 24 hours can be considered for analysis. The user is freed from needing the HYDRO-35 and Atlas 2 documents, as the intensity calculated by HYDRO represent the data used to create these documents and the accompanying maps.

If the State-supplied database option is exercised, HYDRO uses logic modeled after the CALTRANS program to compute the intensity for a given duration and return period using relationships described in the Technical Operation section.

Hyetographs

To apply the steady-state rainfall intensity to a dynamic condition, the triangular hyetograph method, developed by Yen and Chow is used.[7] This method, discussed in detail later, uses the rainfall intensity, the duration and a regional coefficient (α) to create the hyetograph seen in Figure 3. The hyetograph can be used by other PFP programs such as PFP-HYDRA (using the hydrographic analysis), and for analysis such as a Least Total Economic Cost (LTEC) study for storm sewer design.[8]

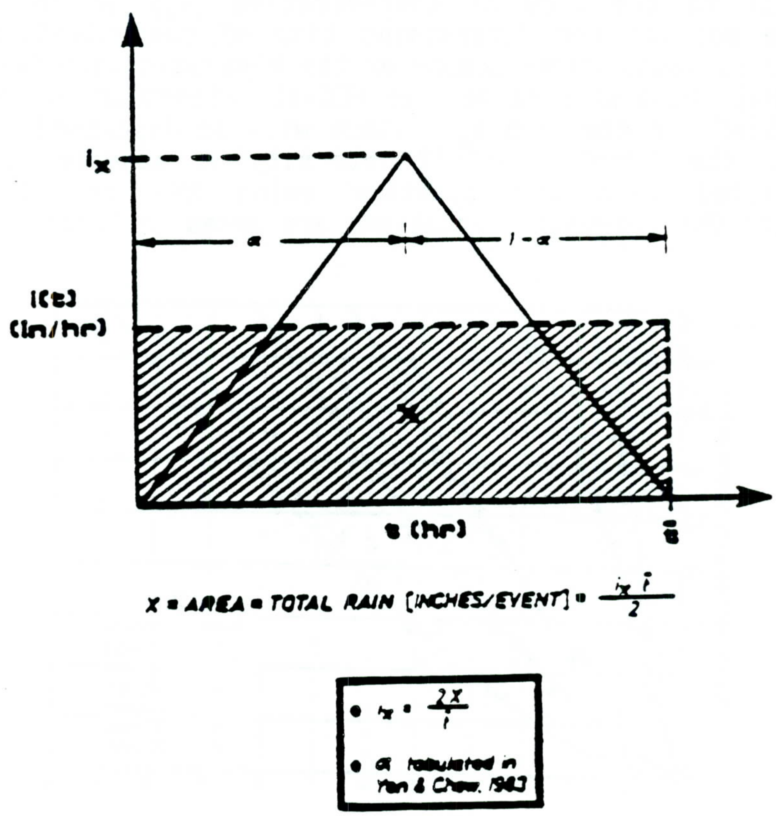


Figure 3. Yen and Chow's triangular hyetograph.

IDF Curves

HYDRO allows the user to create an IDF curve using either of the intensity databases discussed earlier. The curve will show, for a user provided frequency, the duration versus intensity for any location in the continental United States. As mentioned earlier, the frequency can be any whole number between 2 and 100 years and the duration can extend from 5 minutes to 24 hours of rainfall duration. As with the hyetograph, these IDF curves can be used in other PFP programs.

User Supplied Rainfall Values

Should the user desire to implement their own time of concentration or rainfall intensity values, these can be entered and will override any internally computed values. The user supplied time of concentration will override the internal time of concentration calculations, and will be the duration that the 1-hour, n year intensity is adjusted for. A user supplied rainfall intensity will cause HYDRO to override the database entirely. It is assumed that the user supplied rainfall intensity is already adjusted to a desired duration.

Peak Flow

HYDRO allows the user to investigate three flow methods: the rational method, user supplied regression equations, and the log Pearson type III method. Each of these methods produce a single peak or steady state flow value. HYDRO also allows the user to combine the peak flow with the dimensionless hydrograph method so as to consider hydrographic or dynamic flow conditions. The first two flow determination methods, rational and regression, are techniques that are used on ungauged watersheds where runoff is the primary source of flow. The log Pearson type III method requires gauged stream flow as the primary input. Each of the three flow methods will be discussed below.

Rational Method

Developed towards the end of the 19th century, the rational method is still widely used as a method for computing quantities of storm water runoff.

Intended for determining runoff from small (≤ 300 acres) watersheds, use of the rational method hinges on several basic assumptions:

- The duration used to determine an intensity from an IDF curve is that corresponding to the time it takes for water to flow from the most remote point in the watershed to the point in question, also known as the time of concentration.
- The intensity of the rainfall is constant and is applied to the entire watershed.
- The runoff coefficient remains constant throughout the storm event.
- The frequency of the peak flow is equal to the frequency of the rainfall intensity.

Since the utility for obtaining a design rainfall intensity has already been created, it becomes easy, when combined with the area and runoff coefficient, to calculate the rational method peak flow. This value is considered to represent a steady-state flow condition. Once the peak flow has been obtained, a hydrograph can be created if a dimensionless hydrograph and a time lag have been supplied. This allows a dynamic flow condition to be considered, and can be used as input to other PFP programs.

Regression Equations

Peak flow can also be calculated by using regression equations developed by several State and Federal agencies. The equations are in the form of a log-log formula, where the dependent variable would be the peak flow for a given frequency, and the independent variables may be variables such as area, slope and other physical or site specific data. The resultant flow is considered to be steady state, although similar to the rational method, can be used with a dimensionless hydrograph to create a dynamic flow scenario.

Log Pearson Type III Flood Frequency

The third flow method, log Pearson type III, allows the user to contemplate the effects of frequency associated with gauged stream flows. The log Pearson type III distribution is a three parameter (i.e., mean, standard deviation, and skew coefficient) gamma distribution. A logarithmic transform of the independent variable is made so as to "flatten" the distribution, thus lending it to a variety of stream situations. It has been adopted by the Water Resource Council (WRC) as a standard flood frequency determination method for all Federal agencies.[9,10] The peak flow is assumed by HYDRO to be steady state. As with the other flow determination methods, the peak flow can be used to create a hydrograph from a dimensionless hydrograph. It should be noted that this analysis can be applied to any type of data one wishes to analyze with this distribution.

Hydrographs

Currently, HYDRO computes hydrograph coordinates by multiplying dimensionless hydrograph abscissae by a time lag and by multiplying ordinates by the peak flow. The dimensionless hydrograph coordinates used are either supplied by the user or are values derived from a nationwide urban hydrograph study[11]. The time lag, which is defined as the time in hours between the center of mass of the excess rainfall to the center of mass of the resulting runoff hydrograph, is either supplied by the user or is computed by HYDRO using a relationship described in the Technical Operation section.

It has been suggested that a national effort should be made, using the methodology outlined in the study, to produce a national assessment of hydrograph methods. The goal would be to outline a method similar in scope to that which led the WRC to propose log Pearson type III as a flood frequency determination method.

This concludes the system overview section. The next section discusses the technical approach of the topics mentioned above.

3. Technical Information

This section investigates the technical operation of the HYDRO program. The section will be organized in the following manner: Rainfall, including the rainfall databases, weighted averaging of the intensities, frequency adjustment, time of concentration methods, and duration adjustment; Hyetographs; Peak Flow, including the rational method, regression equations, and log Pearson type III methods; and Hydrographs.

Rainfall Databases

The default database, created specifically for HYDRO, contains precipitation - frequency values for the continental United States. The values are for return periods of 2 and 100 years and a 1-hour rainfall duration.

The information used to create the database came from:

1. The final base values used to compute isohyetal maps for eleven western States.[12] The eleven western States are: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Washington and Wyoming.

2. The tape E17383, obtained from the National Weather Service, that contains data for the remaining 37 midwestern and eastern States and the District of Columbia. This is the data that was used to create the HYDRO-35 document.[12]

Resolution of the data is a 30 minute grid in the midwest and east and a 20 minute grid in the west except in Southern California, where the resolution is a 10 minute grid.

The data were then combined into one file and sorted by latitude and longitude. Graphical and statistical analyses were used to discover any errors or discrepancies in the data. Users should satisfy themselves as to the appropriateness of these data for their application. The logic of the file is such that these data can be locally enriched if the user has access to rainfall data as well as guidance from authorities in the field.

The State can choose to supply its own database, consisting of 1-hour intensities for six State-selected return periods and the log-log slope of the IDF curve. The required data can be generated using any statistical method selected by the State.

Lookup and Weighted Averaging of the Data

From the user-supplied site latitude and longitude values, HYDRO enters the database (default or State-supplied) to find the coordinates most closely associated with those of the site. For the default database, this is done by initiating a binary search to locate the approximate location of the site in the data set. If the site corresponds to a specific data element, the 2- and 100-

year, 1-hour storm duration, rainfall intensities associated with that data element are read in as variables, and the program moves to the next module (frequency adjustment). Otherwise, HYDRO constructs a one degree by one degree window around the site, and reads in all the data elements (and their corresponding intensities) within that window. The distance between the site and all the elements within the window are calculated, and a weighted average of the rainfall intensities based on distance are obtained. HYDRO will notify the user if there are less than four points in the window. With the 2- and 100-year, 1-hour duration, weighted average variables, the program will continue to the next module.

For the State-supplied database, HYDRO identifies the four closest stations within a 0.25 degree by 0.25 degree window. If a station is within 3 miles of the site, that station's rainfall intensity is used in determining that of the site. Otherwise, a weighted average (based on distance) of the intensities of the stations selected within the window is computed. HYDRO lists the stations used in the computation so that the user can determine their appropriateness in relation to the site (e.g., a selected station might be located on a slope opposite that of the site). HYDRO also allows the user to select up to four stations to be used in calculating the weighted average.

Frequency Adjustment

If the default database is to be accessed, the user can select any return period between 2 and 100 years. Transforming the frequency of the rainfall intensity from the 2- and 100- year return periods, to a user defined return period is achieved by using regression equations developed by the NWS and shown below. There are four specific NWS equations and a general equation especially for the HYDRO program.

5-Year Equation[3]

$$C = (0.278 \cdot A) + (0.674 \cdot B) \tag{1}$$

10-Year Equation[3]

$$C = (0.449 \cdot A) + (0.496 \cdot B) \tag{2}$$

25-Year Equation[3]

$$C = (0.669 \cdot A) + (0.293 \cdot B) \tag{3}$$

50-Year Equation[3]

$$C = (0.835 \cdot A) + (0.146 \cdot B) \tag{4}$$

General Equation[5]

$$C = ((-0.109 + 0.556 \cdot \log_{10}(n)) \cdot A) + ((1.032 - 0.526 \cdot \log_{10}(n)) \cdot B) \tag{5}$$

where:

A = the intensity for a 100-year storm with a 1-hour duration, in inches per hour,

B = the intensity for a 2-year storm with a 1-hour duration, in inches per hour,

C = the intensity for a user defined return period with a 1-hour duration, in inches per hour, and

n = the user defined frequency or return period, in years.

If the State database is to be accessed, the user must either select one of the six "standard" return periods for which data are provided in the database, or supply the mean 1-hour storm, Log Pearson frequency factor, and coefficient of variation so that the 1-hour intensity for the user-defined return period can be computed from the relationship[13]:

$$I_{1,rp} = I_{mean} * (1 + K_j * C_v) \tag{6}$$

where:

$Imean$ = the mean 1-hour storm in inches

K_j = the Log-Pearson frequency factor

C_v = coefficient of variation

<u>Time of Concentration</u>

The time of concentration is defined as the period required for water to travel from the most remote point on a watershed to the outlet. The time of concentration can be subdivided into two constituents; overland and channel (or gutter) flow. HYDRO approaches time of concentration in this way. Overland time of concentration is developed by one of two methods; the SCS curve number or by the kinematic wave approach. Channel time of concentration can be developed using one of three methods; SCS grassy waterway channel, Manning's formula or the HEC-12 triangular gutter approach. Finally, the possibility exists for the user to enter a combined time of concentration, thereby overriding all other methods.

SCS Curve Number

The Soil Conservation Service, in Technical Release 55, describes a method for determining the overland time of concentration known as the curve number (CN) method.[14,15] This method is limited to small watersheds (≤ 2000 acres) containing consistent land uses and climatological characteristics.

The curve number method begins by subdividing the watershed into smaller watersheds based on land use. HYDRO implements a simplified version of the curve number method by considering seven broad categories of land use: meadows, woods, pasture, crops, residential, urban/right of way and pavement. The next step is to determine the composite type of soil within the watershed. This soil classification helps the method to take into account infiltration. The soil types are categorized as A, B, C, and D, each being defined as:

A = a sandy soil, having deep sand and loess with aggregated silts. The composition is 90 to 100 percent sand/gravel. There is a high infiltration rate of 0.30 to 0.45 inches per hour.

B = a sand/loam soil, having a shallow loess/sandy loam with a moderate infiltration rate of 0.15 to 0.30 inches per hour.

C = a clay/loam soil, having low organic content and usually high in clay. It has a slow infiltration rate of 0.05 to 0.15 inches per hour.

D = a clay soil, having a mixture of heavy plastic clay (90 to 100%) and certain saline soils that swells significantly when wet. Clay has a very low infiltration rate of 0 to 0.05 inches per hour.

The third step is to determine the Antecedent Moisture Condition (AMC), or as called by HYDRO, the climate. This variable also helps to define the watersheds' soil infiltration capacity. The variables are defined below:

1 = a DRY soil, allowing a higher than normal quantity of infiltration, associated with climatological conditions averaging from 0 to 25 inches of rainfall per year,

2 = a TYPICAL soil, allowing a normal quantity of infiltration, associated with climatological conditions averaging from 25 to 50 inches of rainfall per year, and

3 = a WET soil, allowing a lower than normal quantity of infiltration, associated with climatological conditions greater than 50 inches of rainfall per year.

These three steps are applied to each subdivided land use, so that a curve number is selected for each land use, and the soil type and climate. The matrix of curve numbers for each possibility of land use, soil and climate is shown in table 1.

Table 1. Curve Number matrix.

LAND USE	CURVE NUMBER											
SOIL TYPE	SAND			SAND/LOAM			CLAY/LOAM			CLAY		
CLIMATE	DRY	TYP.	WET	DRY	TYP.	WET	DRY	TYP.	WET	DRY	TYP	WET
MEADOW	15	30	50	38	58	77	52	71	88	61	78	93
WOODS	20	36	56	40	60	79	55	73	89	62	79	93
PASTURE	30	49	69	50	69	86	62	79	93	69	84	96
CROPS	41	61	80	55	73	89	64	81	95	69	84	96
RESIDENT.	42	62	81	56	74	90	66	82	95	72	86	97
URBAN/HWAY	56	74	90	69	84	96	78	90	98	82	92	98
PAVEMENT	82	92	98	82	92	98	82	92	98	82	92	98

A composite curve number for the entire watershed is determined by taking a weighted average of the subdivided areas and curve numbers as shown below:

$$CN = \frac{\Sigma\ CN_i \cdot A_i}{\Sigma\ A_i} \qquad (7)$$

where:

CN = the composite curve number for the watershed,

CNi = the curve number associated with each subdivided land use, the watershed soil type and climate, and

A_i = the subarea associated with each subdivided land use, the total area of the watershed is therefore equal to the sums of the subareas.

HYDRO also allows the user to enter their own curve number value. This user defined curve number will override the computed curve number process and will be used by HYDRO in the subsequent step.

The composite curve number (or user defined curve number) is next transformed into an intermediate empirical value using the formula:

$$S = \frac{1000}{CN} - 10 \qquad (8)$$

where:

S = an intermediate empirical value, and

CN = the composite or user defined curve number defined above.

Finally, the SCS overland time of concentration is calculated as:

$$t_{co} = \frac{L_o^{0.8} \cdot (S + 1)^{0.7}}{1140 \cdot S_o^{0.5}} \qquad (9)$$

where:

t_{co} = the overland time of concentration, in hours,

L_o = the overland length, defined as the length from the most remote point of the watershed to the outlet or beginning of channel flow, in feet,

S = the intermediate empirical coefficient, defined above, and

S_o = the average overland slope, in percent.

Kinematic Wave

The alternative overland time of concentration method that is found in HYDRO is the kinematic wave approach. It is used as defined in HEC-12 (FHWA, 1984) and based on research by Regan conducted for the Maryland State Highway Administration and the FHWA.[16] Although the kinematic wave theory is not found in HEC-19, it was felt that it was appropriate to include it in HYDRO so as to provide the user with an alternative to the curve number method.

The kinematic wave approach recognizes that overland flow can be simulated by a moving film of turbulent flow over the watershed surface. The time of concentration for this wave can be expressed as a function of flow length and slope, Manning's surface roughness factor, and the rainfall intensity. The basic formula is given as:

$$t_{co} = \frac{56 \cdot L_o^{0.6} \cdot n^{0.6}}{S_o^{0.3} \cdot i^{0.4}} \qquad (10)$$

where:

t_{co} = the overland time of concentration, in minutes,

L_o = the overland length, defined as the length from the most remote point of the watershed to the outlet or beginning of channel flow, in feet,

n = Manning's friction value for a waterway,

S_o = the average overland slope, in ft/ft, and

i = the rainfall intensity, for a desired frequency or return period, in inches per hour.

Initially, HYDRO uses the 1-hour rainfall intensity (already adjusted for the desired frequency) and will use equation 9 to compute an initial time of concentration. Should the initially calculated time of concentration equal 1-hour, the analysis is complete and HYDRO continues to the next module. If this is not the case (which is more likely), the initially calculated time of concentration is assumed to be the duration, and using equations discussed later, a corresponding intensity is determined.

This intensity is plugged into equation 9, and a second estimate of time of concentration is calculated and compared to the initial estimate. If necessary, a third intensity is determined and plugged back in to the equation. The process is iteratively repeated until the time of concentration estimates converge. HYDRO will use a time of concentration value that is at less than one percent different than the previous estimate; or select a minimum value of 5 minutes or a maximum value of 24 hours. This value of time of concentration is converted to hours and used in the subsequent program modules.

SCS Grassy Waterway

The SCS grassy waterway is a subset of the Upland Method described in the SCS handbook.[14] It describes a linear relationship between velocity and watershed slope when the variables are placed on a log-log graph. To apply the method to the HYDRO program, regression curve fitting techniques were used to determine the equation of this line.[5] The SCS grassy waterway equation is given as:

$$V = 1.942 \cdot S_c^{0.504} \qquad (11)$$

where:

V = the channel velocity, in ft/s, and

S_c = the average slope of the channel, in percent.

Manning's Formula

HYDRO allows open channel and gutter time of concentration to be calculated using Manning's formula for velocity:

$$V = \frac{1.486}{n} \cdot R_h^{0.667} \cdot S_c^{0.5} \quad (12)$$

where:

V = the weighted average velocity occurring within a channel's cross sectional area, in ft/s,

R_h = the hydraulic radius of a channel (channel area divided by wetted parameter), in feet,

S_c = the average channel slope, in ft/ft, and

n = Manning's friction value for the channel.

Triangular Gutter Section

The triangular gutter equation is a special case of the regular Manning's formula. It was described in HEC-12.[2] The equation describes flow in wide, shallow, triangular channels. The area of the gutter and the hydraulic radius are a function of the spread and the roadway cross slope. In other words, a channel with the shape shown in Figure 4 is assumed.

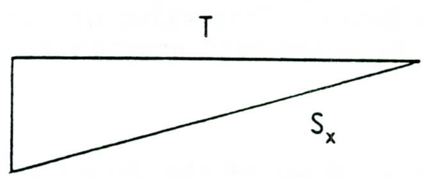


Figure 4. Triangular gutter section.

Substituting basic geometric relationships, derived from Figure 4, into equation 11 yields:

$$V = \frac{1.12}{n} \cdot S_c^{0.5} \cdot S_x^{0.67} \cdot T^{0.67} \quad (13)$$

where:

V = the velocity occurring within a gutter, in ft/s,

n = Manning's friction value for the channel,

S_c = the average channel slope, in ft/ft,

S_x = the roadway cross slope, in ft/ft, and

T = the spread occurring in the gutter section, in feet.

Combining the velocity (calculated using one of the three channel time of concentration methods above) with the channel length, the channel component of the time of concentration is calculated:

$$t_{cc} = \frac{L_c}{(V \cdot 3600)} \tag{14}$$

where:

t_{cc} = the channel time of concentration, in hours,

L_c = the length of the channel, in feet,

V = the velocity of the channel, calculated using one the methods discussed above, and

3600 = conversion factor between seconds and hours.

Combining Overland and Channel Time of Concentrations

The time of concentration for the watershed is calculated as the sum of the overland and channel constituents:

$$t_c = t_{co} + t_{cc} \tag{15}$$

where:

t_c = the combined time of concentration of the watershed, in hours,

t_{co} = the overland time of concentration, in hours, and

t_{cc} = the channel time of concentration, in hours.

The combined time of concentration will be assumed to be equal to the duration by HYDRO. Should a user defined time of concentration be entered, it will override the calculated values and will considered to be the duration by the program.

Adjusting Rainfall Intensity for Duration

If the default database is used in the analysis, transformation of the 1-hour rainfall intensity to the intensity associated with the time of concentration, just calculated, is achieved using NWS and GKY regression equations. The NWS equations are from the HYDRO-35 memorandum.[3] The GKY regression equations are based on Figure 2 shown earlier.[6] There are four equations for transforming the 1-hour intensity to rainfall intensities less than 1 hour:

5 Minute Equation[5]

$$i_{5min} = 4.145 \cdot i_{1hr}^{0.635} \quad (16)$$

10 Minute Equation[3]

$$i_{10min} = 0.59 \cdot i_{15min} + 0.41 \cdot i_{5min} \quad (17)$$

15 Minute Equation[5]

$$i_{15min} = 2.47 \cdot i_{1hr}^{0.817} \quad (18)$$

30 Minute Equation[3]

$$i_{30min} = 0.49 \cdot i_{1hr} + 0.51 \cdot i_{15min} \quad (19)$$

where:

i_{5min} = the 5-minute rainfall intensity derived from a 1-hour rainfall intensity and having a user defined return period, in inches per hour,

i_{1hr} = the 1-hour rainfall intensity having a user defined return period, in inches per hour,

i_{10min} = the 10-minute rainfall intensity derived from the 5- and 15-minute rainfall intensities and having a user defined return period, in inches per hour,

i_{15min} = the 15-minute rainfall intensity derived from a 1-hour rainfall intensity having a user defined return period, in inches per hour, and

i_{30min} = the 30-minute rainfall intensity derived from the 15-minute and 1-hour rainfall intensities and having a user defined return period, in inches per hour.

If the duration is less than 1 hour, and not equal to one of the four equations above, a linear interpolation routine is used to determine the intensity value.

If the duration is greater than 1 hour, but less than 24 hours in length, a general equation is used to transform the rainfall intensity. The equation is of the form:

$$i = i_{1hr} / (0.4461 + 0.5520 \cdot t_c) \qquad (20)$$

where:

i = the rainfall intensity for any storm duration greater than 1 hour and less than 24 hours, having a user defined return period, in inches per hour,

i_{1hr} = the 1-hour rainfall intensity having a user defined return period, in inches per hour, and

t_c = the storm duration (time of concentration), in hours.

If the State-supplied database is used, the intensity for the appropriate duration is calculated from the relationship[13]:

$$I_{d,rp} = I_{1,rp} * D^n \qquad (21)$$

where:

$I_{d,rp}$ = intensity in inches/hour for a specified duration and return period.

$I_{1,rp}$ = intensity in inches/hour for a 1-hour storm and the specified return period duration in hours.

D = duration in hours

n = log-log slope of the IDF curve

The end result of this process is a rainfall intensity that reflects watershed characteristics and a specified storm duration and frequency. Should the user wish to override this intensity, HYDRO allows a user defined rainfall intensity to be entered. As mentioned above, this value represents a rainfall intensity that has been adjusted for frequency and duration by the user.

Hyetograph

The triangular hyetograph concept, used in HYDRO, is based on the work of Yen and Chow for the FHWA.[7] They felt that a typical rain event could be described using a triangular shape defined by three parameters. The first parameter is the "apex" of the triangle, equal to twice the peak rainfall intensity. The "base" of the triangle, equal to the duration of the storm, is the second parameter. The last parameter is the time to the peak intensity, and is based on a localized coefficient shown on a map in the Yen and Chow document. The total volume of rainfall is found by using basic geometric principles. The triangular hyetograph was shown earlier in Figure 3.

To apply the methodology, HYDRO needs these three parameters. HYDRO will either use calculated or user supplied intensity and duration values to satisfy the need for the first two parameters. The final parameter is found using an internal table containing coefficients for 17 regions which make up the continental United States. The region is determined from the user-supplied latitude/longitude of the site.

IDF Curve

The Intensity Duration Frequency curve is produced, for a given frequency and location, by calculating the rainfall intensities associated with the 5, 10, 15, 30 minute, and 1, 2, 4, 8 and 24 hour durations. Specifically, a location and the rainfall database (default or State-supplied) are used to retrieve the appropriate 1-hour rainfall intensities. Next, the rainfall intensities are adjusted (if necessary) to a user supplied frequency using equations 1 through 5 or equation 6. Finally, equations 16 through 20 or equation 21 are used to calculate the rainfall intensities.

Rational Method

The rational method is perhaps one of the most widely used "tools" for determining runoff resulting from a storm event. Although newer methods of determining runoff have been created, the simplicity of the rational method has stood the test of time. The rational method equation is of the form:

$$Q = C \cdot i \cdot A, \tag{22}$$

where:

Q = the peak flow, in ft^3/s,

C = the runoff coefficient,

i = the rainfall intensity, in inches per hour, and

A = the area of the watershed, in acres.

HYDRO applies the rational method by first subdividing the watershed area into one of the seven subareas defined earlier: meadow, woods, pasture, crops, residential, urban/highway right of way and pavement. These are analogous to the land uses found in HEC-12.[2]

Each subarea has a corresponding default runoff coefficient. These default coefficients are shown in Table 2.

Table 2. Default runoff coefficients.

Meadows	0.2	Residential	0.4
Woods	0.2	Urban/Right of Way	0.7
Pasture	0.3	Pavement	0.9
Crops	0.3		

If they desire, the user may use their own runoff coefficient, thereby overriding the internal values.

Once each subarea has been assigned an area and a corresponding runoff coefficient, a weighted runoff coefficient for the entire watershed is computed:

$$C = \frac{\Sigma\, C_i\, A_i}{\Sigma\, A_i} \tag{23}$$

where:

C = the weighted runoff coefficient for the entire watershed, having no dimension,

C_i = the runoff coefficient associated with each subarea, and

A_i = the subarea associated with each subdivided land use, in acres. The total area of the watershed is equal to the sum of the subareas.

The rainfall intensity, used in the rational method, will be a function of location, frequency and duration of the storm. To determine the rainfall intensity, HYDRO repeats the calculations that produced a steady state rainfall intensity value. First, the rainfall intensity is adjusted to a user defined frequency. Since the rational method assumes that duration and time of concentration are equal, the time of concentration methods discussed earlier will be used again. As an alternative to this, the user can assign a value for time of concentration. Finally, the rainfall intensity is adjusted from a 1-hour duration, to the duration just calculated. If the user supplies a rainfall intensity, it will override any internally calculated value.

HYDRO enters the weighted runoff coefficient, rainfall intensity and watershed area into equation 22, and the rational method peak flow is calculated.

<u>Regression Equations</u>

A more sophisticated analysis of flow at ungauged watershed can be achieved through the use of regression equations. These equations related peak flow of a specified frequency to physical or site related factors. The typical regression equation is a log-log formula in the form:

$$Q_p = a \cdot X_1^{b_1} \cdot X_2^{b_2} \cdot \cdot \cdot X_n^{b_n} \quad (24)$$

where:

Q_p = the regression equation peak flow, in ft^3/s,

a = the regression constant, usually a translation factor,

X_i = the independent variables (parameters) for the watershed, and

b_i = the regression coefficients associated with each independent variable.

The regression equation is usually developed for a specific region or State. The FHWA has a document that describes regression equations used to calculate runoff from small watersheds in 24 hydrophysiographic regions.[1] The FHWA equations were developed for a 10-year flood frequency and have three, five, or seven independent variables. The USGS has conducted a nationwide study that developed three and seven parameter regression equations.[1] More recent work has concentrated on developing regional equations.[17] The interested reader is referred to the literature for more information on typical coefficients and variables to be used with these equations.

The HYDRO Input Program contains a module that allows the user to enter, save, and use their customized regression equations. The equation module allows each user to divide each State into two hydrologic regions, each containing five equations.

<u>Log Pearson Type III Flood Frequency</u>

The log Pearson type III method is designed to be applied on watersheds with gauged stream flows. It was chosen by the Water Resources Council for its ability to statistically fit (Pearson's distribution is a three parameter solution of a gamma distribution) a variety of flood frequencies, (WRC, 1967, 1981). Log Pearson type III is the standard flood frequency standard for the agencies of the Federal government.

HYDRO applies log Pearson type III, by first considering the relative location of the watershed to that of the gauging station from where the peak stream flow were obtained. The possibilities are: the watershed is at the same location as the gauging station or the watershed is not at the same location as the watershed.

If the first possibility exists, then no adjustments to the flow data are necessary, and HYDRO continues on towards the next module. An example of this occurrence is demonstrated in Figure 5.

If the watershed is not at the same location as the gauging station, the annual peak stream flows must be adjusted using the following criteria:

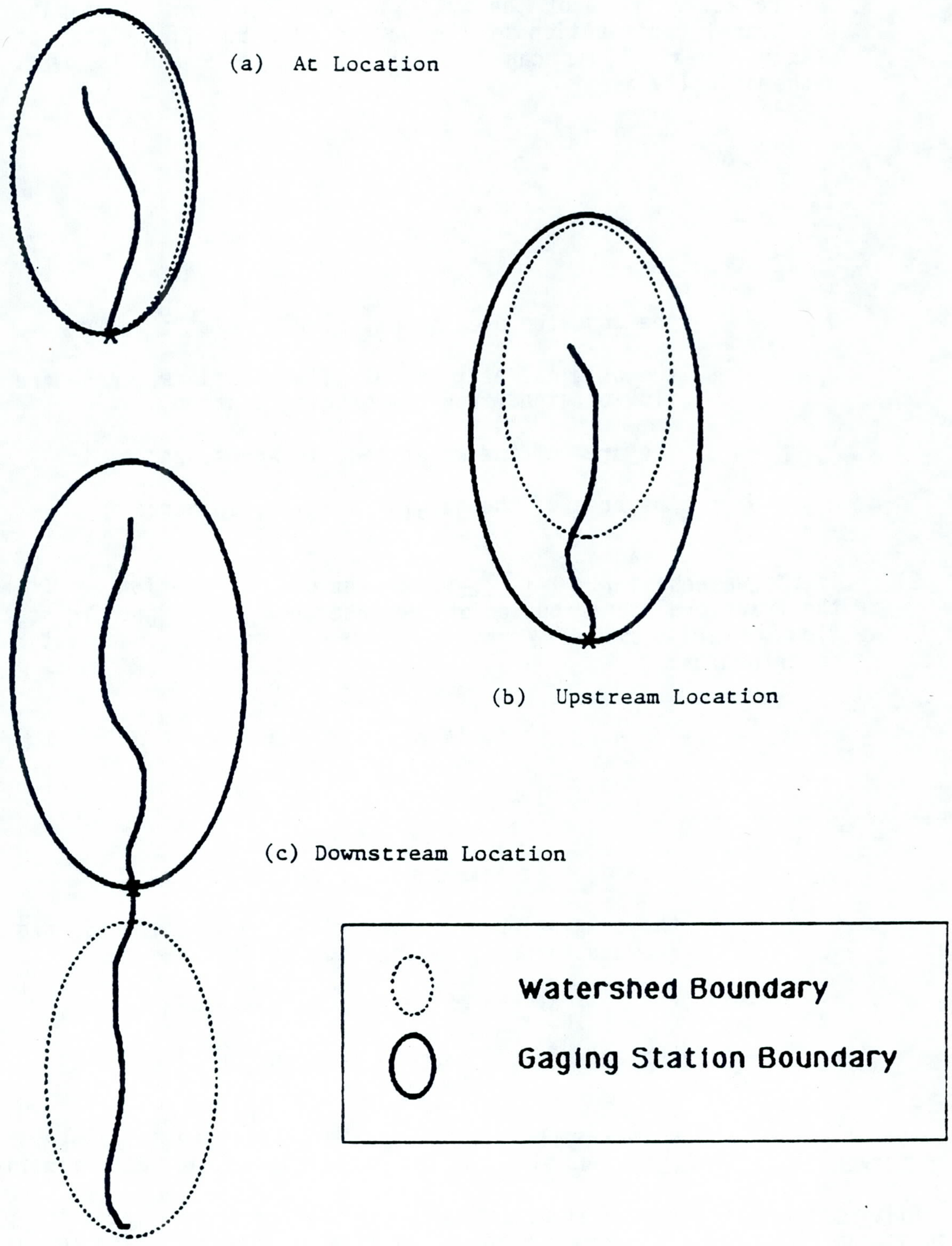


Figure 5. Relative watershed locations.

1) If the watershed is UPSTREAM from the gauging station, HYDRO uses the relative areas of the watershed and station to estimate the fractional contribution of the watershed's runoff to that of the station area. This can be seen in Figure 5 and is described mathematically as:

$$Q_{ia} = Q_i \cdot \frac{A_w}{A_g} \qquad (25)$$

where:

Q_{ia} = the adjusted peak annual flow, in ft^3/s,

Q_i = the original peak annual flow, in ft^3/s, these are the flow obtained from the gauging station,

A_w = the area of the watershed, in acres, and

A_g = the area of the gauging station, in acres.

2) If the watershed is DOWNSTREAM from the gauging station, HYDRO adds the fractional contribution of the watershed to the gauging station flows. This case is seen in Figure 5c and is mathematically described as:

$$Q_{ia} = Q_i \cdot \frac{A_w}{A_g} + Q_i \qquad (26)$$

where:

Q_{ia} = the adjusted peak annual flow, in ft^3/s,

Q_i = the original peak annual flow, in ft^3/s, these are the flows obtained from the gauging station,

A_w = the area of the watershed, in acres, and

A_g = the area of the gauging station, in acres.

In both cases, HYDRO makes the assumption that the respective watersheds are topographically similar, thus allowing for proportional flow determination.

After the proper locational adjustments (if any) have been made, the peak annual stream flows are transformed using a logarithmic function. The intention is to decrease the relative variability of the stream flow distribution.

The three parameters of the distribution are the sample mean, standard deviation, and the skew coefficient. HYDRO defines these parameters as:

Sample Mean; (geometric mean).

$$\bar{Q}_L = \frac{\Sigma \log Q_i}{n} \tag{27}$$

Standard Deviation;

$$S_L = \left[\frac{\Sigma (\log Q_i - \bar{Q}_L)^2}{n - 1} \right]^{0.5} \tag{28}$$

Skew Coefficient;

$$G_L = \frac{n \cdot \Sigma (\log Q_i - \bar{Q}_L)^3}{(n - 1) \cdot (n - 2) \cdot S_L^3} \tag{29}$$

where:

$\bar{Q}_L$ = the mean of the log transformed peak annual stream flows, in ft^3/s,

Q_i = the peak annual stream flow samples, in ft^3/s,

n = the period of record for the gauged stream flows, in years. It is strongly suggested that an adequate number of years be used. The WRC recommends 30 or more records; however, HYDRO has been tested successfully with as few as seven,

S_L = the standard deviation of the peak annual stream flow values, in ft^3/s, and

G_L = the skew coefficient for the sample of peak annual stream flow values, in ft^3/s.

The computed skew coefficients are sensitive to extremes in stream flow and to a small number of records. For this reason, HYDRO allows the user to override the computed skew coefficient with a user supplied regional skew coefficient value. For the interested user, WRC Bulletin 17B provides a map of these regional skew coefficient values.[10]

HYDRO calculates a form of the Incomplete Gamma Function using the methodology outlined by Croley.[18] Simply put, Croley's methodology solves Pearson's integral for a probability that is a function of flow. To begin this analysis, HYDRO first defines three translation coefficients:

$$\alpha = (2 \cdot G_L)^2 \tag{30}$$

$$\beta = \frac{(S_L \cdot G_L)}{2} \tag{31}$$

$$\delta = \bar{Q}_L - \frac{2 \cdot S_L}{G_L} \tag{32}$$

where:

- α = the first Croley translation coefficient, alpha,
- β = the second Croley translation coefficient, beta,
- δ = the third Croley translation coefficient, delta,
- G_L = the skew coefficient for the sample of peak annual stream flow values, in ft^3/s, and
- S_L = the standard deviation of the peak annual stream flow values, in ft^3/s.

HYDRO next defines the upper interval of Pearson's integral as:

$$t_\tau = \frac{(\log Q_\tau - \delta)}{\beta} \tag{33}$$

where:

- t_τ = the τ-quantile point for some logarithmic transformed stream flow, Q_τ,
- Q_τ = a stream flow in the distribution defined by $\bar{Q}_L$, S_L and G_L, in ft^3/s,
- δ = the translation coefficient, delta, defined above, and
- β = the translation coefficient, beta, defined above.

Pearson's integral, is defined as:

$$\tau = \int_0^{t_\tau} \frac{1}{\Gamma(\alpha)} \cdot t^{(\alpha - 1)} \cdot e^{-t} \cdot dt = P(Q \le Q_\tau) \tag{34}$$

Croley developed a first order approximation of the integral which he gives as:

$$P(Q \le Q_\tau) = \left[\frac{\alpha + 5}{2 \cdot \pi}\right]^{0.5} \cdot \frac{(\alpha + 4)! \cdot \alpha}{\alpha!} \cdot \left[\frac{t_\tau}{\alpha + 5}\right]^{\alpha} \cdot \left[\frac{1}{\alpha + 5}\right]^{5} \cdot$$

$$\exp\left[-t_\tau + \alpha + 5 - \frac{1}{12 \cdot (\alpha + 5)} + \frac{1}{(360 \cdot (\alpha + 5))^3}\right] \cdot$$

$$\sum_{j=0}^{14} \frac{t_\tau^{\,j}}{\alpha \cdot (\alpha + 1) \cdots (\alpha + j)} \tag{35}$$

where:

$P(Q \le Q_\tau)$ = the probability that the flow Q_τ is equal or greater than some flow, the inverse of which is that flow's return period,

α = Croley's translation coefficient, defined above,

π = the value of pi, assumed in HYDRO to be 3.1415927,

t_τ = the upper bounds of Pearson's integral, defined above, and

j = a integer variable used in the summation.

HYDRO will enter two values for Q_T into equation 35 (with the two values of Q_T initially equaling the maximum and minimum values for the range of Q_i), which will return two associated probabilities. Since the user defined return period for the peak flow can be expressed as a probability:

$$P(Q_p) = 1 / n \qquad (36)$$

where:

$P(Q_p)$ = the probability associated with the user defined return period, in years^{-1}, and

n = the user defined return period, in years,

an elimination scheme algorithm can be used so that the program will converge to a flow that is a function of the user defined probability. This is the flow that is used by HYDRO as the peak flow value.

There are two potential areas of trouble when using equation 35. First, the upper interval of the integral must satisfy the condition $0 \le t_T \le \infty$. If the upper interval value becomes negative, HYDRO will recognize this condition and will not attempt to solve the integral. The second trouble area is a stream flow distribution that can not be adequately solved using a first order approximation. In this case, the result will be that the Q_T will converge towards infinity. Should either occur, HYDRO will use WRC-17B equations as an alternative.

The alternative method is based on the fact that the value for peak flow is usually within 5 percent of a value derived by a table [19]. The function relates the skew coefficient to the normal deviate, and produces a skew based on a user defined probability:

$$K = \frac{2}{G_L} \cdot \left[\left[1 + \frac{G_L \cdot Z}{6} - \frac{G_L^2}{36} \right]^3 - 1 \right] \qquad (37)$$

where:

K = the skew value based on a user defined frequency,

G_L = the skew coefficient for the sample of peak annual stream flow values, in ft^3/s,

Z = the normal deviate, that is approximated by:

$$Z = 4.91 \cdot ((1 - P)^{0.14} - P^{0.14}) \qquad (38)$$

P =	the user defined probability, defined as the inverse of the return period.

Once the skew has been estimated, it can be combined with the mean and standard deviation to calculate the peak flow for a given return period. This equation is given as:

$$Q_p = 10^{(\bar{Q}_L + K \cdot S_L)} \quad (39)$$

where:

Q_p =	the peak flow for the stream, in ft^3/s, based on a user defined return period,
$\bar{Q}_L$ =	the mean of the log transformed peak annual stream flows, in ft^3/s,
K =	the skew value based on a user defined frequency, and
S_L =	the standard deviation of the peak annual stream flow values, in ft^3/s.

The value derived by using Croley's equation or, if required, by the WRC-17B approximation is taken by HYDRO as representing the log Pearson type III peak flow value of a gauged stream.

<u>Hydrograph Formation</u>

HYDRO uses the dimensionless hydrograph method for generating a hydrograph representing the average runoff for a particular peak flow. Required for using this method are:

- the dimensionless hydrograph
- the time lag
- the peak flow.

Either the default dimensionless hydrograph coordinates or coordinates supplied by the user can be used to define the shape of the hydrograph. Default values, derived from a nationwide urban hydrograph study[11], are listed as follows:

Table 3. Default dimensionless hydrograph coordinates.

Abscissa	Ordinate
0	0
0.1	0.04
0.2	0.08
0.3	0.14
0.4	0.21
0.5	0.37
0.6	0.56
0.7	0.76
0.8	0.92
0.9	1.00
1.0	0.98
1.1	0.90
1.2	0.78
1.3	0.65
1.4	0.54
1.5	0.44
1.6	0.36
1.7	0.30
1.8	0.25
1.9	0.21
2.0	0.17
2.1	0.13
2.2	0.10
2.3	0.06
2.4	0.03
2.5	0

The abscissae are multiplied by the time lag which is either supplied by the user or computed in accordance with the following relationship[11]:

$$TL = 0.85 * L^{0.62} * S^{-0.31} * (13 - BDF)^{0.47} \qquad (40)$$

where:

- TL = time lag, in hours
- L = main channel length, in miles
- S = main channel slope, in feet/mile
- BDF = basin development factor (a value ranging from 0 to 12, where 0 represents an undeveloped basin and 12 represents a basin consisting 100% of storm sewers, lined channels, or curb and gutter streets).

The ordinates are multiplied by the peak flow which is calculated by HYDRO according to one of the previously described methods: rational method, regression equations, or log Pearson type III. These three methods are summarized below:

- Rational - Q_p is calculated using equation 22; the intensity being dependent upon the time of concentration and return period. The time of concentration is determined by either by the summation of overland and channel time of concentration or selection by the user.

- Regression - Q_p is determined by log-log relationships developed by the FHWA and USGS for specific localities.

- Log Pearson type III - Q_p is calculated using a statistical fit to stream flow data for a desired return period.

The time of concentration, t_c, is assumed equal to the duration of the rainfall. For the rational method, time of concentration may be calculated from overland and channel elements. For the regression and log Pearson type III situations (larger drainage areas), time of concentration is inferred by assuming the drainage area is circular and using a flow path equal to the one half of the circumference and a flow velocity of 1 foot per second.

Hydrographs generated by HYDRO can be used as input files to HYDRA and CDS to evaluate dynamic responses of culverts and storm drain systems.

This concludes the technical overview of the HYDRO program. The next section will provide instructions for its use in the HYDRAIN system.

4. User Documentation

Effective use of HYDRO requires an understanding of the interaction between user and the software. While the previous chapter described what HYDRO does, this chapter explains how one communicates with the software to achieve desired results.

The Command Approach - Organizing the Data

HYDRO operates through the command language concept. This means that data entry and data analysis are all dictated by user-supplied commands. A command is a very specific entity that describes one basic task that HYDRO can recognize. There is only a set number of commands in HYDRO's vocabulary and they must each follow a specific format. Currently there are 26 commands that HYDRO can recognize, although this number is subject to change as long as improvements are being made to HYDRO. A complete list, to date, of these commands along with their definitions and format specifications is included in Appendix B.

Commands provide the instructions and necessary data for performing hydrologic analyses. The collection of commands which define a HYDRO job are collectively referred to as a command string. These commands may be arranged in almost any order, provided they satisfy a few, simple requirements. The only requirements are that the **JOB** command must be the first non-REMark command to appear in the string, one of the three branch commands (**RFL**, **IDF**, or **FLW**) must be the second, and the **END** command must occur last in the string. All other commands can appear in any order within the string. Commands operate in "free format" fashion; that is, a space [ ], a comma [,] or a slash [/] are parameter subfield separators that may be used in any amount between each parameter value (spacing between subfields is not critical). Continuation of a command with many or extremely lengthy variables is achieved by simply typing in the data; the editor will wrap the data onto a second line with the same command ID. A brief glossary of all the commands is shown in Table 4. Detailed descriptions, formatting templates, and special notes for each command are provided by the software as long helps (obtained by using the F1 key) and are also reproduced in Appendix C.

Figure 6 shows an example command string, broken down into its command name and accompanying data fields, with an explanation of each command used. Note that the **JOB** command is first. This provides a means of identifying and/or describing the job. The next command is the **FLW** command which determines that a flow analysis (rather than a rainfall or IDF analysis) is to be performed). For this case, the Rational method will be used to calculate peak runoff, as specified by the '1'. The **RTL** command is the third command; it is used to specify the runoff coefficients for the seven classes of land use (i.e., meadow, woods, pasture, crops, residential, urban/highway, and pavement). The **BAS** command is the fourth command in the data set. It specifies the total area in the watershed as well as the land use areas. Site specific data are entered in the **TCO** command to compute the overland time of concentration for a runoff length of 1100 feet, 0.02 ft/ft slope, a soil type of B, and an antecedent moisture condition of 3. The **TCC** command provides the data needed to compute the channel time of concentration for a channel length of 2150 feet and a slope of 0.01. Location of the site is defined by providing the latitude and longitude with the

LOC command. This location is used to access rainfall data for the region from the NWS database. Finally, the return period of 50 years is specified in the **RPD** command.

HYDRO COMMAND	DATA	DESCRIPTION
JOB	COMMAND STRING EXAMPLE	The name of the job.
FLW	1	Use Rational Method to compute peak flow.
RTL	* * * * * * 0.95	Set default runoff coefficients for land uses 1 through 6 and for pavement at 0.95.
BAS	106.7 53 0 0 0 50 0 3.7	Specify basin size and land use areas.
TCO	1100.0 0.02 B 3	Specify data to compute overland time of concentration.
TCC	2150.0 0.01	Specify data to compute channel time of concentration.
LOC	35 14 80 50	Latitude and longitude of site.
RPD	50	50 year return period.
END		End of command string.

Figure 6. Example of a command string.

Table 4. Glossary of commands.

APM - specify a user supplied regional **A** PriMe value for a hyetograph.
BAS - specify **BAS**in size and land use.
CAL - specify **CAL**ifornia (state) rainfall database if NSW isn't used.
CRP - specify California (state) Return Period information.
DHY - signal use of **Dimensi[illegible]graph**.
END - signal the **END** of the command string.
FLW - specify the method for determining peak **FLoW**.
GFL - specify **Gage FLow** for Log Pearson Type III analysis.
IDF - signal computation and plotting of an **IDF** curve.
JOB - initiate **JOB** and specify a job title.
LOC - specify the **LOCation** of a site using latitude and longitude.
LPA - specify constants for **Log Pearson** Type III **Analysis**.
MOF - signal computation of **Maximum Observable Flood**.
QPK - user-supplied **PeaK** flow, **Q**.
REM - to provide **REM**arks or comments.
RFL - specify computation of single **RainFalL** intensity or hyetograph.
RGR - specify **ReGRession** coefficients for peak flow computations.
RPD - specify **Return PerioD** for frequency-dependent calculations.
RTL - specify **RaTionaL** method runoff coefficients.
STN - retrieve rainfall data for a **STatioN** from a state database.
TCC - specify data for **T**ime of **C**oncentration for **C**hannel flow.
TCO - specify data for **T**ime of **C**oncentration for **O**verland flow.
TCU - **U**ser-supplied **T**ime of **C**oncentration.
TLG - specify **T**ime **L**a**G** or information to compute time lag.
UIT - **U**ser-supplied rainfall **I**n**T**ensity of a 1-hour storm.

Figure 7 shows the required and optional commands for each of the three analysis branches. The order of the individual command cards is unimportant except for the first, second, and last non-**REM**ark cards. A **REM**ark card can appear anywhere within a command string.

As shown in Figure 7, two options are available within the Rainfall Analysis branch. The user can instruct HYDRO to compute a single rainfall intensity or a hyetograph by specifying the appropriate option number with the **RFL** branch command. Information related to the basin area, time of concentration, basin location, and return period are provided by the user on the appropriate cards. The **TCO/TCC** cards can be replaced with the **TCU** card if the user wishes to supply the combined overland and channel time of concentration. If the user supplies an intensity using the **UIT** card, then neither the time of concentration cards nor the **LOC**ation card need be used. The CAL card (with or without the **CRP** and **STN** cards) should appear in the command string if the State rainfall data base is to be used.

The second branch within HYDRO generates an IDF curve. Besides the **JOB**, **IDF** branch command, and **END** cards, **LOC** and **RPD** are the only other cards required. As in the rainfall analysis branch, if the user supplies an intensity with the **UIT** card, then the **LOC** card does not need to be used in the command string.

The Flow Analysis branch has four options, as indicated in Figure 7. The user can indicate computation of peak flow using the Rational Method, Log Pearson Type III analysis, or a user-supplied regression equation by specifying the appropriate option number with the **FLW** branch command card. HYDRO will compute a hydrograph if the **DHY** and **TLG** cards are present. Option 4 allows the user to supply the peak flow with the **QPK** card for use in deriving the hydrograph. In addition, with any of the four options, the user can specify that the Maximum Observable Flood be computed by including the **MOF** card in the command string. The **MOF** card requires that the **LOC** and **BAS** cards also be present.

The HYDRAIN Environment

For those users who have obtained HYDRO as part of the Federal Highway Administration's **HYDRAIN** package, additional information is required to run HYDRO within that system. Furthermore, HYDRO - the hydrology component of **HYDRAIN** can be used to provide hydrographs, IDF curves, and hyetographs for use in drainage analyses. HYDRAIN and HYDRO documentation should be consulted for instructions. The following sections discuss the procedures for operating the HYDRAIN System Shell and using the Generic Editor to create HYDRO input data sets. Users not desiring to operate in the HYDRAIN environment can skip this section.

Operating the HYDRAIN System Shell

HYDRO, as well as the other PFP software packages, is implemented through the use of what is known as the PFP "shell". This shell is a separate program that ties the HYDRAIN system together and allows individual components to be accessed. The following text deals specifically with the interaction between the HYDRAIN System Shell and HYDRO; the operation of the other packages will be dealt with separately in their respective documentation.

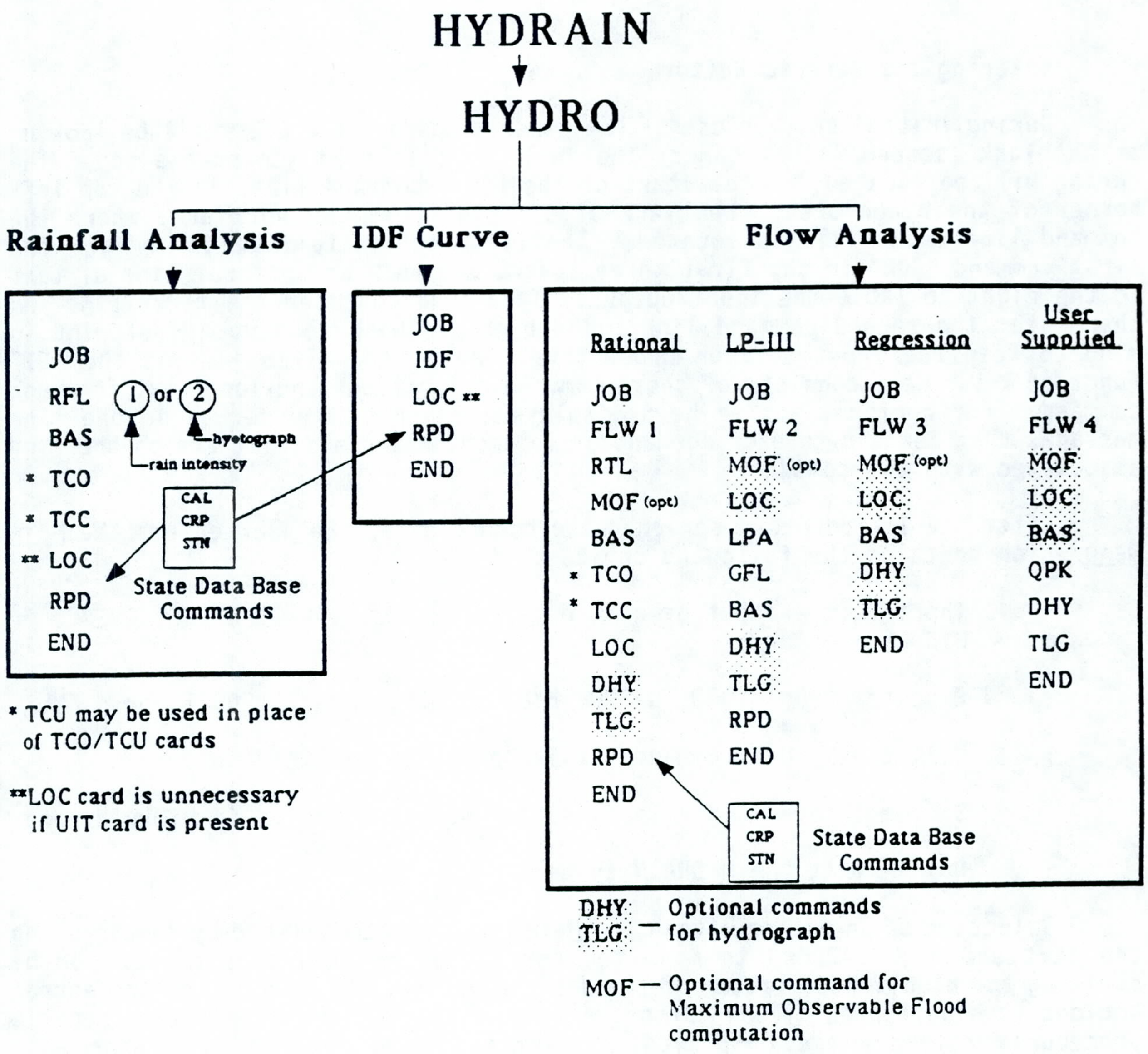


Figure 7. HYDRO footprints.

Before work on a specific HYDRO data set can begin, the HYDRAIN shell must first be entered and HYDRO accessed. This process is begun, from DOS by entering the C:\HYDRAIN directory, typing the command **HYDRAIN**, and striking a carriage return (denoted by <CR>). A screen will appear showing the member sponsors of the Pooled Fund Project. Another <CR> reveals a message (a PFP "disclaimer") to the PFP user. A third <CR> will place the user in the Main Menu.

Entering the Generic Editor

During initial session use of the generic editor, the user will be looking at a "blank" screen with a banner that will be displayed across the top. The cursor will be located, on the start of the first command line, in the top left corner of the blank area; the blank area, itself, is the work area where the command line input file is located. The first action to take is to type the first command "JOB" in the first three spaces and then an optional line of text to the right to lable the input/output. Type <CR> to enter the first line and then enter the second command line. The user may wish to have a footprint in mind to keep the input session productive. Help is available using the "F1" function key. Help consists of short command definitions and long text for each command. Furthermore, active help displayed as input is underway in one line messages that pertain to each command or to each data field that are on the line associated with the command.

After the introductory screens have been cleared the user enters the Main Menu which contains the following choices:

- Input/Edit - input or edit data for HYDRO, WSPRO, HYDRO, CDSV5, or HYCHL;
- Execute - run HYDRO, WSPRO, HYDRO, CDSV5, HY8V3, EQUAT, or HYCHL;
- Utilities - DOS commands, file operation, HYDRAIN setup;
- System Info - long help files for selected topics in HYDRAIN; and
- Quit - exit the HYDRAIN system.

Selection of an option within the Main Menu is accomplished by simply using the left and right ARROWS to move the cursor to the desired procedure or by striking the highlighted letter of the desired option. As each of the procedural options is highlighted by the cursor, a menu of the options within the specific procedural category are displayed. Movement in this field, as before, is accomplished with the ARROWS (in this case, up and down). Since a new file is to be created, place the cursor under the first choice, **Input / Edit** , then, using the down ARROW, highlight HYDRO and strike <CR>.

At this point, the user is asked if the Generic Editor or an Interactive Editor will be used to create/edit the data set. The generic editor allows the user almost complete freedom to edit command line input files. Use of this editor assumes that the user has a basic working knowledge of the generic editor program and its requirements.

To make a selection, move the cursor to the desired field and press <CR>, or, press G for generic or I for interactive. As it is still under development, currently, none of the HYDRAIN programs can access the interactive editor. Should the user select this option, they will be given a message to this effect.

The result of selecting an editor will be a prompt for the user to specify the name of a file to be edited. Pressing <Esc> or <F2> will return the user to the HYDRAIN main menu. Next, the user should select a file to be edited (or created). The bottom of the screen shows the path of the input files for the engineering program selected. It also displays the number of bytes free on the disk being used. Only those files having the .HDO extension will be displayed.

To select a file from those already existing, move the cursor and press <CR>. The file name selected will be moved to the field next to "File:". To begin editing, press <CR>. Should the user wish to change the file name selection, once the filename is in the "File:" field, they may type the name of the file desired (with a three-letter extension) and press <CR>. This newly entered file name will be sent to the editor.

To create a new file (or use a file that does not use the .HDO extension), move the cursor to [..EDIT..] and press <CR>. The cursor will move to the "File:" field. The user should type the name of the file and press <CR> twice to begin editing. After pressing <CR> the second time, the user is placed into the file which was chosen.

Using the Generic Editor

The generic editor provides the HYDRAIN user with a simple method of adding new data and changing existing data to create program input files for programs which have command line inputs, such as HYDRO. The editor itself is a full-screen editor with each line having two fields. The first field has space for three characters and is the location in which the user enters the command ID for a line of data. The cursor is moved to field two using the right arrow key. Field two is the location of the input data associated with a given command ID and consists of a maximum of 72 characters plus any continuation lines.

In addition to its basic editing capabilities, the generic editor relies on the usage of two function keys. The <F1> key allows the user to access Help whle the <F2> key accesses special editing and word processing tools. These two functions act as on/off switches; pressing the key once activates the function, while pressing it a second time deactivates it, returning the screen to edit mode. In addition to the <F1> and <F2> keys, numerous other keys are active in the generic editor. Table 5 provides a listing of these keys and their functions. Appendix A of the HYDRAIN Manual Volume I presents a comprehensive explanation and "walk-through" on the use of the generic editor. This section is intended to provide an overview of the editor and its capabilities.

Table 5
Active Keys and Their Functions

Key	Function
F1 ("Help Key")	Access Long Help.
F2 ("Hot Key")	Access pull-down menus of editing options.
Ctrl End	Delete a line.
Carriage Return <CR>	Insert a line. Move to the next line.
Esc	Return to HYDRAIN main menu.
Arrow keys	Move the cursor throughout the document.
PgUp	View the previous screen of data.
PgDn	View the next screen of data.
Ctrl PgUp	Move to the top of the document.
Ctrl PgDn	Move to the bottom of the document.
Ins	Switch between Insert and Replace modes.
Home	Move to beginning of the field, of the line, of the screen, and then of the file.
End	Move to the end of the field, of the line, of the screen, and then of the file.
Backspace	Move back one space (or field in certain cases).

The generic editor is designed to provide continuous short help displayed at the bottom of the screen for each field. Entering a three character Command in field one triggers a short descriptive help message. Should a more detailed description of the Command ID and the structure of the data to be input into field two be desired, pressing the <F1> key will access a menu of all command IDs for the type of data set (in this case HYDRA). By highlighting the desired command ID and striking <CR>, long help on that command ID is displayed. A complete listing of the command ID long help messages is found in Appendix B.

Editing functions are accessed at any time during the editing process by pressing the <F2> key. These functions are organized in pull-down menus of editing options. Descriptions of the four menus, titled **Select, Search, Modify** and **Block,** follow.

Within the **Select menu,** there are six functions which are presented under two sub-headings. The "File Access" sub-heading has three functions which allow the user to execute basic file management procedures. The "Action" sub-heading has three functions, each of which allows the user to execute a specified procedure.

FILE ACCESS - allows the user to perform one of three operations: Retrieve, Save, and Switch.

Retrieve - In order to Retrieve a file, the following procedure is performed:

a. Select "Retrieve" by moving cursor and pressing <CR>.
b. If the current path, as indicated, is incorrect, enter the correct directory (Note: there must be a backslash (\) before and after the directory name).
c. Using the down arrow, move the highlight bar to the desired file and Press <CR>. Or, type the filename (with extension) in the space next to "Current File:".
d. An inset "Warning" screen will then appear. To retrieve the file and overwrite any text which is on the screen, select "Continue . . .". Or, to cancel the retrieval and return to the Select menu, choose "Abandon . . .".
e. When the text is retrieved and appears on the screen, press <Esc> or <F2> to remove the menu.

Save - In order to Save a file, the following procedure is performed:

a. Select "Save" by moving the cursor and pressing <CR>.
b. If necessary, change the path and directory in which the file will be saved.
c. Using the down arrow, move the highlight bar to the desired file and press <CR>. Or, type the filename (an extension will be assigned automatically) in the space next to "Current File:".
d. If the file being saved is new, it is automatically saved and the user is returned to the Select menu. If the file had already existed, a "Warning" screen will appear. Choose "Continue . . ." to overwrite the existing file or, choose "Abandon . . ." to cancel the save process and return to the Select menu.

It should be noted that an input file will automatically be saved if it is run. Therefore, running a program results in the input file overwriting the previously existing data file.

Switch - The "Switch" function allows the user to bring a new file onto the screen while keeping the original file open. The feature is especially useful for copying or moving a block of text from one file into another through use of the cut/paste option.

To utilize the Switch option, move the cursor to Switch and press <CR>. Proceed as before to retrieve another file. To switch back to the original file, select "Switch" again. In this manner, the user may move between the two files.

ACTION - The "Action" section of the Select menu also contains three functions: Run, DOS, and Quit.

Run - The "Run" option allows the user to run the data file which is displayed on-screen. After running, the screen automatically displays the output. It is important to note, however, that the Run command is only active when the editor is invoked from the HYDRAIN program. As previously mentioned, a program should first be saved before it can be run. In addition, running the program will automatically save the input file.[1]

DOS - The "DOS" option allows the user to return to MS-DOS without actually leaving the editor. Select DOS by moving the cursor and pressing <CR>. The user will then be placed at the DOS prompt and may operate within DOS in a normal fashion. To exit DOS and return to the editor, type EXIT at the DOS prompt. Because of the quantity of space used by the editor and files, there might not be enough memory to use this function.

Quit - After all editing is completed and all files are saved, the user may leave the generic editor by using the "Quit" option. To quit the system, move the cursor to "QUIT" and press <CR>. If all files to which changes were made have been saved, the DOS prompt will be revealed. If changes were made and the files aren't saved, a warning screen will appear. If the choice is made to continue with the exit, all changes will be lost. If the user chooses to abandon the exit, the program will return to the Select menu and the user should then save the file(s).

The **Search menu** is divided into two sections, each of which has five options from which the user may choose. The Search capabilities of the Generic Editor allow the user to quickly locate instances where certain pieces of text occur.

SEARCH - The "Search" section of the Search menu has five available options. The first four options specify the range of a search while the fifth executes the command. First, the user should select the range to be searched (block, row(s), column(s), global) by moving the cursor to the desired choice and pressing <CR>. Note that the "Block" option is not available unless there is already text which is marked as a block. Similarly, the "Continue" option is not made available until one search has already been performed. Each selection displays a screen in which the user will specify the exact text to be found. In the field next to "Pattern to Match", enter the string of characters to be located. Next, select "Floating" for "Pattern Position". Finally, choose "Yes" to

---

[1]This feature of the generic editor is very powerful for a user. Use of the "Run" option initiates execution of the current data file and displays the resulting output file on the monitor for immediate review. After complete review of the output file, the input file is returned to the screen for additional runs, if desired.

begin the search. Choosing "No" will return the program to the Search menu.

The program then highlights the first instance in which the desired pattern is found. There may, however, be more matches. To check for additional matches, move the cursor to "Continue" in the "Search" section of the Search menu and press <CR>. Selecting "Continue" will result in the next instance in which a match occurs being highlighted. This procedure may be repeated as many times as desired until the end of the file is reached.

TRANSLATE - The "Translate" section of the Search menu has the same five options as the "Search" section. Once again, however, the "Block" and "Continue" options are not always available. The purpose of the translate function is to search for a given pattern and then automatically replace or amend it. The translate input screen requires the same information as search. In addition, the user must enter the new pattern which will replace or be added to the old one. This string is entered in the "Translate to pattern" field. Also, the user must specify whether the new pattern is to overwrite the old one or be inserted after it. This is done by moving the cursor to <Overwrite> or <Insert> and pressing <CR>. Again, choosing "Yes" executes the translate command, while choosing "No" returns the program to the Search menu.

Whenever the program locates the pattern to be translated, a prompt screen is displayed which asks the user whether or not that occurrence should be translated. Choosing "Yes" will perform the translation and move on to the next occurrence. Selecting "No" will move to the next occurrence without changing the previous instance. The "Global" option will automatically translate all of the matches and will return to the Search menu. "Quit" will abandon the translate procedure and return to the Search menu. The final option, "Continue", allows the user to continue the most recent translate procedure, even if the Search menu has been exited and normal editing has been resumed.

The **Modify** menu is divided into three sections: Cut, Paste, and Clear. All of the functions allow the user to move or delete text from the current file.

CUT - There are three options in the "Cut" section of the Modify menu. The user is able to cut a block of one or more columns, and one or more rows. In order to select the Block, Row(s), or Column(s) option, move the cursor to the selection and press <CR>. The "Cut" command deletes the specified portion of the text, but keeps it in memory for a short period of time. In order to cut text which has already been blocked from within the Block menu, select "Block". There is no further prompt, so the block is immediately deleted.

In order to cut one or more rows, select "Row(s)". An inset screen titled "Cut Rows from Sheet" will appear. Move to the field for "Number of rows to cut" and enter the desired number. Then, specify the row at which the cut should start. Note that the default row is the row the cursor was in and the default number of rows is one. The area to be cut is now highlighted. To execute the cut, select "Yes". Selecting "No" will abort the process and return the program to the Modify menu. In addition, pressing <Esc> or <F2> at any time will return the screen to edit mode.

In order to cut one or more column(s) from the text, select "Column(s)" and follow the procedure described for cutting rows.

PASTE - The paste function adds to the text a section which has just been cut. This section can be a block, row(s), or column(s). After selecting "Paste", the Paste Block menu will appear and the program will automatically highlight as much text as was previously cut. For instance, if four rows had been cut, four rows would be highlighted, beginning at the location of the cursor.

Several choices are then made. First, choose whether the new text is to be inserted or is to overwrite existing text. As mentioned, a section of the text is highlighted on the screen. If "overwrite" is selected, the highlighted section is where the new text will be displayed. If "insert" is chosen, the new text will be added above the highlighted area in the case of rows, and left of the highlighted area for columns. If the text to be pasted is a block, it will be inserted above the position of the cursor for rows and left of the cursor for columns.

The second choice, where to start the paste, depends on whether rows or columns are being pasted. For rows, the user specifies the row and column at which the paste is to begin. Keep in mind that for "overwrite", the new text will replace the old text beginning at the specified line number, while for "insert", the new text will go above the specified line. For columns, the choices are the same as those for rows, with one addition; the user specifies the character at which the paste should start. "Overwrite" works in the same manner as for rows, while "Insert" will add the column(s) to the left of the highlighted text.

After the paste is completed, select "Deactivate" in the Block menu (by moving the cursor and pressing <CR>) to remove the block notation.

CLEAR - The "Clear" section of the Modify menu also has three options. For each of these options, block, column(s), and row(s), the text in the specified (highlighted) area is erased. The block, columns, or rows remain in the text but are blank (contain no characters). If the "Block" option is chosen, all text in any area marked as a block is erased. If columns or rows are being cleared, the user specifies the number to clear and the starting location. This information is entered on the prompt screen which is displayed after the user has selected the "Clear" option. To execute the "Clear" command, select "Yes". Once again, pressing <Esc> or <F2> will return the program to edit mode while selecting "No" will display the Modify menu.

The **Block function** is used throughout the generic editor to perform a variety of editing tasks. These tasks include: cut/paste, search, clear, and translate. Each of these tasks are presented in detail in their own long helps. Furthermore, the block function allows the user to specify the exact area of the text where the task is to be performed. There are five options available in the Block menu. The first three, "Characters", "Rows", and "Columns", allow the user to block one or more of the chosen item. To use any of these options, select it (by moving the cursor to the desired choice and pressing <CR>) and use the arrow keys to highlight the block area. When the desired area is highlighted, press <CR> to mark it. The "Global" option automatically blocks the entire document. Finally, the "Deactivate" option removes the block notation from all blocked areas and returns it to standard text.

Executing HYDRO

There are two methods by which HYDRO can be run within the HYDRAIN environment. One method is to run HYDRO from the generic editor. This allows the user the option of immediate review, editing capabilities. The second method is to run HYDRO from the HYDRAIN shell using the **Execute** option.

HYDRO can be run from the generic editor by using the "Hot Key" (<F2>) and moving to the **Select** Action option, Run, and pressing <CR>. As the input file executes, the commands in the file will appear sequentially on the terminal screen. The user can "observe" the progress of the HYDRO run by observing which commands are being processed.

Upon completion of the run, the output file, which is automatically assigned an **.LST** filename extension, will be displayed on the screen. Movement through this screen can be accomplished with the cursor, PgUp, PgDn, Home and End keys. After reviewing the file, pressing F2 will return the user to the generic editor. From here, the user can once again edit the same file and rerun it.

HYDRO has the capability to produce three other output files to be used in conjunction with other programs in the PFP system. These optional output files have the following extensions:

- QT - This extension contains the ordinates of a hydrograph (ie: flow (Q) versus time (T)). The file is generated by HYDRO and, at user option, can be incorporated into the other PFP Engineering programs (ie: into HYDRA using the **UHY** Command).
- HYE - This extension contains the ordinates of a hyetograph (ie: rainfall intensity (I) versus time (T)). The file is generated by HYDRO and , at user option, can be incorporated into the other PFP Engineering programs (ie: into HYDRA using the **HYE** Command).
- IDF - This extension contains the ordinates of an Intensity-Duration-Frequency (IDF) curve (for a duration from 5 minutes to 24 hours). The file is generated by HYDRO and, at user option, can be incorporated into the other PFP Engineering programs (ie: into HYDRA using the **RAI** Command).

After saving the data set in the generic editor, HYDRO can be run from the HYDRAIN shell by exiting the editor. This is accomplished by pressing <F2>, selecting the **Selection** Action option, Quit, and striking <CR>. The HYDRAIN main menu screen appears. By selecting the **Execute** procedure, HYDRO may be run by selecting the Run option. Prompts for the data set type and name allow the user to select the appropriate data set. As with the generic editor, while the input file executes, the commands in the file will appear sequentially on the terminal screen. The user can "observe" the progress of the HYDRO run by observing which commands are being processed.

Upon completion of the run, the output file, which is automatically assigned an **.LST** filename extension, will be displayed on the screen. Movement through this screen can be accomplished with the cursor, PgUp, PgDn, Home and End keys. After reviewing the file, pressing F2 will return the user to the HYDRAIN main menu. From this menu, editing of the input data set is accomplished through reentry of the generic editor. As with execution from the generic editor, the additional output files mentioned above are also produced.

Appendix A: Benchmark Examples

The following examples serve to illustrate the types of analyses that HYDRO can perform. While these examples are not intended to illustrate all of the options within HYDRO, they are intended to satisfy the following four objectives.

(1) provide guidance for creating command strings,

(2) demonstrate uses for many of the commands,

(3) provide information on how to set up a problem, and

(4) demonstrate what to expect for output.

The six examples presented here illustrate the three major types of analyses that HYDRO performs. Examples 1, 2, and 3 illustrate rainfall analyses, example 4 illustrates IDF curve generation, and examples 5 and 6 illustrate flow analyses. Specific options addressed by each example are listed below.

(1) Single rainfall intensity calculation using the Pooled Fund data base;

(2) Single rainfall intensity calculation using California's State data base;

(3) Dynamic rainfall analysis (hyetograph generation);

(4) IDF curve generation;

(5) Peak flow calculation using the Rational Method; and

(6) Peak flow calculation using Log Pearson Type III analysis.

RAINFALL ANALYSIS EXAMPLES

Example 1

Input File: RFL1.HDO

```
JOB  HYDRO EXAMPLE:  POOLED FUND DATA BASE
RFL  1
BAS  108.10  53.9  0  0  0  50.5  0 3.7
TCO  1100.0  0.02  0.1
TCC  2150.0  0.01
LOC  41  31  124  2
RPD  50
END
```

Output File: RFL1.LST

```
               *************** HYDRO - Version 901.A ***************
               *  HEC19 / Design Event vs Return Period Program  *
               *               Date of Run: 02-20-90              *
                                                               PAGE NO   1
          HYDRO EXAMPLE:  POOLED FUND DATA BASE

    --- Input File: RFL1.HDO


    JOB  HYDRO EXAMPLE:  POOLED FUND DATA BASE
    RFL  1

*** THE RAINFALL ANALYSIS OPTION HAS BEEN SELECTED WITH THE INTENSITY SUBOPTION.

    BAS  108.10  53.9  0  0  0  50.5  0 3.7
    TCO  1100.0  0.02  0.1

*** OVERLAND RUNOFF LENGTH = 1100.0 FEET
*** OVERLAND RUNOFF SLOPE =    .020 FT/FT
*** THE BASIN MANNINGS COEFFICIENT IS   .100

    TCC  2150.0  0.01

*** CHANNEL LENGTH =  2150.00
*** CHANNEL SLOPE =    .010
     *** NOTE:  GRASSY WATERWAY EQUATION WILL BE USED

    LOC  41  31  124  2

*** THE LATITUDE IS  41 DEGREES, 31 MINUTES
*** THE LONGITUDE IS 124 DEGREES,  2 MINUTES

    RPD  50
```

```
*** THE SELECTED RETURN PERIOD IS   50 YEARS

    END

*** END OF COMMAND FILE


*** THE BASIN AREA =     108.10   ACRES
*** THE SUBAREA ACREAGES ARE:
           MEADOW ..........   53.90
           WOODS ...........     .00
           PASTURE .........     .00
           CROPS ...........     .00
           RESIDENTIAL .....   50.50
           URBAN/HIGHWAY ...     .00
           PAVEMENT ........    3.70


*** OVERLAND TIME OF CONCENTRATION =    .66 HOURS
*** CHANNEL TIME OF CONCENTRATION  =    .31 HOURS

               ***** HYDRO ***** (Version 901.A) *****          DATE 02-20-90
                                                                PAGE NO   2

          HYDRO EXAMPLE:  POOLED FUND DATA BASE

               **************************************************
               *  TIME OF CONCENTRATION EQUALS      .97 HOURS    *
               *      INTENSITY EQUALS   1.34 INCHES/HOUR        *
               **************************************************


*** END OF RUN
```

Example 2

Input File: RFL1A.HDO

```
JOB  HYDRO EXAMPLE:  CALIFORNIA DATA BASE
RFL  1
BAS  108.10  53.9  0  0  0  50.5  0 3.7
TCO  1100.0  0.02  0.1
TCC  2150.0  0.01
LOC  41  31  124  2
RPD  50
CAL  RAIN.ASC
END
```

Output File: RFL1A.LST

```
               *************** HYDRO - Version 901.A ***************
               *  HEC19 / Design Event vs Return Period Program  *
               *              Date of Run: 02-20-90               *
                                                             PAGE NO   1
        HYDRO EXAMPLE:  CALIFORNIA DATA BASE

     --- Input File: RFL1A.HDO


     JOB  HYDRO EXAMPLE:  CALIFORNIA DATA BASE
     RFL  1

*** THE RAINFALL ANALYSIS OPTION HAS BEEN SELECTED WITH THE INTENSITY SUBOPTION.

     BAS  108.10  53.9  0  0  0  50.5  0 3.7
     TCO  1100.0  0.02  0.1

*** OVERLAND RUNOFF LENGTH = 1100.0 FEET
*** OVERLAND RUNOFF SLOPE =   .020 FT/FT
*** THE BASIN MANNINGS COEFFICIENT IS   .100

     TCC  2150.0  0.01

*** CHANNEL LENGTH =  2150.00
*** CHANNEL SLOPE =   .010
   *** NOTE:  GRASSY WATERWAY EQUATION WILL BE USED

     LOC  41  31  124  2

*** THE LATITUDE IS  41 DEGREES, 31 MINUTES
*** THE LONGITUDE IS 124 DEGREES,  2 MINUTES

     RPD  50
```

```
*** THE SELECTED RETURN PERIOD IS   50 YEARS

       CAL  RAIN.ASC
       END

*** END OF COMMAND FILE


*** THE BASIN AREA =     108.10   ACRES
*** THE SUBAREA ACREAGES ARE:
           MEADOW ..........   53.90
           WOODS ...........     .00
           PASTURE .........     .00
           CROPS ...........     .00
           RESIDENTIAL .....   50.50
           URBAN/HIGHWAY ...     .00
           PAVEMENT ........    3.70

*** THE FOLLOWING STATION(S) WILL BE USED IN DETERMINING
*** THE INTENSITY FOR THE SITE:

   STATION ID   ELEV. (FT)   LAT/LONG (DEC. DEG.)   DISTANCE FROM SITE (MILES)


   F304577  0     25           41.517  124.033       .0

*** OVERLAND TIME OF CONCENTRATION =     .70 HOURS
*** CHANNEL TIME OF CONCENTRATION  =     .31 HOURS

               ***** HYDRO ***** (Version 901.A) *****          DATE 02-20-90
                                                                PAGE NO   2

          HYDRO EXAMPLE:  CALIFORNIA DATA BASE

               *************************************************
               *  TIME OF CONCENTRATION EQUALS    1.01 HOURS   *
               *      INTENSITY EQUALS   1.37 INCHES/HOUR      *
               *************************************************


*** END OF RUN
```

Example 3

Input File: RFL2.HDO

```
JOB  HYDRO EXAMPLE:  POOLED FUND DATA BASE
RFL  2
BAS  108.10  53.9  0  0  0  50.5  0 3.7
TCO  1100.0  0.02  0.1
TCC  2150.0  0.01
LOC  41  31  124  2
RPD  50
END
```

Output File: RFL2.LST

```
               *************** HYDRO - Version 901.A **************
               *  HEC19 / Design Event vs Return Period Program  *
               *                Date of Run: 02-20-90             *
                                                                PAGE NO    1
          HYDRO EXAMPLE:  POOLED FUND DATA BASE

      --- Input File: RFL2.HDO


      JOB  HYDRO EXAMPLE:  POOLED FUND DATA BASE
      RFL  2

*** THE RAINFALL ANALYSIS OPTION HAS BEEN SELECTED WITH THE HYETOGRAPH SUBOPTION.


      BAS  108.10  53.9  0  0  0  50.5  0 3.7
      TCO  1100.0  0.02  0.1

*** OVERLAND RUNOFF LENGTH = 1100.0 FEET
*** OVERLAND RUNOFF SLOPE =   .020 FT/FT
*** THE BASIN MANNINGS COEFFICIENT IS   .100

      TCC  2150.0  0.01

*** CHANNEL LENGTH =  2150.00
*** CHANNEL SLOPE =   .010
    *** NOTE:  GRASSY WATERWAY EQUATION WILL BE USED

      LOC  41  31  124  2

*** THE LATITUDE IS  41 DEGREES, 31 MINUTES
*** THE LONGITUDE IS 124 DEGREES,  2 MINUTES

      RPD  50
```

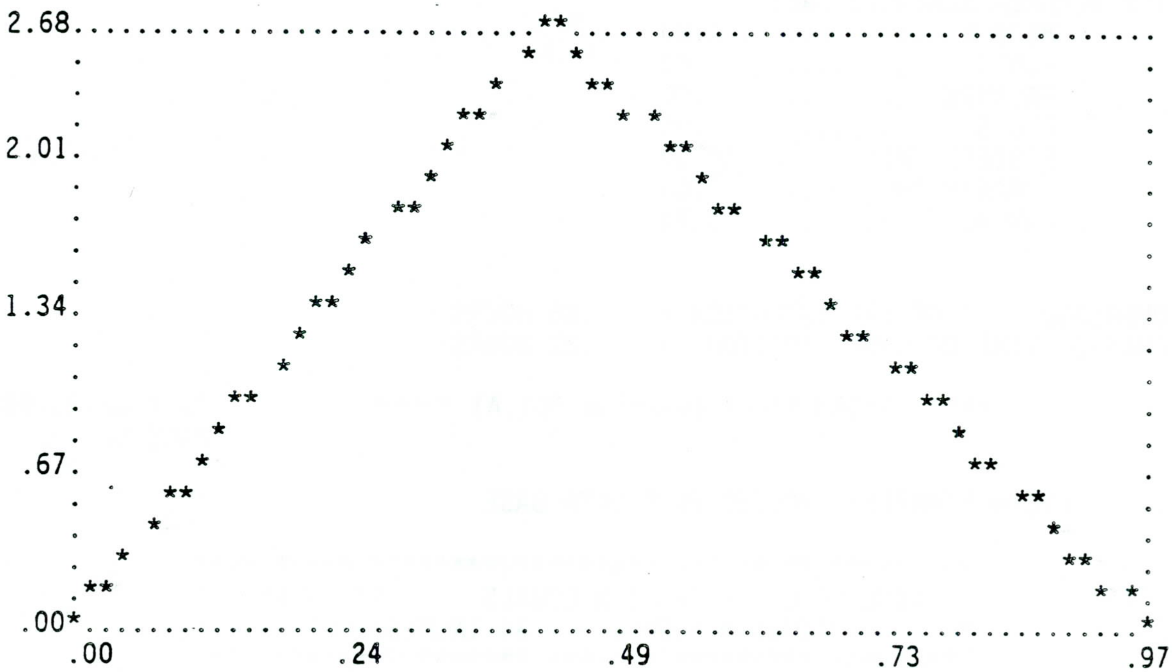
```
*** THE SELECTED RETURN PERIOD IS   50 YEARS

       END

*** END OF COMMAND FILE


*** THE BASIN AREA =     108.10   ACRES
*** THE SUBAREA ACREAGES ARE:
             MEADOW ..........   53.90
             WOODS ...........     .00
             PASTURE .........     .00
             CROPS ...........     .00
             RESIDENTIAL .....   50.50
             URBAN/HIGHWAY ...     .00
             PAVEMENT ........    3.70

*** OVERLAND TIME OF CONCENTRATION =     .66 HOURS
*** CHANNEL TIME OF CONCENTRATION  =     .31 HOURS
```



```
         HYDRO EXAMPLE:  POOLED FUND DATA BASE

               **************************************************
               *  TIME OF CONCENTRATION EQUALS      .97 HOURS   *
               *      INTENSITY EQUALS   1.34 INCHES/HOUR       *
               **************************************************


*** A-PRIME =  .435


                  ********************************************
                  * THE TIME TO PEAK EQUALS    .42290 HOURS *
                  ********************************************
```

HYDRO EXAMPLE: POOLED FUND DATA BASE

GRAPH OF TRIANGULAR HYETOGRAPH
RAINFALL INTENSITY(INCHES/HOUR)-VS-TIME(HOURS)



POINT	TIME (HRS)	INTENSITY (IN/HR)
1	.00000	.00000
2	.01667	.10545
3	.03333	.21089
4	.05000	.31634
5	.06667	.42178
6	.08333	.52723
7	.10000	.63268
8	.11667	.73812
9	.13333	.84357
10	.15000	.94901
11	.16667	1.05446
12	.18333	1.15990
13	.20000	1.26535
14	.21667	1.37080
15	.23333	1.47624
16	.25000	1.58169
17	.26667	1.68713
18	.28333	1.79258

19	.30000	1.89803
20	.31667	2.00347
21	.33333	2.10892
22	.35000	2.21436
23	.36667	2.31981
24	.38333	2.42526
25	.40000	2.53070
26	.41667	2.63615
27	.42290	2.67558
28	.43333	2.62466
29	.45000	2.54331
30	.46667	2.46197
31	.48333	2.38062
32	.50000	2.29928
33	.51667	2.21793
34	.53333	2.13659
35	.55000	2.05524
36	.56667	1.97390
37	.58333	1.89255
38	.60000	1.81121
39	.61667	1.72986
40	.63333	1.64852
41	.65000	1.56717
42	.66667	1.48583
43	.68333	1.40448
44	.70000	1.32313
45	.71667	1.24179
46	.73333	1.16044
47	.75000	1.07910
48	.76667	.99775
49	.78333	.91641
50	.80000	.83506
51	.81667	.75372
52	.83333	.67237
53	.85000	.59103
54	.86667	.50968
55	.88333	.42834
56	.90000	.34699
57	.91667	.26565
58	.93333	.18430
59	.95000	.10296
60	.96667	.02161
61	.97109	.00000

***** HYDRO ***** (Version 901.A) *****   DATE 02-20-90
PAGE NO 4

HYDRO EXAMPLE: POOLED FUND DATA BASE

*** END OF RUN

IDF CURVE EXAMPLE

Example 4

Input File: IDF.HDO

```
JOB  HYDRO EXAMPLE:  IDF CURVE EXAMPLE
IDF  HAPPY CAMP RANGER STATION
LOC  41 48  123 22
RPD  50
END
```

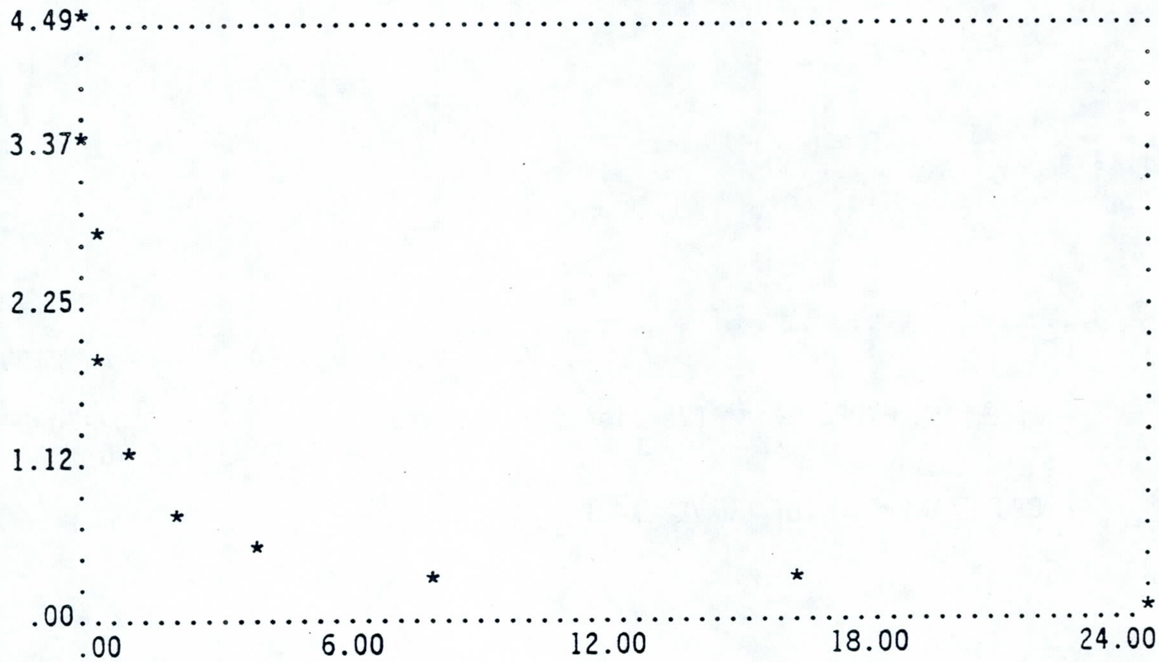
Output File: IDF.LST

```
               *************** HYDRO - Version 901.A ***************
               *  HEC19 / Design Event vs Return Period Program  *
               *               Date of Run: 02-20-90             *
                                                          PAGE NO   1
          HYDRO EXAMPLE:  IDF CURVE EXAMPLE

       --- Input File: IDF.HDO


       JOB  HYDRO EXAMPLE:  IDF CURVE EXAMPLE
       IDF  HAPPY CAMP RANGER STATION

*** THE IDF CURVE OPTION HAS BEEN SELECTED.

       LOC  41 48  123 22

*** THE LATITUDE IS  41 DEGREES, 48 MINUTES
*** THE LONGITUDE IS 123 DEGREES, 22 MINUTES

       RPD  50

*** THE SELECTED RETURN PERIOD IS   50 YEARS

       END

*** END OF COMMAND FILE
```

HYDRO EXAMPLE: IDF CURVE EXAMPLE

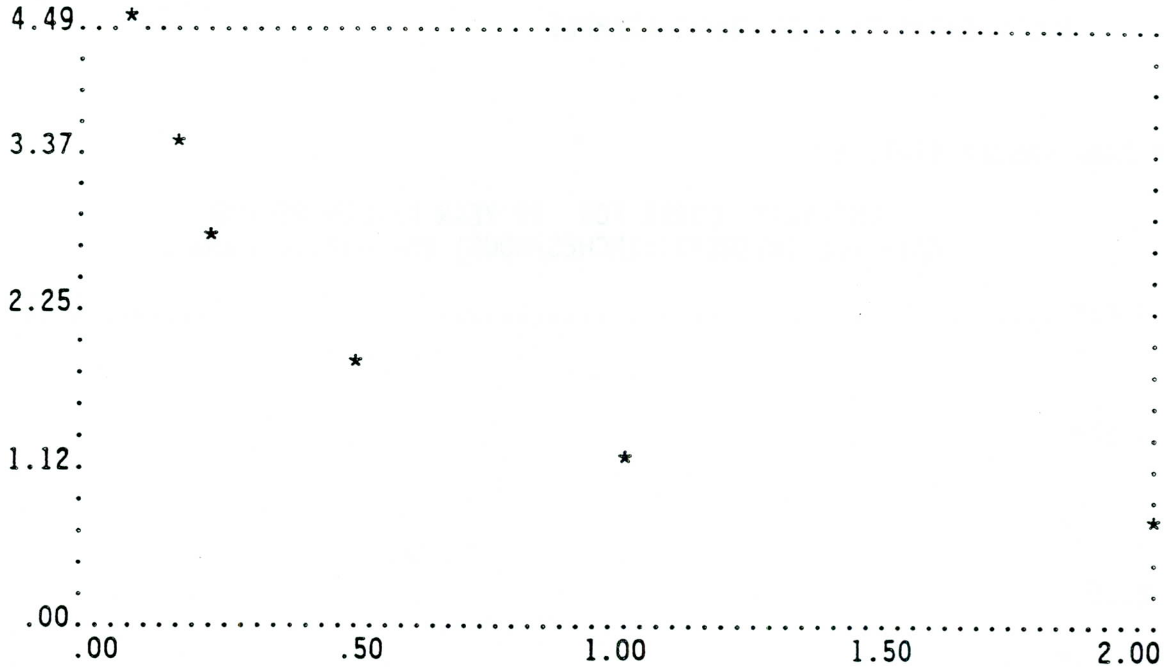
HAPPY CAMP RANGER STATION

INTENSITY CURVE FOR 50 YEAR RETURN PERIOD
RAINFALL INTENSITY(INCHES/HOUR)-VS-DURATION(HOURS)



POINT	DURATION (HRS)	INTENSITY (IN/HR)
1	.08330	4.49419
2	.16670	3.45974
3	.25000	2.74089
4	.50000	1.83649
5	1.00000	1.13584
6	2.00000	.73275
7	4.00000	.42796
8	8.00000	.23361
9	16.00000	.12242
10	24.00000	.08294

IDF CURVE DETAIL



***** HYDRO ***** (Version 901.A) *****

DATE 02-20-90
PAGE NO 3

HYDRO EXAMPLE: IDF CURVE EXAMPLE

*** END OF RUN

Example 5

Input File: **RTN1.HDO**

```
JOB  HYDRO EXAMPLE:  RATIONAL METHOD
FLW  1
RTL  * * * * * * 0.95
BAS  108.10  53.9  0  0  0  50.5  0 3.7
TCO  1100.0  0.02  0.1
TCC  2150.0  0.01
LOC  38  30  80  50
RPD  50
END
```

Output File: **RTN1.LST**

```
              ************** HYDRO - Version 901.A **************
              *  HEC19 / Design Event vs Return Period Program  *
              *                Date of Run: 02-20-90            *
                                                              PAGE NO   1
         HYDRO EXAMPLE:  RATIONAL METHOD

      --- Input File: RTN1.HDO


      JOB  HYDRO EXAMPLE:  RATIONAL METHOD
      FLW  1

*** THE FLOW ANALYSIS OPTION HAS BEEN SELECTED WITH THE RATIONAL METHOD
SUBOPTION.

      RTL  * * * * * * 0.95
      BAS  108.10  53.9  0  0  0  50.5  0 3.7
      TCO  1100.0  0.02  0.1

*** OVERLAND RUNOFF LENGTH = 1100.0 FEET
*** OVERLAND RUNOFF SLOPE =   .020 FT/FT
*** THE BASIN MANNINGS COEFFICIENT IS   .100

      TCC  2150.0  0.01

*** CHANNEL LENGTH =  2150.00
*** CHANNEL SLOPE =   .010
    *** NOTE:  GRASSY WATERWAY EQUATION WILL BE USED

      LOC  38  30  80  50

*** THE LATITUDE IS  38 DEGREES, 30 MINUTES
```

```
*** THE LONGITUDE IS  80 DEGREES, 50 MINUTES

      RPD  50

*** THE SELECTED RETURN PERIOD IS   50 YEARS

      END

*** END OF COMMAND FILE


*** THE BASIN AREA =     108.10  ACRES
*** THE SUBAREA ACREAGES AND RUNOFF COEFFICIENTS ARE:
         MEADOW ..........   53.90 C =  .200*
         WOODS ...........     .00 C =  .200*
         PASTURE .........     .00 C =  .300*
         CROPS ...........     .00 C =  .300*
         RESIDENTIAL .....   50.50 C =  .400*
         URBAN/HIGHWAY ...     .00 C =  .700*
         PAVEMENT ........    3.70 C =  .950
*** NOTE: * INDICATES THAT THE DEFAULT COEFFICIENT WAS USED
*** DUE TO A MISSING OR ILLEGAL USER-SUPPLIED VALUE.


*** OVERLAND TIME OF CONCENTRATION =     .50 HOURS
*** CHANNEL TIME OF CONCENTRATION  =     .31 HOURS

               **************************************************
               *  TIME OF CONCENTRATION EQUALS     .81 HOURS    *
               *      INTENSITY EQUALS   2.88 INCHES/HOUR       *
               **************************************************

              ***** HYDRO ***** (Version 901.A) *****          DATE 02-20-90
                                                               PAGE NO   2

        HYDRO EXAMPLE:  RATIONAL METHOD

                    *************************************
                    * THE PEAK FLOW IS          99. CFS *
                    *************************************


*** END OF RUN
```

Example 6

Input File: **LPA.HDO**

```
JOB  LOG PEARSON EXAMPLE - MEDINA RIVER
FLW  2
LPA  0.236   3   842880.0   A
GFL  MEDINA.FLW
BAS  842880.0
RPD  500
END
```

Input Data File: **MEDINA.FLW**

(Note: This is an external file that is placed in the HYDRAIN intermediate directory. The user could have just as easily placed the flow data in LPA.HDO, following the GFL command. Appendix C has further information on this and other command input formats and syntax.)

```
ANNUAL DISCHARGE - MEDINA RIVER @ SAN ANTONIO, TEXAS: 1940-1982
       43
     2540
     6890
    17500
    12100
     2000
     3540
    31800
     1470
     2050
    17400
     5660
     2150
      801
     4960
      865
     1200
     1750
     5180
     9220
     3350
     3200
     3050
     3960
      890
     2140
     5430
     2160
     5480
    13100
     2730
```

Input Data File: **MEDINA.FLW** (continued)

```
    3360
    2950
    6360
   31900
    9680
    4130
    7510
    4620
    9440
    4750
    1980
   14500
    8160
```

Output File: **LPA.LST**

```
              *************** HYDRO - Version 901.A ***************
              *  HEC19 / Design Event vs Return Period Program  *
              *                 Date of Run: 02-19-90             *
                                                          PAGE NO   1
        LOG PEARSON EXAMPLE - MEDINA RIVER

     --- Input File: LPA.HDO


     JOB  LOG PEARSON EXAMPLE - MEDINA RIVER
     FLW  2

*** THE FLOW ANALYSIS OPTION HAS BEEN SELECTED WITH THE USGS SUBOPTION.

     LPA  0.236  3  842880.0  A

*** THE USER-SUPPLIED SKEW COEFFICIENT IS  .236
*** THE GAGING STATION AREA IS    842880. ACRES
*** THE STUDY BASIN SITE IS AT THE SAME LOCATION AS THE GAGING STATION.

     GFL  MEDINA.FLW
     BAS  842880.0

*** THE BASIN AREA = 842880.00   ACRES

     RPD  500

*** THE SELECTED RETURN PERIOD IS  500 YEARS

     END

*** END OF COMMAND FILE
```

```
****************************************************
   THE MEAN OF THE LOG FLOW VALUES EQUALS    3.6392
       THE STANDARD DEVIATION EQUALS     .39409
    THE COMPUTED SKEW COEFFICIENT EQUALS    .23612
****************************************************
```

```
*** THE USER-SUPPLIED SKEW COEFFICIENT OF    .23600 WILL BE USED
*** IN PLACE OF THE COMPUTED COEFFICIENT.
```

```
                               PROBABILITY (%)
       (99.865) (97.73)  (84.13)  (50.00)  (15.87)  (2.27)  (0.135)
      5.13+.........|.........|.........|.........|.........|.........+
          .                   |         |         |         |         .
          .  x - ACTUAL DATA  |         |         |         |         o.
          .  o - CALCULATED   |         |         |         |    o    .
   L  4.54+  * - BOTH         |         |         |         | *       +
   O      .         |         |         |         |        o|         .
   G      .         |         |         |         |      x  |         .
          .         |         |         |         |xx*      |         .
   F  3.95+         |         |         |     xx*x|         |         +
   L      .         |         |         |  xxx    |         |         .
   O      .         |         |        x*xx       |         |         .
   W      .         |         |     xxxx|         |         |         .
      3.35+         |         |xx x     |         |         |         +
          .         |       x x         |         |         |         .
          .         |    x    |         |         |         |         .
          .         |xxx      |         |         |         |         .
      2.76+.........|.........|.........|.......|.|...|....|.||.|.....|+
                                        2       5    10   25 50 100  500
         (3.0)    (2.0)     (1.0)     (0.0)   (-1.0)    (-2.0)    (-3.0)
                            RETURN PERIOD, (STAND. DEV.)
```

```
**************************************
* THE PEAK FLOW IS       74917. CFS *
**************************************
```

```
*** END OF RUN
```

Appendix B: Required Formats for User-Supplied Input Files

The format of the external rainfall data file to be read by HYDRO as an alternative to RAIN.PFP is modeled after that currently used by the CALTRANS IDF program developed by Jim Varney of the California Department of Transportation.

The rainfall data file must be an ASCII file consisting of not more than 255 records (lines of information). The first record must provide the number of records that follow (i.e., the number of stations in the data file). The following records provide information about the individual stations (one record per station). Required format is as presented below:

Required Format for State Rainfall Data Bases

	VARIABLE DESCRIPTION	FORTRAN FORMAT
RECORD 1:	Number of stations in data file	I3
	Record length =	3
SUBSEQUENT RECORDS:	Name of station	A20
	Station elevation (ft)	I4
	Station latitude (dec. deg.)	F6.3
	Station longitude (dec. deg.)	F7.3
	County abbreviation (not read)	A3
	One-hour rainfall intensity for six default return periods	6F4.2
	Slope of IDF curve (log10/log10)	F6.3
	Station ID	A10
	*Blank character (not read)	1X
	*Beginning year of data (not read)	I4
	*Blank character (not read)	1X
	*Ending year of data (not read)	I4
	Record length =	90

* Optional

Required Format for Gage Flow Files

	VARIABLE DESCRIPTION	FORTRAN FORMAT
RECORD 1:	User's identification (not read)	A73
RECORD 2:	Number (NUM) of years of flow record (NUM)	I10
RECORDS 3-NUM:	Gage flow (cfs)	F10.0

Required Format for Regression Files

	VARIABLE DESCRIPTION	FORTRAN FORMAT
RECORD 1:	User's identification (not read)	A73
RECORD 2:	Number (NUM) of pairs of parameters and exponents (x and b pairs)	I10
RECORD 3:	Intercept (acof)	F10.3
RECORDS 4-NUM	Parameter and associated exponent (x(j), b(j))	2F10.3

Required Format for Dimensionless Hydrograph Files

	VARIABLE DESCRIPTION	FORTRAN FORMAT
RECORD 1:	User's identification (not read)	A73
RECORD 2:	Number (NUM) of dimensionless hydrograph coordinates, (dhydtd, dhydqd pairs)	I10
RECORDS 3-NUM:	dhydtd, dhydqd	2F10.3

Appendix C: HYDRO Commands

This appendix details the meaning and syntax of each command available in HYDRO. The descriptions are ordered alphabetically and include information on the command name, its purpose, and its structure. Any important notes pertaining to the command are also included.

COMMAND APM - user supplied APriMe value

Purpose: To specify a user supplied regional A prime value. This optional command is used when the user wants to create a hyetograph.

Structure:

APM aprm

1) aprm - OPTIONAL - user supplied A prime value. The A prime value is used in conjunction with the Yen and Chow synthetic triangular hyetograph method. The value of A prime is the ratio of the time to peak rainfall to the entire rainfall duration. A prime varies based on the geographical location of the user. If the user does not employ this command, HYDRO will determine a default value of A prime using an internal database that is based on latitude and longitude.

Note: Use of the command APM is only allowed when the RFL switch is set equal to 2.

COMMAND BAS - BASin information

Purpose: To specify basin size and land use.

Structure:

```
BAS  abas       -- or --
BAS  abas, suba(1), suba(2), ..., suba(7)
```

1) abas - area of the basin, in acres.
2) suba(1) - area of land use that contains a meadow or open field, in acres.
3) suba(2) - area of land use that contains forests or woods, in acres.
4) suba(3) - area of land use that contains pasture, in acres.
5) suba(4) - area of land use that is composed of crops, in acres.
6) suba(5) - area of land use that contains residential development, in acres.
7) suba(6) - area of land use that contains urban sections or highway right-of-way, in acres.
8) suba(7) - area of land use that contains pavement, in acres.

Notes:

1) The basin area is broken into 7 different land use subareas - Meadow, Woods, Pasture, Crops, Residential, Urban/Highway Right-of-way, and Pavement.
2) If suba(1-7) are specified (as required when the SCS option of the TCO command is used or when the Rational Method option of the FLO command is selected), a zero can be input for abas.
3) The total of the subareas will be used as the total basin area if abas does not equal the subarea total.
4) The total basin area will be displayed.
5) Depending on the overland time of concentration method used, various basin area limitations may be observed. The equations in the SCS Curve Number method are designed for basin areas of 2000 acres or less. For the Kinematic Wave method, there are no basin area constraints, although for both the Kinematic and Curve Number methods, care should be exercised when using the rational method. HEC-12 suggests that a practical area limitation may be less than 300 acres.

COMMAND CAL - CALifornia (or state) rainfall data base

Purpose: To specify the filename of the state rainfall data base if the NWS data base is not to be used.

Structure:

CAL filename

1) filename - a string of not more than 12 characters which represents the name of the file containing the state rainfall data. (The format of this file is described in Appendix B of the HYDRO documentation.)

Notes:

1) The CAL card allows the user to access a data base developed specifically for a particular state. Use of such a localized data base is particularly appropriate for western states where rainfall patterns can vary greatly over short distances. (For several of the western states, the RAIN.PFP data base has proven to be too coarse for accurate application.)
2) The format of the state data base is that used by the California Department of Transportation. The logic used to calculate intensity is modeled after the CALTRANS IDF program, written by Jim Varney, in which intensity is calculated as follows:

```
I(d,rp) = I(1,rp) * D**n
```

where:

I(d,rp) = intensity for a given duration and return period, in inches per hour.

I(1,rp) = the 1-hour intensity for a given return period, in inches per hour.

D = duration, in hours.

n = log-log slope of the IDF curve.

COMMAND CRP - California (or state) Return Period information

Purpose: To specify the necessary data for computing the 1-hour intensity for a non-default return period and/or to redefine the default return periods.

Structure:

```
CRP  dmean, pfact, cv  -- or --
CRP  dmean, pfact, cv, rp(1), rp(2), ... rp(6)
```

1) dmean	-	mean 1-hour storm, in inches.
2) pfact	-	Log-Pearson frequency factor.
3) cv	-	coefficient of variation.
4) rp(1)	-	minimum default return period, in years. If not specified, this parameter will be assumed to equal 2.
5) rp(2)	-	the next lowest default return period, in years. (If not specified, rp(2) will be assumed to equal 10.)
6) rp(3)	-	the next lowest default return period, in years. (If not specified, rp(3) will be assumed to equal 25.)
7) rp(4)	-	the next lowest default return period, in years. (If not specified, rp(4) will be assumed to equal 50.)
8) r(5)	-	the next lowest default return period, in years. (If not specified, rp(5) will be assumed to equal 100.)
9) rp(6)	-	the maximum default return period, in years. (If not specified, rp(6) will be assumed to equal 10000.)

Notes:

1) Because the state data base only has 1-hour intensities for six return period values, the return period specified in the RPD card should match one of these default return periods. If such a return period is not selected, then the next largest return period will be used unless dmean, pfact, and cv are specified. If these three values are specified, then the 1-hour intensity is computed by HYDRO as:

$$I(1,rp) = dmean * (1 + pfact*cv)$$

2) Unless specified in the CRP command, the default return periods are those used by CALTRANS: 2, 10, 25, 50, 100, and 10,000 years.
3) The CAL card must be present if the CRP command is used.

COMMAND DHY - Dimensionless HYdrograph

Purpose: To signal the computation of a hydrograph from the Nationwide Urban (default) or user-supplied dimensionless hydrograph coordinates.

Structure:

```
      DHY                  -- or --
   DHY  dhydtd(1), dhydqd(1), dhydtd(2), dhydqd(2), ...
                       -- or --
   DHY  filename
```

1) dhydtd - user-supplied abscissa value
2) dhydqd - user-supplied ordinate value
3) filename - a string of not more than 12 characters representing the name of the file containing the dimensionless hydrograph coordinates. Up to 150 pairs of abscissa and ordinate values may be supplied by the user. The format of the file is described in Appendix B of the HYDRO documentation.

Notes:

1) If no fields are specified, then the Nationwide Urban dimensionless hydrograph coordinates will be used in computing the hydrograph.
2) The TLG card must be present in a command string containing the DHY card.

COMMAND END - END of run

Purpose: To signal the end of the command string.

Structure:

    END (no fields)

Note: An END card must be present and must be the last card in a command string.

COMMAND FLW - FLoW analysis method switch

Purpose: To specify the method for determining peak flow.

Structure:
FLW method

1) method - number indicating the method to be used in computing peak flow:
   1 - Rational Method. Command RTL should be used to specify the runoff coefficients unless default values are desired.
   2 - USGS method (Log Pearson Type III). The GFL and LPA commands should be used to specify gage flows and LPIII constants.
   3 - Regression. The RGR command should be used to specify the regression coefficients.

Notes:

1) The FLW command is one of the three "branch" commands. The branch commands determine what general type of computations are to be made. Only one branch command can be used in a command string and the branch command selected must be the second non-REM command in the string.

2) There are three design flow options. These are: Rational Method, Log Pearson Type III Analysis, and User-Developed Regression Equations. These options can produce input to other PFP programs.

   The first option uses the rational method equation (Q = CiA) to calculate the peak flow (in cfs) at a site. The rainfall intensity is calculated for a specific return period and duration (time of concentration) using the default rainfall data base (RAIN.PFP), the state's data base, or a value supplied by the user on a TCU card. The area variable is developed using seven land use subareas (specified on the BAS card). Default runoff coefficients are provided (or can be replaced at the user's option) with the RTL card. A hydrograph can be developed from dimensionless hydrograph coordinates and data provided with the DHY and TLG commands.

   The second option uses Log Pearson Type III analysis with USGS gage station data to calculate the peak flow (in cfs) at a site. The gage station data must be found and input by the user. Several sources of this information are provided in the HYDRAIN System Shell resources help screen. The DHY and TLG cards can be used to develop a hydrograph from dimensionless hydrograph information. The Log-Pearson III type analysis is designed for 30 or more records; however, the program has been run successfully with as few as 7.

If option 3 is selected, a user-developed regression equation can be specified using the RGR command. This option allows the user to develop their own site specific and general peak flow equations (or use USGS 3 and 7 Parameter Regression Peak Flow Equations). The user supplies the coefficients and exponents to develop an equation of the general form:

```
Y = ACOF * X(1)**B(1) * ... * X(NCOF)**B(NCOF) .
```

A hydrograph can be developed using the resulting calculated peak flow, time lag (TLG command), and dimensionless hydrograph coordinates (DHY command).

COMMAND GFL - Gage FLow

Purpose: To specify gage flows for Log Pearson Type III analysis.

Structure:

```
GFL  q(1) ... q(nyr)  -- or --
GFL  filename
```

1) q - gage flow for a particular year, in cfs.
2) filename - a string of not more than 12 characters representing the name of the file containing the gage flows. Up to 150 flows can be specified by the user. The format for the file is described in Appendix B of the HYDRO documentation.

Notes:
1) The flow data are the annual peak flow readings taken at the gage site. Generally, it is recommended that at least thirty years of flow records be obtained for the Log Pearson III analysis to describe the probabilistic nature of streamflow. Contact a local USGS office or NAWDEX for more information.
2) The LPA command must accompany the GFL command and the FLW method switch must be equal to 2.

COMMAND IDF - Intensity-Duration-Frequency curve

Purpose: To signal computation and plotting of an IDF curve.

Structure:

IDF graphtitle

1) graphtitle - alphanumeric characters (up to 73) to be used as the plot label. Commands LOC and RPD must accompany the IDF command.

Notes:

1) The IDF command is one of the three "branch" commands. The branch commands determine what general type of computations are to be made. Only one branch command can be used in a command string and the branch command selected must be the second non-REM command in the string.

2) This command signals computation and plotting of an intensity duration frequency (IDF) curve for a desired site and return period. The desired site is specified using the LOC command and the desired return period is specified with the RPD command. The default rainfall data base RAIN.PFP will be accessed unless the CAL command is used to indicate that the state's data base is to be used. If the default data base is used, the site must be within the continental United States.

3) The duration ranges from 5 minutes up to 24 hours. The return period can range from 2 to 100 years. A plotting routine puts these IDF ordinates on a graph where the y-axis is intensity in inches/hour, and the x-axis is duration in hours. Two graphs are created: one plots all points for durations up to 24 hours; the second details the first two hours of the first curve.

COMMAND JOB - JOB start

Purpose: To initiate job and specify a job title.

Structure:

JOB jobtitle

1) jobtitle -alphanumeric characters (up to 73) describing the job.

Note: JOB must be the first command. Only one JOB command per command string is permitted.

COMMAND LOC - LOCation of site

Purpose: To specify the latitude and longitude for use in computations requiring data base retrievals.

Structure:

LOC lt ltm lng lngm

1) lt - degrees latitude of the site.
2) ltm - minutes latitude of the site.
3) lng - degrees longitude of the site.
4) lngm - degrees longitude of the site.

Note: If the RAIN.PFP data base is to be accessed, then the site location must be within the continental United States. If the state data base is to be accessed, then the location must be within the boundaries of that data base.

COMMAND LPA - Log Pearson type III Analysis

Purpose: To specify constants for Log Pearson Type III analysis.

Structure:

LPA skw pflag ast idau

1) skw - skew coefficient. If an '*' is specified for skw, then HYDRO will compute a skew coefficient.

2) pflag - flag that signals whether probability curve is to be displayed:
  - 0 - probability curve not displayed.
  - 1 - probability curve sent to output file.
  - 2 - probability curve displayed on the screen.
  - 3 - probability curve sent to output file and displayed on the screen.

3) ast - gaging station area, in acres. The station area is the drainage area associated with the flow measured by a USGS (or other) stream gage. Each gage has an associated station, which can be located by the USGS gage number. The station area is measured in acres with limitation of one million acres on the total area.

4) idau - positional flag:
  - A - watershed is at the same location as gage.
  - U - watershed is upstream of gage.
  - D - watershed is downstream of gage.

Notes:

1) The LPA command must accompany the GFL command and the FLW method switch must be equal to 2.

2) The station location should possess the following characteristics:
- Station location is close to the desired point of study.
- Station has a consistent and long record of flow data available. This will increase the accuracy of the probability analysis and output. The Water Resources Council recommends that there be at least 30 years of annual data available. HYDRO has run on as few as 7 years of data.
- Station is not affected by inflow of water systems other than the one chosen for the study.
- Station area characteristics are similar to area of study.

COMMAND MOF - Maximum Observable Flood

Purpose: To signal computation of the maximum observable flood.

Structure:
MOF (no fields)

Note: The LOC and BAS commands must also appear in the command string when MOF is used.

COMMAND QPK - User-supplied peak flow.

Purpose: To supply a peak flow or override the computed peak flow for use in deriving a hydrograph from a dimensionless hydrograph.

Structure:
QPK qpu

1) qpu - user-supplied peak flow in cubic feet per second.

Note: The QPK command can be used with any of the four FLW options. If the command is used with options 1, 2, or 3, the user-supplied peak flow will override that computed by HYDRO for use in deriving the hydrograph. If used with option 4, the command supplies the peak flow value needed for deriving the hydrograph.

COMMAND REM - REMark

Purpose: To provide remarks or comments.

Structure:

```
REM  (any alphanumeric characters)
```

COMMAND RFL - RainFalL computation switch

Purpose: To specify whether a single rainfall intensity or a hyetograph is to be computed.

Structure:
RFL option

1) option - number indicating whether intensity or a hyetograph is to be computed:
1 - compute rainfall intensity.
2 - compute a Yen & Chow hyetograph.

Notes:
1) The RFL command is one of the three "branch" commands. The branch commands determine what general type of computations are to be made. Only one branch command can be used in a command string and the branch command selected must be the second non-REM command in the string.
2) There are two design rainfall options associated with the RFL command. The first option is used to determine a single rainfall intensity for a desired return period and a duration (assumed to be time of concentration in hours) at a site. The second computes the Yen and Chow triangular hyetograph. Both design rainfall options use an unique rainfall intensity database (RAIN.PFP) that contains rainfall values for the contiguous United States to perform calculations. The user can, however, choose to access a data base developed for a particular state by means of the CAL command. Both options also allow the user to input their own duration and/or rainfall intensity values by means of the TCU and UIT commands.

COMMAND RGR - ReGRession

Purpose: To specify regression coefficients for peak flow computations. The equation is log-log and takes the form:

Y = ACOF * X(1)**B(1) * ... * X(NCOF)**B(NCOF) .

Structure:

RGR acof, x(1), b(1), ..., x(ncof), b(ncof) -- or -- RGR filename

1) acof - intercept.
2) x(j) - value of parameter.
3) b(j) - value of exponent.
4) filename - a string of not more than 12 characters representing the name of the file containing the regression coefficients. Up to 150 pairs of x and b values can be specified. The format of the file is described in Appendix B of the HYDRO documentation.

COMMAND RPD - Return PerioD

Purpose: To specify the return period for frequency-dependent calculations.

Structure:

RPD rp

1) rp - return period, in years.

Notes:

1) The return period is a function of the probability of rainfall intensity having a certain value over a given period. The return period is measured in years.
2) The command is required in nearly all command strings, except those which use regression, and can be used anywhere after the second non-REM command. If the default rainfall database is to be accessed, then the return period should be within the range of 2 to 100 years. (Return periods less than 2 years will be set equal to 2 years; return periods greater than 100 years will be set equal to 100 years.) If a state data base is to be accessed, rp should either correspond to one of the default return periods or else appropriate information should be supplied with the CRP command.

COMMAND RTL - RaTionaL method runoff coefficients

Purpose: To specify runoff coefficients for each of seven land use categories.

Structure:

```
RTL            -- or --
RTL  C(1) ... C(7)
```

1) C(1)	-	runoff coefficient for meadow. If a '*' is specified, C(1) will be assumed to equal 0.2.
2) C(2)	-	runoff coefficient for woods. If a '*' is specified, C(2) will be assumed to equal 0.2.
3) C(3)	-	runoff coefficient for pasture. If a '*' is specified, C(3) will be assumed to equal 0.3.
4) C(4)	-	runoff coefficient for crops. If a '*' is specified, C(4) will be assumed to equal 0.3.
5) C(5)	-	runoff coefficient for residential. If a '*' is specified, C(5) will be assumed to equal 0.4.
6) C(6)	-	runoff coefficient for urban/highway right-of-way. If a '*' is specified, C(6) will be assumed to equal 0.7.
7) C(7)	-	runoff coefficient for pavement. If a '*' is specified, C(7) will be assumed to equal 0.9.

Notes:

1) Similar to what appeared in HEC-12, the basin area is broken into 7 different land use subareas - Meadow, Woods, Pasture, Crops, Residential, Urban/Highway Right-of-way, and Pavement, each with a corresponding runoff coefficient. Unless otherwise specified, the program will use the default runoff coefficients. Default values are used for any fields for which a '*' is designated. If the default values for all seven categories are desired, leave all fields blank.
2) This command should appear in all command strings in which the FLW command method is set equal to 1.

COMMAND STN - STatioN identification

Purpose: To retrieve rainfall data for a particular station within a state rainfall data base.

Structure:

STN stnid

1) stnid - a string of not more than 10 characters which identifies a station within a state data base.

Notes:

1) Only one station can be specified per STN card. Up to four STN cards can be used per command chain. The CAL card must be present in the command chain.
2) Care should be used in selecting the stations which will be used for interpolating the 1-hour intensity and log-log slope of the IDF curve. The following points should be kept in consideration:
   - If a station is within 3 miles of the site, then the data collected for that station should be used rather than interpolated data.
   - Avoid selecting stations that are located on the opposite side of a ridge from the site.
   - Avoid stations with elevations greatly different from that of the site.
3) If stations are not specified by the user, then HYDRO will attempt to locate four stations within +/- 0.25 degrees of the site. These four stations should be checked in accordance with the three points above.

COMMAND TCC - Time of Concentration for Channel flow

Purpose: To specify data for computing channel time of concentration by one of three methods.

Structure:

```
TCC  lchl schl smngs sgtr tgtr  -- or --
TCC  lchl schl smngs 0 hydr     -- or --
TCC  lchl schl
```

1) lchl - channel length, in feet.
2) schl - channel slope, in feet per foot. Channel slope refers to the average slope of the channel over its entire length.
3) smngs - Manning's coefficient. If '*' is specified for smngs, the default value of 0.016 will be used.
4) sgtr - gutter cross slope, in feet per foot.
5) tgtr - gutter spread, in feet. The HEC-12 gutter equation will be used to compute channel velocity.
6) hydr - hydraulic radius, in feet. Manning's formula will be used to compute channel velocity.

Notes:

1) The time of concentration is defined as the period required for water to travel from the most remote point on a watershed to the outlet. The time of concentration can be subdivided into two constituents; overland and channel (or gutter) flow. Channel time of concentration can be developed using one of three methods: HEC-12 triangular gutter approach, Manning's formula, or the SCS grassy waterway method.
2) The triangular gutter equation is a special case of the regular Manning's formula. It was developed in HEC-12 (FHWA, 1984). The equation describes flow in wide, shallow, triangular channels. The area of the gutter and the hydraulic radius are a function of the spread and the roadway cross slope. The triangular gutter channel alternative requires that data be placed in every field: channel flow length, channel slope, Manning's roughness coefficient, gutter side slope, and gutter spread.
3) The Manning's formula alternative requires the data to be placed in the first two fields, channel flow length and channel slope. Additionally, the roughness coefficient is placed in the third field, the gutter side slope is set equal to 0 in the fourth field, and the hydraulic radius (in feet) is placed in the fifth field.
4) The SCS grassy waterway method is a subset of the Upland Method described in the SCS handbook (SCS, 1975). It describes a linear relationship between velocity and watershed slope when the variables are placed on a log-log graph. This alternative requires only the first two fields, channel flow length and channel slope.

COMMAND TCO - overland time of concentration

Purpose: To specify data for computing overland time of concentration by one of two methods.

Structure:

```
TCO  llnd slnd isoil iclm cnmbr  -- or --
TCO  llnd slnd rmngs
```

1) llnd - length of overland flow path, in feet. Overland length refers to the maximum length (in feet) of flow to the channel in the basin area. Specifically, it can be thought as the travel path required to convey the most "remote" flow to the channel or basin outlet.

2) slnd - slope of overland flow path, in feet per foot. Overland slope refers to the average slope of the land draining to the channel or basin outlet. For example, an 8 foot rise occurring over a 100 foot length has a slope of 8/100 (rise/run) or 0.08 ft/ft.

3) isoil - letter indicating hydrologic soil type:

A - lowest runoff potential (sand). Sand is defined as deep sand and loess with aggregated silts. The composition is 90 to 100% sand/gravel. There is a high infiltration rate of 0.30 to 0.45 inches/hour.

B - mod. low runoff potential (sand/loam). Sand/loam is defined as shallow loess/sandy loam with a moderate infiltration rate of 0.15 to 0.30 inches/hour.

C - mod. high runoff potential (clay/loam). Clay/loam is defined as soil low in organic content and usually high in clay. It has a slow infiltration rate of 0.05 to 0.15 inches/hour.

D - high runoff potential (clay). Clay is defined as a mixture of heavy plastic clay (90 to 100%) and certain saline soils that swells significantly when wet. Clay has a very low infiltration rate of 0 to 0.05 inches/hour.

4) iclm - climate type:

1 - dry. A dry climate has soil that is dry, but not dry enough to cause plants to wilt. Satisfactory cultivation has taken place. A dry climate has 0 to 25 inches of rain/year.

2 - typical. A typical climate receives 25 to 50 inches of rain/year.

3 - wet. A wet climate experiences heavy rainfall and water-saturated soil. Over 50 inches of rain fall each year.

5) cnmbr - SCS curve number. This field allows the user to supply a curve number value, overriding the calculated value. The field can be left blank if isoil and iclm are input as values greater than 0.

6) rmngs -Manning's coefficient for the basin. Sample ranges can be from 0.4 to 0.01. The user's best judgement is required to select a reasonable value.

Notes:

1) The time of concentration is defined as the period required for water to travel from the most remote point on a watershed to the outlet. The time of concentration can be subdivided into two constituents; overland and channel (or gutter) flow. Overland time of concentration is developed by one of two methods: the SCS curve number or by the kinematic wave approach.
2) The Soil Conservation Service, in Technical Release 55, describes a method for determining the overland time of concentration known as the curve number (CN) method (SCS, 1975). This method is limited to small watersheds (less than or equal to 2000 acres) containing consistent land uses and climatological characteristics.
3) The alternative overland time of concentration method that is found in HYDRO is the kinematic wave approach. It is used as defined in HEC-12 (FHWA, 1984) and based on research by Regan conducted for the Maryland State Highway Administration and the FHWA (Regan, 1971). The kinematic wave approach recognizes that overland flow can be simulated by a moving film of turbulent flow over the watershed surface. The time of concentration for this wave can be expressed as a function of flow length and slope, Manning's surface roughness factor, and the rainfall intensity.
4) The TCO command can be used with or without TCC. If TCO is not used, the overland time of concentration will be set equal to 0.

COMMAND TCU - Time of Concentration supplied by User

Purpose: To specify time of concentration.

Structure:

TCU tc

1) tc - time of concentration, in hours.

Notes:

1) The time of concentration is defined as the period required for water to travel from the most remote point on a watershed to the outlet. The time of concentration can be subdivided into two constituents; overland and channel (or gutter) flow. With the TCU command, the combined time of concentration can be specified by the user.

2) The user-defined time of concentration should represent the total time of concentration (overland + channel). Therefore, the commands TCC and TCO should not appear in the same command string with TCU. If TCU does appear in a string with either TCO or TCC, an error will message will be printed and HYDRO will be terminated.

COMMAND TLG - Time LaG

Purpose: To specify the time lag or the information necessary to compute the time lag so that a hydrograph can be computed from a dimensionless hydrograph.

Structure:

TLG tl -- or --

TLG bdf, dhsl, dhln

1) tl - user-supplied time lag, in hours.
2) bdf - basin development factor. The bdf should be a number between 0 and 12, with 0 representing an undeveloped basin and 12 representing a fully developed basin.
3) dhsl - main channel slope, in feet per mile.
4) dhln - main channel length, in miles.

Note: The TLG card must be present in a command string containing the DHY card.

COMMAND UIT - User-supplied rainfall InTensity

Purpose: To specify the intensity of a 1-hour storm.

Structure:

UIT itc

1) itc -user-supplied intensity, in inches per hour.

Notes:

1) The command can be used in any command string in which the RFL switch is set equal to 2 or in which the FLW switch is set equal to 1. The TCU card must be used with the UIT card.

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HYDRAIN - INTEGRATED DRAINAGE DESIGN COMPUTER SYSTEM

VOLUME III. HYDRA - STORM DRAINS

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Structures Division, HNR-10
Federal Highway Administration

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TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

List of Figures

List of Tables

Preface

This report presents documentation for the HYDRAIN system. HYDRO, HYDRA, CDS, WSPRO and HY8 are five nonproprietary hydrology and hydraulic engineering programs incorporated in the HYDRAIN system. The HYDRAIN personal computer oriented system operates these engineering applications with programs written in the C language. The system is designed with an open architecture for expansion. HYDRAIN is sponsored as a Pooled Fund Project (PFP) of 29 State highway departments and is managed by the Federal Highway Administration (FHWA). The system is expanding with flexible lining design logic and integrated culvert analysis logic under development. Graphic output options are also under development and are available in some areas already.

Within the HYDRAIN concept, the HYDRO, HYDRA, CDS, and WSPRO allow the user to consistently input, edit and run relevant input data files and to scroll through output files. With these applications "short", one-line, and "long", multiple line, help is provided within an editor that services all applications.

HYDRAIN integrates hydraulic and hydrology programs into a unified system. The intent of the integration is to enable users to then learn basic principles of how to operate an application and file manipulation and then be able to apply the same principles to other applications and files within the system. One guiding principle is a **command land input format**. This trend in hydraulic programs is typified by HEC-2 and HYDRA. It is very pragmatic. WSPRO also adopted the command line method. Another guiding principle is a **generic input editor** that works the same for each integrated program--HYDRO, HYDRA, CDS, and WSPRO. The input file for each integrated program is a line by line command language that identifies the computation and/or provides the required data. Each line of data is preceded with a two or three-letter command. A typical command is **XS**, indicating a cross section; both WSPRO and CDS read this command. Another typical command is **PDA**, indicating the line contains the design parameters for pipe analysis (PIPE DATA); HYDRA reads this command.

A strength and a weakness of HYDRAIN is the need to know beforehand the sequence of commands that will result in making an application work. The commands are, of course, the batch input file. The user needs to know a proper sequence or know how to put one together. The sequences are termed "footprints." Given the right "footprint," an application will work; note that footprints are not necessarily unique, in that there may be several ways to get a job done. This documentation includes footprints to get users started and user support will aid in proper "footprint" design. Once a user has a library of footprints for his applications, the use of HYDRAIN should save considerable time and money. HY8 is a stand-alone interactive BASIC program that accepts inputs during processing; HY8 does not require footprints and leads the unfamiliar user through input preparation. All engineering programs but HY8 are batch oriented, and three steps are built into the process of using them: input file generation, programs execution, and output file screen review or listing. HY8 accepts inputs and generates outputs as the engineering program logic is executing.

HYDRO Program

HYDRO is a command line hydrology program. FORTRAN code for HYDRO was developed to combine existing approaches for rainfall and runoff analyses into one computerized program. Within the HYDRAIN system, it can be used independently or it can be used to generate input data for other engineering programs within the system.

HYDRO offers many hydrologic analysis options to the engineer. Each is site specific based on user inputs.

- Design Rain Using Digitized NWS Information or State-Supplied Files - Calculates the rainfall intensity for a specific return period, duration, and site.
- Design Hyetograph using Yen and Chow's method - Calculates the rain versus time plot for a return period, duration and site.
- Intensity-Duration-Frequency Curve Using Either the NWS Information or State-Supplied Files - Analyzes a specific site and creates two graphs: a plot of points for durations up to 24 hours, and a detail graph of the first two hours. Can be input to HYDRA.
- Design Flow by Rational Method - Uses a specific return period, duration and intensity to determine the peak flow for the site.
- Design Flow by USGS Regression Method - Uses USGS log-log regression equations with user-supplied parameters to determine design flow.
- Design Flow by log Pearson type III - Calculates the peak flow for given data.
- Design Hydrograph by USGS Dimensionless Hydrograph - Calculates a hydrograph to support storage routing within HYDRA or CDS.
- Maximum Observable Flood - estimates the largest flow at a site based on the envelope of all floods in a region.

PFP-HYDRA Program

HYDRA is a command line gravity pipe network hydraulics program. FORTRAN code for HYDRA previously existed and the Pooled Fund work effort included substantial improvements. HYDRA is a storm and sanitary sewer system analysis and design program. It can be used either to model an existing sewer system or to design a new system.

HYDRA generates storm flows by using either the Rational Method technique, hydrologic simulation techniques, or accepting a hydrograph generated by a HYDRO analysis. It can be used to design or analyze storm, sanitary or combined collection systems. HYDRA can handle up to 1,000 contributing drainage areas and 2,000 pipes. Additionally, HYDRA can be used for cost estimating. The Rational

Method approximates the peak rate of runoff from a basin resulting from storms of a given return period. HYDRA's hydrologic simulation models the natural rainfall-runoff process. In the simulation, runoff hydrographs are generated, merged together, and routed through the collection system. Inlet limitations can be analyzed: inlet overflow can be passed down a gutter system, while inlets in sumps can store water in ponds.

In the HYDRA design process, the program will select the pipe size, slope and invert elevations given certain design criteria. Additionally, HYDRA will perform analyses on a existing system of pipes (and/or ditches). When an existing system of pipes is overloaded, HYDRA will show suggested flow removal quantities as well as an increased pipe diameter size as an alternative remedy. HYDRA includes HEC-12 inlet theory hydraulic gradeline calculations, and an ability to route flow through internal storage sites using a storage-indication method.

HYDRA requires the forming of an input file of commands to describe the sewer system. Commands for HYDRA are placed in a logical sequence usually from upper to lower elevation. Is it possible that several command sequences can produce the same result. An input file is established for a particular collection system by the engineer and then the HYDRA program is executed. To change the characteristics of the collection system, the input file can be edited.

The HYDRA program requires design criteria for the pipes: friction factor (Manning's "n"), minimum diameter, ideal depth, minimum ground cover, minimum velocity (full flow), minimum slope, and maximum diameter. The friction factor is necessary for both analysis and design, while the remaining values are needed only for design. In the case of a design, the program selects invert elevations and slope as well as the physical sizing of each link given certain design criteria, whereas in the analysis mode, pipe alignment and sizing are predetermined and the impact of proposed flows are analyzed. Design criteria can be changed for each pipe if so desired. HYDRA is not an optimization program, thus individual case studies need to be run and analyzed by the engineer.

CDS Program

CDS is a command line culvert program. The Culvert Design System provides the user with two broad options for investigating culvert characteristics. CDS can either (1) hydraulically design a culvert or (2) analyze an existing or proposed culvert. CDS has capabilities for investigating a variety of hydrograph relationships, culvert shapes, materials, and inlet types. With CDS, the engineer can request any of six culvert types: round concrete, round metal, arch concrete, arch metal, oval concrete, and concrete box. CDS routes hydrographs, considers ponding, and overtopping.

The Design option selects a culvert size and number of barrels that are compatible with engineering data, environmental constraints, and site geometry. In this option, hydraulic performance data are calculated for each new culvert system design. The Review option provides hydraulic performance data for any preselected combination of culvert type and size, inlet type, slope, and number

of barrels. The initial design and analysis options may be followed by up to five additional culvert types or flow frequencies so that a full spectrum of risk scenarios or economic considerations can be simulated at the same time.

Two possible flow scenario methods can be selected: (1) steady state or irrigation, that assumes constant flow through the culvert, or (2) dynamic, that simulates drainage flow conditions. The dynamic option can route a hydrograph through the culvert system using three hydrograph alternatives: a user input hydrograph, a hydrograph produced by the HYDRO program, or the use of an internally produced default hydrograph (simulating semi-arid, high plains conditions). Additionally, the dynamic flow scenario can accommodate upstream pond storage.

CDS will determine culvert size based on the design headwater, headwater/diameter ratio, inundation, outlet velocity, cover limitations, or any combination of these parameters. The program will automatically increase the number of barrels when the upper limit for the greatest vertical dimension is exceeded. There is a limit of six barrels for commercial size culverts and five for concrete box culverts. The program can also be used to assess flood hazards, environmental assessments of upstream pond coverage, downstream flooding, channel impact, inlet type and beveled inlet evaluations, and reservoir facilities which use a culvert type structure for the spillway. Based on these data the program will proceed to identify the flow type and the outlet conditions for velocity, Froude number, and brink depth.

WSPRO Program

WSPRO is a command line step backwater program for natural channels with an orientation to bridge construction. The Water Surface Profile Computation Model Microcomputer Program has been designed to provide a water-surface profile for six major types of open channel flow situations:

- Unconstricted flow.
- Single opening bridge.
- Bridge opening(s) with spur dikes.
- Single opening embankment overflow.
- Multiple alternatives for a single job.
- Multiple openings.

WSPRO was originally developed by the United States Geologic Survey (USGS) for the Federal Highway Administration. The model was a batch mode mainframe program, written in FORTRAN. The members of the Pooled Fund Project decided to use WSPRO as the bridge waterways analysis element of the Integrated Computerized Drainage Design System. WSPRO was downloaded to the microcomputer by the USGS and FHWA. The microcomputer version of WSPRO, is dated August 1987.

The command input file forms a logical description of the physical characteristics of a waterway. Once the user is comfortable with this method of data setup, the program provides a step backwater method for determining water surface profiles. The scheme is similar to the Corps of Engineers HEC-2 program. Both WSPRO and HEC-2 are acceptable to the Federal Emergency Management Agency. WSPRO has the advantage that it utilizes more recent approximation techniques for the backwater effects associated with bridge constrictions.

HY8 Program

HY8 is an interactive culvert analysis basic program that utilizes the FHWA analysis methods and information published by pipe manufacturers. The program includes modules to allow the user to interactively enter, save, and edit data. HY8 will compute the culvert hydraulics for circular, rectangular, elliptical, arch, and user defined geometry. Additionally, improved inlets can be specified and the user can; analyze inlet and outlet control for full and partially full culverts, analyze the tailwater in trapezoidal and coordinate defined downstream channels, analyze flow over the roadway embankment, and balance flows through multiple parallel culverts. A hydrograph can be produced and routed.

The initial logic involves calculating the inlet control and outlet control headwater elevations for the given flow. These elevations are compared and the larger of the two is used as the controlling headwater elevation. Tailwater effects are taken into consideration when calculating these elevations. If the controlling headwater elevation overtops the roadway embankment, an overtopping analysis is done in which flow is balanced between the culvert discharge and the surcharge over the roadway. A balancing technique is also used in the case of multiple barrels. If the culvert is less than full for all or part of its length open channel computations are performed.

A series of data menus, data screens, summary screens, and output screens guides the user through the program. Each menu contains several options to match the desired culvert configuration, while the data screens prompt the user for specific dimensions and coordinates. Summary screens allow the user to edit entered data or change menu selections. Output screens display the output as calculations proceed; hard copy is only obtained using the "print screen" key.

There are three main groups of data to be entered into the program: initial culvert data, downstream channel data, and roadway data. Within the program, the user is sequentially led from one group to the next. From these sets of data, the program develops culvert performance data with or without overtopping. A performance curve can be plotted on a computer with graphics capabilities. For a given flow, HY8 can design a culvert. In addition to developing performance curves, the program generates rating curves for uniform flow, velocity, and maximum shear for the downstream channel. Culvert outlet velocities, inlet control head, and outlet control head are also calculated; energy dissipator design is possible.

HYCHL and HYCULV Programs

HYCHL and HYCULV are command line, flexible channel and culvert programs that are under development. HYCHL will solve for fixed and flexible lined channels. HYCULV will integrate state-of-the-art culvert flow methods and utilize features of both CDS and HY8.

Operation

To allow the software to be used by a wide audience, HYDRAIN operates on an IBM XT/PC or equivalent microcomputer with 640 K RAM, a hard disk, and a monochrome monitor. A math coprocessor is needed. Engineering programs are in Fortran 77. The utility software and editor is in C. The HYDRO, HYDRA, CDS, and WSPRO programs have command line input with are "short" and "long" help files available through the same editor that operates any of them. HY8 has also been integrated into the HYDRAIN system and is available as an interactive BASIC culvert program.

Report Contents

The remaining section of this volume provides technical reference and user instructions for the HYDRA program. There are a total of 6 such volumes for HYDRAIN.

Disclaimer

FHWA, the pooled fund States and their agents have, within the limits of their resources, tested and debugged the HYDRAIN shells. The engineering programs derive from several varied sources and were adapted to HYDRAIN and also underwent testing and debugging. However, this is a very large and somewhat complicated system of logic and coded implementation and errors and omissions may yet remain in the software. Therefore, use at your own risk. Please document problems and errors and report to FHWA. User support and technical assistance will be provided to pooled fund States. Agents of these States using the system should channel their requests for support or assistance through their sponsor State.

1. Introduction

HYDRA is a storm drain and sanitary sewer analysis and design program. This report is intended to introduce HYDRA and guide the user through the necessary steps toward designing or analyzing stormwater drains and/or sanitary sewer systems. The original HYDRA program, released in 1975, was designed and developed to be run on mainframe computer systems. The purpose of developing the original HYDRA program was to provide a means of accurately, easily and quickly designing and analyzing storm, sanitary or combined collection systems. It is thus oriented to hydraulic design engineers. HYDRA has achieved this goal with a high degree of success, and for this reason was selected for incorporation into the PFP system. HYDRA does everything its mainframe-oriented predecessor does, with the same accuracy, ease and quickness. In fact, it offers some improvements over the older version for certain types of system calculations. Furthermore, if it is being used within HYDRAIN there are those advantages associated with HYDRA's ability to interact with other related hydraulic design programs. These interactions are described later in the user documentation section.

In the HYDRA design process, the program will select pipe size, slope and invert elevations if given certain design criteria. Additionally, HYDRA will perform analyses on a existing system of pipes (and/or ditches). When an existing system of pipes is overloaded, HYDRA will indicate suggested flow removal quantities as well as an increased pipe diameter size as an alternative remedy. Additionally, HYDRA can optionally consider the possibility of surcharged systems. The design procedure is not optimized, so alternatives should be examined.

HYDRA requires the creation of an input file, consisting of commands to describe the drainage system. The commands are placed in a logical sequence, usually from higher to lower elevations. It is possible that several command sequences can produce the same result. The input file, established for a particular collection system by the user, is then executed using the HYDRA analysis program.

This documentation consists of three remaining sections. The first section provides the user with an overview of the components that form the HYDRA program. The second section deals specifically with the technical methods utilized by HYDRA, beginning with a general description of several topics, followed by narratives on methodologies and a discussion of relevant formulas and commands. The topics include: storm flow computed by the rational method, storm flow calculated using hydrographic methods, and sanitary flow. The section also discusses conveyance of the water (resulting from the three methods outlined above) when it has entered the system (i.e., a pipe or channel), describes inlet design or analysis computations, discusses the methodologies used in calculating estimated costs, and explains the hydraulic gradeline methodology. The third section provides the user with instruction on how to apply HYDRA within the HYDRAIN System.

2. System Overview

This documentation is aimed at providing information to new users (as well as infrequent or "rusty" users) of HYDRA to bring them to a level of ability sufficient for them to utilize any feature that HYDRA offers. It is not meant to show every possible type of analysis or situation that HYDRA can handle (however clear examples of several major types of applications are demonstrated).

This section provides an overview of HYDRA by briefly describing its capabilities and structure. A key to some of the more frequently used terms and concepts is included at the end of this section. The following sections provide more detailed information to help the user make the most of HYDRA. The user is advised to scan the "Table of Contents" of this document to see exactly what this text offers, how it is arranged, and where to turn to for specific information.

Capabilities and Limitations

HYDRA operates in two modes; design and analysis. There are three possible types of systems that HYDRA can work on:

- Storm water systems.
- Sanitary (sewage) systems.
- Combined (storm and sanitary) sewer systems.

In this documentation, these types are collectively referred to as storm drain systems or sewer systems, or simply, systems.

As implied by the preceding text, HYDRA is made to perform the following tasks:

(1) analyze a drainage system design given user-supplied specifications, or

(2) "free design" its own drainage system based on design criteria supplied by the user.

To meet these broad objectives, HYDRA was necessarily designed to be an extremely flexible and powerful program. The user is warned that care and responsibility should be exercised when the program is utilized as a decision making tool. HYDRA is a design aid only and is not a substitute for sound engineering judgement. This being mentioned, the following is a list of some of HYDRA's more useful features:

- Cost estimation - Capabilities that allow for consideration of dewatering, traffic control, sheeting, shrinkage of backfill, costs of borrow, bedding costs, surface restoration, rock excavation, pipe zone costs, etc. HYDRA is also sufficiently flexible to allow cost criteria to be varied for any segment of pipe in a system, if desired. Ground profiles, either upstream or downstream from any specified point along the system, can also be accepted for consideration in cost estimation, if desired.

- **Models storm flow and offers choice of methods** - HYDRA is capable of "generating" storm flow based on either the **rational method** or **hydrologic simulation**, at the user's discretion. This may be particularly advantageous for engineers who wish to compare designs or analysis results based on different methods.

- **Models sanitary flow** - HYDRA "generates" sanitary flow based on the traditional "peaking factor" concept.

- **Models drainage systems of any size** - HYDRA has a data handling algorithm especially designed to accept a drainage system of any realistically conceivable design.

- **Infiltration/Inflow analysis** - HYDRA is ideally suited for making these analyses.

- **Easy data input structure and quick editing design** - Since all data needed to run HYDRA is in one user-supplied file, data editing is simplified. Furthermore, if the program is run from within the HYDRAIN environment, the input file may be modified without leaving the HYDRAIN program by using the built-in editor. (The capabilities of this screen editor and instructions for its use are described in the section on User Documentation.) Time required for data modification and job resubmission is thus minimized, which enables the user to spend more time on his or her own decision analysis.

- **Planning** - HYDRA can be used for determining the most practical alternate choices for unloading an existing overloaded storm drain or wastewater system and for formulating Master Plans to allow for an orderly growth of these systems. The program's features and capabilities should have far-reaching implications for municipal agencies whose existing sewer systems are under stress from rapid population growth and/or changes in land use patterns.

Structure of HYDRA

The structure and organization of the HYDRA program is similar to many other computer programs. The program reads data, analyzes it, and outputs information for the user's review. When the original HYDRA program was developed, a central design criteria was that the program would maximize simplicity in file maintenance and data editing. Unlike many other hydraulic analysis programs, HYDRA requires only a single input data file. This data file is made up of a list of user-supplied **commands** that specify (describe) the system. All internal analysis by HYDRA is performed according to these commands. Once the commands are assembled into a final working data set, they are collectively called a **command string**.

(These concepts are explored in more detail in the following section.) During analysis (program execution), the command string is checked for proper format and executability. Output is generated according to the user-supplied instructions of the command string and sent to a separate output file which the user may in turn send to either a printer or screen display. If a run aborts prematurely (before intended analysis is completed), appropriate descriptive error messages are then sent to the output file. There is also a "status report" feature within HYDRA itself that displays (on the user's screen) when each command in the command string is being worked on, in "echo" format. This allows the user to trace program progress.

Key to HYDRA Terms

To use HYDRA, an understanding of how to prepare a program data file is central. For this reason, it is important to have a clear grasp of the more fundamental modeling terms as they are used in this documentation. The more comfortable the user is with the following terms (and their associated concepts), the easier it will be to put this documentation to use.

- **Command** - A three-letter user-supplied "key word" and its associated completed data field, that HYDRA recognizes and accepts as input data for performing a specific task. The user selects these commands according to the function(s) that he or she wishes for HYDRA to perform. Each command must be listed (entered) on a separate line of data. These data lines make up the user's input data set, which is collectively referred to as a **command string** (See entry below.) Command names are three-letter "descriptors" (often abbreviations or acronyms) of the tasks that the commands perform. For example, **PDA** is the command name for "**P**ipe **DA**ta," the command that allows for user-provided specifications of pipes within the system. A complete listing and explanation of available commands is provided in the appendix.

- **Command string** - An arrangement of **commands** that describes a given **system**. A command string is the fundamental user-provided data set that allows HYDRA to analyze or design a system. This data set may be edited to adjust for modifications to the system without having to build a new command string from scratch. Commands and command strings are further discussed in the next section.

- **Lateral** - Either a single **link** (see entry below) or a number of links connected in a series. Other laterals may connect with any given lateral, but each lateral is continuous. Laterals can be any length, and there can be any number of links that describe a lateral and any number of laterals within a system. In this documentation, trunks, mains and interceptors are all referred to as laterals.

- **Link** - A segment connecting two **nodes** (synonymous to a connecting drainage or sewer pipe). As it represents a length, it is specified in feet. A link is the smallest unit that can transport a flow, and is the sole building block of **laterals**. The amount of flow in a given link is a constant.

- **Node** - A point where storm, sewage or combined flow can be either injected into or removed from the system.

- **System** - Collectively, the entire assemblage of **links** and **nodes** (and thus **laterals**) as defined by the user-supplied **commands** of the **command string**. The **system** in this modeling concept is totally synonymous with a stormwater system, a sanitary system, or a combined sewer system.

This concludes the first section of the HYDRA documentation. The next section will provide a technical overview of the methods and operations found in the analysis program.

3. Technical Information

This section provides technical descriptions of the key methodologies employed by HYDRA to assist users in selecting the appropriate solution technique for a given problem. Included are the methods for generating storm and sanitary flows, flow conveyance, inlet computations, storage, cost estimating, and calculating the hydraulic gradeline.

Storm Flow: The Rational Method

Developed towards the end of the 19th century, the rational method is still widely used as a method for computing quantities of stormwater runoff. The rational method equation is of the form:

$$Q = C \cdot i \cdot A, \tag{1}$$

where:

Q	=	the peak flow, in ft^3/s,
C	=	the dimensionless runoff coefficient,
i	=	the rainfall intensity, in inches per hour, and
A	=	the area of the watershed, in acres.

Intended for determining runoff from small, urban watersheds, use of the rational method hinges on several basic assumptions:

- The duration used to determine an intensity from an Intensity Duration Frequency (IDF) curve is that corresponding to the time it takes for water to flow from the most remote point in the watershed to the point in question, also known as the time of concentration.

- The intensity of the rainfall is constant and is applied to the entire watershed.

- The runoff coefficient remains constant throughout the storm event.

Taking a look at the above assumptions, it becomes clear why this method is intended for small, urban watersheds. To begin, picking an intensity from an IDF curve at a duration equal to the time of concentration makes the most sense in a small, urban environment. Consider, as an ideal case, a large, gently sloping parking lot to be a watershed and apply a rainfall of constant intensity over the entire watershed. It is apparent that the peak flow at the outfall will occur when the entire area is contributing flow; or, to put it another way, when flow from the most remote point in the watershed reaches the outfall. As the watershed characteristics deviate from this ideal case, it becomes more difficult to justify the rational method because this assumption is likely to be violated. This is particularly true of large rural watersheds.

Another good reason not to apply the rational method to large watersheds pertains to the second assumption: rainfall is constant throughout the entire watershed. Severe storms, say of a 100-year return period, generally cover a very small area. Applying the high intensity corresponding to a 100-year storm to the entire watershed could produce greatly exaggerated flows, as only a fraction of the area may be experiencing such an intensity at any given time.

The variability of the runoff coefficient also favors the application of the rational method to small, urban watersheds. Although the coefficient is assumed to remain constant, it actually changes during a storm event. The greatest fluctuations take place on unpaved surfaces, as in rural settings. In addition, runoff coefficient values are much more difficult to determine and may not be as accurate for surfaces that are not smooth, uniform, and impervious.

To summarize, the rational method provides the most reliable results when applied to small, urban watersheds. If it is necessary to apply the method to large (greater than 300 acres) or rural areas, then the validity of each assumption should be verified for the site before proceeding.

HYDRA generates storm flows using the rational method with the **RAI** and **STO** commands (see the appendix for the proper command syntax for these or any other commands mentioned in this documentation). The **RAI** command provides the IDF curve, while the **STO** command provides the balance of the data and triggers the calculations.

To produce flows using the rational method, HYDRA multiplies the sum of the effective areas (effective area is defined as the product of the area and its respective runoff coefficient, i.e. Σ C·A) by the intensity (from the IDF curve specified in the **RAI** command) corresponding to the longest time of concentration (T_c). To determine the longest T_c, the program examines the origin of all flows entering the junction. The longest time will either be: 1) the T_c specified in one or more **STO** commands directly contributing flow to the junction under analysis, or 2) the sum of the T_c specified by a previous **STO** command and the travel time of that flow through the system to the junction in question. Each time a **PIP** command is encountered, HYDRA recalculates both the effective area and the time of concentration.

An exception to this approach occurs when the flow in an individual area exceeds the sum using the long T_c. In situations such as this, the time of concentration corresponding to the area contributing the largest flow is employed, rather than simply using the largest time of concentration. The effective area contributing the lesser flow is then reduced by the ratio of the respective times of concentration. The justification for such a reduction is that in utilizing the smaller T_c, only a fraction of the area corresponding to the greater T_c will contribute flow. This methodology produces greater flows, ultimately resulting in conservative estimates of pipe size. If such a recalculation occurs during a HYDRA run, the user is notified in the output: "***** READJUSTING SUM OF C·A**". The appendix provides such an example, for the interested reader.

HYDRA provides the user with three options for generating time of concentration. These are: 1) user supplied T_c, 2) overland T_c calculated, gutter T_c supplied by user and 3) both overland and gutter Tc calculated by the program. Should the user desire to supply other values, numerous references (notably FHWA HEC-12 and HEC-19) that will provide theory and guidance in calculating T_c can be consulted.[2,3] If, however, the user requests that HYDRA calculate the time of concentration, a formula recommended by the Federal Aviation Administration, is used for overland time of concentration.[4]

$$T_c = (1.8 \cdot (1.1 - C) \cdot L^{0.5}) / S^{0.33} \qquad (2)$$

where:

C = the dimensionless runoff coefficient,

L = the distance traveled, in feet, and

S = the slope, in percent.

If the gutter time is to be calculated, a second formula is used:

$$T_c = L / (K \cdot S^{0.5}) \qquad (3)$$

where:

L = the distance traveled, in feet,

S = the slope, in ft/ft, and

K = an empirical coefficient equal to 32, in ft/sec.

Storm Flow: Hydrographic Analysis

Hydrographic analysis enables the user to mathematically simulate "rain" on an area to determine runoff quantities. Unlike the rational method, which simply calculates peak flows, hydrographic simulation takes into account a very important factor when studying rainfall/runoff relationships - timing. HYDRA actually "steps" through a rainfall event, at regular, user-specified intervals, accounting for all the water that has fallen on the land segment. Once initial abstraction has been determined (initial abstraction is that portion of a rainfall event that is lost to storage, i.e., puddles, vegetation, etc. or infiltrates into the ground), HYDRA develops a runoff hydrograph and routes it through the system.

The hydrograph can be developed in two ways: 1) by using an externally produced hydrograph, with the **UHY** command; or 2) by developing a hydrograph through a user-supplied hyetograph, via the **HYE** command, and using HYDRA to apply the procedure described in the following section.

The user begins by providing a rainfall hyetograph to the program, using the HYE command. By adjusting the time step as specified in the **STE** command, storm events of varying lengths can be modeled. When HYDRA performs the calculations that convert a hyetograph into a runoff hydrograph, up to 96 time steps are analyzed. If the step is set to 15 minutes, then the longest possible duration of the modeled event is 24 hours. A 5-minute time step allows modeling a period of up to 8 hours, and so on.

After the hyetograph has been introduced, the land segment characteristics need to be defined. By manipulating the characteristics describing both pervious and impervious land types, as defined in the **UNP** and **PAV** commands, respectively, flows can be generated that very closely coincide with measurements taken from actual storm events.

On impervious land areas such as parking lots, roads, and sidewalks, losses are attributed almost entirely to puddle storage. HYDRA accounts for puddle storage on impervious land areas through the use of several parameters defined in the **PAV** command. Two of the parameters, **depthpud and slope work in conjunction** with the "slope" parameter expressed in the **HYD** command to define the detention capacity of the depression on the land segment. This is accomplished as follows: **depthpud** provides what might be described as an "equivalent depth" the land segment would experience from the puddle storage, assuming that the area was flat. To set this factor, multiply the average depth of all the puddles (again, assuming the land segment has no slope) times the percentage of the area the puddles would occupy. To determine the puddle storage of the actual, sloped land segment, **depthpud** is multiplied by a ratio derived from the **slope** term in the **HYD command**, which is the actual slope of the land segment, and the **slope** term in the **PAV** command, which corresponds to the slope the land segment would have to be tilted in order to drain all the puddles.

Three additional parameters in the **PAV** command that also deal with puddle storage are **topud**, **toweep**, and **timedrain**. The first term is simply the portion of the rainfall that is diverted to puddle storage. Of this portion, a fraction, as defined by **toweep**, is diverted to "weeping" puddles. These puddles detain water, but not permanently. After a certain time period, as specified in **timedrain**, their contents leak back into the system. The remainder of **topud** is the portion of the rainfall that is detained in "dead" puddle storage (water detained does not contribute to system flow), as described above.

Determining the quantity of runoff from unpaved land areas is more difficult; water can be lost, stored, or delayed in a variety of ways. Trees, shrubs, and grasses act as "buckets" which must be filled before rainfall reaches the ground. Once on the ground, a portion is lost to infiltration, the rate of which changes during the course of the rainfall event. Part of the flow introduced into the ground water does not reappear, while some may be reintroduced into the system. Modeling these complicated interactions and accounting for losses and delays on pervious areas is the task of the eleven parameters in the **UNP** command.

Three of the eleven required parameters, **intrcpt**, **depth1**, and **depth2** allow for interception storage, i.e., on trees, shrubs, and grass. HYDRA allows the user to specify depths (**depth1** and **depth2**) corresponding to two different types of vegetation cover. The amount of precipitation detained by the surface described by **depth1** is defined as a ratio of the total precipitation by the **intrcpt** parameter. The remainder of the rainfall is directed to that area as described by **depth2**.

Once **depth1** and **depth2** have been "filled", water reaches the ground and infiltration begins. HYDRA calculates the effects of infiltration by solving the following equation:

$$\text{infltrn} = \text{satinf} + (\text{maxinf} - \text{satinf}) \cdot e^{(-\text{idecay} \cdot t)} \qquad (4)$$

where:

infltrn	=	the infiltration capacity at time t, in inches per hour,
satinf	=	the saturated capacity, in inches per hour,
maxinf	=	the initial capacity (dry conditions, maximum capacity), in inches per hour,
idecay	=	the infiltration decay constant, and
t	=	the time from start of precipitation excess, in hours.

This formula, known as Horton's equation, calculates infiltration capacity as a function of time.[5] Time variable infiltration is an important consideration as the infiltration rate of a given soil decays as the soil becomes more saturated. Ultimately, when the soil becomes fully saturated, the infiltration rate approaches a constant value. The infiltration capacity at each time step is determined. When precipitation ceases, the infiltration rate begins to recover towards the maximum capacity (**maxinf**) value. The time of recovery is defined by the **timerec** parameter, that becomes important during storms that have a period in which the precipitation actually stops and then begins again.

With the losses from both pervious and impervious areas essentially "removed" from the incoming hyetograph, the remainder of the precipitation is converted to a runoff hydrograph for conveyance.

Sanitary Flow

HYDRA allows the user to generate average and peak sanitary flows for both the analysis of existing sewers and the design of new sewers. In addition, the program has the capability for investigating infiltration.

In HYDRA, average sanitary flow is calculated using the parameters specified in one or both of the following combinations of commands: **GPC** and **SAN** or **IPU**, **GPC**, and **SUN**. In the first combination (GPC, SAN), average flow is calculated by multiplying the number of gallons produced per capita per day, (specified in the

GPC command), by the number of people per acre times the number of acres, (specified in the **SAN** command). Therefore, flow in a given conveyance is calculated as follows:

$$Q_a = \Sigma(\text{uflow} \cdot \text{pop} \cdot \text{area}) \tag{5}$$

where:

Q_a = the average flow, using the first combination, in gallons per day,

uflow = the unit flow of generated wastewater, in gallons per capita per day,

pop = the equivalent population density, in persons per acre, and

area = the area of sanitary collection, in acres.

The flow is internally converted to ft^3/s. In most circumstances, it will not be necessary to change the value of uflow, reducing the equation to:

$$Q_a = \text{uflow} \cdot \Sigma(\text{pop} \cdot \text{area}) \tag{6}$$

In the second combination (**IPU**, **GPC**, **SUN**), average flow is determined by multiplying the cumulative product of number of sanitary units (e.g. houses, apartment buildings, that are specified in the **SUN** command), multiplied by the number of individuals per sanitary unit (specified in the **IPU** command). This total is then multiplied by the number of gallons produced per capita per day. This is expressed as:

$$Q_a = \text{uflow} \cdot \Sigma(\text{units} \cdot \text{ipu}) \tag{7}$$

where:

Q_a = the average flow, using the second combination, in gallons per day,

uflow = the unit flow of generated wastewater, in gallons per capita per day,

units = the number of dwelling units contributing to the system at each node, and

ipu = the number of people per dwelling unit.

As with the first combination, flow is internally converted to ft^3/s.

The decision to utilize the methods discussed above is dependant on the type and availability of data. The **IPU** and **GPC** commands will in most cases only have to be entered once at a point near the beginning of the command string. The **SAN** and **SUN** commands actually introduce flow into the system and are be placed throughout the command string where needed.

In performing calculations to determine peak sanitary flow in a system, HYDRA employs the "peaking factor" concept. The peaking factor is a number, greater than or equal to one, that is multiplied by the average flow to estimate peak loads on the system. In the initial few links of a network, where flows are relatively low, experience has shown that the peaking factor may be as high as 4.0. Further down the line, where the physical length of the system, as well as the increase in flow, makes individual contributions less important, the peaking factor decreases. Since the peaking factor, which is entered in the **PEA** command, can have a significant effect on the amount of flow generated, great care should be taken in selecting the flow/flow factor ordered pairs.

Each time one of the transport commands, either **PIP** or **CHA**, is encountered, the average flow is calculated and a new peaking factor is calculated. At that point, the peak flow in the system is equal to the following:

$$Q_p = pkfctr \cdot Q_a \qquad (8)$$

where:

Q_p = the peak daily flow, in gallons per day,

pkfctr = the peaking factor, resulting from the flow versus factor curve provided in the **PEA** command,

Q_a = the average daily flow, in gallons per day.

In addition to accounting for known, anticipated inflows, undesirable inputs, namely infiltration, must also be taken into consideration. Infiltration plays a particularly important role in sanitary sewer systems in that it can comprise a significant percentage of the flow, especially in older networks. Infiltration can be included with the use of the **INF** command. This flow contribution is calculated each time the **SAN** and/or **SUN** command is encountered. It is added to the system flow after the peaking factor has been applied.

Flow Conveyance

Flow generated in any of the previously described sections is eventually transported through pipes and/or channels. Sizing of these conduits as well as the determination of other flow characteristics can now be accomplished.

To evaluate the adequacy of an existing system to analyze imposed flows or to design a new system, HYDRA employs Manning's formula for gravity flow:

$$Q = \frac{1.486}{n} \cdot A \cdot R_h^{0.667} \cdot S^{0.5} \qquad (9)$$

where:

Q = the pipe flow, in ft^3/s,

A = the area of the flow cross-section, in square feet,

R_h = the hydraulic radius of the flow cross-section, in feet,

S = the pipe slope, in ft/ft, and

n = Manning's friction coefficient for the pipe.

In the design case, this equation is algebraically manipulated to solve for the diameter necessary to handle the design flow. When the pipe is between 12 and 48 inches in diameter, the calculated diameter is rounded up to the nearest 3-inch increment. When the calculated pipe diameter is greater than 48 inches, it is rounded up to the nearest 6-inch increment. This value, or the minimum diameter value as defined in the **PIP** command, whichever is larger, is then utilized as the design size. (It is important to note that even though in certain circumstances design flows may be very low, HYDRA will design no pipe smaller than 12 inches in diameter).

Having utilized the design flow to determine the pipe diameter, both parameters can now be employed to calculate flow velocity. HYDRA again makes use of Manning's equation:

$$V = \frac{1.486}{n} \cdot R_h^{0.667} \cdot S^{0.5} \qquad (10)$$

where:

V = the pipe velocity, in ft/s,

R_h = the hydraulic radius of the flow cross-section, in feet,

S = the pipe slope, in ft/ft, and

n = Manning's friction coefficient for the pipe.

Since the hydraulic radius is a function of depth and in most cases the pipes will not be carrying capacity flows, this term is expressed as follows:

$$R_h = \frac{D}{4} \cdot \left(1 - \frac{\sin 2\theta}{2\theta}\right) \qquad (11)$$

where:

D = the diameter of the pipe, in feet, and

θ = theta, in radians, measured as shown below in Figure 1.

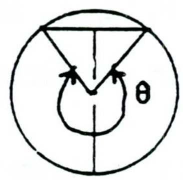


Figure 1. Measurement of θ.[6]

For an open channel, HYDRA presents the user with two alternatives for computing depth and velocity of flow. One alternative, as with calculating flow in pipes, is Manning's equation. Using the design flow and channel geometry, as defined in the **CHA** command, HYDRA employs a trial and error process to determine depth. Once depth is obtained, Manning's equation is solved for velocity.

The second option available for determining depth and velocity of flow in open channels involves the use of a formula developed by Izzard, which is an approximation for hydraulics in gutters.[2]

$$Q = \frac{0.56}{n} \cdot S_x^{1.67} \cdot S^{0.5} \cdot T^{2.67} \qquad (12)$$

where:

S_x = the roadway cross slope, in ft/ft,

S = the longitudinal slope of the gutter, in ft/ft,

T = the spread of flow in the gutter, in feet, and

n = Manning's friction coefficient for the gutter.

This equation was derived from Manning's equation to describe flow in wide, shallow, triangular channels. If this option is selected, HYDRA selects the greater of the two side slopes entered and ignores the bottom width. In other words, a channel of the shape depicted in Figure 2 is assumed:

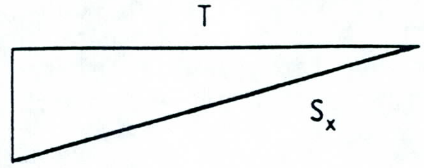


Figure 2. Triangular gutter shape.

The **GUT** command has the same two analyses options as that described for the **CHA** command, and an additional alternative of analyzing composite gutter sections, as shown in Figure 3:

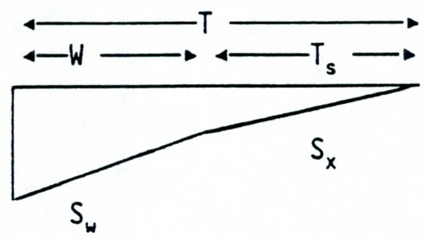


Figure 3. Composite Gutter Shape

Equation 12 is also used with this type of gutter section. A trial and error approach is employed, with the width of flow incremented by .01 feet each iteration, until the flow computed in the composite section is equal to the flow produced by HYDRA.

A **GUT** command must precede every **INL** command in order for the inlet to be analyzed or designed correctly. If the gutter option is selected in which the cross slope (S_x) is not entered, then the larger of the two side slope values (larger because the slopes are entered as feet horizontal to feet vertical; so it is actually the flatter slope that is selected) is used as the cross slope.

The **GUT** command, as with the **CHA** command, is available in both hydrographic and non-hydrographic runs. However, in non-hydrographic runs, the **GUT** command is used only to provide spread, cross slope, and flow to the **INL** command.

Inlet Computations

Through use of the **INL** command, the user has the ability to design the length or analyze the performance of an inlet given the flows calculated by HYDRA. The capability is available in both hydrographic runs and rational method peak flow runs, with one important difference. In the hydrographic analysis, the **INL** command is the sole means by which a runoff hydrograph can be introduced into the system. As such, it must appear immediately before one of the system transport commands, either **PIP** or **CHA**. The inlet size or configuration has a direct influence on system flows. For the rational method runs, however, the **INL** command serves only to design or analyze an inlet given calculated peak flows. The inlet has no affect on system flows. It is, therefore, an option in non-hydrographic runs.

The basis for the inlet calculations is the HEC-12 manual "Drainage of Highway Pavements"(2). An integral element in the design of pavement drainage is not only the inlet itself, but also the gutter leading to the inlet. The gutter configuration has a direct bearing on the design or performance of the inlet. Therefore, in accordance with the actual pavement drainage process, a gutter command, **GUT**, is required before each **INL** command.

The user has the option of designing and/or analyzing the inlet types listed below and shown in figures 4 through 7:

- grate inlets
- curb inlets
- combination inlets (future release)
- slotted drain inlets
- user defined inlets

Another distinction is made regarding inlet location. Inlet performance is not the same on-grade versus in a sump condition; thus both types of analyses are available. Having outlined the basic uses of the **INL** command, it is necessary to provide a detailed description of the methodologies and equations used for analyzing or designing each of the inlet types.

Grate Inlet

Grate inlets on grade, as shown in Figure 4, will intercept all of the gutter flow passing over the grate, or the frontal flow, if the grate is sufficiently long and the gutter flow velocity is low. Only a portion of the frontal flow will be intercepted if the velocity is high or the grate is short and splash-over occurs. A part of the flow along the side of the grate will be intercepted, depending on the cross slope of the pavement, the length of the grate, and flow velocity.

The ratio of frontal flow to total gutter flow, E_o, for a uniform cross slope is calculated by equation (13):

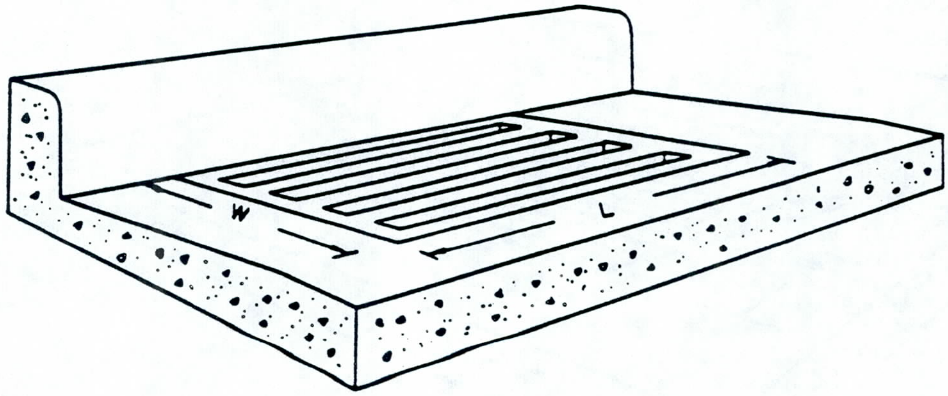


Figure 4. Perspective View of Grate Inlet

Source: HEC-12

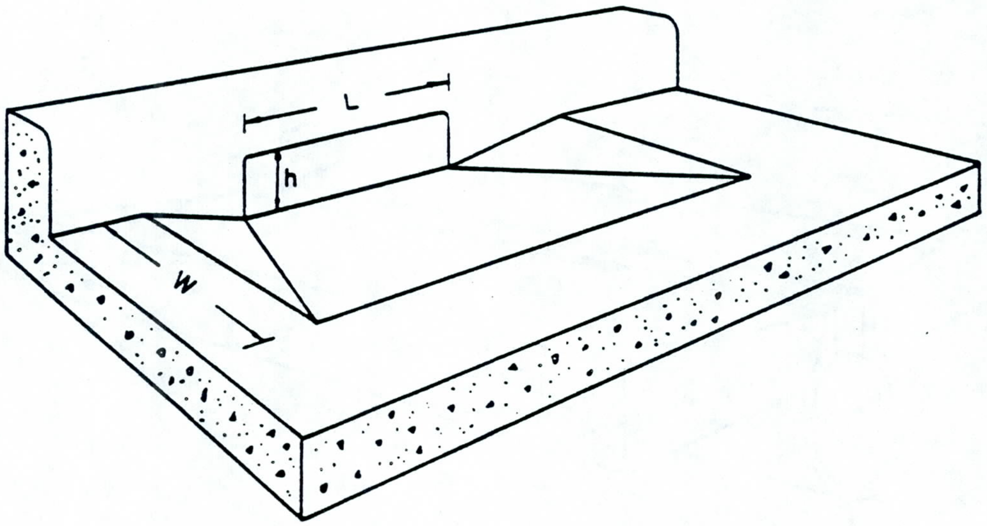


Figure 5. Perspective View of Curb Inlet

Source HEC-12

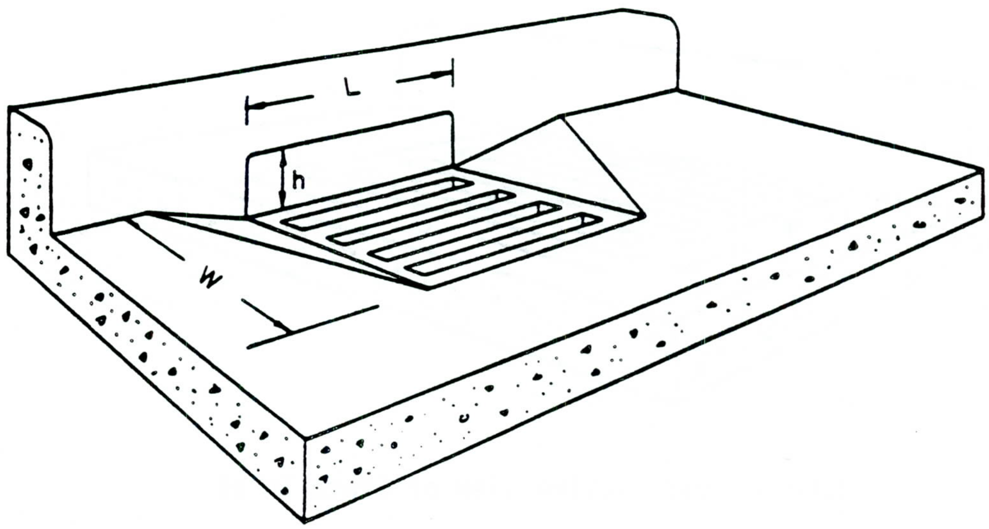


Figure 6. Perspective View of Combination Inlet

Source: HEC-12

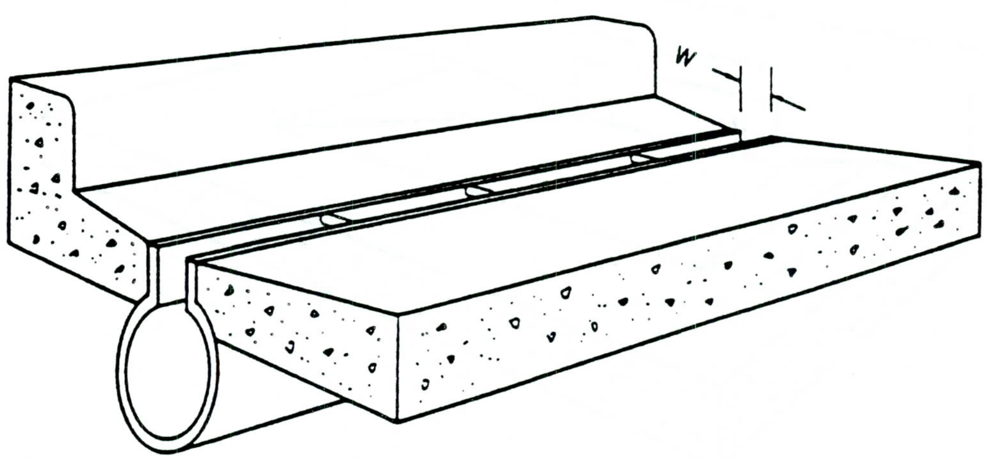


Figure 7. Perspective View of Slotted Drain Inlet

Source HEC-12

$$E_o = \frac{Q_w}{Q} = 1 - (1 - W/T)^{2.67} \quad (13)$$

where:

Q = total gutter flow, ft^3/s

Q_w = flow in width W, ft^3/s

W = width of depressed gutter or grate, ft

T = total spread of water in the gutter, ft

The ratio of side flow, Q_s, to total gutter flow is:

$$\frac{Q_s}{Q} = 1 - \frac{Q_w}{Q} = 1 - E_o \quad (14)$$

The ratio of frontal flow intercepted to total frontal flow, R_f, or frontal flow efficiency, is calculated by equation (15):

$$R_f = 1 - 0.09\,(V - V_o) \quad (15)$$

where:

V = velocity of flow in the gutter, ft/s

V_o = gutter velocity where splash over first occurs, ft/s

The ratio of side flow intercepted to total side flow, R_s, or side flow interception efficiency, is calculated by equation (16):

$$R_s = 1/\left(1 + \frac{0.15V^{1.8}}{S_x L^{2.3}}\right) \quad (16)$$

where:

L = length of the grate, ft

S_x = cross slope of pavement, ft/ft

V = velocity of flow in the gutter, ft/s

The efficiency, E, of a grate is calculated by equation (17):

$$E = R_f E_o + R_s(1 - E_o) \tag{17}$$

The first term on the right side of equation (17) is the ratio of intercepted frontal flow to total gutter flow, and the second term is the ratio of intercepted side flow to total side flow. The second term is insignificant with high velocities and short grates.

The interception capacity of a grate inlet, on grade, is equal to the efficiency of the grate multiplied by the total gutter flow:

$$Q_i = EQ = Q[R_f E_o + R_s(1 - E_o)] \tag{18}$$

For the analysis case, equations 13-18 need only be applied one time. Since the inlet dimensions are known, the interception capacity can be determined directly. Flows in excess of the grate capacity are stored for later recall as specified by the user in the INL command.

In order to design a grate inlet, on grade, length to accept a design flow, HYDRA iterates through equations 13-18, increasing the grate length until the flow calculated by equation 18 is within 1/2 of 1 percent of the design flow, or the design length reaches 20.0 feet. The tolerance is employed because, in cases where the width of flow is greater than the width of the inlet grate, then the percentage of flow captured by the inlet can never be 100 percent. This occurs, computationally, because the R_s term in equation 18, which represents the amount of side flow captured, will always be less than 1.0. Even though it can get very small, it will always reduce the efficiency of the grate, making 100 percent capture impossible. Thus an infinite grate length would be required. By assuming that 99.5 percent capture is sufficient, reasonable grate lengths can be achieved. If the width of flow is less than or equal to the grate width, 100 percent capture is achieved with no unrealistic computational problems occurring.

The second condition described above, which will not allow a grate design of greater than 20 feet, is included as a practical limitation. The design equations are empirical in nature, based on experiments providing design guidance for grates up to 4.0 feet in length. While there is no reason to doubt the validity of the design equations for lengths greater than 4.0 feet, conditions requiring excessive grate lengths should be examined.

A grate inlet in a sag, sump, location operates as a weir, to depths dependent on the bar configuration and size of the grate, and as an orifice at greater depths. Grates of larger dimension and grates with more open area, i.e., with less space occupied by lateral and longitudinal bars, will operate as weirs to greater depths than smaller grates or grates with less open area.

In analyzing a grate inlet of given dimension, the capacity, assuming the inlet is operating as a weir, is computed as:

$$Q_i = C_w P d^{1.5} \quad (19)$$

where:

P = perimeter of the grate, disregarding bars and the side against the curb, ft

C_w = weir coefficient equal to 3.0

d = depth of water, ft

Since the grate dimensions are known for the analysis condition, the perimeter is computed as 2 x grate width + grate length.

The capacity of a grate inlet operating as an orifice is computed as:

$$Q_i = C_o A (2gd)^{0.5} \quad (20)$$

where:

C_o = orifice coefficient equal to 0.67

A = clear opening area of the grate, ft^2

g = acceleration due to gravity equal to 32.16 ft/s^2

d = depth of water, ft

The clear opening area of the grate is calculated as grate width x grate length x opening ratio. The clear opening area, as well as the perimeter, can be overriden by entering these values in the **INL** command. In this manner, the potential effects of clogging can be studied. The opening ratio is the ratio of open area to the area of the bars projected to a horizontal plane. As an example, a grate inlet with 30° tilt bars would have a higher opening ratio than the same grate with 45° tilt bars. In fact, a 45° tilt bar grate is not recommended for sump situations because the opening ratio is so small. While it is clear some flow does enter such a grate, technically speaking the opening ratio is zero. Thus, if a 45° tilt bar subtype is selected in a sump situation, the program uses the opening ratio for a 30° tilt bar. The opening ratios used in HYDRA are taken from HEC-12[2] and are shown in Table 1.

Table 1
Opening Ratios for Various Grate Inlets

Grate	Opening Ratio
P-1-7/8-4	0.80
P-1-7/8	0.90
P-1-1/8	0.60
Reticuline	0.80
Curved Vane	0.35
30° Tilt-bar	0.34

Before equation 19 and equation 20 can be applied to determine the capacity of the inlet, it must be determined whether the inlet is operating under weir flow or orifice flow. To make this determination, HYDRA calculates the maximum depth at which weir flow will take place:

$$\text{max weir depth} = 0.26 + (0.07 \times P) \qquad (21)$$

Also calculated is the minimum depth at which orifice flow will occur:

$$\text{min orif depth} = 0.87 + (0.14 \times A) \qquad (22)$$

The inlet depth is then compared to the values computed above to determine the governing flow regime. Once this is established, the correct equation, equation 19 or equation 20, can be applied to calculate the capacity of the inlet. For cases where the flow is transitional, i.e., neither weir flow or orifice flow clearly dominates, the minimum flow computed from equations 19 and 20 is selected.

To design the size of a grate inlet in a sump situation, HYDRA solves equation 19 for the required perimeter and equation 20 for the clear opening area. The type of flow regime is then computed, again by comparing the flow-depth to equations 21 and 22, and either the perimeter or the area is solved for the required grate length.

Curb Inlet

Curb-opening inlets, as shown in Figure 5, are effective in the drainage of highway pavements where flow depth at the curb is sufficient for the inlet to perform efficiently. Curb openings are relatively free of clogging and offer little interference to traffic operation. They are a viable alternative to grates in many locations where grates would be in traffic lanes or would be hazardous for pedestrians or bicyclists.

The length of curb-opening inlet, on grade, necessary to intercept 100 percent of flow in the gutter is computed by:

$$L_T = KQ^{0.42}S^{0.3}\left(\frac{1}{nS_e}\right)^{0.6} \tag{23}$$

where:

K	=	coefficient equal to 0.6
Q	=	gutter flow, ft^3/s
S	=	longitudinal slope, ft/ft
n	=	roughness coefficient
S_e	=	equivalent cross slope, ft/ft

The equivalent cross slope, S_e, is computed by the following equation:

$$S_e = S_x + S_w' E_o \tag{24}$$

where:

S_w'	=	cross slope of the gutter measured from the cross slope of the pavement, S_x
	=	(a/W)
a	=	inlet depression, ft
E_o	=	ratio of flow in the depressed section to total gutter flow (equation 13)

In the analysis mode, equation 23 is solved for Q to determine the amount of flow the inlet of specified length can accept. Flows exceeding the inlet capacity are stored for later recall as specified by the user in the INL command.

The capacity of a curb-opening inlet in a sag, sump, depends on water depth at the curb, the curb opening length, and the height of the curb opening. The inlet operates as a weir to depths equal to the curb opening height and as an orifice at depths greater than 1.4 times the opening height. At depths between 1.0 and 1.4 times the opening height, flow is in a transition stage.

The weir location for a depressed curb-opening inlet is at the edge of the gutter, and the effective weir length is dependent on the width of the depressed gutter and the length of the curb opening. The weir location for a curb-opening inlet that is not depressed is at the lip of the curb opening, and its length is equal to that of the inlet. Limited experiments and extrapolation of the results of tests on depressed inlets indicate that the weir coefficient for curb-opening inlets without depression is approximately equal to that for a depressed curb-opening inlet.

HYDRA calculates the interception capacity of a depressed curb opening inlet as:

$$Q_i = C_w(L + 1.8W)d^{1.5} \qquad (25)$$

where:

C_w = weir coefficient equal to 2.3

L = length of curb opening, ft

W = lateral width of depression, ft

d = depth at curb measured from the normal cross slope, ft

The weir equation is applicable to depths at the curb approximately equal to the height of the opening plus the depth of the depression. Thus, the limitation on the use of equation (25) for a depressed curb-opening inlet is:

$$d \leq h + a$$

where:

h = height of curb-opening inlet, ft

a = depth of depression, ft

The weir equation for curb-opening inlets without depression ($W = 0$) is computed by:

$$Q_i = C_wLd^{1.5} \qquad (26)$$

The depth limitation for operation as a weir becomes:

$$d \leq h$$

Curb-opening inlets operate as orifices at depths greater than approximately 1.4h. The orifice equation for curb opening inlets is used for d > h and is calculated by:

$$Q_i = C_o hL(2gd_o)^{.5} \tag{27}$$

where:

C_o = orifice coefficient equal to 0.67

h = height of curb opening inlet, ft

d_o = effective head on the center of the orifice throat, ft

L = curb opening inlet length, ft

In designing the length of curb opening inlet for a given flow, HYDRA solves one of the above equations depending on the flow regime as defined by the depth. The necessary length is calculated from equation (26) or (27) as is appropriate.

Combination Inlets

The interception capacity of a combination inlet consisting of a curb opening and grate placed side-by-side, as shown in Figure 6, is not appreciably greater than that of the grate alone. Capacity is computed by neglecting the curb opening. A combination inlet is sometimes used with the curb opening or a part of the curb opening placed upstream of the grate. The curb opening in such an installation intercepts debris which might otherwise clog the grate and has been termed a "sweeper" by some. A combination inlet with a curb opening upstream of the grate has an interception capacity equal to the sum of the two inlets, except that the frontal flow and thus the interception capacity of the grate is reduced by interception by the curb opening. This type of inlet is not yet available in the HYDRA program.

Combination inlets consisting of a grate and a curb opening are considered advisable for use in sags where hazardous ponding can occur. The interception capacity of the combination inlet is essentially equal to that of a grate alone in weir flow unless the grate opening becomes clogged. In orifice flow, the capacity is equal to the capacity of the grate plus the capacity of the curb opening. This type of inlet is not yet available in the HYDRA program.

Slotted Inlets

Slotted inlets, as shown in Figure 7, are effective pavement drainage inlets which have a variety of applications. They can be used on curbed or uncurbed sections and offer little interference to traffic operations.

Flow interception by slotted inlets and curb-opening inlets is similar in that each is a side weir and the flow is subjected to lateral acceleration due to the cross slope of the pavement. Thus, the calculations for designing or analyzing a slotted inlet on grade are the same as for a curb inlet (equation 23).

Slotted inlets in sag locations perform as weirs to depths of about 0.2 ft, depending on slot width and length. At depths greater than about 0.4 ft, they perform as orifices. Between these depths, flow is in a transition stage. The interception capacity of a slotted inlet operating as an orifice is computed by equation (28):

$$Q_i = 0.8LW(2gd)^{0.5} \qquad (28)$$

where:

W = width of slot, ft

L = length of slot, ft

d = depth of water at slot, ft

g = acceleration due to gravity equal to 32.16 ft/s/s

For slotted inlets under weir flow, equation (25), which is the equation for a curb inlet acting under weir flow, is used. For transitional flow depths (between 0.2 ft and 0.4 ft), equation (27) is used with one modification: the coefficient of 0.8 is set to 1.0.

User-Defined Inlets

The user has the option of analyzing the performance of an inlet of a type other than the four described above. This is accomplished through the use of the **INL** command immediately followed by the **EFF** command. The latter command defines the flow-efficiency relationship of a non-standard inlet type. This curve is consulted to determine what percentage of the flows generated by HYDRA are accepted into the inlet.

Flow Storage

The user has the option of including the effects of storage on surface flows as well as on system flows with the use of the **PON** and **RES** commands, respectively. Both commands are operational only during hydrographic runs.

The **PON** command allows for surface ponding of flows from the **HYD**, **GET**, or **GUT** commands. The user has two options:

1. to determine the necessary pond capacity given a maximum outflow or;

2. to determine the maximum outflow given a pond capacity.

For option number 1, hydrographic flows above the specified outflow are stored. These flows accumulate over the length of the hydrograph, the summation equal to the required pond capacity.

For option 2, the hydrograph is truncated with the volume of the truncated portion equal to the given pond capacity. The flow of the hydrograph at this truncated level is the maximum return rate. The user is also informed of the duration at which the pond had any affect on the hydrograph.

The **RES** command allows the user to study the affects of storage on system flows, i.e., flows in a channel or pipe. The user has three options, described below:

1. design the required capacity given a maximum outflow;

2. determine the adequacy of a reservoir size given capacity and maximum outflow; and

3. perform a routing through the reservoir using the storage indication routing method.

For option 1, when hydrographic flows start to exceed the maximum outflow, the reservoir starts to fill. The summation of flows exceeding the maximum outflow minus the maximum outflow determines the required reservoir capacity.

If the user chooses a reservoir capacity (option 2) and it is not large enough to accept the entire hydrograph, flows in excess of the capacity will be bypassed. The user will be informed that this has occurred via a message in the output.

Option 3 allows the user to perform a routing through the reservoir using the storage indication routing method[7]. The stage-storage and stage-discharge curves for the reservoir are entered in the **SST** and **SDI** commands, respectively. HYDRA then solves equation (29) for the inflow and outflow at the end of each time step:

$$\left[\left(\frac{I_i + I_j}{2} - \frac{O_i + O_j}{2}\right)\right] \Delta t = \Delta s \qquad (29)$$

where:

I_i = the inflow at the beginning of the time step, ft^3/s

I_j = the inflow at the end of the time step, cfs, ft^3/s

O_i = the outflow at the beginning of the time step, ft^3/s

O_j = the outflow at the end of the time step, ft^3/s

Δt = time step, sec

Δs = the change in storage, ft^3

Equation (29) assumes linearity of flow from the beginning to the end of the time step. This is a good assumption for small time increments. As the time increment increases, the assumption of linearity becomes less valid, resulting in mathematical errors in the routing procedure.

Cost Estimating

HYDRA, through the use of criteria established in the following commands, performs a cost estimate to design pipe in place:

1) **CST** - ditch geometry and unit prices for material and haul,
2) **EXC** - ditch excavation costs,
3) **PCO** - pipe costs,
4) **TSL** - establishes trench side slopes,
5) **ECF** - extra excavation costs,
6) **PCF** - extra pipe costs, and
7) **LPC** - **summary table of unit costs and materials**

In order for HYDRA to calculate costs for pipe in place, the first four of the above commands must be utilized; the remaining three are optional. HYDRA performs numerous calculations to arrive at the final cost estimates. These estimates are calculated by first determining the amount of a given material and then multiplying that value by its unit cost. This process is carried out on a link by link basis. As a general representation, cost can be said to be equal to the following:

$$\text{cost} = \Sigma(X_i \cdot U_i) + \text{lcost} \quad (38)$$

where:

cost = the cost associated with the sanitary sewer or storm drain project, in dollars,

X_i = the quantity of excavation, backfill material, pipe zone material, bedding material, and pipe,

U_i = the cost of excavation, backfill material, pipe zone material, bedding material, and pipe, in dollars per item or quantity, and

lcost = lump sum costs (e.g. inlets, pumps), in dollars.

The "lump sum costs" term includes monies that are simply added on directly. Included in this category is the **lcost** term in the **PIP** command as well as the **cost** parameter specified in the **PUM** command.

Hydraulic Gradeline Methodology

The user has the option, through the use of **HGL command**, of initiating the calculation of the hydraulic gradeline through the system under investigation. Using information supplied in the **PNC** and **PIP** commands concerning pipe-node connectivity and characteristics, the calculations proceed from the system outfall upstream to each of the terminal nodes. Calculation of the hydraulic gradeline includes the determination of major and minor losses within the system. Major losses result from friction losses within the pipe. Minor losses include those losses attributed to bends in pipes, manhole losses, expansion and contraction losses, and losses at appurtenances such as valves and meters.

The detailed methodology employed in calculating the hydraulic gradeline through the system begins at the system outfall with the tailwater elevation. This value can be determined in one of two ways: 1) the flow depth in the outfall link as calculated by HYDRA, or 2) input by the user via the **TWE** command. It is important to note that the program detects the outfall, and hence where to begin the hydraulic gradeline calculations, by reading a node width (diameter of the manhole) of 0 in the relevant **PNC** command. If a node width of 0 is not entered for the outfall point, the hydraulic gradeline calculations will not take place.

Once the tailwater elevation is established, HYDRA checks to see if the value is greater than or equal to the crown elevation of the downstream end of the outfall link. If the above condition is true, HYDRA assumes that the pipe is surcharged and calculates, using Manning's equation, the friction slope necessary to achieve the calculated flow. This slope is then multiplied by the length of the pipe to estimate the major friction losses. Any additional pipe losses (either bend losses, as detailed in the **BEN** command, or user-supplied losses, as input in the **LOS** command) are added. This elevation is compared to the summation of the flow depth, as calculated by HYDRA, plus the upstream invert elevation.

The greater of the two values is then assumed to be the hydraulic gradeline at the upstream end of the pipe. If the outfall link is not flowing full, then the potential hydraulic gradeline elevation at the upstream end is calculated as the flow depth plus the upstream invert elevation.

Minor losses occurring as flow passes through a manhole are determined for the particular connection. This value is then added to the hydraulic gradeline of the downstream pipe to arrive at the hydraulic gradeline which is experienced just inside the upstream pipe, and is compared with the crown elevation of the upstream pipe. At this point, a new "tailwater elevation" has been calculated for the next upstream pipe. This process is repeated for each pipe on the system.

The basis for determining the minor head loss experienced at manholes is the energy equation (i = inflow pipe, o = outflow pipe):

$$\frac{V_i^2}{2g} + \frac{P_i}{\delta} + Z_i = \frac{V_o^2}{2g} + \frac{P_o}{\delta} + Z_o + (\Delta E)_{i \to o} \qquad (30)$$

where:

V	=	velocity
g	=	acceleration due to gravity
P	=	pressure
δ	=	specific gravity of water
Z	=	water surface elevation (elevation head)
ΔE	=	head loss
$\frac{V^2}{2g}$	=	velocity head
$\frac{P}{\delta}$	=	pressure head

The head loss encountered in going from one pipe to another is commonly represented as being proportional to the velocity head at the outlet pipe. Using K to signify this constant of proportionality, the energy loss is approximated as $K \times (V_o^2/2g)$. Including this expression in Equation 30 and solving for K yields:

$$K = \frac{(V_i^2/2g + P_i/\delta + Z_i) - (V_o^2/2g + P_o/\delta + Z_o)}{V_o^2/2g} \qquad (31)$$

Due to the complex nature of the theory involved in determining head loss in manholes, several experimental studies have been conducted[8, 9, 10]. It has been determined that the K value can be approximated as follows:

$$K = K_o \times C_D \times C_d \times C_Q \times C_p \times C_B \qquad (32)$$

where:

- K = adjusted head loss coefficient
- K_o = initial head loss coefficient based on relative manhole size
- C_D = correction factor for pipe diameter
- C_d = correction factor for flow depth
- C_Q = correction factor for relative flow
- C_B = correction factor for benching
- C_p = correction factor for plunging flow

The first term in Equation (32), the initial head loss coefficient K_o, is estimated as a function of the relative manhole size and angle of deflection (shown in Figure 8) between the inflow and outflow pipes:

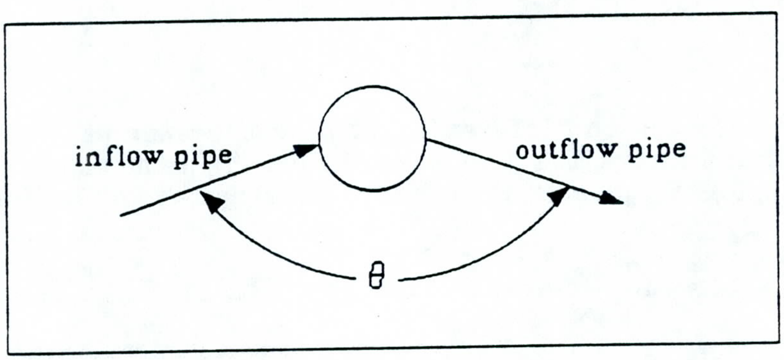


Figure 8. Angle of Deflection

$$K_o = 0.1 \times (b/D_o) \times (1 - \sin\theta) + 1.4 \times (b/D_o)^{0.15} \times \sin\theta \qquad (33)$$

where:

K_o = initial head loss coefficient based on relative manhole size

θ = the angle between the inflow and outflow pipes

b = manhole diameter

D_o = outlet pipe diameter

It has been shown that there are only slight differences in head loss coefficient between round and square manholes. Therefore, manhole shape can be ignored when estimating head losses for design purposes.

The correction factor for pipe diameter, C_D, was determined to be:

$$C_D = (D_o/D_i)^3 \qquad (34)$$

where:

C_D = correction factor for variation in pipe diameter

D_i = incoming pipe diameter

D_o = outgoing pipe diameter

A change in head loss due to differences in pipe diameter was found to only be significant in pressure flow situations when the depth in the manhole to outlet pipe diameter ratio, d/D_o, is greater than 3.2. Therefore, it is only applied in such cases.

The correction factor for flow depth, C_d, is calculated by the following:

$$C_d = 0.5 \times (d/D_o)^{0.6} \qquad (35)$$

where:

C_d = correction factor for flow depth

d = water depth in manhole above outlet pipe invert

D_o = outlet pipe diameter

This correction factor was found to be significant only in cases of free surface flow or low pressures, when d/D_0 ratio is less than 3.2, and is only applied in such cases.

The correction factor for relative flow, C_Q, is computed by:

$$C_Q = (1 - 2\sin\theta) \times (1 - Q_i/Q_o)^{0.75} + 1 \quad (36)$$

where:

C_Q = correction factor for relative flow

θ = the angle between the inflow and outflow pipes

Q_i = flow in the inflow pipe

Q_o = flow in the outlet pipe

As can be seen from Equation (36), C_Q is a function of the angle of the incoming flow as well as the percentage of flow coming in through the pipe of interest versus other incoming pipes. To illustrate this effect, consider the manhole shown in Figure 9 and assume that Q_1 = 3 cfs, Q_2 = 1 cfs, and Q_3 = 4 cfs. Solving for the relative flow correction factor in going from the outlet pipe (#3) to one of the inflow pipes (#2):

$$C_{Q_{3-2}} = (1 - 2\sin(90°)) \times (1 - 1/4)^{0.75} + 1$$

$$= 0.19$$

For a second example, consider the following flow regime: Q_1 = 1 cfs, Q_2 = 3 cfs, Q_3 = 4 cfs. Calculating C_Q for this case:

$$C_{Q_{3-2}} = (1 - 2\sin(90°)) \times (1 - 3/4)^{0.75} + 1$$

$$= 0.65$$

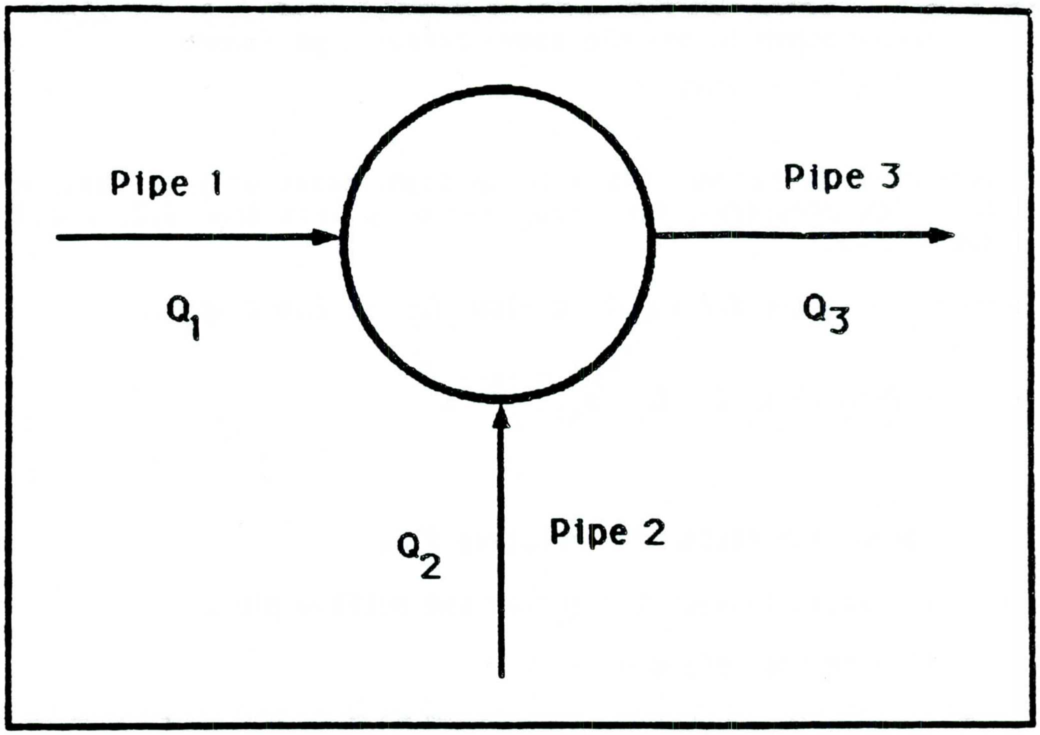


Figure 9. Example of Relative Flow Effect

In both of these cases, the flow coming in through pipe no. 2 has to make a 90-degree bend before it can go out pipe no. 3. In case 1, the larger flow traveling straight through the manhole, from pipe no. 1 to pipe no. 3, assists the flow from pipe no. 2 in making this bend. In case 2, a majority of the flow is coming in through pipe no. 2. There is less assistance from the straight through flow in directing the flow from pipe no. 2 into pipe no. 3. As a result, the correction factor for relative flow in case 1 (0.19) was much smaller than the correction factor for case 2 (0.65).

The correction factor for plunging flow, C_p, is calculated by the following:

$$C_p = 1 + 0.2 (h / D_o) \times (h - d / D_o) \tag{37}$$

where:

C_p = correction for plunging flow

h = vertical distance of plunging flow from the center of the outlet pipe

D_o = outlet pipe diameter

d = water depth in the manhole

This correction factor corresponds to the effect of another inflow pipe, plunging into the manhole, on the inflow pipe for which the head loss is being calculated. Using the notations in Figure 9, for example, C_p is calculated for pipe #2 when pipe #1 discharges plunging flow.

The final correction factor multiplied by the initial head loss coefficient K_o to get the adjusted head loss coefficient K is the correction for benching in the manhole, C_B. Benching tends to direct flows through the manhole, resulting in reductions in head loss. The types of benching considered in HYDRA are shown in Figure 10. The benching correction factors employed by HYDRA are shown in Table 2. For flow depths between the submerged and unsubmerged conditions, a linear interpolation is performed.

Table 2
Correction factors, C_B, for benching

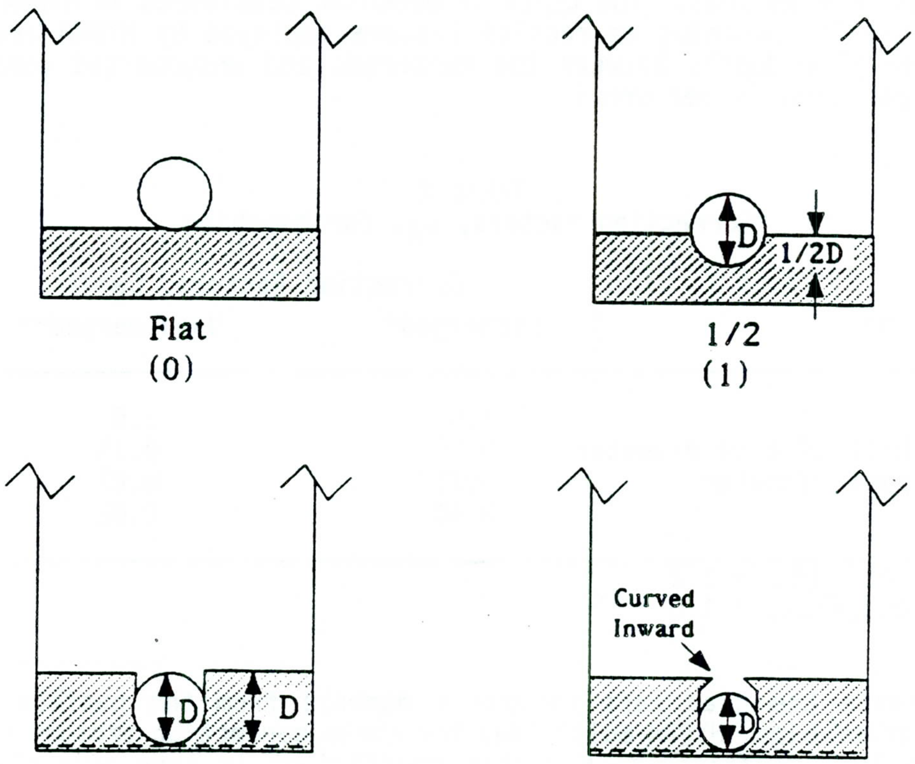
Bench Type	Correction Factors, C_B	
	Submerged*	Unsubmerged**
Flat floor	1.0	1.0
Benched one-half of pipe diameter	0.95	0.15
Benched one pipe diameter	0.75	0.07
Improved	0.40	0.02

* pressure flow, $d/D_o > 3.2$
** free surface flow, < 1.0

To estimate the head loss through a manhole from the outflow pipe to a particular inflow pipe, HYDRA multiplies the above correction factors together to get the head loss coefficient, K. This coefficient is then multiplied by the velocity head in the outflow pipe to estimate the minor loss for the connection.

Summary

Methodologies used for the key features of HYDRA have been described including techniques for flow generation, flow conveyance, inlet computations, storage, cost estimation, and hydraulic gradeline computations. Not all of these methodologies will be used in any given design or analysis. However, it is important for the user to understand the methodologies applied in a given situation to insure that appropriate application of the techniques is achieved.



Flat
(0)

1/2
(1)

Full
(2)

Improved
(3)

Figur_ 10. Schematic Representation of Benching Types

4. User Documentation

Effective use of HYDRA requires an understanding of the interaction between user and the software. While the previous chapter describes what HYDRA does, this chapter explains how one communicates with the software to achieve desired results.

The Command Approach - Organizing the Data

HYDRA operates through the command language concept. This means that data entry and data analysis are all dictated by user-supplied commands. A command is a very specific entity that describes one basic task that HYDRA can recognize. There is only a set number of commands in HYDRA's vocabulary and they must each follow a specific format. Currently there are 60 commands that HYDRA can recognize, although this number is subject to change as long as improvements are being added to HYDRA. A complete list, to date, of these commands along with brief definitions, is shown in Table 3. A more detailed description, including format specifications, is included in Appendix B and also in the form of long helps (activated by the F1 key) within the software.

Table 3. Glossary of commands.

BAS - sets very BASic parameters for a land segment.
BEN - specifies Pipe BENd data such as angle and radius.
CHA - allows you to define an open CHAnnel or ditch.
CRI - determines whether inverts or crowns are to be matched (CRIteria).
CST - sets geometry factors and unit prices (CoSTs in place).
DEL - sets the DELay time of a storm relative to its entry into a basin.
DIR - establishes DIRection and other characteristics of a storm cell.
DIV - splits the system flow into two components (DIVerts flow).
ECF - allows Extra Costs per linear Foot to be added to the pipe cost.
EFF - describes inlet performance in ordered pairs of flow vs. EFFiciency.
END - ENDs a command string.
EXC - establishes trench EXCavation costs.
FIL - causes HYDRA to read commands from a slave FILe.
FLO - adds or subtracts a constant FLOw to the system.
GET - GETs a gutter hydrograph from storage.
GPC - sets the Gallons Per Capita per day for flow calculations.
GUT - establishes GUTter characteristics.
HGL - signals that Hydraulic GradeLine computations should be made.
HOL - HOLds system flow at the lower end of a lateral.
HYD - generates a HYDrograph from a land segment.
HYE - allows input of a HYEtograph.
INF - inputs INFiltration flows by population or area.
INL - sets parameters for a storm water INLet.
IPU - establishes the number of Individuals Per sanitary Unit.
JOB - initiates JOB and enters JOB title.
LOA - LOAds flows at the end of a lateral stored using the SAV command.
LOS - allows input of additional pipe LOSses.
LPC - calculates and Lists Pipe Costs in place.
MAP - establishes factor for converting square inches on a MAP to acres.
NEW - clears some registers and loads NEW lateral name.

Table 3. Glossary of commands (continued).

PAV - sets parameters for **PAV**ed portion of land.
PCF - establishes a Pipe Cost Factor.
PCO - establishes Pipe COsts per foot in place.
PDA - establishes Pipe design DAta.
PEA - translates average daily flow into **PEA**k daily flow.
PIP - moves water from one point to another in a circular **PIP**e.
PNC - specifies Pipe-Node Connections for hydraulic gradeline computation.
PON - allows surface **PON**ding of flows **HYD**, **GUT**, **GET** commands.
PUM - lifts the hydraulic gradient a specified amount (**PUM**p).
PUT - **PUT**s gutter flow into storage.
RAI - sets the values on a **RAI**nfall intensity versus duration curve.
REC - **REC**alls flow previously stored using the **HOL** or **DIV** commands.
REM - allows a line for **REM**arks or comments.
RES - allows the analysis of in-line storage (**RES**ervoir).
RET - **RET**urns command reading to the master file.
SAF - applies **SAF**ety factors to calculated flows.
SAN - enters **SAN**itary flow into the system.
SAV - **SAV**es flows at the end of a lateral in a disk file.
SDI - allows input of Stage-DIscharge curve.
SST - allows input of Stage-STorage curve.
STE - sets the length of time increments (**STE**ps).
STO - enters sub-basin data for determining **STO**rm water design flow.
SUN - enters the number of contributing **S**anitary **UN**its.
SUR - allows analysis of the possibility of **SUR**charging the system.
SWI - sets **SWI**tch for determining method of storm/sanitary flow analysis.
TRA - **TRA**nsfer system flow to surface flow.
TSL - determines Trench side wall **SL**ope.
TWE - allows for the input of a tailwater elevation at the system outfall.
UHY - enables use of externally produced hydrographs (User HYdrograph).
UNP - sets parameters for **UNP**aved area.

Commands are the data that a user must specify to describe a system for analysis. These commands may be arranged in almost any order, provided they follow a few, simple guidelines. These guidelines ensure that the users system is described appropriately and logically, and will become more clear as the user gains familiarity with this section and the examples provided in the appendix. Once these commands are arranged in their final working order, they are collectively referred to as a command string. The command string is what HYDRA needs to define a system model for analysis.

Figure 11 shows an example command string, broken down into its command name and accompanying data field, with an explanation of each command used. Ordering commands in a HYDRA command string is a relatively easily acquired skill. For instance, using Figure 11 as an example, note that the **JOB** command is first. This establishes the file name that will be used for the output. The next command is the **PDA** command which establishes certain pipe data criteria such as the Manning's "n" friction factor, minimum diameter, ideal depth, minimum cover, minimum velocity, and minimum slope. The **PDA** command does not need to be the second command, but if it is used, it must precede the first **PIP** (pipe) command so that

HYDRA COMMAND*	DATA	DESCRIPTION
JOB	COMMAND STRING EXAMPLE	The name of the job.
PDA	.014 12 8 4 2 .005	Sets the design criteria, such as Manning's "n", min diameter, etc.
NEW	MAIN STREET	Starts a new lateral and names it.
FLO	11.0	Puts a flow of 11.0 cubic feet per second (ft^3/s) into the system at this location.
PIP	300 110 110	Pipe parameters. (Transports the flow in a pipe 300 feet long - ground elevation at both the upper and lower ends is 110 feet.)
PIP	400 110 112	Continues to transport the flow into another pipe 400 feet long.
FLO	4	Adds another 4.0 ft^3/s to the system at this point.
PDA	0.025 12 8 4 2 .005	Change the pipe friction factor to 0.025 (corrugated metal pipe).
PIP	450 112 100	Transports the flow another 450 feet.
END		Terminates the HYDRA run and prints the results.

* All commands must be expressed in upper case letters.

Figure 11. Example of a command string.

HYDRA will have the criteria necessary to formulate a preliminary pipe design. The **PIP** command is the third command in the data set. In most cases, commands may be used more than once. This allows the user to change specifications or design criteria at any point in the system. For example, the **PDA** command was used twice. Although this example shows modification only to the friction factor, any parameter value may be modified by changing the appropriate subfield in the data field.

Figure 12 shows the organization of all the HYDRA commands. Although the rules for ordering commands are not listed in this figure, the reader should grasp that HYDRA command strings are assembled according to the loose hierarchy of Figure 12. Commands operate in "free format" fashion; that is, a space [ ], a comma [,] or a slash [/] are parameter subfield separators that may be used in any amount between each parameter value (spacing between subfields is not critical). All commands must be expressed in upper case letters. Continuation of a command with many or extremely lengthy variables is achieved by simply continuing the data onto the next line.

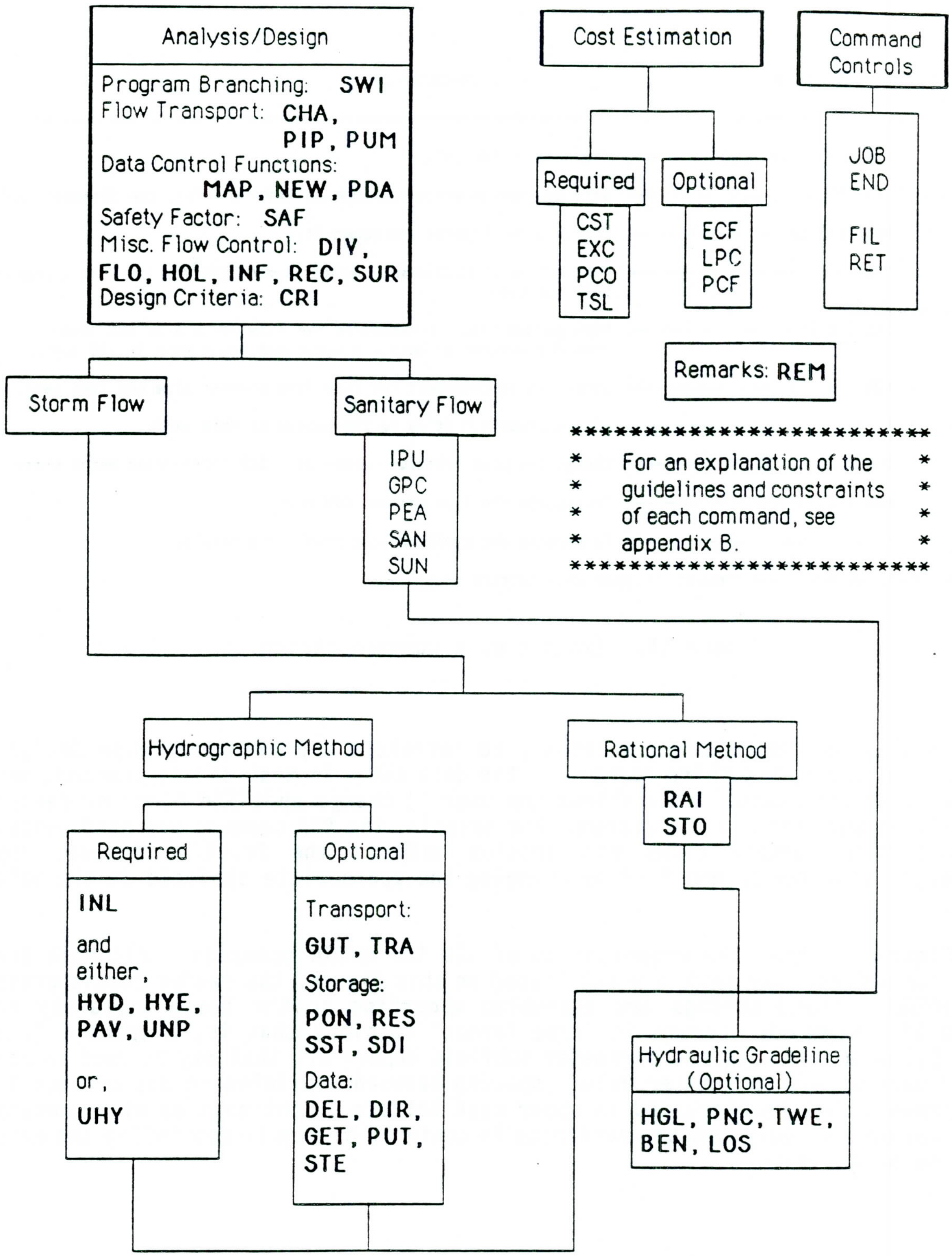


Figure 12. Organization of HYDRA commands

The HYDRAIN Environment

For those users who have obtained HYDRA as part of the Federal Highway Administration's **HYDRAIN** package, additional information is required to run HYDRA within that system. Furthermore, HYDRO - the hydrology component of **HYDRAIN** can be used to provide hydrographs, IDF curves, and hyetographs for use in drainage analyses. HYDRAIN and HYDRO documentation should be consulted for instructions. The following sections discuss the procedures for operating the HYDRAIN System Shell and using the Generic Editor to create HYDRA input data sets. Users not desiring to operate in the HYDRAIN environment can skip this section.

Operating the HYDRAIN System Shell

HYDRA, as well as the other PFP software packages, is implemented through the use of what is known as the PFP "shell". This shell is a separate program that ties the HYDRAIN system together and allows individual components to be accessed. The following text deals specifically with the interaction between the HYDRAIN System Shell and HYDRA; the operation of the other packages will be dealt with separately in their respective documentation.

Before work on a specific HYDRA data set can begin, the HYDRAIN shell must first be entered and HYDRA accessed. This process is begun, from DOS by entering the C:\HYDRAIN directory, typing the command **HYDRAIN,** and striking a carriage return (denoted by <CR>). A screen will appear showing the member sponsors of the Pooled Fund Project. Another <CR> reveals a message (a PFP "disclaimer") to the PFP user. A third <CR> will place the user in the Main Menu.

Entering the Generic Editor

During initial session use of the generic editor, the user will be looking at a "blank" screen with a banner that will be displayed across the top. The cursor will be located on the start of the first command line, in the top left corner of the blank area; the blank area, itself, is the work area where the command line input file is located. The first action to take is to type the first command "**JOB**" in the first three spaces and then an optional line of text to the right to label the input/output. Type <CR> to enter the first line and then enter the second command line. The user may wish to have a footprint in mind to keep the input session productive. Help is available using the "F1" function key. Help consists of short command definitions and long text for each command. Furthermore, active help displayed as input is underway in one line messages that pertain to each command or to each data field that are on the line associated with the command.

After the introductory screens have been cleared the user enters the Main Menu which contains the following choices:

- Input/Edit - input or edit data for HYDRA, WSPRO, HYDRO, CDSV5, or HYCHL;

- Execute - run HYDRA, WSPRO, HYDRO, CDSV5, HY8V3, EQUAT, or HYCHL;
- Utilities - DOS commands, file operation, HYDRAIN setup;
- System Info - long help files for selected topics in HYDRAIN; and
- Quit - exit the HYDRAIN system.

Selection of an option within the Main Menu is accomplished by simply using the left and right ARROWS to move the cursor to the desired procedure or by striking the highlighted letter of the desired option. As each of the procedural options is highlighted by the cursor, a menu of the options within the specific procedural category are displayed. Movement in this field, as before, is accomplished with the ARROWS (in this case, up and down). Since a new file is to be created, place the cursor under the first choice, **Input / Edit** , then, using the down ARROW, highlight HYDRA and strike <CR>.

At this point, the user is asked if the Generic Editor or an Interactive Editor will be used to create/edit the data set. The generic editor allows the user almost complete freedom to edit command line input files. Use of this editor assumes that the user has a basic working knowledge of the generic editor program and its requirements.

To make a selection, move the cursor to the desired field and press <CR>, or, press G for generic or I for interactive. As it is still under development, currently, none of the HYDRAIN programs can access the interactive editor. Should the user select this option, they will be given a message to this effect.

The result of selecting an editor will be a prompt for the user to specify the name of a file to be edited. Pressing <Esc> or <F2> will return the user to the HYDRAIN main menu. Next, the user should select a file to be edited (or created). The bottom of the screen shows the path of the input files for the engineering program selected. It also displays the number of bytes free on the disk being used. Only those files having the .HDA extension will be displayed.

To select a file from those already existing, move the cursor and press <CR>. The file name selected will be moved to the field next to "File:". To begin editing, press <CR>. Should the user wish to change the file name selection, once the filename is in the "File:" field, they may type the name of the file desired (with a three-letter extension) and press <CR>. This newly entered file name will be sent to the editor.

To create a new file (or use a file that does not use the .HDA extension), move the cursor to [..EDIT..] and press <CR>. The cursor will move to the "File:" field. The user should type the name of the file and press <CR> twice to begin editing. After pressing <CR> the second time, the user is placed into the file which was chosen.

Using the Generic Editor

The generic editor provides the HYDRAIN user with a simple method of adding new data and changing existing data to create program input files for programs which have command line inputs, such as HYDRA. The editor itself is a full-screen editor with each line having two fields. The first field has space for three characters and is the location in which the user enters the command ID for a line of data. The cursor is moved to field two using the right arrow key. Field two is the location of the input data associated with a given command ID and consists of a maximum of 72 characters plus any continuation lines.

In addition to its basic editing capabilities, the generic editor relies on the usage of two function keys. The <F1> key allows the user to access Help whle the <F2> key accesses special editing and word processing tools. These two functions act as on/off switches; pressing the key once activates the function, while pressing it a second time deactivates it, returning the screen to edit mode. In addition to the <F1> and <F2> keys, numerous other keys are active in the generic editor. Table 4 provides a listing of these keys and their functions. Appendix A of the HYDRAIN Manual Volume I presents a comprehensive explanation and "walk-through" on the use of the generic editor. This section is intended to provide an overview of the editor and its capabilities.

Table 4
Active Keys and Their Functions

Key	Function
F1 ("Help Key")	Access Long Help.
F2 ("Hot Key")	Access pull-down menus of editing options.
Ctrl End	Delete a line.
Carriage Return <CR>	Insert a line. Move to the next line.
Esc	Return to HYDRAIN main menu.
Arrow keys	Move the cursor throughout the document.
PgUp	View the previous screen of data.
PgDn	View the next screen of data.
Ctrl PgUp	Move to the top of the document.
Ctrl PgDn	Move to the bottom of the document.
Ins	Switch between Insert and Replace modes.
Home	Move to beginning of the field, of the line, of the screen, and then of the file.
End	Move to the end of the field, of the line, of the screen, and then of the file.
Backspace	Move back one space (or field in certain cases).

The generic editor is designed to provide continuous short help displayed at the bottom of the screen for each field. Entering a three character Command in field one triggers a short descriptive help message. Should a more detailed description of the Command ID and the structure of the data to be input into field two be desired, pressing the <F1> key will access a menu of all command IDs for the type of data set (in this case HYDRA). By highlighting the desired command ID and striking <CR>, long help on that command ID is displayed. A complete listing of the command ID long help messages is found in Appendix B.

Editing functions are accessed at any time during the editing process by pressing the <F2> key. These functions are organized in pull-down menus of editing options. Descriptions of the four menus, titled **Select, Search, Modify and Block**, follow.

Within the **Select menu**, there are six functions which are presented under two sub-headings. The "File Access" sub-heading has three functions which allow the user to execute basic file management procedures. The "Action" sub-heading has three functions, each of which allows the user to execute a specified procedure.

FILE ACCESS - allows the user to perform one of three operations: Retrieve, Save, and Switch.

Retrieve - In order to Retrieve a file, the following procedure is performed:

a. Select "Retrieve" by moving cursor and pressing <CR>.
b. If the current path, as indicated, is incorrect, enter the correct directory (Note: there must be a backslash (\) before and after the directory name).
c. Using the down arrow, move the highlight bar to the desired file and Press <CR>. Or, type the filename (with extension) in the space next to "Current File:".
d. An inset "Warning" screen will then appear. To retrieve the file and overwrite any text which is on the screen, select "Continue . . .". Or, to cancel the retrieval and return to the Select menu, choose "Abandon . . .".
e. When the text is retrieved and appears on the screen, press <Esc> or <F2> to remove the menu.

Save - In order to Save a file, the following procedure is performed:

a. Select "Save" by moving the cursor and pressing <CR>.
b. If necessary, change the path and directory in which the file will be saved.
c. Using the down arrow, move the highlight bar to the desired file and press <CR>. Or, type the filename (an extension will be assigned automatically) in the space next to "Current File:".
d. If the file being saved is new, it is automatically saved and the user is returned to the Select menu. If the file had already existed, a "Warning" screen will appear. Choose "Continue . . ." to overwrite the existing file or, choose "Abandon . . ." to cancel the save process and return to the Select menu.

It should be noted that an input file will automatically be saved if it is run. Therefore, running a program results in the input file overwriting the previously existing data file.

Switch - The "Switch" function allows the user to bring a new file onto the screen while keeping the original file open. The feature is especially useful for copying or moving a block of text from one file into another through use of the cut/paste option.

To utilize the Switch option, move the cursor to Switch and press <CR>. Proceed as before to retrieve another file. To switch back to the original file, select "Switch" again. In this manner, the user may move between the two files.

ACTION - The "Action" section of the Select menu also contains three functions: Run, DOS, and Quit.

Run - The "Run" option allows the user to run the data file which is displayed on-screen. After running, the screen automatically displays the output. It is important to note, however, that the Run command is only active when the editor is invoked from the HYDRAIN program. As previously mentioned, a program should first be saved before it can be run. In addition, running the program will automatically save the input file.[1]

DOS - The "DOS" option allows the user to return to MS-DOS without actually leaving the editor. Select DOS by moving the cursor and pressing <CR>. The user will then be placed at the DOS prompt and may operate within DOS in a normal fashion. To exit DOS and return to the editor, type EXIT at the DOS prompt. Because of the quantity of space used by the editor and files, there might not be enough memory to use this function.

Quit - After all editing is completed and all files are saved, the user may leave the generic editor by using the "Quit" option. To quit the system, move the cursor to "QUIT" and press <CR>. If all files to which changes were made have been saved, the DOS prompt will be revealed. If changes were made and the files aren't saved, a warning screen will appear. If the choice is made to continue with the exit, all changes will be lost. If the user chooses to abandon the exit, the program will return to the Select menu and the user should then save the file(s).

The **Search menu** is divided into two sections, each of which has five options from which the user may choose. The Search capabilities of the Generic Editor allow the user to quickly locate instances where certain pieces of text occur.

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[1]This feature of the generic editor is very powerful for a user. Use of the "Run" option initiates execution of the current data file and displays the resulting output file on the monitor for immediate review. After complete review of the output file, the input file is returned to the screen for additional runs, if desired.

SEARCH - The "Search" section of the Search menu has five available options. The first four options specify the range of a search while the fifth executes the command. First, the user should select the range to be searched (block, row(s), column(s), global) by moving the cursor to the desired choice and pressing <CR>. Note that the "Block" option is not available unless there is already text which is marked as a block. Similarly, the "Continue" option is not made available until one search has already been performed. Each selection displays a screen in which the user will specify the exact text to be found. In the field next to "Pattern to Match", enter the string of characters to be located. Next, select "Floating" for "Pattern Position". Finally, choose "Yes" to begin the search. Choosing "No" will return the program to the Search menu.

The program then highlights the first instance in which the desired pattern is found. There may, however, be more matches. To check for additional matches, move the cursor to "Continue" in the "Search" section of the Search menu and press <CR>. Selecting "Continue" will result in the next instance in which a match occurs being highlighted. This procedure may be repeated as many times as desired until the end of the file is reached.

TRANSLATE - The "Translate" section of the Search menu has the same five options as the "Search" section. Once again, however, the "Block" and "Continue" options are not always available. The purpose of the translate function is to search for a given pattern and then automatically replace or amend it. The translate input screen requires the same information as search. In addition, the user must enter the new pattern which will replace or be added to the old one. This string is entered in the "Translate to pattern" field. Also, the user must specify whether the new pattern is to overwrite the old one or be inserted after it. This is done by moving the cursor to <Overwrite> or <Insert> and pressing <CR>. Again, choosing "Yes" executes the translate command, while choosing "No" returns the program to the Search menu.

Whenever the program locates the pattern to be translated, a prompt screen is displayed which asks the user whether or not that occurrence should be translated. Choosing "Yes" will perform the translation and move on to the next occurrence. Selecting "No" will move to the next occurrence without changing the previous instance. The "Global" option will automatically translate all of the matches and will return to the Search menu. "Quit" will abandon the translate procedure and return to the Search menu. The final option, "Continue", allows the user to continue the most recent translate procedure, even if the Search menu has been exited and normal editing has been resumed.

The **Modify menu** is divided into three sections: Cut, Paste, and Clear. All of the functions allow the user to move or delete text from the current file.

CUT - There are three options in the "Cut" section of the Modify menu. The user is able to cut a block of one or more columns, and one or more rows. In order to select the Block, Row(s), or Column(s) option, move the cursor to the selection and press <CR>. The "Cut" command deletes the specified portion of the text, but keeps it in memory for a short period of time. In order to cut text which has already been blocked from within the Block menu, select "Block". There is no further prompt, so the block is immediately deleted.

In order to cut one or more rows, select "Row(s)". An inset screen titled "Cut Rows from Sheet" will appear. Move to the field for "Number of rows to cut" and enter the desired number. Then, specify the row at which the cut should start. Note that the default row is the row the cursor was in and the default number of rows is one. The area to be cut is now highlighted. To execute the cut, select "Yes". Selecting "No" will abort the process and return the program to the Modify menu. In addition, pressing <Esc> or <F2> at any time will return the screen to edit mode.

In order to cut one or more column(s) from the text, select "Column(s)" and follow the procedure described for cutting rows.

PASTE - The paste function adds to the text a section which has just been cut. This section can be a block, row(s), or column(s). After selecting "Paste", the Paste Block menu will appear and the program will automatically highlight as much text as was previously cut. For instance, if four rows had been cut, four rows would be highlighted, beginning at the location of the cursor.

Several choices are then made. First, choose whether the new text is to be inserted or is to overwrite existing text. As mentioned, a section of the text is highlighted on the screen. If "overwrite" is selected, the highlighted section is where the new text will be displayed. If "insert" is chosen, the new text will be added above the highlighted area in the case of rows, and left of the highlighted area for columns. If the text to be pasted is a block, it will be inserted above the position of the cursor for rows and left of the cursor for columns.

The second choice, where to start the paste, depends on whether rows or columns are being pasted. For rows, the user specifies the row and column at which the paste is to begin. Keep in mind that for "overwrite", the new text will replace the old text beginning at the specified line number, while for "insert", the new text will go above the specified line. For columns, the choices are the same as those for rows, with one addition; the user specifies the character at which the paste should start. "Overwrite" works in the same manner as for rows, while "Insert" will add the column(s) to the left of the highlighted text.

After the paste is completed, select "Deactivate" in the Block menu (by moving the cursor and pressing <CR>) to remove the block notation.

CLEAR - The "Clear" section of the Modify menu also has three options. For each of these options, block, column(s), and row(s), the text in the specified (highlighted) area is erased. The block, columns, or rows remain in the text but are blank (contain no characters). If the "Block" option is chosen, all text in any area marked as a block is erased. If columns or rows are being cleared, the user specifies the number to clear and the starting location. This information is entered on the prompt screen which is displayed after the user has selected the "Clear" option. To execute the "Clear" command, select "Yes". Once again, pressing <Esc> or <F2> will return the program to edit mode while selecting "No" will display the Modify menu.

The **Block function** is used throughout the generic editor to perform a variety of editing tasks. These tasks include: cut/paste, search, clear, and translate. Each of these tasks are presented in detail in their own long helps. Furthermore, the block function allows the user to specify the exact area of the text where the task is to be performed. There are five options available in the Block menu. The first three, "Characters", "Rows", and "Columns", allow the user to block one or more of the chosen item. To use any of these options, select it (by moving the cursor to the desired choice and pressing <CR>) and use the arrow keys to highlight the block area. When the desired area is highlighted, press <CR> to mark it. The "Global" option automatically blocks the entire document. Finally, the "Deactivate" option removes the block notation from all blocked areas and returns it to standard text.

Executing HYDRA

There are two methods by which HYDRA can be run within the HYDRAIN environment. One method is to run HYDRA from the generic editor. This allows the user the option of immediate review, editing capabilities. The second method is to run HYDRA from the HYDRAIN shell using the **Execute** option.

HYDRA can be run from the generic editor by using the "Hot Key" (<F2>) and moving to the **Select** Action option, Run, and pressing <CR>. As the input file executes, the commands in the file will appear sequentially on the terminal screen. The user can "observe" the progress of the HYDRA run by observing which commands are being processed.

Upon completion of the run, the output file, which is automatically assigned an **.LST** filename extension, will be displayed on the screen. Movement through this screen can be accomplished with the cursor, PgUp, PgDn, Home and End keys.

After reviewing the file, pressing F2 will return the user to the generic editor. From here, the user can once again edit the same file and rerun it.

After saving the data set in the generic editor, HYDRA can be run from the HYDRAIN shell by exiting the editor. This is accomplished by pressing <F2>, selecting the Selection Action option, Quit, and striking <CR>. The HYDRAIN main menu screen appears. By selecting the Execute procedure, HYDRA may be run by selecting the Run option. Prompts for the data set type and name allow the user to select the appropriate data set. As that with the generic editor while the input file executes, the commands in the file will appear sequentially on the terminal screen. The user can "observe" the progress of the HYDRA run by observing which commands are being processed.

Upon completion of the run, the output file, which is automatically assigned an .LST filename extension, will be displayed on the screen. Movement through this screen can be accomplished with the cursor, PgUp, PgDn, Home and End keys. After reviewing the file, pressing F2 will return the user to the HYDRAIN main menu. From this menu, editing of the input data set is accomplished through reentry of the generic editor.

Appendix A: Benchmark Examples

The following examples are hypothetical systems modeled by HYDRA which are provided to illustrate some of the program's capabilities. It should be recognized that these examples are not meant to give a comprehensive guide of every command option. The user is referred to appendix B for this information. It is intended that these examples will achieve at least these four objectives:

(1) provide guidance for creating command strings,

(2) demonstrate uses for many of the commands,

(3) provide information on how to set up a problem, and

(4) demonstrate what to expect for output.

The five examples offered here collectively make use of most of the available commands. In each case, a figure is included to schematically represent a given problem. Following each figure, the input data set for the run and its corresponding output are given. Each of the five examples provides a different type of application of HYDRA. These are:

1) Sanitary sewer design;

2) Sanitary sewer analysis;

3) Rational method storm drain design;

4) Combined system analysis; and

5) Hydrographic simulation storm drain analysis/design.

Example One: Sanitary Sewer Design

This example demonstrates the use of HYDRA in the design mode. A sanitary sewer is planned in which each individual in the service area contributes 100 gallons per day to the sewer (GPC 100) and such that infiltration into the system occurs at a rate of 1000 gallons/day/acre. The exception is the area serviced by the Kenyon Street lateral, where there is a rate of 2000 gallons/day/acre. Figure 13 shows the example site.

Peaking factor data are expressed in the PEA command. This command provides ordered pairs of flow versus peaking factor for flows between 0.01 ft^3/s and 10,000 ft^3/s. Note that the PEA command requires two lines. Continuation of a line is achieved by making the first three columns in the second line blank.

Other commands shown in the example include the PDA command (pipe data), which gives pipe characteristics, such as Manning's "n" value, and the XST, EXC, PCO, and TSL commands, which work together in making cost estimates for the preliminary design. These costs include trench construction, as well as pipe materials.

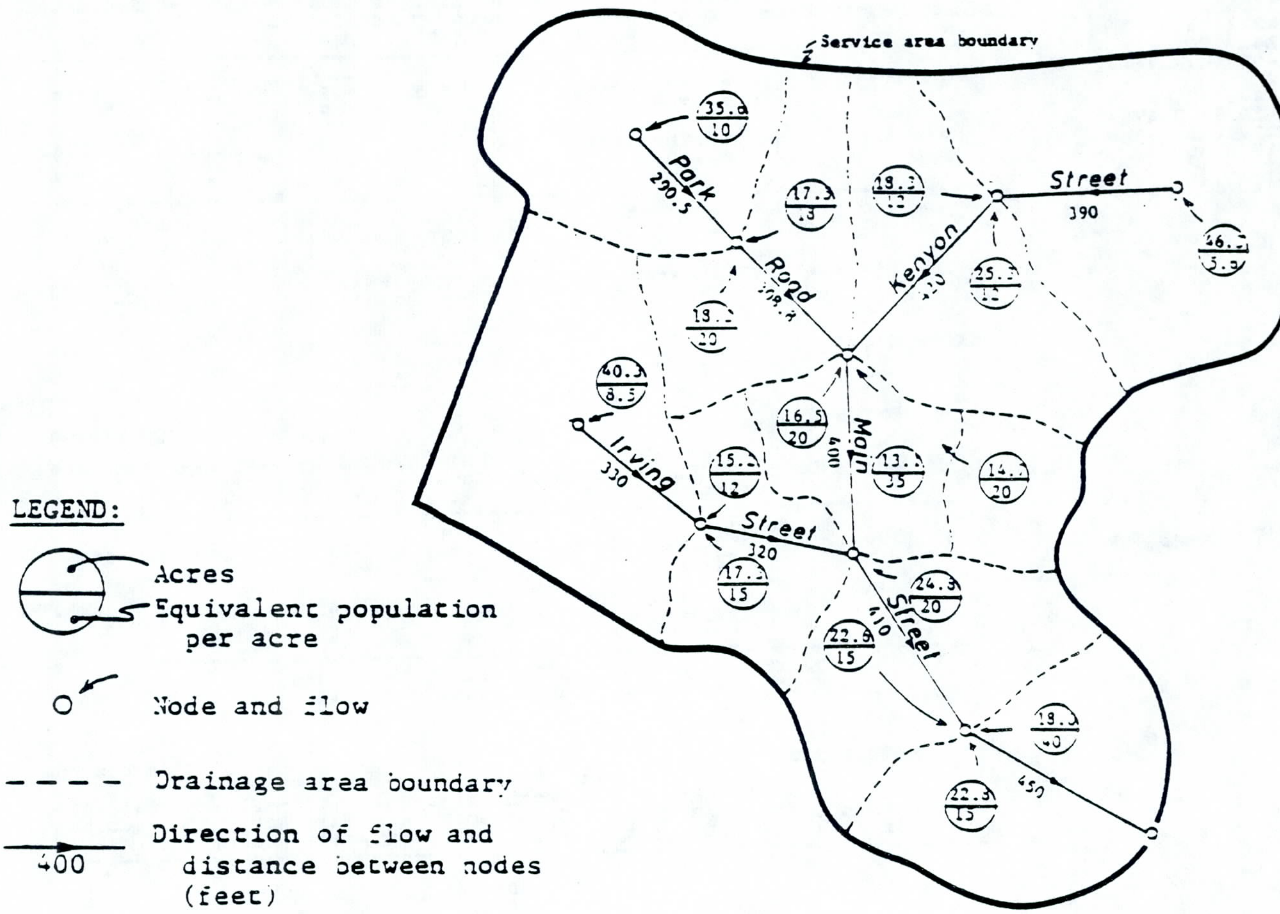


Figure 13. Sanitary Sewer Design

INPUT

```
JOB EXAMPLE ONE
REM
GPC 100
PEA .01 4.46 .05 3.78 .1 3.3 1 2.6 10 2.1 100 1.7
    1000 1.4 10000 1.13
INF 0 1000
CST 1.5 1.5 0 0 .5 0 2.5 .5 0 4 1.15 .4 2.5 3.5 .25
EXC 0 .75 10 .75
PCO 8 2.5 10 3.5
PDA .013 6 7 4 2.5 .001
TSL 0 .2 10 .2
REM
NEW PARK ROAD
SAN 35.6 10
PIP 290.5 100.8 93.6
SAN 17.5 18
SAN 18.2 20
PIP 308.8 93.6 84.7
HOL 1
REM
NEW IRVING STREET
SAN 40.3 8.5
PIP 330 95 81.2
SAN 15.2 12
SAN 17.3 15
PIP 320 81.2 74.3
HOL 2
REM
NEW KENYON STREET
INF 0 2000
SAN 46.3 5.6
PIP 390 97.5 89
SAN 18.3 12
SAN 25.3 12
PIP 420 89 84.7
HOL 3
REM
NEW MAIN STREET
INF 0 1000
REC 1
REC 3
SAN 16.5 20
SAN 13.1 35
SAN 14.7 20
PIP 400 84.7 74.3 -.8
REC 2
SAN 24.8 20
PIP 410 74.3 67
SAN 22.6 15
SAN 18.0 40
SAN 22.8 15
PIP 450 67 65.1
END
```

****** HYDRA ******* (Version 3.0) *****

Date 02-22-90
PAGE NO 3

EXAMPLE ONE

*** PARK ROAD

Pipe Design

Link	Length (ft)	Diam (in)	Invert Up/Dn (ft)	Slope (ft/ft)	Depth Up/Dn (ft)	Min. Cover (ft)	Velocity Act/Full (ft/sec)	--Flow-- Act/Full (cfs)	Estimated Cost ($)
1	291	6	93.80 86.60	.02478	7.0 7.0	6.5	3.9 4.5	.26 .89	1213.
2	309	6	86.60 77.70	.02882	7.0 7.0	6.5	5.2 4.9	.63 .96	1289.

LENGTH = 599. TOTAL LENGTH = 599.
COST = 2502. TOTAL COST = 2502.

*** IRVING STREET

Pipe Design

Link	Length (ft)	Diam (in)	Invert Up/Dn (ft)	Slope (ft/ft)	Depth Up/Dn (ft)	Min. Cover (ft)	Velocity Act/Full (ft/sec)	--Flow-- Act/Full (cfs)	Estimated Cost ($)
3	330	6	88.00 74.20	.04182	7.0 7.0	6.5	4.7 5.9	.26 1.15	1378.
4	320	6	74.20 67.30	.02156	7.0 7.0	6.5	4.4 4.2	.51 .83	1336.

LENGTH = 650. TOTAL LENGTH = 650.
COST = 2714. TOTAL COST = 2714.

****** HYDRA ******* (Version 3.0) *****

Date 02-22-90
PAGE NO 4

EXAMPLE ONE

*** KENYON STREET

Pipe Design

OUTPUT

Link	Length (ft)	Diam (in)	Invert Up/Dn (ft)	Slope (ft/ft)	Depth Up/Dn (ft)	Min. Cover (ft)	Velocity Act/Full (ft/sec)	--Flow-- Act/Full (cfs)	Estimated Cost ($)
5	390	6	90.50 82.00	.02179	7.0 7.0	6.5	3.9 4.2	.30 .83	1628.
6	420	9	82.00 77.70	.01024	7.0 7.0	6.2	3.6 3.8	.68 1.68	2443.

LENGTH = 810. TOTAL LENGTH = 810.
COST = 4071. TOTAL COST = 4071.

*** MAIN STREET

Pipe Design

Link	Length (ft)	Diam (in)	Invert Up/Dn (ft)	Slope (ft/ft)	Depth Up/Dn (ft)	Min. Cover (ft)	Velocity Act/Full (ft/sec)	--Flow-- Act/Full (cfs)	Estimated Cost ($)
7	400	9	77.70 67.30	.02600	7.0 7.0	6.2	6.5 6.1	1.82 2.67	2327.
8	410	12	67.30 60.00	.01780	7.0 7.0	5.9	6.1 6.1	2.47 4.77	3051.
9	450	15	60.00 58.10	.00422	7.0 7.0	5.6	3.7 3.4	3.04 4.21	4159.

LENGTH = 1260. TOTAL LENGTH = 3319.
COST = 9537. TOTAL COST = 18824.

Example Two: Sanitary Sewer Analysis

HYDRA is a useful tool in analyzing existing systems. For this example, the system suggested by HYDRA in example 1 is entered in the command string as an existing system and analyzed. (Note the extra parameters on the PIP commands.) If no other changes are made, the same flows would be calculated, but the costing data are ignored. However, to fully demonstrate the review features of HYDRA, additional flow is added to the system by adding to the person/acre numbers in the SAN commands and adding 3.5 ft^3/s through a FLO command on Main Street. (The FLO command might represent the discharge of water from an industrial facility.)

The output shows that the sewer system is still able to adequately pass the flows on Park Road, Irving Street, and Kenyon Street, but portions of the Main Street lateral are overloaded. In these cases, HYDRA suggests remedies. For the 410-foot link 8 under Main Street, HYDRA suggests somehow removing 1.60 ft^3/s or constructing an additional 12-inch pipe to pass the flow.

```
JOB EXAMPLE TWO
REM
GPC 100
PEA .01 4.46 .05 3.78 .1 3.3 1 2.6 10 2.1 100 1.7
    1000 1.4 10000 1.13
INF 0 1000
CST 1.5 1.5 0 0 .5 0 2.5 .5 0 4 1.15 .4 2.5 3.5 .25
EXC 0 .75 10 .75
PCO 8 2.5 10 3.5
PDA .013 6 7 4 2.5 .001                                  <—— INPUT
TSL 0 .2 10 .2
REM
NEW PARK ROAD
SAN 35.6 13
PIP 290.5 100.8 93.6 93.8 86.6 -6
SAN 17.5 28
SAN 18.2 30
PIP 308.8 93.6 84.7 86.6 77.7 -6
HOL 1
REM
NEW IRVING STREET
SAN 40.3 11.5
PIP 330 95 81.2 88.0 74.2 -6
SAN 15.2 15
SAN 17.3 18
PIP 320 81.2 74.3 74.2 67.3 -6
HOL 2
REM
NEW KENYON STREET
INF 0 2000
SAN 46.3 8.6
PIP 390 97.5 89 90.5 82. -6
SAN 18.3 15
SAN 25.3 15
PIP 420 89 84.7 82.0 77.7 -12
HOL 3
REM
NEW MAIN STREET
INF 0 1000
FLO 3.5
REC 1
REC 3
SAN 16.5 23
SAN 13.1 38
SAN 14.7 23
PIP 400 84.7 74.3 77.7 67.3 -12
REC 2
SAN 24.8 23
PIP 410 74.3 67 67.3 60.0 -12
SAN 22.6 18
SAN 18.0 43
SAN 22.8 18
PIP 450 67 65.1 60.0 58.1 -18
END
```

OUTPUT

****** HYDRA ******* (Version 3.0) *****

Date 02-22-90
PAGE NO 3

EXAMPLE TWO

*** PARK ROAD

Analysis of Existing Pipes

Link	Length (ft)	Diam (in)	Invert Up/Dn (ft)	Slope (ft/ft)	Depth Up/Dn (ft)	Cover Up/Dn (ft)	Velocity Act/Full (ft/sec)	--Flow-- Act/Full (cfs)	Load (%)	-Solutions- Remove (cfs)	-Solutions- Diam (in)
1	291	6	93.80	.02478	7.0	6.5	4.1	.31	35		
			86.60		7.0	6.5	4.5	.89			
2	309	6	86.60	.02882	7.0	6.5	5.5	.85	89		
			77.70		7.0	6.5	4.9	.96			

LENGTH = 599. TOTAL LENGTH = 599.

*** IRVING STREET

Analysis of Existing Pipes

Link	Length (ft)	Diam (in)	Invert Up/Dn (ft)	Slope (ft/ft)	Depth Up/Dn (ft)	Cover Up/Dn (ft)	Velocity Act/Full (ft/sec)	--Flow-- Act/Full (cfs)	Load (%)	-Solutions- Remove (cfs)	-Solutions- Diam (in)
3	330	6	88.00	.04182	7.0	6.5	5.0	.32	28		
			74.20		7.0	6.5	5.9	1.15			
4	320	6	74.20	.02156	7.0	6.5	4.6	.62	75		
			67.30		7.0	6.5	4.2	.83			

LENGTH = 650. TOTAL LENGTH = 650.

*** KENYON STREET

Analysis of Existing Pipes

Link	Length (ft)	Diam (in)	Invert Up/Dn (ft)	Slope (ft/ft)	Depth Up/Dn (ft)	Cover Up/Dn (ft)	Velocity Act/Full (ft/sec)	--Flow-- Act/Full (cfs)	Load (%)	-Solutions- Remove (cfs)	-Solutions- Diam (in)
5	390	6	90.50	.02179	7.0	6.5	4.1	.37	44		
			82.00		7.0	6.5	4.2	.83			
6	420	12	82.00	.01024	7.0	5.9	3.7	.81	22		
			77.70		7.0	5.9	4.6	3.61			

LENGTH = 810. TOTAL LENGTH = 810.

****** HYDRA ******* (Version 3.0) *****

Date 02-22-90
PAGE NO 4

EXAMPLE TWO

*** MAIN STREET

Analysis of Existing Pipes

Link	Length (ft)	Diam (in)	Invert Up/Dn (ft)	Slope (ft/ft)	Depth Up/Dn (ft)	Cover Up/Dn (ft)	Velocity Act/Full (ft/sec)	--Flow-- Act/Full (cfs)	Load (%)	-Solutions- Remove (cfs)	-Solutions- Diam (in)
7	400	12	77.70	.02600	7.0	5.9	8.4	5.66	98		
			67.30		7.0	5.9	7.3	5.76			
8	410	12	67.30	.01780	7.0	5.9	8.1	6.37	134	1.60	9
			60.00		7.0	5.9	6.1	4.77			
9	450	18	60.00	.00422	7.0	5.4	4.0	6.99	102	.15	6
			58.10		7.0	5.4	3.9	6.84			

LENGTH = 1260. TOTAL LENGTH = 3319.

Example Three: Rational Method Design

The example shown in Figure 14 illustrates the use of HYDRA for design of a storm drain using the rational method. As for any design problem, the cost commands (EXC, TSL, PCO, and CST) must be used if cost estimates are desired. Also, a PDA command must be provided to inform HYDRA what pipe characteristics are desired. This command can be used as many times as desired, but must be used at least once.

Four additional commands are introduced in this example: STO, RAI, HGL, and PNC. The STO command provides the physical characteristics of a drainage area required for the rational method: size, runoff coefficient, and time of concentration. The RAI command supplies the Intensity-Duration-Frequency (IDF) curve for the return period and location the user desires to analyze. HYDRA uses the time of concentration for each individual area and then consults the IDF curve to find an intensity for the rational formula. As HYDRA proceeds through the system, it continually adjusts the time of concentration as more areas are being aggregated. The HGL and PNC commands are related to the calculation of the hydraulic gradeline through the system. The HGL commands acts as a switch to "turn on" the computations. The PNC commands details the pipe-node connectivity through the system, as well as the other parameters required to calculate minor losses.

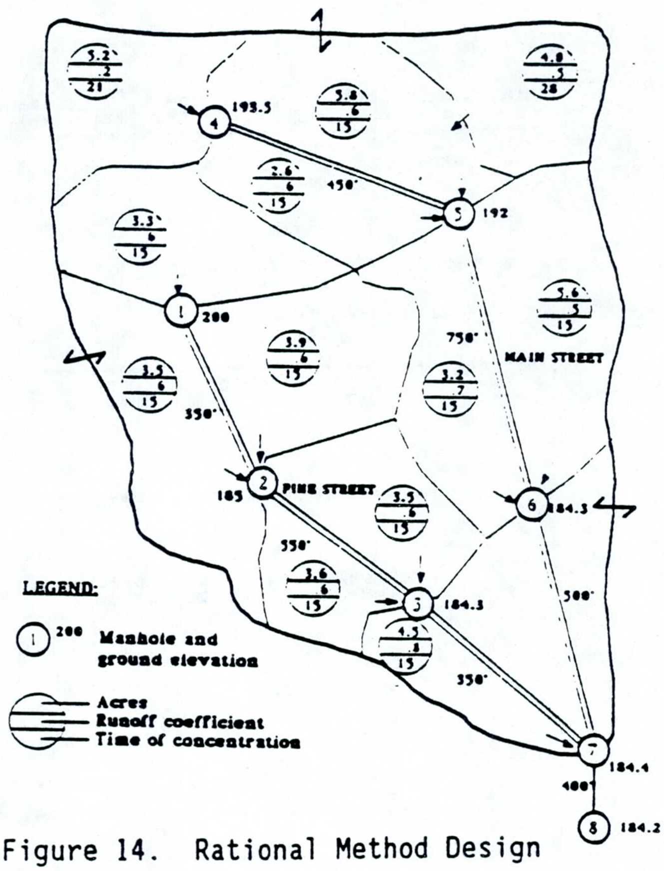


Figure 14. Rational Method Design

```
JOB EXAMPLE THREE: RATIONAL METHOD DESIGN
SWI 2
PDA .013 12 4 3 2 .001
RAI FOXHALL.IDF
EXC 5 .72 25 1.13
TSL 0 .25 10 .15
PCO 12 4.58 36 24.84
CST 1.5 1.5 0 0 0 .5 6.21 1 0 1.52 1.05 .6 1.56 1.52 0
HGL 1
NEW PINE STREET
STO 3.3 .6 18
PIP 350 200 185
PNC 1 2 3 155 1
STO 3.5 .6 18
STO 3.9 .6 18
PIP 550 185 184.4
PNC 2 3 3 180 2
STO 103.6 .6 15
STO 3.5 .6 5
PIP 350 184.3 185.4
PNC 3 7 4 150 3
HOL 1
NEW MAIN STREET
STO 5.2 .2 21
PIP 450 193.5 192
PNC 4 5 3 125 1
STO 4.0 .5 28
STO 5.8 .6 15
STO 2.6 .6 15
PIP 750 192 184.3
PNC 5 6 3 180 0
STO 5.6 .5 15
STO 21.0 .85 15
PIP 500 184.3 184.4
PNC 6 7 4 180 3
STO 14.5 .9 15
REC 1
PIP 400 184.4 184.2
PNC 7 8 0 180
END
```

← INPUT

****** HYDRA ******* (Version 3.0) *****

Date 02-22-90
PAGE NO 3

EXAMPLE THREE: RATIONAL METHOD DESIGN

***** PINE STREET** — Pipe Design

Link	Length (ft)	Diam (in)	Invert Up/Dn (ft)	Slope (ft/ft)	Depth Up/Dn (ft)	Min. Cover (ft)	Velocity Act/Full (ft/sec)	--Flow-- Act/Full (cfs)	Estimated Cost ($)
1	350	12	195.92 180.92	.04286	4.1 4.1	3.0	8.0 9.4	2.00 7.40	2087.
2	550	24	179.78 179.23	.00100	5.2 5.2	3.0	2.6 2.3	6.39 7.17	9534.
3	350	60	175.88 175.53	.00100	8.4 9.9	3.0	4.7 4.2	72.70 82.58	18929.

LENGTH = 1250. TOTAL LENGTH = 1250.
COST = 30550. TOTAL COST = 30550.

***** MAIN STREET** — Pipe Design

Link	Length (ft)	Diam (in)	Invert Up/Dn (ft)	Slope (ft/ft)	Depth Up/Dn (ft)	Min. Cover (ft)	Velocity Act/Full (ft/sec)	--Flow-- Act/Full (cfs)	Estimated Cost ($)
4	450	12	189.42 187.92	.00333	4.1 4.1	3.0	2.6 2.6	.99 2.06	2683.
5	750	18	187.29 179.68	.01016	4.7 4.6	3.0	6.4 6.0	6.74 10.61	8706.
6	500	39	177.78 177.28	.00100	6.5 7.1	3.0	3.6 3.2	23.00 26.18	16088.
7	400	66	175.44 175.04	.00100	9.0 9.2	3.0	5.0 4.5	85.79 106.48	24070.

OUTPUT → (Link 7)

LENGTH = 2100. TOTAL LENGTH = 3350.
COST = 51547. TOTAL COST = 82097.

****** HYDRA ******* (Version 3.0) *****

Date 02-22-90
Page No 4

Pipe #	Downstream Node #	Hydraulic Gradeline Elevation	Crown Elevation	Possible Surcharge	Ground Elevation
1	2	181.3	181.9	N	185.0
2	3	179.5	181.2	N	184.3
3	4	179.2	180.5	N	184.4
4	6	188.2	188.9	N	192.0
5	7	180.2	181.2	N	184.3
6	4	179.2	180.5	N	184.4
7	8	178.8	180.5	N	184.2

Pipe	Terminal Node #	Hydraulic Gradeline Elevation	Ground Elevation
1	1	197.8	200.0
4	5	190.1	193.5

Example Four: Combined System Analysis

HYDRA may be used to design or analyze a combined sanitary and storm sewer system. The example shown in Figure 15 illustrates an analysis of a small drainage and service area feeding into a lateral under Hitda Road. No new commands are required beyond those used in separate analyses of storm drains or sanitary sewers. The hydrographic technique may also be used for combined sewer analysis and/or design.

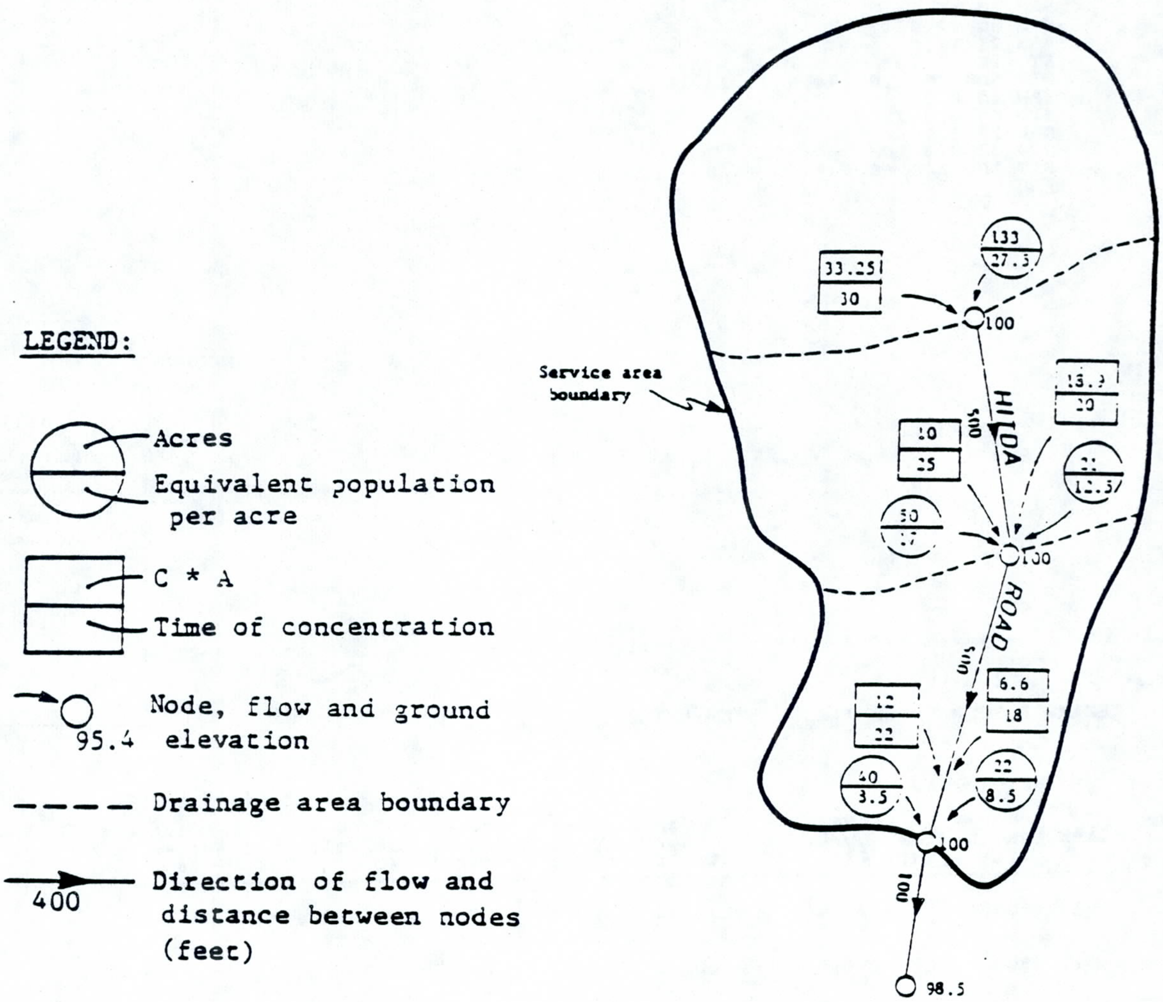


Figure 15. Combined System Analysis

INPUT

```
JOB EXAMPLE FOUR - COMBINED SYSTEM ANALYSIS
PEA .015 3.71 .023 3.54 .03 3.45 .054 3.28
    .1 3.1 .5 2.67 1 2.5 5 2.15 10 2.01 50 1.73 100 1.62
RAI 0 1.55 5 1.55 8 1.2 10 1.1 15 .9 18 .8 24 .7 32 .6
    44 .5 50 .46
INF 0 500
GPC 100
PDA .013 8 4 3 2 .001
EXC 5 .73 25 1.15
TSL 3 .5 10 .5
PCO 8 2.69 36 24.84
CST 1.5 1.5 0 0 0 .5 6.21 1 0 1.52 1.05 .6 1.56 1.52 0
NEW HITDA ROAD
SAN 133 27.5
STO 133 .25 30
PIP 500 100 100 95.4 94.8 -18
SAN 50 17
STO 50 .2 25
SAN 21 12.5
STO 21 .9 20
PIP 500 100 100 94.8 94.2 -18
SAN 40 8.5
STO 40 0.3 22
SAN 22 8.5
STO 22 0.3 18
PIP 100 100 98.5 94.2 94.0 -21
END
```

OUTPUT

****** HYDRA ******* (Version 3.0) *****

Date 02-22-90
PAGE NO 3

EXAMPLE FOUR - COMBINED SYSTEM ANALYSIS

*** HITDA ROAD

Analysis of Existing Pipes

Link	Length (ft)	Diam (in)	Invert Up/Dn (ft)	Slope (ft/ft)	Depth Up/Dn (ft)	Cover Up/Dn (ft)	Velocity Act/Full (ft/sec)	--Flow-- Act/Full (cfs)	Load (%)	-Solutions- Remove (cfs)	Diam (in)
1	500	18	95.40 94.80	.00120	4.6 5.2	3.0 3.6	2.0 2.1	1.60 3.65	44		
2	500	18	94.80 94.20	.00120	5.2 5.8	3.6 4.2	2.1 2.1	2.07 3.65	57		
3	100	21	94.20 94.00	.00200	5.8 4.5	3.9 2.6	2.6 3.0	2.30 7.11	32		

LENGTH = 1100. TOTAL LENGTH = 1100.

Example Five: Hydrographic Simulation and Design

The site shown in Figure 16 is a section of roadway between two high points in the centerline profile. A set of six inlets are used to capture flow from eight identical pavement sections, each 0.5 acres in size. Gutter flow between the inlets is expected in situations where the inlet is not able to accept portions of the peak flow. Once captured by one of the six inlets, the flow is directed through a feeder network of pipes to the main outfall pipe which empties into a downstream channel.

The hydrographic commands featured in this example are STE (step), HYE (hyetograph, UNP (unpaved), PAV (paved), HYD (hydrograph), GUT (gutter), and INL (inlet). The STE command sets the time step for the analysis. In this example, it is set at 2.2 minutes which is relatively small for many analyses. The HYE command provides the rainfall data for the storm to be analyzed while the PAV and UNP commands describe most of the generic physical parameters for the drainage areas. The HYD command provides additional physical data for a specific drainage area, including its slope and area. The HYD command informs HYDRA that this is where a runoff hydrograph is to be generated. The GUT command, as previously mentioned, allows for surface flow at the curb's edge. Finally, the INL command serves to transfer surface flow from a gutter into a pipe network below. Various inlet type can be analyzed or designed, either on grade or in a sump condition.

Another transport command called CHA (channel) is introduced in this example. The CHA command models open channel flow for a variety of cross sections. The CHA and GUT commands, in addition to the PIP command, give the user significant flexibility in transporting flow.

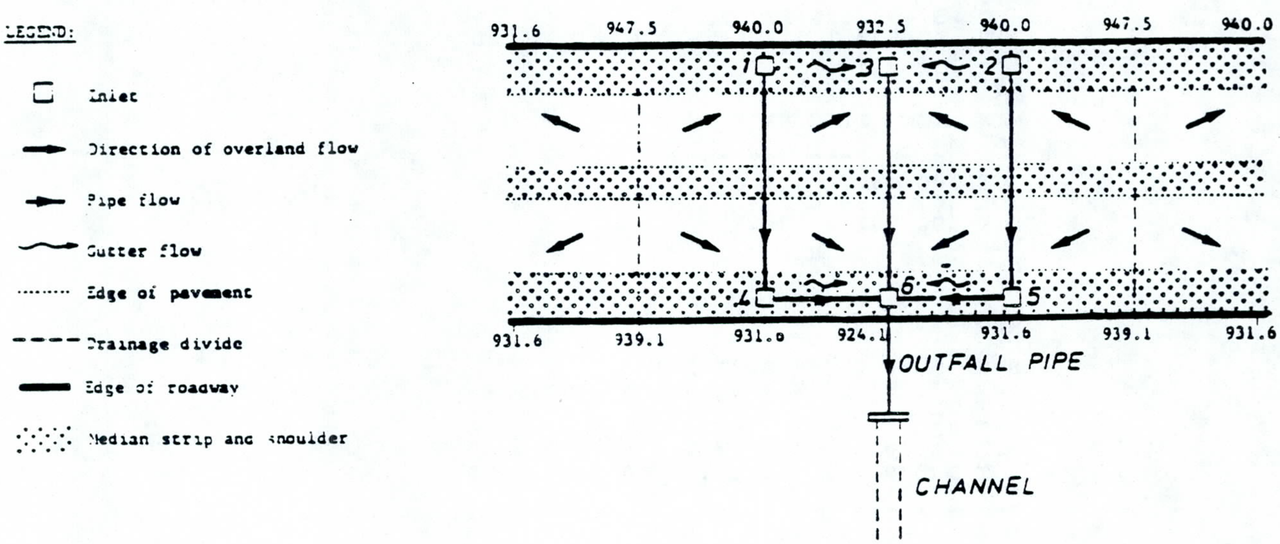


Figure 16. Hydrographic Analysis

INPUT

```
JOB EXAMPLE FIVE: HYDROGRAPHIC SIMULATION AND DESIGN
SWI 3
PDA .013 12 5 4 2.5 .001
PCO 12 46 15 51 18 57 21 63 24 69 27 74 30 80 33 86 36 97
    42 109 48 126 54 143 60 160 66 177 72 206 84 297
CST 1.5 1.5 0 0 0 .5 6.21 1 0 1.52 1.05 .6 1.56 1.52 0
EXC 5 .72 25 1.13
TSL 0 .25 10 .25
STE 2
HYE 0.0 3.51 7.03 10.54 9.03 7.53 6.02 4.52 3.01 1.51
UNP .15 .5 .1 .1 4.0 1.5 .07 45 .03 24 48
PAV .013 .1 .05 .2 .5 30 .4
NEW FEEDER 1
HYD .5 49 .025 .77 2.2
GUT 500 947.5 940.0 .013 0 2 0 30 20
INL 1 1 1 26 0 2 4
PIP 88 940 931.62
HOL 1
NEW FEEDER 2
HYD .5 49 .025 .77 2.2
GUT 500 947.5 940.0 .013 0 2 0 30 20
INL 2 1 1 27 0 2 4
PIP 88 940 931.62
HOL 2
NEW FEEDER 3
GET 26
HYD 1.0 49 0.025 0.77 2.2
GUT 500 940 932.5 .013 0 2 0 30 20
PUT 28
GET 27
HYD .5 49 .025 .77 2.2
GUT 500 940 932.5 .013 0 2 0 30 20
GET 28
INL 3 6 1 0 0 2
PIP 88 932.5 924.1
HOL 4
NEW LEFT-SIDE MAIN
REC 1
HYD .5 49 .025 .77 2.2
GUT 500 939.1 931.6 .013 0 2 0 30 20
INL 4 1 1 29 0 2 4
PIP 500 931.6 924.1
HOL 5
NEW RIGHT-SIDE MAIN
REC 2
HYD .5 49 .025 .77 2.2
GUT 500 939.1 931.6 .013 0 2 0 30 20
INL 5 1 1 30 0 2 3
PIP 500 931.6 924.1
HOL 6
NEW OUTFALL PIPE
REC 4
REC 5
REC 6
GET 29
HYD .5 49 0.025 0.77 2.2
GUT 500 931.6 924.1 .013 0 2 0 30 20
PUT 31
GET 30
HYD .5 49 0.025 0.77 2.2
GUT 500 931.6 924.1 .013 0 2 0 30 20
GET 31
INL 6 6 1 0 0 2 2
PIP 50 924.1 920 0 0 0 0 1 1
HOL 7
NEW OUTFALL CHANNEL
REC 7
CHA 1000 914.0 912.0 .034 1 4 1
END
```

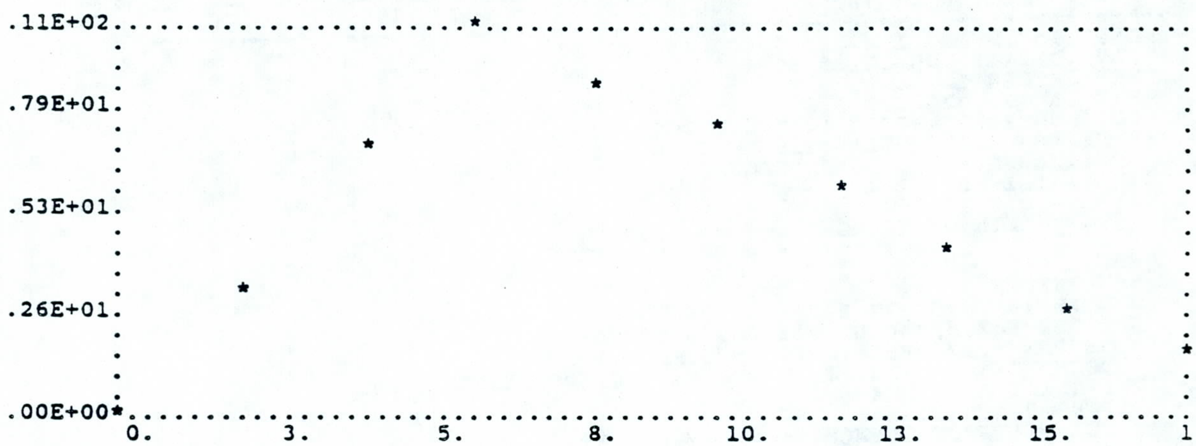
OUTPUT

```
****** HYDRA ******* (Version 3.0) *****                    Date 02-22-90
                                                            PAGE NO    1

   EXAMPLE FIVE: HYDROGRAPHIC SIMULATION AND DESIGN

Commands Read From File D:\HDRN\EXAMPLE5.HDA
   JOB
   SWI 3
   PDA .013 12 5 4 2.5 .001
   PCO 12 46 15 51 18 57 21 63 24 69 27 74 30 80 33 86 36 97
    42 109 48 126 54 143 60 160 66 177 72 206 84 297
   CST 1.5 1.5 0 0 0 .5 6.21 1 0 1.52 1.05 .6 1.56 1.52 0
   EXC 5 .72 25 1.13
   TSL 0 .25 10 .25
   STE 2
*** STEP RESET FROM 15.0 MINUTES
   HYE 0.0 3.51 7.03 10.54 9.03 7.53 6.02 4.52 3.01 1.51
```

HYETOGRAPH (IN/HR)



OUTPUT

```
****** HYDRA ******* (Version 3.0) *****                    Date 02-22-90
                                                             PAGE NO   2

EXAMPLE FIVE: HYDROGRAPHIC SIMULATION AND DESIGN
```

PLOT-DATA (TIME Vs.VALUE)

0.	.00	40.	.00	80.	.00	120.	.00	160.	.00
2.	3.51	42.	.00	82.	.00	122.	.00	162.	.00
4.	7.03	44.	.00	84.	.00	124.	.00	164.	.00
6.	10.54	46.	.00	86.	.00	126.	.00	166.	.00
8.	9.03	48.	.00	88.	.00	128.	.00	168.	.00
10.	7.53	50.	.00	90.	.00	130.	.00	170.	.00
12.	6.02	52.	.00	92.	.00	132.	.00	172.	.00
14.	4.52	54.	.00	94.	.00	134.	.00	174.	.00
16.	3.01	56.	.00	96.	.00	136.	.00	176.	.00
18.	1.51	58.	.00	98.	.00	138.	.00	178.	.00
20.	.00	60.	.00	100.	.00	140.	.00	180.	.00
22.	.00	62.	.00	102.	.00	142.	.00	182.	.00
24.	.00	64.	.00	104.	.00	144.	.00	184.	.00
26.	.00	66.	.00	106.	.00	146.	.00	186.	.00
28.	.00	68.	.00	108.	.00	148.	.00	188.	.00
30.	.00	70.	.00	110.	.00	150.	.00	190.	.00
32.	.00	72.	.00	112.	.00	152.	.00	0.	.00
34.	.00	74.	.00	114.	.00	154.	.00	0.	.00
36.	.00	76.	.00	116.	.00	156.	.00	0.	.00
38.	.00	78.	.00	118.	.00	158.	.00	0.	.00

```
  UNP .15 .5 .1 .1 4.0 1.5 .07 45 .03 24 48
  PAV .013 .1 .05 .2 .5 30 .4
  NEW FEEDER 1
  HYD .5 49 .025 .77 2.2
  GUT 500 947.5 940.0 .013 0 2 0 30 20
*** DEPTH=   .27   VEL= 4.19   WIDTH= 7.12
   DISCHARGE =       3.68   SLOPE =     .01500 FT/FT
  INL 1 1 1 26 0 2 4
  PIP 88 940 931.62
*** TOP WIDTH OF TRENCH ---> UP   5.0 FT
                        ---> DN   5.0 FT
  HOL 1
  NEW FEEDER 2
  HYD .5 49 .025 .77 2.2
  GUT 500 947.5 940.0 .013 0 2 0 30 20
*** DEPTH=   .27   VEL= 4.19   WIDTH= 7.12
   DISCHARGE =       3.68   SLOPE =     .01500 FT/FT
  INL 2 1 1 27 0 2 4
  PIP 88 940 931.62
*** TOP WIDTH OF TRENCH ---> UP   5.0 FT
                        ---> DN   5.0 FT
  HOL 2
  NEW FEEDER 3
  GET 26
  HYD 1.0 49 0.025 0.77 2.2
  GUT 500 940 932.5 .013 0 2 0 30 20
*** DEPTH=   .34   VEL= 4.93   WIDTH= 9.35
   DISCHARGE =       7.35   SLOPE =     .01500 FT/FT
  PUT 28
  GET 27
```

OUTPUT

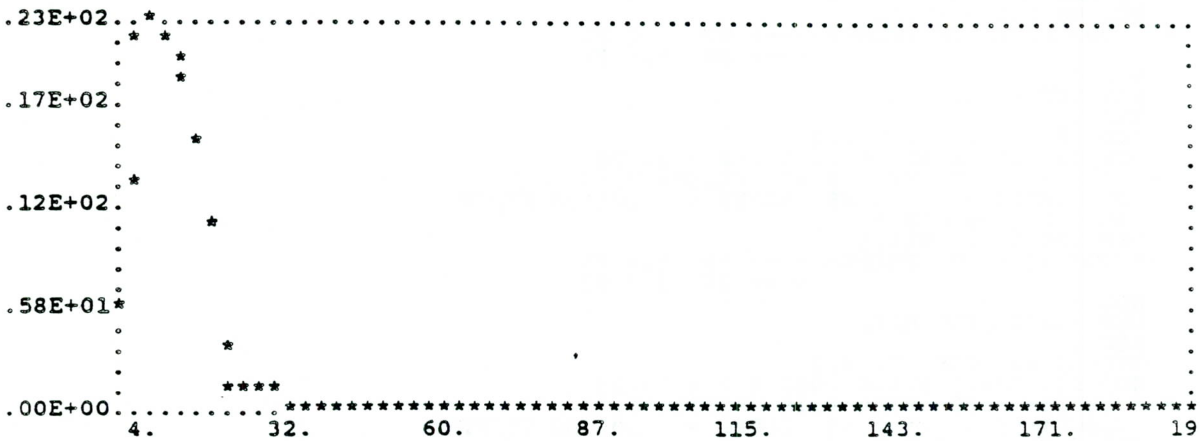

```
   EXAMPLE FIVE: HYDROGRAPHIC SIMULATION AND DESIGN
   HYD .5 49 .025 .77 2.2
   GUT 500 940 932.5 .013 0 2 0 30 20
*** DEPTH=  .27  VEL= 4.19  WIDTH= 7.12
  DISCHARGE =     3.68  SLOPE =    .01500 FT/FT
   GET 28
   INL 3 6 1 0 0 2
** INLET LENGTH =  6.60
   PIP 88 932.5 924.1
*** TOP WIDTH OF TRENCH ---> UP  5.0 FT
                        ---> DN  5.0 FT
   HOL 4
   NEW LEFT-SIDE MAIN
   REC 1
   HYD .5 49 .025 .77 2.2
   GUT 500 939.1 931.6 .013 0 2 0 30 20
*** DEPTH=  .27  VEL= 4.19  WIDTH= 7.12
  DISCHARGE =     3.68  SLOPE =    .01500 FT/FT
   INL 4 1 1 29 0 2 4
   PIP 500 931.6 924.1
*** TOP WIDTH OF TRENCH ---> UP  5.4 FT
                        ---> DN  5.4 FT
   HOL 5
   NEW RIGHT-SIDE MAIN
   REC 2
   HYD .5 49 .025 .77 2.2
   GUT 500 939.1 931.6 .013 0 2 0 30 20
*** DEPTH=  .27  VEL= 4.19  WIDTH= 7.12
  DISCHARGE =     3.68  SLOPE =    .01500 FT/FT
   INL 5 1 1 30 0 2 3
   PIP 500 931.6 924.1
*** TOP WIDTH OF TRENCH ---> UP  5.4 FT
                        ---> DN  5.4 FT
   HOL 6
   NEW OUTFALL PIPE
   REC 4
   REC 5
   REC 6
   GET 29
   HYD .5 49 0.025 0.77 2.2
   GUT 500 931.6 924.1 .013 0 2 0 30 20
*** DEPTH=  .27  VEL= 4.19  WIDTH= 7.12
  DISCHARGE =     3.68  SLOPE =    .01500 FT/FT
   PUT 31
   GET 30
   HYD .5 49 0.025 0.77 2.2
   GUT 500 931.6 924.1 .013 0 2 0 30 20
*** DEPTH=  .27  VEL= 4.19  WIDTH= 7.12
  DISCHARGE =     3.68  SLOPE =    .01500 FT/FT
   GET 31
   INL 6 6 1 0 0 2 2
DEFAULT ORIF AREA =     3.60 , PERIMETER (3 SIDES) =    6.00
*** MAXIMUM STORAGE =         3362.3 CU.FT.
*** PONDING TIME =          16.0 MINUTES
   PIP 50 924.1 920 0 0 0 0 1 1
*** TOP WIDTH OF TRENCH ---> UP  5.9 FT
                        ---> DN  5.8 FT
```

OUTPUT

****** HYDRA ******* (Version 3.0) *****   Date 02-22-90
PAGE NO 4

EXAMPLE FIVE: HYDROGRAPHIC SIMULATION AND DESIGN

SYSTEM HYDROGRAPH IN CFS



PLOT-DATA (TIME Vs.VALUE)

4.	5.87	44.	.19	84.	.02	124.	.01	164.	.00
6.	13.76	46.	.16	86.	.02	126.	.01	166.	.00
8.	21.59	48.	.13	88.	.01	128.	.00	168.	.00
10.	23.26	50.	.11	90.	.01	130.	.00	170.	.00
12.	22.02	52.	.10	92.	.01	132.	.00	172.	.00
14.	20.25	54.	.08	94.	.01	134.	.00	174.	.00
16.	19.47	56.	.07	96.	.01	136.	.00	176.	.00
18.	15.71	58.	.06	98.	.01	138.	.00	178.	.00
20.	10.72	60.	.06	100.	.01	140.	.00	180.	.00
22.	3.72	62.	.05	102.	.01	142.	.00	182.	.00
24.	1.35	64.	.04	104.	.01	144.	.00	184.	.00
26.	1.19	66.	.04	106.	.01	146.	.00	186.	.00
28.	.96	68.	.03	108.	.01	148.	.00	188.	.00
30.	.77	70.	.03	110.	.01	150.	.00	190.	.00
32.	.62	72.	.03	112.	.01	152.	.00	192.	.00
34.	.50	74.	.02	114.	.01	154.	.00	194.	.00
36.	.41	76.	.02	116.	.01	156.	.00	0.	.00
38.	.33	78.	.02	118.	.01	158.	.00	0.	.00
40.	.27	80.	.02	120.	.01	160.	.00	0.	.00
42.	.23	82.	.02	122.	.01	162.	.00	0.	.00

*** SYSTEM HYDROGRAPH REGISTERS FULL AT TIME = 192. MIN
HOL 7

OUTPUT

```
****** HYDRA ******* (Version 3.0) *****                 Date 02-22-90
                                                           PAGE NO   5

EXAMPLE FIVE: HYDROGRAPHIC SIMULATION AND DESIGN
NEW OUTFALL CHANNEL
REC 7
CHA 1000 914.0 912.0 .034 1 4 1
END
END OF RUN.
```

```
****** HYDRA ******* (Version 3.0) *****                 Date 02-22-90
                                                           PAGE NO   6

EXAMPLE FIVE: HYDROGRAPHIC SIMULATION AND DESIGN
```

*** FEEDER 1 — Pipe Design

Link	Length (ft)	Diam (in)	Invert Up/Dn (ft)	Slope (ft/ft)	Depth Up/Dn (ft)	Min. Cover (ft)	Velocity Act/Full (ft/sec)	--Flow-- Act/Full (cfs)	Estimated Cost ($)
1	88	12	934.92 926.54	.09523	5.1 5.1	4.0	11.5 14.0	2.59 11.02	4190.

```
LENGTH =     88.   TOTAL LENGTH =     88.
COST   =   4190.   TOTAL COST   =   4190.
```

*** FEEDER 2 — Pipe Design

Link	Length (ft)	Diam (in)	Invert Up/Dn (ft)	Slope (ft/ft)	Depth Up/Dn (ft)	Min. Cover (ft)	Velocity Act/Full (ft/sec)	--Flow-- Act/Full (cfs)	Estimated Cost ($)
2	88	12	934.92 926.54	.09523	5.1 5.1	4.0	11.5 14.0	2.59 11.02	4190.

```
LENGTH =     88.   TOTAL LENGTH =     88.
COST   =   4190.   TOTAL COST   =   4190.
```

OUTPUT

****** HYDRA ******* (Version 3.0) *****

Date 02-22-90
PAGE NO 7

EXAMPLE FIVE: HYDROGRAPHIC SIMULATION AND DESIGN

*** FEEDER 3

Pipe Design

Link	Length (ft)	Diam (in)	Invert Up/Dn (ft)	Slope (ft/ft)	Depth Up/Dn (ft)	Min. Cover (ft)	Velocity Act/Full (ft/sec)	--Flow-- Act/Full (cfs)	Estimated Cost ($)
3	88	12	927.42 919.02	.09545	5.1 5.1	4.0	16.0 14.1	11.01 11.04	4190.

LENGTH = 88. TOTAL LENGTH = 88.
COST = 4190. TOTAL COST = 4190.

*** LEFT-SIDE MAIN

Pipe Design

Link	Length (ft)	Diam (in)	Invert Up/Dn (ft)	Slope (ft/ft)	Depth Up/Dn (ft)	Min. Cover (ft)	Velocity Act/Full (ft/sec)	--Flow-- Act/Full (cfs)	Estimated Cost ($)
4	500	15	926.18 918.75	.01487	5.4 5.4	4.0	6.9 6.4	5.19 7.90	26460.

LENGTH = 500. TOTAL LENGTH = 588.
COST = 26460. TOTAL COST = 30650.

OUTPUT

****** HYDRA ******* (Version 3.0) *****

Date 02-22-90
PAGE NO 8

EXAMPLE FIVE: HYDROGRAPHIC SIMULATION AND DESIGN

*** RIGHT-SIDE MAIN

Pipe Design

Link	Length (ft)	Diam (in)	Invert Up/Dn (ft)	Slope (ft/ft)	Depth Up/Dn (ft)	Min. Cover (ft)	Velocity Act/Full (ft/sec)	--Flow-- Act/Full (cfs)	Estimated Cost ($)
5	500	15	926.18 918.75	.01487	5.4 5.4	4.0	6.8 6.4	5.01 7.90	26460.

LENGTH = 500. TOTAL LENGTH = 588.
COST = 26460. TOTAL COST = 30650.

*** OUTFALL PIPE

Pipe Design

Link	Length (ft)	Diam (in)	Invert Up/Dn (ft)	Slope (ft/ft)	Depth Up/Dn (ft)	Min. Cover (ft)	Velocity Act/Full (ft/sec)	--Flow-- Act/Full (cfs)	Estimated Cost ($)
6	50	18	918.12 914.38	.07492	6.0 5.6	4.0	18.1 16.3	23.26 28.83	2964.

LENGTH = 50. TOTAL LENGTH = 1314.
COST = 2964. TOTAL COST = 68455.

*** OUTFALL CHANNEL

Channel

Link	Length (ft)	-Channel Shape-- Left (ft)	Ctr (ft)	Right (ft)	Slope (ft/ft)	Invert Up/Dn (ft)	Surface Up/Dn (ft)	Depth (ft)	Surf Width (ft)	Flow (cfs)	Vel (fps)
7	1000	1.0	4.0	1.0	.00200	914.00 912.00	915.84 913.84	1.8	7.7	23.2	2.2

LENGTH = 1000. TOTAL LENGTH = 2314.

Appendix B: HYDRA Commands

This appendix details the meaning and syntax of each command available in HYDRA. The descriptions are ordered alphabetically and include information on the command name, its purpose, and its structure. Any important notes pertaining to the command are also included.

COMMAND BAS - BASic land surface parameters

Purpose: This command sets some very basic parameters for a land segment.

Structure:

```
BAS  K30, K31, K32, K33, K34, K35, K36
```

1) K30 - pan evaporation in inches per day.
2) K31 - initial depth of B1 in inches.
3) K32 - initial depth of B2 in inches.
4) K33 - initial depth of B3 in inches.
5) K34 - initial depth of B4 in inches.
6) K35 - initial depth of B5 in inches.
7) K36 - initial infiltration capacity in inches per hour.

Note: Default value for all parameters is equal to zero.

COMMAND BEN - Pipe BENd data

Purpose: This command specifies the bend angle and radius for the computation of losses due to curved alignment of a pipe. This command should be placed after the PNC statement describing the pipe in which the bend occurs.

Structure:

BEN Rad, Angle

1) Rad - Bend radius of the link described by the previous PNC statement, in feet.
2) Angle - Bend angle of the link described by the previous PNC statement, in degrees.

Note: The bend angle is usually between 0 to 120 degrees.

COMMAND CHA - CHAnnel

Purpose: CHAnnel is one of the HYDRA transport commands. It allows you to define an open channel or ditch.

Structure:

```
CHA  length, invup, invdn, n, leftslope, bottomwidth,
     rightslope, eq
```

1) length - length of link (distance between nodes), in feet.
2) invup - invert elevation at the upstream end of the link, in feet.
3) invdn - invert elevation at the downstream end of the link, in feet. If this value is less than 1.0 but greater than 0.0, HYDRA will take the value as a slope.
4) n - friction factor (Manning's "n").
5) leftslope - slope of the channel's left side, in feet horizontal to feet vertical.
6) bottomwidth - width of the bottom (trapezoidal section), in feet.
7) rightslope - slope of the channel's right side, in feet horizontal to feet vertical.
8) eq - OPTIONAL- enter 1 if gutter equation is to be used; leave blank if Manning's equation is to be used.

COMMAND CRI - CRIteria

Purpose: A "switch" to tell HYDRA how you want certain calculations to take place. At the present time it is a single switch that indicates if the inverts or the crowns in a "free design" are to be matched.

Structure:

CRI switch1

switch1 - if set to zero, inverts will be matched in a free design; if set to 1, crowns will be matched.

Notes:

1) Initially, all switches are set to zero. In other words, if the command is not used, inverts will be matched.
2) This command may be used at any location in the command string and any number of times.

COMMAND CST - CoSTs in place

Purpose: CST sets several trench geometry factors and unit prices for material and haul.

Structure:

```
CST  wmul, wadd, wmin / bmul, badd, bmin, $bed /
     pzmul, pzadd, $pz / shrink, back, $waste, $borrow,
     $surf
```

1) wmul - factor to establish trench width.
2) wadd - added to the product of wmul and ID.
3) wmin - minimum trench width, in feet.
4) bmul - factor to establish depth of bedding.
5) badd - added to above to get depth of bedding.
6) bmin - minimum depth of bedding, in feet.
7) $bed - cost per cubic yard of bedding in place.
8) pzmul - factor to establish the depth of pipe zone material.
9) pzadd - added to above to depth of pipe zone.
10) $pz - cost per cubic yard of pipe zone material in place.
11) shrink - shrinkage of backfill material in place (greater than 1.0).
12) $back - cost per cubic yard of replacing excavated backfill.
13) $waste - cost per cubic yard to remove excess native material.
14) $borrow - cost per cubic yard of borrow material in place.
15) $surf - cost per square foot to restore surface.

COMMAND DEL - DELay rainfall

Purpose: This command allows the user to move the storm across the basin. The HYE command allows the intensity of the storm to be varied as it moves. The combination of these commands allows even a small cell of rainfall to be moved around the basin.

Structure:

```
DEL  delay
```

delay - the delay time in minutes relative to the time the storm first entered the basin.

COMMAND DIR - DIRection

Purpose: This is a hydrographic command establishing the starting location, size, direction, velocity, and other characteristics of a storm cell.

Structure:

DIR north, east, vel, azmuth, width1, width2, max

1) north - one of two starting coordinate for the storm cell. Both NORTH and EAST must be positive and be SW of all land segments. This value must be on the same scale as the "width1" and "width2" parameters.
2) east - one of two starting coordinate for the storm cell. Both NORTH and EAST must be positive and be SW of all land segments. This value must be on the same scale as the "width1" and "width2" parameters.
3) vel - velocity of the storm cell, in mi/hr.
4) azmuth - direction of the storm cell from the origin in degrees clockwise from North.
5) width1 - width of the storm cell, in feet.
6) width2 - width of the storm cell plus taper zone, if feet.
7) max - maximum intensity of the storm outside the limits of the intense portion of the storm cell, in inches per hour.

Notes:

1) Radar maps prepared by the FAA may prove useful in establishing the normal direction, velocity, and size of storm cells in your study area. Normally storm cells move about twice the ground windspeed and quite often at a slightly different direction (perhaps by as much as 30 degrees).
2) If this command is used, HYDRA will ignore any DEL commands.
3) This command requires that North-East coordinates be established for the centroid of each land segment (HYD command). There is no need for this coordinate to be very accurate, but it must be on the same scale as the "width1" and "width2" parameters. If it is not there, the coordinates of the land segment will be assumed to equal the storm coordinates.
4) Three different rainfall scenarios can occur depending on how close the storm center comes to the land segment center. These scenarios are:
   a) If the land segment center is within the inner cell (width1) of the storm at its closest point, the hyetograph is not altered.
   b) If the land segment center is outside the outer cell of the storm center at its closest point, the hyetograph intensities greater than the "max" parameter are set equal to the "max" parameter.
   c) If the land segment center falls between the storm cells (transition zone), hyetograph intensities greater than the "max" parameter are reduced by the percentage of the distance across the transition zone that the land segment passes.

COMMAND DIV - DIVert flow

Purpose: The primary function of this command is to model some form of overflow weir. It splits the system flow into two components - one that continues down the main system and another that is diverted in another direction.

Structure:

DIV hold, Qsys/Qdiv ... Qsys/Qdiv (up to a maximum of 20 sets or a minimum of 2 sets - all values of Qsys must increase).

1) hold - a HOLd number between 1 and 25 where DIVerted system flow is to be held. May be recalled with a REC command.

nx) Qsys - system flow, in cubic feet per second.

ny) Qdiv - flow to be diverted. If the Qdiv exceeds Qsys then all of the system flow will be diverted, but not more than the system flow regardless of the value of Qdiv. If set equal to 0.0 then no flow is diverted.

COMMAND ECF - Extra Cost per lineal Foot

Purpose: An optional command, it allows costs that are related to depth to invert to be added to the pipe cost calculations. Examples of this are dewatering, sheeting, traffic control, etc.

Structure:

ECF depth, $/foot, depth, $/foot ... (up to a maximum of 20 sets or a minimum of 2 sets - all values of depth must increase).

nx) depth - depth from the surface to the pipe invert, in feet.

ny) $/foot - added cost per foot of depth at the above depth, in cost per foot.

COMMAND EFF - EFFiciency

Purpose: Ordered pairs of flow versus efficiency describing the performance of a user supplied inlet. Specifies the performance characteristics of an inlet type other than those included in the INL command. (Must immediately follow INL command.)

Structure:

```
EFF  flow, eff, flow, eff,... flow, eff
```

1) flow - flow arriving at the inlet, in cubic feet per second.
2) eff - capture efficiency corresponding to previous flow, expressed as a percentage.

COMMAND END - END of run

Purpose: This is the correct way to end a command string. When this command is encountered, HYDRA will end the run no matter how many commands follow.

Structure:

```
END  (no data)
```

COMMAND EXC - EXCavation costs

Purpose: One of the required commands for a HYDRA cost estimate of pipe in place. It establishes trench excavation cost.

Structure:

EXC depth, $/cy, depth, $/cy ... (up to a maximum of 20 sets or a minimum of 2 sets - all values of depth must increase).

nx) depth - depth from surface to excavation depth, in feet.
ny) $/cy - the cost in dollars per cubic yard at excavation "depth".

COMMAND FIL - Read a "slave" FILe

Purpose: FIL, a command in the master file, transfers HYDRA to another disk file. HYDRA will read its commands from this new disk file until it encounters a RETurn command, at which time control will return to the master file.

Structure:

FIL name

name - up to five alphanumeric characters. This is the name of the "slave" disk file to which the reading is to be transferred. Do not indicate on which drive the file will be found (e.g. B:START): HYDRA assumes it will be on the same drive as your master file.

COMMAND FLO - miscellaneous FLOw

Purpose: FLO command adds a constant flow to the system.

Structure:

FLO cuft/sec

cuft/sec - the number of cubic feet per second of water to be entered into or removed from the system. In the case of removing flow, the value would be negative.

COMMAND GET - GET gutter hydrograph

Purpose: GET is very similar to the REC command in function except it retrieves a gutter hydrograph from storage that was put there by the PUT or INL command. It has no use in non-hydrographic analysis.

Structure:

GET number

number - a number between 26 and 50 representing the gutter hydrograph that was put in storage by the PUT or INL command.

COMMAND GPC - Gallons Per Capita per day

Purpose: This command allows you to set the gallons per capita per day that HYDRA is to use in its flow calculation in the SAN and SUN commands.

Structure:

```
GPC  gals/cap/day
```

gals/cap/day - number of gallons per capita population or equivalent population per day contributed to the system. This value will be used in conjunction with the peaking factor curve (PEA) and population data supplied through the SAN command to calculate actual sanitary flow.

COMMAND GUT - GUTter

Purpose: This is one of the transport commands and is available for storm drain analysis using the hydrographic technique and, to a limited extent, for rational method analysis. In the hydrographic analysis, it allows the user to transport the hydrograph "overland", in a gutter, before merging it into the main system hydrograph. For the rational method analysis, it is simply used to provide information the inlet command.

Structure:

```
GUT  length, invup, invdn, n, leftslope, botwidth,
     rightslope, cxslope, cgslope, eq, plot
```

1) length - total length of the gutter, in feet.
2) invup - invert elevation at the upstream end, in feet (this must be greater or equal to 10.0 feet).
3) invdn - invert elevation at the downstream end, in feet.
4) n - friction factor of gutter (Manning's "n").
5) leftslope - side slope in feet horizontal to feet vertical.
6) botwidth - width of the bottom of the gutter, in feet.
7) rightslope - side slope in feet horizontal to feet vertical.
8) cxslope - cross slope for composite gutter in feet HORIZONTAL to feet VERTICAL.
9) cgslope - composite gutter slope, in feet HORIZONTAL to feet VERTICAL.
10) eq - OPTIONAL - enter 1 if gutter equation is to be used; enter 0 or leave blank if Manning's equation is to be used.
11) plot - OPTIONAL - enter 1 if a plot is desired; enter 0 or leave blank if no plot is desired or if Rational Method is used.

Notes:

1) Manning's Equation - the user has the option of having a trapezoidal gutter section (or V-notch if "w" is set to 0.0) analyzed using Manning's equation by entering 1 (one) in parameter ten, "eq". The cross-slope parameter, "cxslope" (used for inlet calculations), will be assumed to be the smaller of the two side slopes (the larger value of "leftslope" or "rightslope").
2) UNIFORM SECTION: HYDRA will use the gutter equation, shown in the technical document, if parameter ten ("eq") is set to 0 (zero) or left blank. The bottom width of the gutter will be assumed to be 0.0 and the cross-slope parameter, "cxslope" (used for inlet calculations), will be assumed to be the smaller of the two side slopes (the larger value of "leftslope" or "rightslope"). The parameters "cxslope" and "cgslope" should be set to 0.
   COMPOSITE SECTION: HYDRA recognizes a composite gutter section by reading in values greater than 0 in the "cxslope" and "cgslope" parameters. The bottom width for this type of gutter must be specified. Parameter ten, "eq", should be entered as zero of left blank.
3) There is an automatic ditto feature in this command in that "n", left slope, bottom width, right slope, cross scope, and gutter slope will all

be copied from the previous GUT command unless overridden by entries in this command. The value of "n" may be changed without touching the gutter geometry parameters, but all geometry parameters must be reentered if one is. In other words, Hydra will accept 3, 4, 7, 8, 9, 10, or 11 parameters for this command, but any other numbers of parameters will be assumed to be an error.

4) The friction factor or "n" has a major influence in the gutter calculations so it should be selected with care.

5) All slopes, "leftslope", rightslope", "cxslope", and "cgslope", are in units of feet horizontal per foot vertical. Therefore, large values (e.g., >10) for the slopes mentioned would mean mild slopes and small values (e.g., <3) would represent steep slopes.

COMMAND HGL - Hydraulic Gradeline Computation Switch

Purpose: This command signals to HYDRA that gradeline computations should be made. It should be placed before any flow generation commands.

Structure:

HGL Swi

Swi - A value of 0 or 1 should be entered to control the HGL computations:

0 - bypasses the computations. This is the default value.
1 - directs HYDRA to perform the HGL computations.

Note: Omission of this command will cause the HGL computations to be bypassed.

COMMAND HOL - HOLd lateral

Purpose: Holds system flow at the lower end of a lateral. This flow can then be recalled into a trunk at the appropriate time with the REC command.

Structure:

HOL number

number - a register number from 1 to 25 in which lateral data is to be stored. The REC command can then be used to bring this data back into the system. You can re-use a register any number of times but any previously stored data will be lost. This should be of no concern if a REC command has already retrieved the data.

COMMAND HYD - runoff HYDrograph

Purpose: To generate a runoff hydrograph from a land segment.

Structure:

```
HYD  acres, dis, slope, paved, delay, roof, north, east
```

1) acres - acres in the land segment. If this value is negative, the map scale entered in the MAP command will be used to convert to acres.
2) dis - maximum distance that water must flow over the ground as sheet flow.
3) slope - average slope of the land segment for the ground surface where sheet flow takes place.
4) paved - ratio of paved surface to then total land segment area.
5) delay - OPTIONAL - delay time in minutes before runoff hydrograph becomes "visible" to the system.
6) roof - OPTIONAL - the ratio of flat roof area to paved area.
7) north - OPTIONAL - the North coordinate of the centroid of the land segment.
8) east - OPTIONAL - but must be used with "north". the East coordinate of the centroid of the land segment.

COMMAND HYE - HYEtograph

Purpose: This command allows you to input a hyetograph, or "picture" of the rainfall over a period of time (for example 6 hours).

Structure:

HYE increment, in/hr, in/hr, ... (up to 96 values)

1) increment - the time increment for each inches per hour step (between 5 and 60 minutes).

nx) in/hr - average intensity of rainfall in inches per hour (in/hr) during each step. Unless you use the STEp command, the default length of each step is 15 minutes or 24 hours for 96 steps.

COMMAND INF - INFiltration

Purpose: Inputs infiltration flows based on population or area.

Structure:

INF gal/cap/day, gal/ac/day (Use either)

gal/cap/day - gallons per capita per day of ground water finding its way into the system.

\- or -

gal/ac/day - gallons per acre per day of ground water finding its way into the system.

Note: Infiltration is only calculated on sanitary (SAN or SUN) data, not storm HYD or STO data.

COMMAND INL - stormwater INLet

Purpose: Allows specification of inlet characteristics and/or performance. Adds a runoff hydrograph generated by a HYD or UHY command to the system (as specified in the subsequent CHA or PIP command) modified by inlet performance.

Structure:

INL id, itype, subtype, store, depr, wgrate, lgrate, hcurb, lcurb, perim, area, plot

1) id - inlet identification number (used to help analyst keep track of the inlets in the HYDRA dataset.

2) itype - one digit code, between 1 and 9, that informs program the inlet type to be analyzed or designed. (codes listed below)
   1) grate on grade
   2) curb opening on grade
   3) combination grate and curb opening on grade. NOT CURRENTLY ACTIVE - TRY USER DEFINED OPTION.
   4) slotted drain on grade
   5) user-defined (command EFF must follow immediately after INL command in this case). ON GRADE ONLY.
   6) grate in sump condition
   7) curb opening in sump condition
   8) combination grate and curb opening in sump condition. NOT CURRENTLY ACTIVE - TRY USER DEFINED OPTION.
   9) slotted drain in sump condition.

3) subtype - one digit code, between 1 and 7, used for grate and combination grate & curb opening inlet types (i.e., for inlet types one, three, six, & nine). This parameter must be set to zero if considering the other three inlet types. (codes listed below)

   1) parallel bar P-1-1/8"
   2) narrow parallel bar P-1-1/8"
   3) curved vane
   4) tilt bar - 45 degrees
   5) safety parallel bar P-1-7/8-4"
   6) tilt bar - 30 degrees
   7) reticuline

4) store - storage register for excess flow for ANALYSIS of inlets on grade. If used, it must be a number from 26 to 50 and represent the storage location for all excess flows. When using the DESIGN mode (for either sump or on grade), set this parameter equal to zero.

5) depr - depth of inlet depression, in feet

6) wgrate - width of inlet grate, in feet. If the inlet is a curb opening (types two and seven), enter a value of zero.

7) lgrate - length of inlet grate, in feet. If the inlet is a curb opening (types two and seven), enter a value of zero.
8) hcurb - height of curb opening or width of slot opening, in feet
9) lcurb - length of curb opening or slotted drain, in feet
10) perim - OPTIONAL - inlet perimeter, in feet. Used only for grate inlet in sump condition.
11) area - OPTIONAL - area of orifice opening of the inlet, in square feet. Used only for grate inlet in sump condition.
12) plot - OPTIONAL - enter 1 if a plot is desired; enter 0 or leave blank if no plot is desired or if Rational Method is used.

Notes:

1) Grate length can be greater than four feet, although if this occurs, a message will be displayed.
2) Zeros should be used as place holders to skip past unwanted parameters. For example, designing a grate inlet (with a curved vave), on a grade, with the plot option, would result in a command similar to that depicted below:

"INL id 1 3 0 depr wgrate 0 0 0 0 0 1"

If no plots were desired, the same command would revert to the following form:

"INL id 1 3 0 depr wgrate"

COMMAND IPU - Individuals Per Unit

Purpose: Establishes population per "sanitary unit" for SUN command.

Structure:

```
IPU  ipu
```

ipu - number of individuals per each sanitary unit (SUN).

COMMAND JOB - JOB title

Purpose: Initiates job and enters job title.

Structure:

    JOB jobtitle

jobtitle - up to 50 alphanumeric characters describing your job.

Note: This must be the first command and there may be only one JOB in any command file. It allows you to "load" a job title into HYDRA that will be printed on every page of your output.

COMMAND LOA - LOAd lateral from file

Purpose: LOA and SAV are sister commands that allow you to save and load system data to and from a disk file. HOL and REC are more commonly used for this purpose but SAV and LOA are very useful if you want to save the flows at the end of a lateral onto a disk for recall back into the system on another run.

Structure:

LOA filename

filename - name of the disk file where lateral data was saved with the SAV command. The file name should use standard MS-DOS file name formats. The user should not contain any drive or path references (such as "B:" or "C:\HYDRA\") as HYDRA assumes that the file will be on the same drive and path as the input dataset. A ".SAV" extension is the default, but the user can use any other extension at their discretion.

COMMAND LOS - Additional pipe LOSses

Purpose: This command allows for the input of pipe losses in addition to those determined by the sewer system configuration. Losses input through this command will be included in the hydraulic gradeline computations.

Structure:

```
LOS  ploss

     ploss    - A value for losses, in feet, in addition to those
                calculated by the hydraulic gradeline computations,
                experienced by the pipe described by the previous PNC
                command.
```

Note: This loss applies only to the previous pipe.

COMMAND LPC - List the Pipe Costs

Purpose: This command calculates and prints cost of pipe in place in a tabular form. The costs calculated are the unit costs resulting from parameters that you define with CST, EXC, PCO, and TSL commands.

Structure:

LPC diam, start depth, end depth, increment

1) diam - inside diameter of pipe in inches.
2) start depth - invert depth, in feet, at which cost estimate table is to start.
3) end depth - invert depth, in feet, of last cost estimate.
4) increment - the number of feet between each cost estimate. If left blank or set to 0, HYDRA will set to 1. This parameter must be a whole number.

COMMAND MAP - MAP scale

Purpose: The SAN, SUN, STO, and HYD commands all require entry of land segment areas in acres. If the user chooses, he may enter square inches instead with a negative sign preceding each value. HYDRA converts square inches to acres using the value set by this command. Even if the MAP command is in the command file, the user may still choose to enter acres directly.

Structure:

```
MAP  scale

    scale      - the scale of the map being used in feet per inch.
```

COMMAND NEW - start NEW lateral

Purpose: This command is used to start a new lateral. It clears some storage registers and loads the lateral name.

Structure:

NEW lateral name

lateral name - up to 20 alphanumeric characters.

COMMAND PAV - PAVed surface parameters

Purpose: Sets hydrographic parameters for paved portion of land segment used by HYD.

Structure:

```
    PAV  n, depthpud, slope, topud, toweep, timedrain,
         roofdrain
```

1) n - friction factor (Manning's "n") for the paved area.
2) depthpud - average depth of the puddle storage in inches if the ground is very flat.
3) slope - slope of the paved surface for no puddles.
4) topud - maximum diversion ratio to "weeping" puddle storage.
5) toweep - portion of rain on paved surface that is diverted to puddles. Try 0.2 as a start.
6) timedrain - time in minutes to drain weeping puddle storage. A good place to start is 15 minutes.
7) roofdrain - drainage rate from flat roof storage in cfs per acre. A good place to start is 0.4 cfs per acre.

COMMAND PCF - Pipe Cost Factor

Purpose: An optional command for cost estimates. Its purpose is to increase cost of pipe in place to reflect the additional cost of higher class pipe as trench depth increases and/or extra cost for laying the pipe.

Structure:

PCF depth/factor, depth/factor ... (up to a maximum of 20 sets or a minimum of 2 sets - all values of depth must increase).

nx) depth - depth from the surface to the pipe invert, in feet.

ny) factor - some factor which when multiplied by pipe cost from the PCO command will result in a reasonable adjustment for a class of pipe.

COMMAND PCO - Pipe COsts

Purpose: One of the required commands for cost estimate. It establishes the cost per foot of pipe in place.

Structure:

PCO dia, $/ft dia, $/ft ... (up to a maximum of 20 sets or a minimum of 2 sets - all values of dia must increase).

nx) dia - inside diameter of pipe, in inches.

ny) $/ft - cost in dollars per foot of pipe laid in place but not backfilled.

COMMAND PDA - Pipe DAta

Purpose: This command establishes design criteria for use with the PIP command.

Structure:

PDA n, mindia, mindepth, mincover, minvel, minslope, maxdia

1) n - pipe friction factor (Manning's "n").
2) mindia - the minimum diameter of a pipe in a "free design", in inches.
3) mindepth - in a free design, HYDRA will not place the invert shallower than this depth. Units are in feet.
4) mincover - in a free design, HYDRA will not allow cover over the pipe to be less than this value. Units are in feet.
5) minvel - in a free design, HYDRA will not allow the full flow velocity to drop below this value. Units are in feet per second.
6) minslope - in a free design, HYDRA will not select a slope less than this value. Units are in feet per foot, and MUST be greater than zero (0.0).
7) maxdia - OPTIONAL - If it is used, HYDRA will not select a pipe larger than this diameter. This parameter should probably not be used for the first run on any design. Units are in feet.

Note: PDA is usually placed near the beginning of a input dataset. It MUST be used somewhere prior to the first PIP command. Any changes in design criteria (i.e. two different pipes having different roughness factors) can be accomplished by repeated use of this command.

COMMAND PEA - PEAking factor

Purpose: In order to calculate sanitary flow in a sewer system, HYDRA must be given a "peaking factor" curve. This peaking factor curve is used to translate average daily flow into peak daily flow. This command is used to supply HYDRA with that curve.

Structure:

PEA cfs/factor, cfs/factor ... (up to a maximum of 20 sets or a minimum of 2 sets - all values of cfs must increase).

nx) cfs - accumulated average daily flow from SAN and SUN commands.
ny) factor - the peaking factor. Normally ranges between 1.0 and 4.0 .

Note: The last data set should be greater than the maximum expected cfs in the system, otherwise the interpolating features of the command may yield unexpected results. Also, experience indicates that your curve should start at zero, as initial flows in a system are often very small.

COMMAND PIP - Circular PIPe

Purpose: This is one of the transport commands. It moves water from one point to another in a circular pipe. A PDA command is required somewhere in the command file ahead of the first PIP command.

Structure:

PIP length, grup, grdn, invup, invdn, mindia, lscost, trfac

1) length - the length of the link or pipe, in feet.
2) grup - elevation of the ground at the upstream end of the link, in feet.
3) grdn - elevation of the ground at the downstream end of the link, in feet.
4) invup - OPTIONAL - elevation of the invert of the pipe at the upstream end of the link, in feet.
5) invdn - OPTIONAL - elevation of the invert of the pipe at the downstream end of the link, in feet.
6) mindia - minimum diameter of pipe, in inches.
7) lscost - the lump sum to be added to the link cost calculated by HYDRA when cost parameters are used.
8) trfac - trench cost factor.

COMMAND PNC - Pipe-Node Connection

Purpose: This command specifies the connection of links and nodes for the computation of the hydraulic gradeline. Each PNC statement must immediately follow a PIP statement.

Structure:

PNC Unode, Dnode, Bdn, Angle, Bench

1) **Unode** - Node number connecting the upstream end of the link specified by the previous PIP statement.
2) **Dnode** - Node number connecting the downstream end of the link specified by the previous PIP statement.
3) **Bdn** - The width of the manhole at the downstream end of the link (or the width of Dnode). This value must be set to 0 for the outfall link.
4) **Angle** - The angle between the link specified by Unode and Dnode above and the outflow pipe leaving Dnode.
5) **Bench** - For this parameter a value of 0, 1, 2, 3, or 4 should be entered to signify the type of benching present at Dnode:

   0 - flat bench
   1 - 1/2 bench
   2 - full bench
   3 - improved bench

   The default value is a flat bench.

Note: Four or five parameters will be accepted.

COMMAND PON - surface PONding

Purpose: This command allows surface ponding of flows HYD, GUT, and GET commands. Pond size can be designed or reviewed.

Structure:

PON A(1), A(2)

A(1) - desired pond capacity in cubic feet. (Enter zero to design pond size.)

A(2) - maximum return discharge in cubic feet per second (cfs). (Enter zero to design maximum return discharge.)

COMMAND PUM - PUMp

Purpose: Lifts hydraulic gradient the specified amount and sizes discharge pipe.

Structure: There are 4 different pump commands:

```
PUM 1, length, elevout, maxvel  >>> design new fixed
                                    speed pump ...

PUM 2, length, elevout, maxvel  >>> design new variable
                                    speed pump ...

PUM 3, length, elevout, maxdis  >>> analyze existing
                                    fixed speed pump ...

PUM 4, length, elevout, maxdis  >>> analyze an existing
                                    variable speed pump.
```

1) length - the length of the discharge pipe, in feet.
2) elevout - discharge invert elevation, in feet.
3) maxvel - maximum velocity in the discharge pipe, in feet per second (fps).
4) maxdis - maximum possible discharge of the pump, in cubic feet per second (cfs). Includes all friction losses, head losses, etc.

COMMAND PUT - PUT gutter flow into storage

Purpose: This is one of the hydrographic commands. It is ignored by HYDRA on non-hydrographic runs. It is very similar to the HOL command in function except it stores away the gutter hydrograph. This gutter hydrograph is recalled by GET.

Structure:

```
PUT  number
```

number - a number from 26 to 50 that labels the storage location. These storage locations are identical to those used by the inlet command, and can be re-used any number of times - however, if the same register is used more than once the previous data will be destroyed. Recalling information from a PUT register can only be done with a GET command.

COMMAND RAI - RAInfall data

Purpose: The Rational Formula requires an intensity versus duration curve. This command allows you to set the values of the curve.

Structure:

RAI time/intensity, time/intensity ... (up to a maximum of 20 sets or a minimum of 2 sets - all values of time must increase).

nx) time - the duration of a specific rainfall intensity, in minutes, which is experienced in a storm of a certain return period (such as a 5 year storm).

ny) intensity - rainfall intensity in inches per hour.

Note: It is always wise to make the last two points the same intensity so that the extension of the curve will never go negative.

COMMAND REC - RECall lateral

Purpose: Recalls flow into the system that was stored using the HOL or DIV command.

Structure:

REC number

number - a number from 1 to 25 representing the storage location of data previously stored by a HOL or DIV command.

Notes:

1) CAUTION - HOL and DIV commands use the same 25 registers to store flow, so do not inadvertently overwrite them - however, HYDRA will warn you of this problem.
2) There is a limit to 5 recalls at one node. If more than 5 laterals contribute to a downstream link, insert a short PIPe (say 0.1 foot) and then recall the rest.

COMMAND REM - REMarks

Purpose: Allows a line for remarks or comments.

Structure:

```
REM  any alphanumeric information
```

COMMAND RES - REServoir

Purpose: This command allows the user to analyze the effect of in-line storage on system flows. It is ignored on non-hydrographic runs.

Structure:

RES Cap, Return

-- Option 1 --

1) Cap - The capacity of the reservoir in cubic feet. If cap is set to 0.0, HYDRA will select the required capacity and print the size immediately following the command. If you select the size and it is not sufficient, HYDRA will use what it can, bypass the excess and let you know the capacity was exceeded.

2) Return - The maximum rate of return to the system from the reservoir, in cubic feet per second. If the upstream system flow is less than this value, the reservoir is not used. If the upstream system flow ever exceeds this value, the reservoir will start to fill.

-- Option 2 --

Analysis using user supplied stage-storage and stage-discharge curves as specified in the SST and SDI commands, respectively. Routing by the storage-indication method is perfpormed.

1) Cap - 0 (zero value needed)
2) Return - 0 (zero value needed)

Notes:

1) Because this command must deal with a system hydrograph for its analysis, flows being carried in the INF, SAN, and FLO registers are transferred to the storm hydrograph, and these registers cleared. This causes two minor problems that should not normally have a significant impact on the results.
2) Must be immediately preceeded by a transport command.

COMMAND RET - RETurn

Purpose: The FIL command in the master command file transfers reading to a slave disk command file - the RET command finishes the slave file and returns the reading sequence back to the master disk file. (The return can only be to the master file.)

Structure:

RET (no parameters)

COMMAND SAF - SAFety factors

Purpose: Provides a safety factor to be applied to flows calculated by HYDRA.

Structure:

```
SAF  san, inf, storm, flo
```

1) san - safety factor for sanitary flows generated by the SAN and SUN commands.
2) inf - safety factor for infiltration flow generated by the INF command working on data supplied by the SAN and SUN commands.
3) storm - safety factor for all flows generated by either the STO or HYD commands.
4) flo - safety factor for flow generated by the FLO command.

COMMAND SAN - SANitary flow

Purpose: Enters sanitary flow into the system. It uses data supplied in the PEA and GPC commands.

Structure:

SAN acres, ind/acre

1) acres - area in acres served by the following link. The user can input map measurements in square inches (as a negative value) using the MAP command to make the conversion to acres.

2) ind/acre - the equivalent population per acre. This value normally ranges from 6 to 50.

COMMAND SDI - Stage-Discharge Curve

Purpose: This command allows the user to input a stage-discharge pairs for the purpose or analyzing the effect of in-line storage on system flows. This command is intended for use with the RES and SST commands.

Structure:

SDI stage, dschrge, stage, dschrge, ..., stage, dschrge

1) **stage** - **the stage of the reservoir in feet.**
2) **dschrge** - **the discharge of the reservoir corresponding to the stage specified above, in cubic feet per second.**

Notes:

1) This command must come before the RES command specifying the reservoir to which it applies. It will apply to all following reservoirs, that are to be analyzed using the storage-indication routing methodology, until a new SDI command is encountered.
2) Up to 20 stage, discharge pairs can be accepted.

COMMAND STE - STEp

Purpose: Sets the length of the step in hydrographic simulation.

Structure:

```
STE  min/step
```

min/step - minutes per step. If this command is not used the min/step defaults to 15 minutes. In this case there will be 15*96 or 24 hours total simulation.

COMMAND STO - STOrm flow

Purpose: Enters sub-basin data for use in the Rational Formula determination of storm water design flow. There are three options for this command, each allowing an additional level of complexity in determining the time of concentration.

Structure:

STO acres, C, time

1) acres - number of acres in service area (or square inches if input with a negative value).
2) C - a value between 0.0 and 1.0 which represents the fraction of rainfall that runs off.
3) time - minimum time, in minutes, that runoff takes to get from the most remote point of the sub-basin to the inlet.

-- or --

STO acres, C, oup, odn, odis, gtime

1) acres - same definition as above.
2) C - same definition as above.

3) oup - upper overland flow elevation, in feet.
4) odn - lower overland flow elevation, in feet.
5) odis - overland flow distance, in feet (measured from oup to odn).
6) gtime - gutter time, in minutes, (measured from odn to the inlet).

-- or --

STO acres, runoff coef, oup, odn, odis, gup, gdn, gdis

1) acres - same definition as above.
2) C - same definition as above.
3) oup - same definition as above.
4) odn - same definition as above.
5) odis - same definition as above.

6) gup - upper gutter elevation, in feet.
7) gdn - lower gutter elevation, in feet.
8) gdis - length of the gutter, in feet (measured from odn to the inlet).

COMMAND SST - Stage-STorage Curve

Purpose: This command allows the user to input stage-storage pairs for the purpose of analyzing the effect of in-line storage on system flows. This command is intended for use with the RES and SDI commands.

Structure:

SST Stage, Strge, Stage, Strge, ... Stage, Strge

1) Stage - The stage of the reservoir, in feet.
2) Strge - The storage of the reservoir corresponding to the stage specified above, in cubic feet.

Notes:

1) This command must come before the RES command specifying the reservoir to which it applies. It will apply to all following reservoirs, that are to be analyzed using the storage-indication routing methodology, until a new SST command is encountered.

2) Up to 20 stage/storage pairs can be accepted.

COMMAND SUN - Sanitary UNits

Purpose: Enters the number of "sanitary units" contributing to the sanitary flow at a node.

Structure:

SUN units, acres

1) units - the number of "units" (as in dwelling units) contributing to the system at this node.

2) acres - OPTIONAL - The number of acres containing the units. If the MAP command has been used, square inches can be entered (as a negative value) and HYDRA will calculate the acreage.

Notes:

1) IPU, GPC and PEA commands must precede this command.
2) The set of commands GPC, IPU, and SUN can be included in the same link with the SAN command and HYDRA will assume that there are 2 contributing areas.

COMMAND SUR - SURcharge

Purpose: Provides the necessary parameters to analyze the possibility of surcharging the system.

Structure:

SUR entranceloss, dwnstrmsurchg

entranceloss	- a coefficient ranging between 0.0 and 1.0 that corresponds to the entrance loss.
dwnstrmsurchg	- the depth, in feet, of the tailwater over the top of the downstream end of the pipe. (Normally zero).

COMMAND SWI - criteria SWItch

Purpose: This command establishes the method by which HYDRA is to analyze storm and/or sanitary flows.

Structure:

SWI switch

switch	- a number 1, 2, 3, 4, or 5
1	- Traditional analysis only. All commands having to do with hydrographic simulation are to be ignored.
2	- Hydrographic and Sanitary analysis only.
3	- Sanitary analysis only.
4	- Rational Method analysis only.
5	- Hydrographic analysis only.

COMMAND TRA - TRAnsfer system flow to surface flow

Purpose: This command enables system flow (pipe flow) to be added to surface flow (gutter flow).

Structure:

```
TRA  (no parameters required)
```

COMMAND TSL - Trench side SLope

Purpose: One of the required commands for HYDRA to make a cost estimate of a pipe in place. It sets the slope of the trench side walls above the top of the pipe.

Structure:

TSL depth/slope, depth/slope ... (up to a maximum of 20 sets or a minimum of 2 sets - all values of depth must increase).

nx) depth - depth from ground surface to the invert, in feet.
ny) slope - slope of the portion of the trench above the top of the pipe when the invert is at the above depth, in feet per feet.

COMMAND TWE - TailWater Elevation

Purpose: This command allows for the input of a tailwater elevation at the system outfall.

Structure:

```
TWE  elout
```

elout - the tailwater elevation at the system outfall, in feet. This command will only be recognized after the PNC command describing the outfall link.

COMMAND UHY - User HYdrograph

Purpose: Enables the user to use externally produced hydrographs in an analysis.

Structure:

UHY filename

filename - the filename of the hydrograph data set. The HYDRO produced hydrographs have the file extension "QT".

Notes:

1) Data in the file must be in the following format (HYDRO uses this format):

```
Line 1 : Comment Line 1
Line 2 : NPTS
Line 3+: N, T(N), Q(N)

    where: NPTS = number of points
              N = point number
           T(N) = time value (minutes)
           Q(N) = flow value (cfs)
```

2) The data in lines three through the end must be in adjacent 10 space fields beginning in column 1.

COMMAND UNP - UNPaved surface parameters

Purpose: Sets the hydrographic parameters for unpaved or pervious area. (Used with the HYD command.)

Structure:

UNP n, intrcpt, depth1, depth2, maxinf, satinf, idecay, timerec, interflo, delay, deplete

n	-	friction factor (Manning's "n") for unpaved ground surface. (Default = 0.05)
intrcpt	-	portion of precipitation directed to interception storage one. (Default = 0.5)
depth1	-	maximum capacity of interception storage one (inches). (Default = 0.15)
depth2	-	maximum capacity of interception storage two (inches). (Default = 0.15)
maxinf	-	maximum infiltration capacity (inches/hour). (Default = 0.5)
satinf	-	saturated infiltration capacity (inches/hour). (Default = 0.08)
idecay	-	infiltration decay constant. (Default = 0.05)
timerec	-	infiltration recovery time (minutes). (Default = 120)
interflo	-	portion of infiltration to interflow. (Default = 0.0)
delay	-	delay before interflow appears (hours). (Default = 2)
deplete	-	time to deplete interflow (hours). (Default = 48)

Notes:

1) The following parameters can be used as a guide for the selection of the above coefficients:

DESCRIPTION OF GROUND SURFACE	Depth 1 Depth 2	Maxin	satin	infildecay	timerec
Hilly forest	.40				
Flat woodland	.30				
Old pasture and fields	.25				
Flat lawn and parkland	.20				
Sloping lawns	.15				
Undisturbed forest		5.0	3.0		
Managed woodlot		4.0	1.0-1.5		
Grassland-shrubs		3.0	1.0-1.5		
Old pasture		2.0	0.7-1.0		
New pasture-lawns-playing fields		1.0	0.3-0.4		
Row crops-sandy loam		0.6	0.2-0.3		

COMMAND UNP (Continued)

DESCRIPTION OF GROUND SURFACE	Depth 1 Depth 2	Maxin	satin	infildecay	timerec
Row crops-clay loam		0.4	0.1-0.2		
Bare soil-sand, gravel		0.7	.30-.45		
Bare soil-medium		0.4	.15-.30		
Bare soil-clay loam		0.2	.05-.10		
Woodland, slope 2%				.005	15
Woodland, flat				.01	60
Grass & gravel soil, slope 2%				.05	30
Grass & gravel soil, flat				.07	150
Bare soil (clay), slope 2%				.08	120
Bare soil (clay), flat				.1	480

2) If all default parameters are adequate, then the UNP command may be omitted. If one or more parameters require different values, the command must be included with all 11 parameters.

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HYDRAIN - INTEGRATED DRAINAGE DESIGN COMPUTER SYSTEM

VOLUME IV. CDS - CULVERTS

by:

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for:

Structures Division, HNR-10
Federal Highway Administration

Under Contract #DTFH61-88-C-00083

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TABLE OF CONTENTS

TABLE OF CONTENTS
(continued)

List of Tables

<u>Preface</u>

This report presents documentation for the HYDRAIN system. HYDRO, HYDRA, CDS, WSPRO and HY8 are five nonproprietary hydrology and hydraulic engineering programs incorporated in the HYDRAIN system. The HYDRAIN personal computer oriented system operates these engineering applications with programs written in the C language. The system is designed with an open architecture for expansion. HYDRAIN is sponsored as a Pooled Fund Project (PFP) of 29 State highway departments and is managed by the Federal Highway Administration (FHWA). The system is expanding with flexible lining design logic and integrated culvert analysis logic under development. Graphic output options are also under development and are available in some areas already.

Within the HYDRAIN concept, the HYDRO, HYDRA, CDS, and WSPRO allow the user to consistently input, edit and run relevant input data files and to scroll through output files. With these applications "short", one-line, and "long", multiple line, help is provided within an editor that services all applications.

HYDRAIN integrates hydraulic and hydrology programs into a unified system. The intent of the integration is to enable users to then learn basic principles of how to operate an application and file manipulation and then be able to apply the same principles to other applications and files within the system. One guiding principle is a **command land input format**. This trend in hydraulic programs is typified by HEC-2 and HYDRA. It is very pragmatic. WSPRO also adopted the command line method. Another guiding principle is a **generic input editor** that works the same for each integrated program--HYDRO, HYDRA, CDS, and WSPRO. The input file for each integrated program is a line by line command language that identifies the computation and/or provides the required data. Each line of data is preceded with a two or three-letter command. A typical command is **XS**, indicating a cross section; both WSPRO and CDS read this command. Another typical command is **PDA**, indicating the line contains the design parameters for pipe analysis (<u>PI</u>PE <u>DA</u>TA); HYDRA reads this command.

A strength and a weakness of HYDRAIN is the need to know beforehand the sequence of commands that will result in making an application work. The commands are, of course, the batch input file. The user needs to know a proper sequence or know how to put one together. The sequences are termed "footprints." Given the right "footprint," an application will work; note that footprints are not necessarily unique, in that there may be several ways to get a job done. This documentation includes footprints to get users started and user support will aid in proper "footprint" design. Once a user has a library of footprints for his applications, the use of HYDRAIN should save considerable time and money. HY8 is a stand-alone interactive BASIC program that accepts inputs during processing; HY8 does not require footprints and leads the unfamiliar user through input preparation. All engineering programs but HY8 are batch oriented, and three steps are built into the process of using them: input file generation, programs execution, and output file screen review or listing. HY8 accepts inputs and generates outputs as the engineering program logic is executing.

HYDRO Program

HYDRO is a command line hydrology program. FORTRAN code for HYDRO was developed to combine existing approaches for rainfall and runoff analyses into one computerized program. Within the HYDRAIN system, it can be used independently or it can be used to generate input data for other engineering programs within the system.

HYDRO offers many hydrologic analysis options to the engineer. Each is site specific based on user inputs.

- Design Rain Using Digitized NWS Information or State-Supplied Files - Calculates the rainfall intensity for a specific return period, duration, and site.
- Design Hyetograph using Yen and Chow's method - Calculates the rain versus time plot for a return period, duration and site.
- Intensity-Duration-Frequency Curve Using Either the NWS Information or State-Supplied Files - Analyzes a specific site and creates two graphs: a plot of points for durations up to 24 hours, and a detail graph of the first two hours. Can be input to HYDRA.
- Design Flow by Rational Method - Uses a specific return period, duration and intensity to determine the peak flow for the site.
- Design Flow by USGS Regression Method - Uses USGS log-log regression equations with user-supplied parameters to determine design flow.
- Design Flow by log Pearson type III - Calculates the peak flow for given data.
- Design Hydrograph by USGS Dimensionless Hydrograph - Calculates a hydrograph to support storage routing within HYDRA or CDS.
- Maximum Observable Flood - estimates the largest flow at a site based on the envelope of all floods in a region.

HYDRA Program

HYDRA is a command line gravity pipe network hydraulics program. FORTRAN code for HYDRA previously existed and the Pooled Fund work effort included substantial improvements. HYDRA is a storm and sanitary sewer system analysis and design program. It can be used either to model an existing sewer system or to design a new system.

HYDRA generates storm flows by using either the Rational Method technique, hydrologic simulation techniques, or accepting a hydrograph generated by a HYDRO analysis. It can be used to design or analyze storm, sanitary or combined collection systems. HYDRA can handle up to 1,000 contributing drainage areas and 2,000 pipes. Additionally, HYDRA can be used for cost estimating. The Rational

Method approximates the peak rate of runoff from a basin resulting from storms of a given return period. HYDRA's hydrologic simulation models the natural rainfall-runoff process. In the simulation, runoff hydrographs are generated, merged together, and routed through the collection system. Inlet limitations can be analyzed: inlet overflow can be passed down a gutter system, while inlets in sumps can store water in ponds.

In the HYDRA design process, the program will select the pipe size, slope and invert elevations given certain design criteria. Additionally, HYDRA will perform analyses on a existing system of pipes (and/or ditches). When an existing system of pipes is overloaded, HYDRA will show suggested flow removal quantities as well as an increased pipe diameter size as an alternative remedy. HYDRA includes HEC-12 inlet theory hydraulic gradeline calculations, and an ability to route flow through internal storage sites using a storage-indication method.

HYDRA requires the forming of an input file of commands to describe the sewer system. Commands for HYDRA are placed in a logical sequence usually from upper to lower elevation. Is it possible that several command sequences can produce the same result. An input file is established for a particular collection system by the engineer and then the HYDRA program is executed. To change the characteristics of the collection system, the input file can be edited.

The HYDRA program requires design criteria for the pipes: friction factor (Manning's "n"), minimum diameter, ideal depth, minimum ground cover, minimum velocity (full flow), minimum slope, and maximum diameter. The friction factor is necessary for both analysis and design, while the remaining values are needed only for design. In the case of a design, the program selects invert elevations and slope as well as the physical sizing of each link given certain design criteria, whereas in the analysis mode, pipe alignment and sizing are predetermined and the impact of proposed flows are analyzed. Design criteria can be changed for each pipe if so desired. HYDRA is not an optimization program, thus individual case studies need to be run and analyzed by the engineer.

CDS Program

CDS is a command line culvert program. The Culvert Design System provides the user with two broad options for investigating culvert characteristics. CDS can either (1) hydraulically design a culvert or (2) analyze an existing or proposed culvert. CDS has capabilities for investigating a variety of hydrograph relationships, culvert shapes, materials, and inlet types. With CDS, the engineer can request any of six culvert types: round concrete, round metal, arch concrete, arch metal, oval concrete, and concrete box. CDS routes hydrographs, considers ponding, and overtopping.

The Design option selects a culvert size and number of barrels that are compatible with engineering data, environmental constraints, and site geometry. In this option, hydraulic performance data are calculated for each new culvert system design. The Review option provides hydraulic performance data for any preselected combination of culvert type and size, inlet type, slope, and number

of barrels. The initial design and analysis options may be followed by up to five additional culvert types or flow frequencies so that a full spectrum of risk scenarios or economic considerations can be simulated at the same time.

Two possible flow scenario methods can be selected: (1) steady state or irrigation, that assumes constant flow through the culvert, or (2) dynamic, that simulates drainage flow conditions. The dynamic option can route a hydrograph through the culvert system using three hydrograph alternatives: a user input hydrograph, a hydrograph produced by the HYDRO program, or the use of an internally produced default hydrograph (simulating semi-arid, high plains conditions). Additionally, the dynamic flow scenario can accommodate upstream pond storage.

CDS will determine culvert size based on the design headwater, headwater/diameter ratio, inundation, outlet velocity, cover limitations, or any combination of these parameters. The program will automatically increase the number of barrels when the upper limit for the greatest vertical dimension is exceeded. There is a limit of six barrels for commercial size culverts and five for concrete box culverts. The program can also be used to assess flood hazards, environmental assessments of upstream pond coverage, downstream flooding, channel impact, inlet type and beveled inlet evaluations, and reservoir facilities which use a culvert type structure for the spillway. Based on these data the program will proceed to identify the flow type and the outlet conditions for velocity, Froude number, and brink depth.

WSPRO Program

WSPRO is a command line step backwater program for natural channels with an orientation to bridge construction. The Water Surface Profile Computation Model Microcomputer Program has been designed to provide a water-surface profile for six major types of open channel flow situations:

- Unconstricted flow.
- Single opening bridge.
- Bridge opening(s) with spur dikes.
- Single opening embankment overflow.
- Multiple alternatives for a single job.
- Multiple openings.

WSPRO was originally developed by the United States Geologic Survey (USGS) for the Federal Highway Administration. The model was a batch mode mainframe program, written in FORTRAN. The members of the Pooled Fund Project decided to use WSPRO as the bridge waterways analysis element of the Integrated Computerized Drainage Design System. WSPRO was downloaded to the microcomputer by the USGS and FHWA. The microcomputer version of WSPRO, is dated August 1987.

The command input file forms a logical description of the physical characteristics of a waterway. Once the user is comfortable with this method of data setup, the program provides a step backwater method for determining water surface profiles. The scheme is similar to the Corps of Engineers HEC-2 program. Both WSPRO and HEC-2 are acceptable to the Federal Emergency Management Agency. WSPRO has the advantage that it utilizes more recent approximation techniques for the backwater effects associated with bridge constrictions.

HY8 Program

HY8 is an interactive culvert analysis basic program that utilizes the FHWA analysis methods and information published by pipe manufacturers. The program includes modules to allow the user to interactively enter, save, and edit data. HY8 will compute the culvert hydraulics for circular, rectangular, elliptical, arch, and user defined geometry. Additionally, improved inlets can be specified and the user can; analyze inlet and outlet control for full and partially full culverts, analyze the tailwater in trapezoidal and coordinate defined downstream channels, analyze flow over the roadway embankment, and balance flows through multiple parallel culverts. A hydrograph can be produced and routed.

The initial logic involves calculating the inlet control and outlet control headwater elevations for the given flow. These elevations are compared and the larger of the two is used as the controlling headwater elevation. Tailwater effects are taken into consideration when calculating these elevations. If the controlling headwater elevation overtops the roadway embankment, an overtopping analysis is done in which flow is balanced between the culvert discharge and the surcharge over the roadway. A balancing technique is also used in the case of multiple barrels. If the culvert is less than full for all or part of its length open channel computations are performed.

A series of data menus, data screens, summary screens, and output screens guides the user through the program. Each menu contains several options to match the desired culvert configuration, while the data screens prompt the user for specific dimensions and coordinates. Summary screens allow the user to edit entered data or change menu selections. Output screens display the output as calculations proceed; hard copy is only obtained using the "print screen" key.

There are three main groups of data to be entered into the program: initial culvert data, downstream channel data, and roadway data. Within the program, the user is sequentially led from one group to the next. From these sets of data, the program develops culvert performance data with or without overtopping. A performance curve can be plotted on a computer with graphics capabilities. For a given flow, HY8 can design a culvert. In addition to developing performance curves, the program generates rating curves for uniform flow, velocity, and maximum shear for the downstream channel. Culvert outlet velocities, inlet control head, and outlet control head are also calculated; energy dissipator design is possible.

HYCHL and HYCULV Programs

HYCHL and HYCULV are command line, flexible channel and culvert programs that are under development. HYCHL will solve for fixed and flexible lined channels. HYCULV will integrate state-of-the-art culvert flow methods and utilize features of both CDS and HY8.

Operation

To allow the software to be used by a wide audience, HYDRAIN operates on an IBM XT/PC or equivalent microcomputer with 640 K RAM, a hard disk, and a monochrome monitor. A math coprocessor is needed. Engineering programs are in Fortran 77. The utility software and editor is in C. The HYDRO, HYDRA, CDS, and WSPRO programs have command line input with are "short" and "long" help files available through the same editor that operates any of them. HY8 has also been integrated into the HYDRAIN system and is available as an interactive BASIC culvert program.

Report Contents

The remaining section of this volume provides technical reference and user instructions for the CDS program. There are a total of 6 such volumes for HYDRAIN.

Disclaimer

FHWA, the pooled fund States and their agents have, within the limits of their resources, tested and debugged the HYDRAIN shells. The engineering programs derive from several varied sources and were adapted to HYDRAIN and also underwent testing and debugging. However, this is a very large and somewhat complicated system of logic and coded implementation and errors and omissions may yet remain in the software. Therefore, use at your own risk. Please document problems and errors and report to FHWA. User support and technical assistance will be provided to pooled fund States. Agents of these States using the system should channel their requests for support or assistance through their sponsor State.

1. Introduction

This documentation is intended to serve as a technical, user and program supplement to the Culvert Design System (CDS) report.[1] It consists of three sections. The first section introduces CDS, describing its intent and providing a system overview. The second section investigates the technical and operational methods used by CDS to analyze a culvert. The final section provides user documentation, guiding the user through the steps required to design or review a culvert without detailed technical explanations.

The objective of this documentation will be to provide the user with an understanding of CDS as it has been implemented under the Pooled Fund Project.

The CDS code was developed by the Wyoming State Highway Department[1] and has ten years of operations to its credit within which bugs have been identified and eliminated. Hydraulic routing computations are a feature of this code; ponding analyses to downsize openings can be conducted. Additionally, the code can iterate through alternative sizes subject to headwater or pond surface area constraints to identify trial designs. Trial designs can be found for steady-state design flows or for design hydrographs representing a dynamic flow condition.

2. System Overview

System Background

The release of the Culvert Design System (CDS), in December, 1980, provided a generalized technology for the analysis of traditional issues in culvert design, as well as a state specific technology suitable for evaluating temporary upstream pond storage. CDS allowed the engineer to directly avoid using manually time consuming flood routing and improved culvert hydraulics techniques. These techniques were more easily applied by using an automated computer system than developing them by hand. CDS is written in FORTRAN, and constructed in a modular fashion to facilitate changes and enhancements.

The system provides four distinct types of analysis that can be classified into two broad options: design and review. The design option selects a culvert size and number of barrels compatible with user selectable criteria. With this option, the User can request that the program consider any or all of the following culvert types: round concrete, round metal, arch concrete, arch metal, oval concrete (horizontal placement only), and concrete box.

There is an upper limit of six barrels for commercial culverts or five for concrete box culverts. This limit is only in the design mode; any number of barrels or odd sizes can be reviewed. At present all culverts must have the same inlet elevation, slope and size unless manual manipulations of the site data are made which is beyond the scope of this documentation; in general, an analysis is made for each culvert barrel location and type after which the resulting performance curves must be manually combined.

The review option provides hydraulic performance data for a specific culvert identified by the User. In this option, the User identifies the culvert type (in accordance with those listed above), size, inlet type, slope, and number of barrels.

Within the design option, the User must select one of two methods of design: peak (irrigation) design or hydrograph design. The peak design method ignores any upstream pond storage and selects a culvert capable of passing the peak discharge. The drainage design method computes the effects of temporary upstream pond storage and determines a culvert size meeting the constraints set by the User. If the design mode produces a culvert that the designer believes is unsuitable then the User may use the program to review the size of the structure that is considered appropriate or can change the design criteria until the desirable sizes is obtained. Although the program produces a culvert size meeting the user specified constraints engineering judgement must ultimately be used in selecting a suitable structure. The review option uses the same equations as the design option.

Provision has been made for the User to obtain data for manually plotting a culvert performance curve. This is accomplished by the user specifying that the headwater rating curve data be written to a file that plot programs can access.

With the design discharge, the system will first size a culvert using the design option and then review this design culvert size using the five performance discharges. It is not necessary to input all five performance discharges in order to obtain a design.

The review option can also be used to obtain a culvert performance curve for a predetermined culvert size and geometry. With this option, the program reviews the specified culvert size, type, and geometry using the discharges provided (six maximum) or will provide a discharge rating curve for a range of discharges through the specified maximum.

The system has a choice of three hydrograph input alternatives in both the design option or review option.

Alternative 1.

The User inputs up to six hydrographs per run. The hydrographs may be contained in DOS files or typed into the CDS batch file.

Alternative 2.

The user inputs the peak discharge and flood volume (ac-ft) for each hydrograph. The program computes a hydrograph internally based on Wyoming's flood studies (1). The internal shape is quite similar to hydrographs produced from methods such as SCS for a given volume and peak discharge.

Alternative 3.

The third alternative is to input synthetic unit hydrograph ordinates to replace the internal synthetic hydrograph. The peak discharge and volume are then input to allow the program to compute hydrographs based on the synthetic shape.

The regional peak discharge and flood volume studies provide data for Wyoming's use of the internal hydrograph. These studies are for semiarid regions having watersheds ranging from 0 to about 15 square miles. Although the internal hydrograph shape was determined from Wyoming data it has been compared to many other hydrograph methods where the shapes were found to closely correlate with other methods provided that the same peak discharge and flood volume are used in the comparison. This is not to say that Wyoming's peak flood frequency and volume relationships are to be used in other regions but the Wyoming hydrograph shape is one of many reasonable shapes and should only be used provided a peak discharge and flood volume are computed for the region under study. The USGS lag time method will also produce a hydrograph comparable to the internal hydrograph if the peak discharge and volume from the lag time analysis are input into the program. In other words the internal hydrograph is a reasonable generic shape provided the peak discharge and flood volume are input.

System Operation

The program consists of five major modules that are transparent to the user with the command line inputs: stage-discharge, stage-storage, roadway overflow, culvert design/review and flow distribution.

Stage-discharge is used to define the culvert tailwater conditions. The user can input a cross section for a single section stage-discharge analysis based on Manning's equation or the user may input a rating curve.

Stage-storage is used to define upstream ponding geometry for flood routing. This is not necessary for peak culvert analysis. The user can input stream cross sections that are used to compute the stage-storage relationship or input his own tabular relationships. This might be necessary in order to define a complex upstream storage geometry or to reflect complex tailwater situations such as backwater from existing culverts or bridges.

Roadway overtopping provides a depth discharge rating curve to define road overflow. This provides a culvert headwater depth including the road overflow characteristics.

Culvert design/review provides data for culvert hydraulics and flood routing as well as outlet scour.

Flow distribution provides a more detailed hydraulic analysis of the single-section used in the stage-discharge analysis. This may be useful in erosion control design or bridge or channel scour analysis. This analysis is optional and is not required for culvert analysis.

Having quantified the hydraulic site conditions, CDS selects an initial trial size culvert when in the design option (both steady-state and dynamic methods of design). This initial trial size is an 18-inch round or equivalent size commercial culvert. The minimum box culvert size is a 4-foot square opening (in accordance with Wyoming practices). The user may select an incremental hydrograph time interval (flood routing period) or use the internally generated time interval based on the hydrograph shape, thereby allowing the program to compute an incremental volume for routing. With this incremental volume selection, CDS computes an average discharge over the selected time interval for use in flood routing. A headwater rating curve is computed using the tabular stage-discharge relationship for tailwater conditions. The computation considers both inlet and outlet control parameters and selects the governing control.[4] Having determined the headwater rating curve, CDS uses the stage-storage relationship and the rating curve to apply the Storage Indication routing technique.[5]

From the hydrograph time interval an incremental flood volume arriving at the site during the selected time interval or routing period can be identified.

Mathematically, the basic flood routing equation is:

$$I - O = \frac{S}{t} \qquad (1)$$

where:

I	=	the average hydrograph inflow to the pond,
O	=	the average outflow of the pond,
S	=	the upstream storage volume, and
t	=	the time interval.

This can be expanded as:

$$2\frac{S_1}{\delta t} - O_1 + I_1 + I_2 = 2\frac{S_2}{\delta t} + O_2 \qquad (2)$$

where:

S_1	=	the storage volume in the pond at the beginning of the incremental time period, δt,
O_1	=	the instantaneous outflow at the beginning of the incremental time period, δt,
I_1	=	is the instantaneous inflow at the beginning of the incremental time period, δt,
I_2	=	is the instantaneous inflow at the end of the incremental time period, δt,
S_2	=	is the storage volume in the pond at the end of the incremental time period, δt,
O_2	=	is the instantaneous outflow at the end of the incremental time period, δt, and
δt	=	the time interval.

The basic flood routing equation as used in CDS considers the accumulation of storage in a culvert's temporary upstream pond as depending upon the difference between the rates of inflow and outflow. For an interval of time, the basic flood routing equation can express this relationship as:

$$\delta S = Q_i \cdot \delta t - Q_i \cdot \delta t \quad (3)$$

where:

δS = the change in pond storage during time period, δt, and

Q_i = the average rate of inflow flood discharge from the watershed.

This yields:

$$\frac{(I_1 + I_2)}{2} = \delta S + \frac{O_1}{2} + \frac{O_2}{2} \quad (4)$$

On the initial trial for a given culvert size, CDS assumes:

$$Q_d = (Q_i + Q_{i-1}) / 2 \quad (5)$$

where:

Q_d = the average outflow discharge being routed through a culvert occurring over time interval, δt.

Once these equations have been developed, upstream pond routing is accomplished using conventional reservoir routing techniques, specifically, the Storage Indication method.[5] A headwater rating table (upstream discharge versus stage curve) is first developed. Then the table is linked with the stage-storage relationship. The routing equations utilize these tables at each time step to calculate the pond discharge at that time increment.

After an incremental volume balance is reached, the time is advanced another increment, δt, on the hydrograph. Each subsequent incremental volume balance must necessarily consider the amount of pond storage, S_2, occupied by the previous incremental volume balance.

This processing of the hydrograph through successive time increments continues until the outflow hydrograph drops below 0.5 ft^3/s. CDS monitors the increase in upstream pond depth to ensure it does not exceed a design maximum (termed design headwater). If the design headwater is exceeded, the program increments the culvert opening, returns to the beginning of the hydrograph and repeats the flood routing process until a culvert size is obtained that precluded the upstream pond from exceeding the design headwater. In addition, CDS also monitors the pond's surface area and the ratio of headwater over vertical culvert dimension (H_w/D), and similarly increments the culvert size should these optional input constraints be exceeded.

In the design mode, CDS will increase the number of culvert barrels if it cannot satisfy the design headwater, surface area, and H_w/D ratio limitations with a culvert having the greatest allowable vertical culvert dimension specified for the site. The greatest allowable culvert dimension is an input value to prevent CDS from selecting a culvert that is not compatible with embankment cover requirements. CDS increments the number of barrels when it reaches the upper limit for the greatest vertical dimension established by the available structure geometries. The maximum vertical barrel dimension for each culvert type are 10 feet for boxes, 21 feet for round metal, 8 feet for round concrete, 158 inches for metal arches, 54 inches for concrete arches and 116 inches for concrete ovals. CDS can be used for any size of culvert in the review mode. For example, a 22-foot round metal culvert or a 13-foot round concrete culvert could be reviewed.

Once a culvert size commensurate with the design headwater, pond surface area, H_w/D ratio and cover limitations has been determined, CDS proceeds to identify the flow type. Knowing the flow type allows CDS to quickly identify the outlet conditions and thus compute velocity, flow type, Froude number, and brink depth.

When the peak (steady-state) method is selected, CDS omits the flood routing process and only seeks to satisfy the design headwater limitation or to review the specified size, for the peak discharge, Qp.

Program logic can be subdivided into six general engineering categories. These are: stage-discharge, stage-storage, hydrograph, headwater rating curve, flow types and outlet conditions, and flow distribution. These categories are discussed in a technical, operational, and engineering sense in the following chapters to facilitate understanding of CDS by the engineer.

3. System Technical and Operation Information

Stage-Discharge

A unique site feature affecting a culvert's performance is the stage-discharge relationship, often termed a rating curve. This relationship is portrayed graphically by plotting flow depth versus discharge. From this relationship, the program can obtain the various tailwater values necessary in evaluating flow characteristics immediately downstream of the culvert outlet.

The cross section profile and slope used to compute the stage-discharge relationship must be typical of downstream conditions. This relationship predicts the natural flow depth of a flood for any particular discharge within the capacity limits of the channel cross section.

This program does not employ a water surface profile to compute the stage-discharge relationship. Rather, a single section normal depth analysis that assumes that channel profile slope approximates the hydraulic gradient is used. A typical channel cross section located near the outfall or at a nearby constricted controlling section is recommended.

The various depth discharge relationships necessary in defining the stage-discharge (or tailwater rating curve) are computed using Manning's equation:

$$V = \frac{1.486}{n} \cdot R_h^{0.667} \cdot S_o^{0.5} \qquad (6)$$

where:

- V = the weighted average velocity occurring within a waterway channel's cross sectional area, in ft/s,
- R_h = the hydraulic radius of a waterway (waterway area divided by wetted perimeter), in feet,
- S_o = the downstream channel slope, in ft/ft, and
- n = Manning's friction value for a waterway.

Also;

$$Q = V \cdot A \qquad (7)$$

where:

Q	=	the total discharge occurring within a cross section of area a, in ft^3/s,
V	=	the weighted average velocity occurring within a waterway channel's cross sectional area, in ft/s, and
A	=	the channel's waterway cross sectional area, in square feet.

The stage-discharge (and flow distribution) logic uses the channel cross section in one of two ways to compute hydraulic properties and the stage-discharge relationship.

1. With a homogeneous channel cross section, the program provides hydraulic characteristics for the entire cross section. The output reflects only average values for the entire cross section. A homogeneous cross section is defined as having uniform Manning's roughness coefficient and geometry across the entire cross section.

2. When the cross section is subdivided to reflect irregular shapes or different vegetal and friction patterns, the output will reflect the hydraulic properties from each individual subsection. The program can accommodate up to nine subsections per cross section. In the analysis, program logic subdivides each subsection further into relatively equal increments.

The computational procedure is similar for both of the above applications. Both applications use equations 6 and 7 for the discharge and velocity relationships. The application of these equations is accomplished by starting at the lowest point within a subsection and using simple geometry relationships, computing the initial incremental cross sectional area and wetted perimeter as well as an incremental discharge. Next, the depth is incremented to a higher elevation level and the process is repeated.

The Froude number evaluates the gravitational and momentum effects on the flow and is computed using the equation below:

$$F_r = V / (g \cdot H_d)^{0.5} \tag{8}$$

where:

F_r	=	the Froude number (a dimensionless measure of gravity's effect on the state of flow),
V	=	the weighted average velocity occurring within a waterway channel's cross sectional area, in ft/s,

g = the gravitational acceleration (32.2 ft/sec^2), and

H_d = the channel's cross section hydraulic depth, in feet.

The program evaluates the streambed stability by estimating the tractive shear occurring on the bed. This is a gross estimate found in most texts.[6] It is computed using the equation below:

$$Tau = \gamma \cdot S_f \cdot T_w \qquad (9)$$

where:

Tau = the tractive shear, in lbs per square foot,
= the unit weight of water (62.4 lbs/ft^3),

S_f = the friction slope in the downstream reach, in ft/ft. CDS assumes that this equals the downstream channel slope, in ($S_f = S_o$), and

T_w = the tailwater depth, or the maximum depth of flow occurring in the natural channel just beyond the culvert outlet, in feet.

Comparing the tractive shear with allowable values for various streambed materials as found in modern open channel texts provides the user with an estimate of channel stability.

<u>Stage-Storage</u>

Routing flood hydrographs through a culvert and over a roadway embankment requires quantification of upstream storage. The program accomplishes this by generating an internal stage-storage table. In this case, 'stage' is the upstream pond depth above the culvert inlet flow line and not the natural flow depth discussed under Stage-Discharge. Storage is the volumetric storage occurring upstream from the culvert for a given stage or pond depth. The program provides three alternative means of computing the stage-storage relationship.

Alternative 1

Input channel cross sections and channel slope. Provision has been made for the user to include ten or more cross sections in order to define the upstream stage-storage characteristics. Propagation of a template cross section is an optional feature.

If the upstream cross section is not located at the culvert entrance, (i.e. the cross section is "offset" from the culvert entrance) the program will internally assume the upstream cross section that is provided also defines the cross section at the culvert inlet. In other words, if the cross section is offset, CDS will propagate the cross section downstream until it reaches the culvert location.

The stage-storage relationship is computed using either the cross section provided at the culvert inlet by the user or the first upstream cross section as the initial cross section at the culvert inlet, and then any other upstream cross sections. A downstream cross section may be input to serve as the cross section reflecting upstream storage provided the elevations are adjusted accordingly; the user is cautioned that in this simplistic solution, the downstream section must be typical of upstream storage capacities.

"Humps" or islands in a cross section introduce a unique problem in the internal stage-volume definition. If only one cross section is used to define upstream pond storage and it reflects an island or "hump", the program must then assume that this island or "hump" has no length. With large, permanent islands, this assumption could introduce a significant error in the stage-storage relationship. Where "humps" are small or reflect temporary or mobile bars, this assumption may be acceptable. The problem of permanent islands can be alleviated in one of two ways. The first way is to provide several upstream cross sections sufficient to define the island length; say one cross section across both ends and another across the center of the island. The second way is to compute and input a stage-storage table as discussed earlier.

The internal logic procedure for computing the stage-storage relationship is based on the average end area method commonly associated with earthwork computations. The average end area equation is internally incremented through the elevation levels (stages) identified on the cross section, thereby resulting in a table of stage-storage relationships. Whether any given upstream cross section will be used in defining the storage prism depends on whether the ponded water will be sufficiently deep so as to reach upstream to that cross section. This is done by having the program search and determine that portion, if any, of a cross section which is within the pond. Upstream from the last cross section and still within the incremental storage prism for any incremental depth, the program assumes a triangular-shaped prism by projecting the upstream slope (input) to where it intercepts the incremental pond level. This projection identifies the length, L_v, and computes this volume by setting the last upstream cross section end area to zero. Note, that portion of the upstream pond storage lying above the roadway fill slope which is excluded from the pond storage. Compared to the entire area, this portion is relatively small.

The surface area for any incremental level of ponding (inundated area), A_p, is computed in a similar manner using the cross section top widths, t', for a given depth (stage) of pond and the distance, L_v, between cross sections.

The pond's surface area for the remaining triangular portion on the upstream end of any incremental prism assumes one of the top widths to be zero rather than, more correctly, the width of the natural flood stage at that particular point.

Alternative 2

A second method uses an externally computed stage-storage table which can be input to override the internally computed stage-storage table computed using the cross section alternative.

Contour mapping facilitates identification of complex upstream storage areas. Planimetering the surface area for various elevation levels provides areas that can be used to manually compute a stage-storage relationship. The stage versus area inundated is tabulized manually and input to the system to define this relationship.

Alternative 3

The user can input a depth area table and the program will compute the volume using the average end area technique.

The user can do several things to improve the accuracy of the stage-storage relationships:

1. When using the downstream cross section to define the upstream storage pond is justified, be sure to raise all cross section elevations so they are relative to the streambed elevation at the culvert entrance.

2. The storage existing above the upstream fill slope will be ignored. At present, the program does not account for this storage. This storage could be significant with high fills and/or wide cross sections which would justify entering manually computed stage-storage and area-inundated tables.

3. When either the downstream cross section or an available upstream cross section does not adequately reflect the cross section at the culvert entrance, then consider using the road's centerline cross section as the initial cross section to be used in computing the stage-storage relationship. Again, be sure to adjust the elevations to agree with the culvert's inlet elevation and also adjust the lateral distances to normalize a section taken from a skewed or curved roadway centerline.

4. Always use the average channel slope occurring upstream from the last upstream cross section to compute the stage-storage relationship. This slope will often vary from the average slope through a site.

5. The user should be aware of inaccuracies arising from "humps" or islands in the cross section. Small, mobile and temporary islands should not introduce significant errors, whereas large islands could result in a gross under-design. Input at least three cross sections when a permanent island or "hump" will significantly affect the storage; consider developing and entering a stage-storage and area inundated table as an alternative. It may be possible to synthesize the necessary cross sections where none are available by estimating

an island's length using the survey plan view or aerial photographs and using this as the length between the synthesized cross sections.

6. Use the stage-storage table input alternative on very complex sites. This added design cost should be weighed against the site's importance, however.

7. Use average distance rather than survey station distances between upstream cross sections for storage areas having a sinuous shape.

8. When storage is significant the estimate of the upstream storage volume is one of the most significant variables.

Hydrograph

In order to route floods through the culvert, roadway, and site geometry, it is necessary to define a hydrograph; the time versus discharge relationship for flood.

As stated earlier, CDS has the capability of considering two hydrograph alternatives in both the design option or review option. The first alternative allows the user to input a hydrograph of his choice for a given discharge. The second alternative is where the user does not elect to input a hydrograph, but to use a default, internal dimensionless hydrograph based on Wyoming's flood studies.(3) These studies are for semiarid regions having watersheds ranging from 0 to 15 square miles.

Producing data for the first hydrograph alternative is left to the user. Any appropriate procedure for developing a hydrograph can be used. The FHWA report, HEC-19, outlines several different methods for creating a hydro-graph.(5) Additionally, most States have their own practices that can be used. The HYDRO model can also be used to generate a hydrograph; this approach can apply the many hydrographic options in HYDRO.

Input data consists of a series of incremental discharges and their corresponding incremental time values. The minimum number of discharge and time values needed to describe a hydrograph would be three (as in the commonly used "triangular" hydrograph). The maximum number of discharge and time values is 100. This alternative makes CDS viable in any geographic region in the world provided a reasonable hydrograph can be synthesized.

The rest of the hydrograph portion will dwell on the second hydrograph alternative. It is the result of research, conducted by the USGS in Wyoming, that produced a dimensionless hydrograph curve.

The total volume contained under the hydrograph curve for a given frequency is identified by the USGS report as a function of drainage area.(3) The standard error of estimate for the volume relationship can be significantly improved by also including such watershed parameters as maximum basin relief, basin slope, and channel slope in the expression used to compute the hydrograph volume. Therefore, because the flood volume varies with the standard error for various combinations of watershed variables, the user must identify and input the desired volume, such that the user is confident that a permissible level of accuracy has been achieved.

From the USGS study report, it was possible to identify a simple hydrograph shape that provided a reasonable simulation of the time/discharge relationship for watersheds in semiarid regions having approximately 15 or fewer square miles in contributing area. This shape is a function of volume and peak discharge.

Headwater

The logic for computing the headwater include inlet control nomographs, Bernoulli's equation for full-flow and a water surface profile analysis for partially flowing full. The flow type analysis indicates the flow conditions for a given discharge. To avoid discontinuities between culvert sizes and their respective capacities for a given discharge, the LARGER of the INLET control and OUTLET control methods of headwater computation is selected. The methodology determines the upstream pond depth, identifies flow types, and computes the culvert barrel's outlet properties: velocity, depth, and Froude number.

The inlet control headwater for various culvert and inlet types is defined by headwater equations obtained through regression of data generated by laboratory studies conducted by the National Bureau of Standards between 1955 and 1967. An example of such an equation is shown below:

$$H_{wi} = (A + B \cdot X + C \cdot X^2 + D \cdot X^3 + E \cdot X^4 + F \cdot X^5) \cdot D \qquad (10)$$

where:

H_{wi} = the inlet control headwater, in feet,

D = the height of the culvert barrel, in feet,

A to F = regression coefficients for each type of culvert, and

X = a function of the average outflow discharge being routed through a culvert, culvert barrel height, and, for box and pipe arch culverts, the width of the barrel.

A complete table of coefficients used for each culvert type is found in the publication, "Culvert Design System" referenced in the bibliography.[1]

The headwater for outlet control is computed using a form of Bernoulli's equation as shown below:

$$H_{wo} = H + h_o - \left[L \cdot S_o \right] \qquad (11)$$

where:

H_{wo} = the outlet control headwater, in feet,

H = the head loss through the culvert including barrel friction, entrance losses, and outlet velocity head, in feet,

h_o = the vertical distance from the outlet culvert invert to the hydraulic grade line, in feet,

L = the length of the culvert barrel, and

S_o = the downstream channel slope.

The vertical distance for part full-flow at the outlet, h_o, has been approximated by using the larger of either the tailwater or the hypothetical value below:

$$(d_c + d) / 2 \tag{12}$$

where:

d_c = the critical culvert flow depth for a specific discharge, in feet, and

d = the normal flow depth that would occur within a culvert assuming uniform flow, in feet. HEC-5 discusses a similar variable, D, the culvert height.[4] For part full-flow, these variables do not have the same meaning, although, as the culvert approaches full-flow, d becomes equal to D.

This situation is considered to be tailwater control which is one type of outlet control.

When the culvert reaches full-flow, the outlet energy line is defined by using the larger of either the tailwater or the outlet energy (which as mentioned above is expressed only as the vertical culvert height). This situation is considered to be barrel control, another form of outlet control.

The product of culvert length and slope defines the elevation difference between the culvert inlet and outlet as required by Bernoulli's equation.

Any time the average outflow discharge is equal to or greater than the full barrel flow, a full barrel condition is used.

The head or energy, H, required to pass a given quantity of water through a culvert consists of three components, a velocity head, H_v, an entrance loss, H_e, and a barrel friction loss, H_f. This energy is obtained through ponding water at the entrance and the energy equation may be expressed as:

$$H = H_v + H_e + H_f \tag{13}$$

The velocity head is, in turn, governed by flow in the barrel. Full-flow gives a velocity head of:

$$H_v = V_f^2 / 2g \tag{14}$$

where:

H_v = the velocity head,

V_f = the full-flow velocity, in ft/s, and

g = the gravitational acceleration (32.2 ft/sec^2).

In the case where barrel flow is not full, a partial flow area is used to generate a velocity, V, which is bounded by the velocity at critical depth, V_c, and the full flowing velocity, V_f such that $V_c \geq V \geq V_f$.

These cases are dependent upon inlet control and/or the ability of the culvert slope to generate this velocity. Outlet control will require yet another velocity head consideration.

If the tailwater momentum is greater than the pipe flow, the velocity head is computed using the velocity associated with either the tailwater depth or the culvert barrel height, whichever is less. If tailwater momentum governs and the tailwater depth is less than the flow depth that would occur in the culvert barrel due to uniform flow (exclusive of inlet/tailwater/culvert length), then the velocity associated with this flow depth governs and is used to compute the velocity head.

The second part of the energy equation is the entrance head loss. This loss is expressed in terms of the velocity and an entrance loss coefficient that is unique for various types of commonly used culvert entrances. The following expression is used to compute the entrance head loss for all cases:

$$H_e = k_e \cdot V^2 / 2g \tag{15}$$

where:

H_e = the entrance loss,

k_e = the entrance loss coefficient,

V = the unique flow velocity (such that $V_c \geq V \geq V_f$), and

g = the gravitational acceleration (32.2 ft/sec^2).

The final part of the energy equation, barrel friction loss, is obtained through manipulation of Manning's equation. The expression for barrel friction loss, seen below, is continuous between partially full and full flows.

$$H_f = \left| \frac{29.1 \times n^2 \times L}{R_h^{1.33}} \right| \left| \frac{V_f}{V_o} \right|^{0.667} \frac{V^2}{2g} \qquad (16)$$

where:

H_f = the barrel friction loss,

R_h = the hydraulic radius of the culvert, in feet,

n = Manning's friction value for the culvert,

L = the length of the culvert barrel, in feet,

V_f = the velocity when the culvert is flowing full, in ft/s,

V_o = the outlet velocity ($V_c \geq V_o \geq V_f$), in ft/s,

V = the flow velocity ($V_c \geq V \geq V_f$), in ft/s, and

g = the gravitational acceleration (32.2 ft/sec^2).

The hydraulic radius is subject to the same boundary scheme as velocity. It corresponds to the barrel flow conditions bounded by critical and full-flow conditions such that $R_c \leq R_n \leq R_f$.

Flow Types and Outlet Conditions

This section discusses the methods for determining the flow types used to compute the hydraulic conditions at the culvert outlet. CDS does not presently contain the logic to evaluate the need for outlet protection or the protection requirements, but does generate the necessary input to such logic.

CDS internally identifies the flow types using USGS criteria. Once the flow types have been identified, the program then estimates the hydraulic properties existing at the outlet. These properties include outlet flow depth, brink depth, velocity, specific force, and Froude number. These are the desirable properties to evaluate outlet protection alternatives. The flow types are also useful in determining the location of hydraulic jumps, if any occur.

Overflow/Overtopping Analysis

This portion of the program is optional and can be used only with the design and review alternatives. Two options are available for each alternative:

1. Input a depth versus roadway overflow discharge rating table, or

2. Input roadway profile coordinates.

Option 1 allows the user to input any roadway overtopping rating curve that will simulate the overtopping for such things as road overtopping and overflow structures. The table discharges must always increase with depth.

Option 2 uses roadway profile coordinates to internally compute a roadway overtopping depth discharge table.

The unsubmerged broad crested weir equation (17) using a coefficient of discharge at 3.0 is used in the computations. Actual coefficients of discharge vary from 2.9 to 3.08 (HDS-1). This is roughly a ± 6 percent possible error depending upon depth. This level of accuracy is considered reasonable when considering the accuracy of the discharges and volumes used in the analysis. Future program improvements may include more accurate technology in estimating overtopping discharges as well as estimates of potential erosion. The incipient overtopping depth (DHWO) can be used to determine if it is advisable to raise or lower the gradeline; however, the elevation is not adjusted internally.

$$Q_{ov} = 3.0 \cdot L \cdot H^{1.5} \tag{17}$$

where:

Q_{ov} = the weir discharge, in cfs,

L = the crest length, in feet, and

H = the height relative to the crest (head), in feet.

The elevations used in the roadway profile do not require the same datum as those used in the channel x-section of the stage-storage or stage-discharge data decks.

Flow Distribution

Flow distribution, by itself, does not aid in designing or reviewing a culvert, rather, when combined with a stage-discharge analysis, generates and accumulates incremental discharges across a typical cross sectional profile. This will illustrate, for a given elevation or discharge, what percentage of the flow will be found at any point in the cross section.

Other information provided by the flow distribution for each of the incremental segments used in computing the stage-discharge relationship include Froude number, tractive shear, velocity, and discharge. The flow distribution also sums the incremental discharges to obtain the total subsection and hence channel discharge. In addition, the flow distribution provides the average depth, velocity, and Froude number. The nonuniform velocity coefficient, and nonuniform momentum coefficient, for the cross section are also provided by this option. The flow distribution option also identifies the maximum velocity occurring within the cross section, the specific force of the cross section, and the cross section's specific head.

4. User Documentation

The Command Approach - Organizing the Data

CDS operates through the command language concept. This means that data entry and data analysis are all dictated by user-supplied commands. A command is a very specific entity that describes one basic task that CDS can recognize. There is only a set number of commands in CDS's vocabulary and they must each follow a specific format. Currently there are 31 commands that CDS can recognize, although this number is subject to change as long as improvements are being added to CDS. An abbreviated glossary of these commands is given in Table 1. A complete definition, to date, of these commands along with their definitions and format specifications is included in Appendix B (Note: These are the long helps which are available during editing).

(Note: A conversion program can be used to convert old CDS batch files into the new format without retyping the data. This conversion program is available and is called CONVERT.BAS. It is executed by loading it into BASICA and running. It may be very useful to transform the old batch file into the new command format for users that already have existing files.)

The new Command CDS has been updated to include the following features.

1. Free format command structure.
2. Input Hydrographs from DOS files (created by HYDRO).
3. Water surface profile computations for partial full-flow.
4. Headwater rating curves are available for both peak and hydrograph modes.
5. Propagation of upstream cross sections can be accomplished.
6. Stage-discharge for tailwater is much like WSPRO allowing transfer of input data.
7. Stage/Area data can be input to compute storage volume table.
8. Multiple culvert design or review can be chained together in one run.
9. Printer program allows selection of output data to print.
10. The hydraulic analysis is based on the HEC-5 manual.

Table 1. Culvert Command Glossary

1. **Site Data Commands**

XS	Analysis Cross Section Header
XT	Template Cross Section Header
XR	Road Cross Section Header
GR	Cross Section Data (Follows Header)
GT	Template Adjustment(s), (Follows Header)
SSC	Stage-Storage Data
SDC	Tailwater Rating Data (Stage-Discharge)
SOC	Overtopping Rating Data (Overtop Depth-Discharge)
SSA	Stage-Area Data
N	Manning's Friction Factor(s), (Follows Header)
SA	Friction Break Point Data (Flows **N** Command)
USL	Upstream Slope Above Highest Cross Section

2. **Logical Choices Commands**

2.a **Analysis Commands**

PR	Analyze/Review for Given Peak Flow(s) and Size(s)
HR	Analyze/Review for Given Hydrograph and Size(s)

2b. **Design Commands**

PD	Design (Select Size Given Type(s)) for Given Peak Flow(s)
HD	Design (Select Size Given Type(s)) for Hydrograph(s)

3. **Culvert Type Commands**

RCP	Round Concrete Pipe
CMP	Corrugated Metal Pipe-Round
CPA	Concrete Pipe Arch
MPA	Corrugated Pipe Arch
ECP	Elliptical Concrete Pipe
RCB	Reinforced Concrete Box

4. **Culvert Data Command**

SL	Essential Culvert Data (Slope, Length, Etc)

5. **Hydrologic Condition Commands (One or Other)**

Q	Peak Flow(s)
RPD	Return Period(s) to Label Results (Optional)
HYD	Hydrograph Data or Data File (Immediately Precedes Run)

6. **Program Control Commands**

JOB	First Command
PRT	Second Command - Selects Output Volume
REM	Remark - Doesn't Influence Command String
RUN	Initiates Run
END	End Command String

Commands are the data that a user must specify to describe a system for analysis. These commands may be arranged in almost any order, provided they follow a few, simple guidelines. These guidelines ensure that the users system is described appropriately and logically, and will become more clear as the user gains familiarity with this section and the examples provided in the appendix. Once these commands are arranged in their final working order, they are collectively referred to as a command string. The command string is what CDS needs to define a system model for analysis.

Table 2 provides information on command line footprints. The typical sequence is site data commands, logical choice command, culvert type command, and hydrologic condition command. Careful reading of Table 2 will save a user time and avoid input errors.

CDS commands operate in "free format" fashion; that is CDS is structured to read data from an input file containing a command in the first three columns and data from columns 4 - 70. The data can be placed in any column and does not need decimal places. The data can be separated by either a space or comma or combinations thereof. The data will be executed in sequence.

Continuation of a command with many variables, or extremely lengthy variables, is achieved by one of two methods:

1. By re-entering the command name on the next line, or

2. By continuing to the next line and leaving the command name blank; the parameter information is added as normal.

There are no real limits to the number of lines that could be used for continuation of parameter information. There are limits to the total number of parameters that can be entered on a particular command. These are discussed in the long helps and documentation.

Ordering commands in a CDS command string is a relatively easily acquired skill. For instance, using Table 2 as an example, note that the **JOB** command is first. This command initiates the computations, and provides space for the title or commentary that will appear in the output. The next command is the **PRT**, which informs the program what information is to be printed out. The following commands allow for a tailwater rating curve, possible overtopping, possible routing, and specify the culvert type and type of analysis. A **RUN** command gets CDS to make the analysis; another **RUN** command allows a change to the analysis and must, at least, be followed by another culvert type. An **END** command terminates the command line file.

In conclusion, recall that data are input into CDS by way of commands and that a working arrangement of these commands is called a footprint.

Table 2. CDSV5 Footprints

A. <u>Program Control Sequence (JOB, RUN, END)</u>

```
JOB
 .
 .
 .
"Command String"
 .
 .
 .
RUN
Updated Commands (optional) including Culvert Type
RUN
Updated Commands (optional) including Culvert Type
END
```

B. <u>Command String (typical sequencing of different type of commands)</u>

```
JOB or RUN
 .
 .
 .
"Site Data Command(s)"          :Tailwater, Storage Prisms, Overtopping
"Logical Choice Command"        :Analyze or Design
"Culvert Type Command"          :Material & Entrance Condition
"Culvert Data Command"          :Essential Culvert Data
"Hydrologic Condition Command":Flow(s) or Hydrograph
 .
 .
 .
RUN
```

C. <u>Site Data Commands(s) (XS, GR, XT, XR, *N, SA, USL, SDC, SSC, SSA, SOC)</u>

XS is a header command with a station that precedes cross-section data.

GR is a cross-section data command.

XT is a header command that precedes template cross-section data.

GT provides data to adjust template cross-section data (up, down, shrink).

XR is a header command that precedes cross-section data that corresponds to the road grades to allow overtopping analysis.

Table 2 (continued)

Possible command groupings are:

XT this grouping specifies a cross-section template which is then
GR transposed and utilized when subsequent cross sections are needed in the command string. Templates are not necessary, but can be convenient if only one set of field data exist.

If a template is used, it should immediately follow the JOB command. Thus, template data should appear first.

XS this is a cross section
GR and its cross-section data.

XS this is a cross section that utilizes template data from
GT earlier in the command string. GT transposes template.

XR this is a roadway cross section.
GR (templates will not work for these)

XR this command grouping is necessary for tailwater-rating.
GR or GT It needs a negative station with magnitude equal to the length
N of culvert thus locating it at the culvert exit.
SA

USL this command provides the slope upstream from the last cross section and is needed to compute upstream storage prism.

The station in the XS, XT, and XR commands governs use of cross-section data. The "zero" station is located at the culvert entrance. Positive station numbers are used to define the upstream storage prism for generation of a stage-volume relationship. The XR needs a negative station giving the culvert centerline distance from the culvert entrance to the road cross section. One XS command must have a negative station corresponding to the culvert exit to start the generation of a tailwater rating curve. The only essential command is an XS command group for tailwater rating or alternatively, a SDC command to directly supply the tailwater data. Overtopping data and stage-storage data may either provided with XS and XR commands or can also be supplied with SSC, SSA, and SOC commands.

C. <u>Logical Choices Command (PR, HR, PD, HD)</u>

These commands direct the programs to either analyze or design for either a peak flow or a hydrograph.

D. <u>Culvert Type Command (RCP, CMP, CPA, MPA, ECP, RCB)</u>

These commands specify the type culvert and its inlet conditions. All culverts in a multiple setting are the same invert and are of the same type.

Table 2 (continued)

E. Culvert Data Command (SL)

This command provides essential culvert data.

F. Hydrologic Condition Commands (Q, RPD, HYD)

These commands provide either peak flows or analysis.

G. Typical Footprints

1. Analyze a box culvert to pass a given flow. L = length of culvert.

```
JOB
PRT            :print control
XS - L         :locate section at culvert exit
GR
N
SA
RCB
PR             :peak review
SL  A  L  E1  E2
Q  q1          :peak flow
RPD            :associated return period
RUN
END
```

2. Develop a performance curve for case one.

Replace "Q q_1" with
"Q q_1 q_2 q_3 q_4 q_5

The program will analyze each q_i.
The user has to tabulate HW vs q_i and generate a plot.

3. Select a design size for case one.

Replace "PR" with "PD"

4. Analyze a corrugated metal pipe culvert with storage routing and roadway overtopping. (OH is vertical distance to road from invert.)

```
JOB
PRT
XS  0.0
GR
USL
GR - L/2       :station at center of culvert
XS - L
```

Table 2 (continued)

```
GR
N
SA
HR              :hydrograph review
CMP
SL  A  L  E1  E2  OH
HYD             :hydrograph
RUN
END
```

This command will do a routing/overtopping with a storage prism defined by one cross section and the upstream slope.

5. Design a corrugated metal pipe culvert with allowable headwater depth less than overtopping depth using storage routing.

```
JOB
PRT
XS  0.0
GR
USL
XS - L
GR
N
SA
HD  AHW GVD :hydrographic design
CMP
SL
HYD             :hydrograph can be data or a "file"
RUN
END
```

6. Add more definition to the upstream storage prism with a cross section at STA Z and redo case 5.

```
JOB
PRT
XS  Z
GR
XS  0.0
GR
USL
 .
 .
 .
"as before:case 5"
```

Table 2 (continued)

7. Use a template cross section and redo case 5.

```
JOB
PRT
XT          :template header
GR          :x-section data associated with template
XS  0.0
GT
USL
XS - L
GT
N
 .
 .
 .
"as before:case 5"
```

H. Set up Hint

There is active short help on all the commands and the data fields in the generic editor. Type in the footprint and move the cursor to the right to determine data needs and units.

The HYDRAIN Environment

For those users who have obtained CDS as part of the Federal Highway Administration's **HYDRAIN** package, additional information is required to run CDS within that system. Furthermore, HYDRO - the hydrology component of HYDRAIN can be used to provide hydrographs, for use in drainage analyses. HYDRAIN and HYDRO documentation should be consulted for instructions. The following sections discuss the procedures for operating the HYDRAIN system shell and the CDS input program - otherwise known as the generic editor. Users not desiring to operate in the HYDRAIN environment can skip this section.

Operating the HYDRAIN System Shell

CDS, as well as the other HYDRAIN software packages, is implemented through the use of what is known as the HYDRAIN "system shell". This shell is a separate program that ties the HYDRAIN system together and allows individual components to be accessed. The following text deals specifically with the interaction between the Hydrain System Shell and CDS; the operation of the other packages will be dealt with separately in their respective documentation.

Before work on a specific CDS dataset can begin, the HYDRAIN shell must first be entered and CDS accessed. This process is begun, from DOS, by typing the command **HYDRAIN** and striking the carriage return (denoted by <CR>). Two introductory screens will then be displayed. Pressing <CR> each time will allow the program to continue to the Main Menu.

Entering the Generic Editor

During initial session use of the generic editor, the user will be looking at a "blank" screen with a banner that will be displayed across the top. The cursor will be located, on the start of the first command line, in the top left corner of the blank area; the blank area, itself, is the work area where the command line input file is located. The first action to take is to type the first command "JOB" in the first three spaces and then an optional line of text to the right to lable the input/output. Type <CR> to enter the first line and then enter the second command line. The user may wish to have a footprint in mind to keep the input session productive. Help is available using the "F1" function key. Help consists of short command definitions and long text for each command. Furthermore, active help displayed as input is underway in one line messages that pertain to each command or to each data field that are on the line associated with the command.

After the introductory screens have been cleared the user enters the Main Menu which contains the following choices:

- Input/Edit - input or edit data for HYDRA, WSPRO, HYDRO, CDSV5, or HYCHL;
- Execute - run HYDRA, WSPRO, HYDRO, CDSV5, HY8V3, EQUAT, or HYCHL;
- Utilities - DOS commands, file operation, HYDRAIN setup;
- System Info - long help files for selected topics in HYDRAIN; and
- Quit - exit the HYDRAIN system.

Selection of an option within the Main Menu is accomplished by simply using the left and right ARROWS to move the cursor to the desired procedure or by striking the highlighted letter of the desired option. As each of the procedural options is highlighted by the cursor, a menu of the options within the specific procedural category are displayed. Movement in this field, as before, is accomplished with the ARROWS (in this case, up and down). Since a new file is to be created, place the cursor under the first choice, Input / Edit , then, using the down ARROW, highlight CDSV5 and strike <CR>.

At this point, the user is asked if the Generic Editor or an Interactive Editor will be used to create/edit the data set. The generic editor allows the user almost complete freedom to edit command line input files. Use of this editor assumes that the user has a basic working knowledge of the generic editor program and its requirements.

To make a selection, move the cursor to the desired field and press <CR>, or, press G for generic or I for interactive. As it is still under development, currently, none of the HYDRAIN programs can access the interactive editor. Should the user select this option, they will be given a message to this effect.

The result of selecting an editor will be a prompt for the user to specify the name of a file to be edited. Pressing <Esc> or <F2> will return the user to the HYDRAIN main menu. Next, the user should select a file to be edited (or created). The bottom of the screen shows the path of the input files for the engineering program selected. It also displays the number of bytes free on the disk being used. Only those files having the .CLV extension will be displayed. To select a file from those already existing, move the cursor and press <CR>. The file name selected will be moved to the field next to "File:". To begin editing, press <CR>.

Should the user wish to change the file name selection, once the filename is in the "File:" field, they may type the name of the file desired (with a three-letter extension) and press <CR>. This newly entered file name will be sent to the editor.

To create a new file (or use a file that does not use the .CLV extension), move the cursor to [..EDIT..] and press <CR>. The cursor will move to the "File:" field. The user should type the name of the file and press <CR> twice to begin editing. After pressing <CR> the second time, the user is placed into the file which was chosen.

Using the Generic Editor

The generic editor provides the HYDRAIN user with a simple method of adding new data and changing existing data to create program input files for programs which have command line inputs, such as CDSV5. The editor itself is a full-screen editor with each line having two fields. The first field has space for three characters and is the location in which the user enters the command ID for a line of data. The cursor is moved to field two using the right arrow key. Field two is the location of the input data associated with a given command ID and consists of a maximum of 72 characters plus any continuation lines.

In addition to its basic editing capabilities, the generic editor relies on the usage of two function keys. The <F1> key allows the user to access Help whle the <F2> key accesses special editing and word processing tools. These two functions act as on/off switches; pressing the key once activates the function, while pressing it a second time deactivates it, returning the screen to edit mode. In addition to the <F1> and <F2> keys, numerous other keys are active in the generic editor. Table 3 provides a listing of these keys and their functions. Appendix A of the HYDRAIN Manual Volume I presents a comprehensive expanation and "walk-through" on the use of the generic editor. This section is intended to provide an overview of the editor and its capabilities.

The generic editor is designed to provide continuous short help displayed at the bottom of the screen for each field. Entering a three character Command in field one triggers a short descriptive help message. Should a more detailed description of the command ID and the stucture of the data to be input into field two be desired, pressing the <F1> key will access a menu of all command IDs for the type of data set (in this case HYDRO). By highlighting the desired command ID and stiking <CR>, long help on that command ID is displayed. A complete listing of the Command ID long help messages is found in Appendix B.

Table 3
Active Keys and Their Functions

Key	Function
F1 ("Help Key")	Access Long Help.
F2 ("Hot Key")	Access pull-down menus of editing options.
Ctrl End	Delete a line.
Carriage Return <CR>	Insert a line. Move to the next line.
Esc	Return to HYDRAIN main menu.
Arrow keys	Move the cursor throughout the document.
PgUp	View the previous screen of data.
PgDn	View the next screen of data.
Ctrl PgUp	Move to the top of the document.
Ctrl PgDn	Move to the bottom of the document.
Ins	Switch between Insert and Replace modes.
Home	Move to beginning of the field, of the line, of the screen, and then of the file.
End	Move to the end of the field, of the line, of the screen, and then of the file.
Backspace	Move back one space (or field in certain cases).

Editing functions are accessed at any time during the editing process by pressing the <F2> key. These functions are organized in pull-down menus of editing options. Descriptions of the four menus, titled **Select**, **Search**, **Modify** and **Block**, follow.

Within the **Select** menu, there are six functions which are presented under two sub-headings. The "File Access" sub-heading has three functions which allow the user to execute basic file management procedures. The "Action" sub-heading has three functions, each of which allows the user to execute a specified procedure.

FILE ACCESS -allows the user to perform one of three operations: Retrieve, Save, and Switch.

Retrieve - In order to Retrieve a file, the following procedure is performed:

a. Select "Retrieve" by moving cursor and pressing <CR>.

b. If the current path, as indicated, is incorrect, enter the correct directory (Note: there must be a backslash (\) before and after the directory name).

c. Using the down arrow, move the highlight bar to the desired file and Press <CR>. Or, type the filename (with extension) in the space next to "Current File:".

d. An inset "Warning" screen will then appear. To retrieve the file and overwrite any text which is on the screen, select "Continue . . .". Or, to cancel the retrieval and return to the Select menu, choose "Abandon . . .".

e. When the text is retrieved and appears on the screen, press <Esc> or <F2> to remove the menu.

Save - In order to Save a file, the following procedure is performed:

a. Select "Save" by moving the cursor and pressing <CR>.

b. If necessary, change the path and directory in which the file will be saved.

c. Using the down arrow, move the highlight bar to the desired file and press <CR>. Or, type the filename (an extension will be assigned automatically) in the space next to "Current File:".

d. If the file being saved is new, it is automatically saved and the user is returned to the Select menu. If the file had already existed, a "Warning" screen will appear. Choose "Continue . . ." to overwrite the existing file or, choose "Abandon . . ." to cancel the save process and return to the Select menu.

It should be noted that an input file will automatically be saved if it is run. Therefore, running a program results in the input file overwriting the previously existing data file.

Switch - The "Switch" function allows the user to bring a new file onto the screen while keeping the original file open. The feature is especially useful for copying or moving a block of text from one file into another through use of the cut/paste option.

To utilize the Switch option, move the cursor to Switch and press <CR>. Proceed as before to retrieve another file. To switch back to the original file, select "Switch" again. In this manner, the user may move between the two files.

ACTION - The "Action" section of the Select menu also contains three functions: Run, DOS, and Quit.

Run - The "Run" option allows the user to run the input file which is displayed on-screen. After running, the screen automatically displays the output. It is important to note, however, that the Run command is only active when the editor is invoked from the HYDRAIN program. As previously mentioned, a program should first be saved before it can be run. In addition, running the program will automatically save the input file.[1]

DOS - The "DOS" option allows the user to return to MS-DOS without actually leaving the editor. Select DOS by moving the cursor and pressing <CR>. The user will then be placed at the DOS prompt and may operate within DOS in a normal fashion. To exit DOS and return to the editor, type EXIT at the DOS prompt. Because of the quantity of space used by the editor and files, there might not be enough memory to use this function.

Quit - After all editing is completed and all files are saved, the user may leave the generic editor by using the "Quit" option. To quit the system, move the cursor to "QUIT" and press <CR>. If all files to which changes were made have been saved, the DOS prompt will be revealed. If changes were made and the files aren't saved, a warning screen will appear. If the choice is made to continue with the exit, all changes will be lost. If the user chooses to abandon the exit, the program will return to the Select menu and the user should then save the file(s).

The **Search menu** is divided into two sections, each of which has five options from which the user may choose. The Search capabilities of the Generic Editor allow the user to quickly locate instances where certain pieces of text occur.

SEARCH - The "Search" section of the Search menu has five available options. The first four options specify the range of a search while the fifth executes the command. First, the user should select the range to be searched (block, row(s), column(s), global) by moving the cursor to the desired choice and pressing <CR>. Note that the "Block" option is not available unless there is already text which is marked as a block. Similarly, the "Continue" option is not made available until one search has already been performed. Each selection displays a screen in which the user will specify the exact text to be found. In the field next to "Pattern to Match", enter the string of characters to be located. Next, select "Floating" for "Pattern Position". Finally, choose "Yes" to begin the search. Choosing "No" will return the program to the Search menu.

---

[1]This feature of the generic editor is very powerful for a user. Use of the "RUN" option, runs the program on the file being worked upon and moves the resulting output file onto the monitor for immediate review. The user leaves the output review and the monitor shows the input file. In other words, the user can go back and forth between the input and output easily and fast.

The program then highlights the first instance in which the desired pattern is found. There may, however, be more matches. To check for additional matches, move the cursor to "Continue" in the "Search" section of the Search menu and press <CR>. Selecting "Continue" will result in the next instance in which a match occurs being highlighted. This procedure may be repeated as many times as desired until the end of the file is reached.

TRANSLATE - The "Translate" section of the Search menu has the same five options as the "Search" section. Once again, however, the "Block" and "Continue" options are not always available. The purpose of the translate function is to search for a given pattern and then automatically replace or amend it. The translate input screen requires the same information as search. In addition, the user must enter the new pattern which will replace or be added to the old one. This string is entered in the "Translate to pattern" field. Also, the user must specify whether the new pattern is to overwrite the old one or be inserted after it. This is done by moving the cursor to <Overwrite> or <Insert> and pressing <CR>. Again, choosing "Yes" executes the translate command, while choosing "No" returns the program to the Search menu.

Whenever the program locates the pattern to be translated, a prompt screen is displayed which asks the user whether or not that occurrence should be translated. Choosing "Yes" will perform the translation and move on to the next occurrence. Selecting "No" will move to the next occurrence without changing the previous instance. The "Global" option will automatically translate all of the matches and will return to the Search menu. "Quit" will abandon the translate procedure and return to the Search menu. The final option, "Continue", allows the user to continue the most recent translate procedure, even if the Search menu has been exited and normal editing has been resumed.

The Modify menu is divided into three sections: Cut, Paste, and Clear. All of the functions allow the user to move or delete text from the current file.

CUT - There are three options in the "Cut" section of the Modify menu. The user is able to cut a block of one or more columns, and one or more rows. In order to select the Block, Row(s), or Column(s) option, move the cursor to the selection and press <CR>. The "Cut" command deletes the specified portion of the text, but keeps it in memory for a short period of time. In order to cut text which has already been blocked from within the Block menu, select "Block". There is no further prompt, so the block is immediately deleted.

In order to cut one or more rows, select "Row(s)". An inset screen titled "Cut Rows from Sheet" will appear. Move to the field for "Number of rows to cut" and enter the desired number. Then, specify the row at which the cut should start. Note that the default row is the row the cursor was in and the default number of rows is one. The area to be cut is now highlighted. To execute the cut, select "Yes". Selecting "No" will abort the process and return the program to the Modify menu. In addition, pressing <Esc> or <F2> at any time will return the screen to edit mode.

In order to cut one or more column(s) from the text, select "Column(s)" and follow the procedure described for cutting rows.

PASTE - The paste function adds to the text a section which has just been cut. This section can be a block, row(s), or column(s). After selecting "Paste", the Paste Block menu will appear and the program will automatically highlight as much text as was previously cut. For instance, if four rows had been cut, four rows would be highlighted, beginning at the location of the cursor.

Several choices are then made. First, choose whether the new text is to be inserted or is to overwrite existing text. As mentioned, a section of the text is highlighted on the screen. If "overwrite" is selected, the highlighted section is where the new text will be displayed. If "insert" is chosen, the new text will be added above the highlighted area in the case of rows, and left of the highlighted area for columns. If the text to be pasted is a block, it will be inserted above the position of the cursor for rows and left of the cursor for columns.

The second choice, where to start the paste, depends on whether rows or columns are being pasted. For rows, the user specifies the row and column at which the paste is to begin. Keep in mind that for "overwrite", the new text will replace the old text beginning at the specified line number, while for "insert", the new text will go above the specified line. For columns, the choices are the same as those for rows, with one addition; the user specifies the character at which the paste should start. "Overwrite" works in the same manner as for rows, while "Insert" will add the column(s) to the left of the highlighted text.

After the paste is completed, select "Deactivate" in the Block menu (by moving the cursor and pressing <CR>) to remove the block notation.

CLEAR - The "Clear" section of the Modify menu also has three options. For each of these options, block, column(s), and row(s), the text in the specified (highlighted) area is erased. The block, columns, or rows remain in the text but are blank (contain no characters). If the "Block" option is chosen, all text in any area marked as a block is erased. If columns or rows are being cleared, the user specifies the number to clear and the starting location. This information is entered on the prompt screen which is displayed after the user has selected the "Clear" option. To execute the "Clear" command, select "Yes". Once again, pressing <Esc> or <F2> will return the program to edit mode while selecting "No" will display the Modify menu.

The **Block function** is used throughout the generic editor to perform a variety of editing tasks. These tasks include: cut/paste, search, clear, and translate. Each of these tasks are presented in detail in their own long helps. Furthermore, the block function allows the user to specify the exact area of the text where the task is to be performed. There are five options available in the Block menu. The first three, "Characters", "Rows", and "Columns", allow the user to block one or more of the chosen item. To use any of these options, select it (by moving the cursor to the desired choice and pressing <CR>) and use the arrow keys to highlight the block area. When the desired area is highlighted, press <CR> to mark it. The "Global" option automatically blocks the entire document. Finally, the "Deactivate" option removes the block notation from all blocked areas and returns it to standard text.

Executing CDS from HYDRAIN

Aside from running CDS from the editor, CDS can also be run in HYDRAIN by moving to the **Execute** option, moving the cursor to CDSV5, and pressing <CR>. As the input file executes, the commands in the file will appear sequentially on the terminal screen. The user can "observe" the progress of the CDS run by observing which commands are being processed.

Upon completion of the run, the output file, which is automatically assigned an **.LST** filename extension, will be displayed on the screen. Movement through this screen can be accomplished with the cursor, PgUp, PgDn, Home and End keys. After reviewing the file, pressing <Esc> will return the user to the Execute Sub-menu. From there, the user can select any of HYDRAIN's four sub-option menus, or QUIT to exit HYDRAIN and return to DOS.

Appendix A: Benchmark Examples

The following examples serve to illustrate the types of analyses that CDS can perform. While these examples are not intended to illustrate all of the options within CDS, they are intended to satisfy the following four objectives:

(1) provide guidance for creating command strings,
(2) demonstrate uses for many of the commands,
(3) provide information on how to set up a problem, and
(4) demonstrate what to expect for output.

The first example uses CDS to perform a culvert analysis, considering hydrograph routing and storage. The second example modifies the first to consider overtopping. The intent is to allow the user to take raw data and use the generic editor to enter the data into proper CDS datasets.

Example 1: Culvert Design with Hydrograph Routing

Perform a culvert design for a 634 foot section of a secondary road, Twin Bridges Road, crossing over the Glade in Reston, Virginia. A dynamic (hydrograph) flow condition, representing a 10-year storm event will be routed through the culvert. This roadway was the subject of an FHWA report on risk analysis in box culverts and provided the physical data.[8]

Basin Characteristics:

Long, narrow drainage area consisting of residential (40%) and wooded (60%) land uses.

Area: 830 acres — Channel Slope: 0.0143 ft/ft
Length: 16,250 feet — Width: 2,000 feet

Manning's n: 0.03 for natural watercourses, 0.05 for banks

Culvert and Roadway Characteristics:

Roadway width: 54 feet

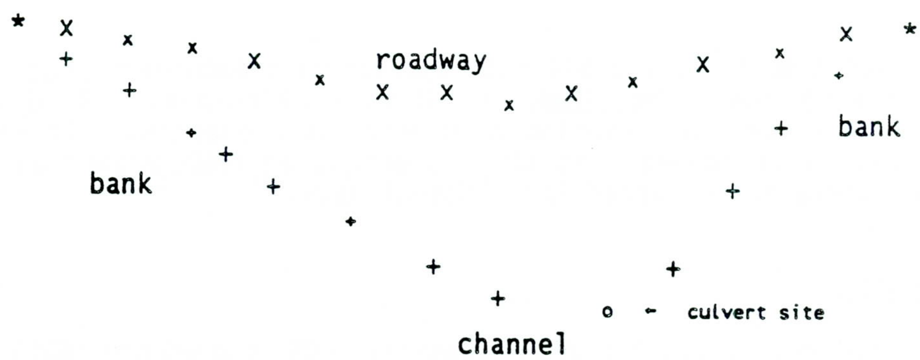
Culvert location:	at station 15+86
type:	Concrete box (with Manning's ≈ 0.012)
inlet:	1 : 1 top bevel headwall (k_e = 0.2)
slope:	0.010 ft/ft
length:	267 feet (width of roadway)
inlet elev:	272.0.0 feet
outlet elev:	269.3 feet
overtopping depth:	53.2 feet

Hydrograph Information:

Triangular Hydrograph with a Peak Flow of 1,200 ft^3/s (10-year storm) at

t = 120 minutes and Q = 0 at 318 minutes

Upstream Cross Sectional Representation of Channel (not to scale):



Cross Sectional Coordinates:

Station	Upstream Channel Cross Section (0+00)	Roadway Elevation	Manning's Roughness
11 + 50	344.3	344.3	
12 + 00	337.5	341.3	
12 + 50	328.5	338.3	
13 + 00	317.9	335.3	
13 + 50	306.0	332.3	
14 + 00	294.0	329.4	
14 + 50	282.5	327.2	0.05
15 + 00	272.0	325.8	
15 + 50	272.4	325.2	
15 + 86	273.0	325.2	
16 + 00	274.5	325.4	0.03
16 + 50	281.0	326.3	
17 + 00	296.3	326.2	
17 + 50	315.0	328.2	
17 + 84	328.9	328.9	0.05

Sample Input Dataset

Using the CDS commands and the data above, the example input dataset can be produced. This example dataset is reproduced below. The name of the dataset is called **GLADE.CLV**. The .CLV extension is used by the HYDRAIN programs to designate a input file containing CDS data.

GLADE.CLV

```
JOB    EXAMPLE 1:  10 YR STORM DESIGN, TWIN BR RD @ GLADE
PRT    1  1  0  1
XT     0
GR     1150 344.3  1200 337.5  1250 328.5
GR     1300 317.9  1350 306.0  1400 294.
GR     1450 282.5  1500 272.0  1550 272.
GR     1586 273.0  1600 274.5  1650 281.
GR     1700 296.3  1750 315.0  1784 328.8
XS     0       0      .0143
GT     0
USL    .0143
XS     -267.0  0  .0143
GT     -2.67
SA     1450  1600  1784
N      .05  .03  .05
HD     20  10
RCB    61
SL     .01  267  272.0  269.3
HYD    0  0  120  1200  318  0
RUN
END
```

If you enter the above file into the generic editor, watch the actual help, then **run it**. The file has a template cross section at station 0. The template is located at station 0 for computation of stage storage. The template is located at station -267 for computation of tailwater-rating. The HD card commands a hydrographic design with a maximum headwater of 20 feet and the largest allowable culvert span being 10 feet.

Example 2: Culvert Analysis with Hydrograph Routing and Overtopping

Evaluate overtopping flor for twin 8 x 7 box culverts subject to a hydrograph having a peak flow of 2,500 cfs that occurs in 45 minutes with a total duration of 120 minutes (use triangular approximation). The channel at the entrance can be approximated as a trapezoid with (x, y) coordinates: (0, 130), (45, 100), (75, 100), (120, 100); the sides have n = .05 and bottom n = .03. The culvert invert is at elevation 100, upstream slope is 0.5 percent, and slope through the culvert is 1 percent. The road is 50 feet wide, the culvert is 100 feet long, and the road grade (x, y) coordinates are: (0, 130), (30, 117), (60, 115), (90, 117), (120, 130). At the minimum road grade the culverts are 15 feet over the inlet invert.

Sample Input Dataset

Using the CDS commands and the data above, the example input dataset can be produced. This example dataset is reproduced below. The name of the dataset is called **OVTOP.CLV**. The .CLV extension is used by the HYDRAIN programs to designate a input file containing CDS data.

OVTOP.CLV

```
JOB   EXAMPLE 2:  CULVERT ANALYSIS WITH ROUTING AND OVERTOPPING
PRT   1  1  1  1
XS    0  0  .01
GR    0, 130   45, 100   75, 100   120, 130
USL   .005
XR    -50.0  50  1
GR    0, 130  30, 114  60, 112  90, 114  120, 130
XS    -100  0  .005
GR    0, 129  45, 99  75, 99  120, 99
SA    45  75  120
N     .05  .03  .05
HR    2  8  7
RCB   61
SL    0.01  100  100  99  12
HYD   0, 0  45, 2500  120, 0
RUN
END
```

This example generates an overtopping analysis. It differs from the first example in the following ways:

- Example 2 has an XR command to indicate overtopping. Notice that the station value is negative.

- Example 2 does not use a template. Cross-section data are input for each stream centerline station. The necessary centerline stations are: A) "0+00", for the upstream storage prism that is used to develop a stage-storge curve, B) "0-50", for the road surface, and C) "-1+00", for the tailwater rating curve cross-section.

- Example 2 is a review of twin 8'x 7' box culverts, rather than a design (as was example 1).

Appendix B: CDSV5 Command Long Helps

This appendix details the meaning and syntax of each command available in CDSV5. The descriptions are ordered alphabetically and include information on the command name, its purpose, and its structure. Any important notes pertaining to the command are also included.

CMP - Corrugated Metal Pipe culvert

Purpose: Allows user to design or review several types of inlet geometric configurations common to corrugated metal pipe culverts in frequent use.

Structure:

CMP inlet type

inlet type - a two digit code that describes one of twenty four inlet types associated with this type of culvert. They are divided into four categories: riveted, riveted & 25% paved, structural plate, and structural plate & 25% paved. These inlet types have an associated entrance loss coefficient and Manning's n value. Each code is provided below with an accom-panying description.

Riveted, n = 0.024

21 - Projecting - The projecting inlet is the simplest form of culvert entrance. The large entrance loss coefficient, Ke, equal to 0.9, reflects the greater amount of energy required to turn the flow and put it through the culvert entrance.

41 - Headwall - This is the most efficient of the simple entrance types. It has a Ke value of 0.5. The thick wall of the headwall acts as a guide to flow and improves hydraulic performance.

51 - Flared End Section - This inlet type is similar to the headwall in terms of efficiency. The flared entrance acts as a guide to flow and improves hydraulic performance. The Ke is 0.5.

61 - 0.067 Bevel - A beveled inlet usually results in the most efficient standard type of inlet. The R/D value (0.067) refers to the radius of rounding (R) to the pipe diameter (D). The entrance loss coefficient is 0.2.

71 - 0.033 Bevel - A beveled inlet usually results in the most efficient standard type of inlet. The R/D value is 0.033. The entrance loss coefficient is 0.2.

81 - Mitered - A mitered inlet is the same as a projecting inlet except the end has been cut off flush with the embankment slope for aesthetic reasons. The Ke is 0.7.

Riveted & 25% paved, n = 0.021 **

22 - Projecting - The projecting inlet has a large entrance loss, Ke equals 0.9.

42 - Headwall - This inlet type has an entrance loss (Ke) value of 0.5.

52 - Flared End Section - This inlet type has an entrance loss (Ke) value of 0.5.

62 - 0.067 Bevel - The R/D ratio for this inlet type is 0.067. The value for the entrance loss coefficient is 0.2.

72 - 0.033 Bevel - The R/D ratio for this inlet type is 0.067. The value for the entrance loss coefficient is 0.2.

82 - Mitered - A mitered inlet has an entrance loss (Ke) equal to 0.7.

Structural plate, n = 0.032 **

23 - Projecting - The projecting inlet has a large entrance loss, Ke equals 0.9.

43 - Headwall - This inlet type has an entrance loss (Ke) value of 0.5.

53 - Flared End Section - This inlet type has an entrance loss (Ke) value of 0.5.

63 - 0.067 Bevel - The R/D ratio for this inlet type is 0.067. The value for the entrance loss coefficient is 0.2.

73 - 0.033 Bevel - The R/D ratio for this inlet type is 0.067. The value for the entrance loss coefficient is 0.2.

83 - Mitered - A mitered inlet has an entrance loss (Ke) equal to 0.7.

Structural plate & 25% paved, n = 0.026 **

24 - Projecting - The projecting inlet has a large entrance loss, Ke equals 0.9.

44 - Headwall - This inlet type has an entrance loss (Ke) value of 0.5.

54 - Flared End Section - This inlet type has an entrance loss (Ke) value of 0.5.

64 - 0.067 Bevel - The R/D ratio for this inlet type is 0.067. The value for the entrance loss coefficient is 0.2.

74 - 0.033 Bevel - The R/D ratio for this inlet type is 0.067. The value for the entrance loss coefficient is 0.2.

84 - Mitered - A mitered inlet has an entrance loss (Ke) equal to 0.7.

Note: Only one inlet code can be used per command, although the command can be repeated several times in an input dataset. Each command would represent a different inlet type for a single culvert type.

CPA - Concrete Pipe Arch

<u>Purpose</u>: Allows user to design or review several types of inlet geometric configurations common to reinforced concrete pipe arch culverts in frequent use.

<u>Structure</u>:

CPA inlet type

inlet type- a two digit code that describes one of three inlet types. These inlet types have an associated entrance loss coefficient. Each code is provided below with an accompanying description.

11 - Socket-end Projecting - The projecting inlet is the simplest form of culvert entrance. The socket end is the most hydraulically efficient type of projecting inlet. This is reflected by the small entrance loss coefficient, Ke, that is equal to 0.2.

31 - Socket-end Headwall - This is the most efficient of the simple headwall entrance types. It has a Ke value of 0.2.

81 - Mitered - A mitered inlet is the same as a projecting inlet except the end has been cut off flush with the embankment slope for aesthetic reasons. The Ke is equal to 0.5.

Note: Only one inlet code can be used per command, although the command can be repeated several times in an input dataset. Each command would represent a different inlet type for a single culvert type.

ECP - Elliptical Concrete Pipe

Purpose: Allows user to design or review several types of inlet geometric configurations common to elliptical reinforced concrete pipe culverts in frequent use.

Structure:

ECP inlet type

inlet type- a two digit code that describes one of seven inlet types. These inlet types have an associated entrance loss coefficient. Each code is provided below with an accompanying description.

11 - Socket-end Projecting - The projecting inlet is the simplest form of culvert entrance. The socket end is the most hydraulically efficient type of projecting inlet. This is reflected by the small entrance loss coefficient, Ke, that is equal to 0.2.

21 - Square Edge Projecting - The square edge is not as hydraulically efficient as the socket-end. The entrance loss coeff-cient, Ke = 0.5, reflects this effect.

31 - Socket-end Headwall - This is the most efficient of the simple headwall entrance types. It has a Ke value of 0.2.

41 - Square Edge Headwall·- This inlet type is similar to the square edge projecting in terms of efficiency. The thick wall acts as a guide to flow and improves hydraulic performance. The Ke is 0.5.

51 - Flared End Section - This inlet type is similar to the square edge headwall in terms of efficiency. The flared entrance acts as a guide to flow and improves hydraulic performance. The Ke is 0.5.

61 - 0.067 Bevel - A beveled inlet usually results in the most efficient standard type of inlet. The R/D value (0.067) refers to the radius of rounding (R) to the pipe diameter (D). The entrance loss coefficient is 0.2.

71 - 0.033 Bevel - The R/D value of this beveled inlet equals 0.033. The entrance loss coefficient is 0.2.

Note: Only one inlet code can be used per command, although the command can be repeated several times in an input dataset. Each command would represent a different inlet type for a single culvert type.

END - End Command String

Purpose: This command ends the command string.

Structure:

END

GR - Cross-section Data (Follows Header)

Purpose: Specifying x, y-coordinates to define cross-section geometry.

Structure: GR x(1), y(1), x(2), y(2), ..., x(NGP), y(NGP)

Definition of Variables:

X(i) - x-coordinate, in feet from from an arbitrary horizontal datum on the left bank, of the ith ground point.

Y(i) - y-coordinate, in feet above common elevation datum, of the ith ground point.

The parenthetical notation is for illustration purposes only. The model automatically assigns these order numbers with 1 assigned to the first coordinate (left most ground point) and NGP being the order number of the right most point. The maximum number of x, y-coordinates that can be coded is 50, with no limit on the number of GR records used.

GT - Template Adjustment(s), (Follows Header)

Purpose: Replaces GR data for cross sections being synthesized from template section.

Structure: GT YSHIFT, XLIML, XLIMR, SCALE, XORIG

Definition of variables:

YSHIFT - Vertical distance, in feet, that the template section elevations are to be shifted to provide appropriate elevations for the cross section being "built."

XLIML,XLIMR - X-coordinate of the left and right limits of the portion of the template cross section to be retained to represent the cross section being "built." Neither value must coincide with x,y-coordinates specified on GR Cards. Vertical walls to the maximum elevation of the cross section are placed at XLIML and/or XLIMR by the model.

SCALE - A scaling factor to be used for stretching or shrinking the horizontal dimensions of the template section geometry.

XORIG - An x-coordinate in the template section which will be held to its original value when the SCALE factor is used. This permits preservation of cross section alignment when necessary because SCALE will alter the horizontal dimensions to either side of XORIG.

HD - Design (Select Size Given Type(s) for Hydrograph(s)

Purpose: This commands a design to be made for a given hydrograph.

Structure: HD AHW, GVD, VEL, POND, HW/D, POND

1) AHW - allowable headwater depth above culvert entrance elevation, in feet.

2) GVD - greatest vertical diameter, or the maximum allowable culvert height, in feet, desired for design. CDS uses a minimum starting culvert height 4 feet for box culverts, and 18 inches for all other types. The maximum vertical barrel dimension for each culvert type are 10 feet for boxes, 21 feet for round metal, 8 feet for round concrete, 158 inches for metal arches, 54 inches for concrete arches and 116 inches for concrete ovals. Upon reaching these limitations without adequately passing the flow, another barrel is added to the system.

3) VEL - OPTIONAL - maximum velocity limit for the culvert, in feet per second. If the velocity is exceeded then the culvert size is increased to attempt to reduce outlet velocity. This feature only works well if the culvert is flowing full.

4) HW/D - OPTIONAL - maximum headwater/diameter ratio. This parameter limits the HW/D to the specified ratio. If the ratio is exceeded the culvert size is increased.

5) POND - OPTIONAL - The allowable maximum pond area (acres).

Notes: The most conservative combination of the parameters will be used by the program in designing a culvert. For example, if an allowable headwater of 15 feet, a maximum culvert height of 12 feet and a HW/D ratio of 1.0 is entered, the program will constrain the headwater to 12 feet.

HR - Analyze/Review for Given Hydrograph and Size(s)

<u>Purpose</u>: This commands an analysis of a given size using a hydrograph.

<u>Structure</u>: HR n, B, H

n - number of barrels (#)

B - width (ft) or diameter (ft)

H - height (ft) or diameter (ft)

(Note: for diameter set B = H)

HYD - Hydrograph Data or Data File (Immediately Precedes Run Command)

Purpose: Provide hydrograph data.

Structure:

```
HYD filename or HYD T(1), Q(1), T(2), Q(2), ... T(n), Q(n)

file name format (xxxxx.QT is suffix convention):

  line 1:  comment
  line 2:  NPTS
  line 3+: N, T(N): 3 ten space fields per line
  where NPTS = number of points
           N = point number
T(I) = time value (minutes)
Q(I) = flow value (cfs)
```

Note: this command should immediately precede the RUN command.

JOB - First Command

Purpose: This initiates the command string.

Structure:

JOB "Comment"

"Comment" - A labeling header used in the output.

MPA - Corrugated Pipe Arch

Purpose: Allows user to design or review two types of inlet geometric configurations common to corrugated metal pipe arch culverts.

Structure:

MPA inlet type

inlet type - a two digit code that describes one of six inlet types associated with this type of culvert. They are divided into two categories: unpaved and 25% paved. These inlet types are either a conventional or improved inlet and have an associated entrance loss coefficient and Manning's n value. Each code is provided below with an accompanying description.

Unpaved, n = 0.032 **

23 - Projecting - The projecting inlet is the simplest form of culvert entrance. The large entrance loss coefficient, Ke, equal to 0.9, reflects the greater amount of energy required to turn the flow and put it through the culvert entrance.

43 - Headwall - This is the most efficient of the simple entrance types. It has a Ke value of 0.5. The thick wall of the headwall acts as a guide to flow and improves hydraulic performance.

83 - Mitered - A mitered inlet is the same as a projecting inlet except the end has been cut off flush with the embankment slope for aesthetic reasons. The Ke is equal to 0.7.

25% paved, n = 0.026 **

24 - Projecting - The projecting inlet has a large entrance loss coefficient (Ke) equal to 0.9.

44 - Headwall - This inlet type has a Ke value equal to 0.5.

84 - Mitered - A mitered inlet has an entrance loss (Ke) equal to 0.7.

Note: Only one inlet code can be used per command, although the command can be repeated several times in an input dataset. Each command would represent a different inlet type for a single culvert type.

N - Manning's Friction Factor(s), (Follows Header)

Purpose: To specify values of Manning's "n" roughness coefficient.

Structure:

N mn(1), mn(2), ... (nsa)

Note:
(1) nsa is the number of subareas in the channel cross section.
(2) up to 9 Manning's numbers can be entered.

PD - Design (Select Size Given Type(s)) for Given Peak Flow(s)

Purpose: This commands a design to be made for a given peak flow.

Structure: PD AHW, GVD, VEL, HW/D

1) AHW - allowable headwater depth above culvert entrance elevation, in feet.

2) GVD - greatest vertical diameter, or the maximum allowable culvert height, in feet, desired for design. CDS uses a minimum starting culvert height 4 feet for box culverts, and 18 inches for all other types. The maximum vertical barrel dimension for each culvert type are 10 feet for boxes, 21 feet for round metal, 8 feet for round concrete, 158 inches for metal arches, 54 inches for concrete arches and 116 inches for concrete ovals. Upon reaching these limitations without adequately passing the flow, another barrel is added to the system.

3) VEL - OPTIONAL - maximum velocity limit for the culvert, in feet per second. If the velocity is exceeded then the culvert size is increased to attempt to reduce outlet velocity. This feature only works well if the culvert is flowing full.

4) HW/D - OPTIONAL - maximum headwater/diameter ratio. This parameter limits the HW/D to the specified ratio. If the ratio is exceeded the culvert size is increased.

PR - Analyze/Review for Given Peak Flow(s) and Size(s)

Purpose: This commands an analysis of a given size using steady state peak flows.

Structure: PR n, B, H

n - number of barrels (#)

B - width (ft) or diameter (ft)

H - height (ft) or diameter (ft)

(Note: for diameter set B = H)

PRT - Print Command - Selects Quantity of Output.

Purpose: This command allows the user to select volume of output. This command should always be the second command entered.

Structure:

PRT N1, N2, N3, N4

N1 - stage discharge N1 = 1 print stage discharge input data and stage discharge table, and
= 0 none

N2 - stage storage N2 = 1 print stage storage input data and stage storage table, and
= 0 none

N3 - road overtopping N3 = 1 print input data and overflow table,
= 2 print input data and detailed output data for each roadway subsection
= 0 none

N4 - culvert output (See Table)

Culvert Print Option Table (N4)

Logical Choice Command (Analysis Type)	N4 Summary	Detailed	Brief	None
PD (Peak Design)	1	default 1	default 1	0
PR (Peak Review)	1	default 1	default 1	·0
HD (Hydrograph Design)	1	2	3	0
HR (Hydrograph Review)	1	2	3	0

Note: PRT command must precede the input data for any particular analysis. The PRT command can be used with each run command to change print option for that particular run.

EXAMPLES:

```
PRT  1  1  1  1   (prints everything and prints summary culvert data)
PRT  0  0  0  2   (prints detailed culvert data only)
PRT  1  0  1  3   (prints stage discharge, road overflow,
                   brief culvert data)
```

Q - Peak Flow(s)

Purpose: Provide steady state flow data.

Structure:

Q q_1, q_2, . . ., q_6

q_i - discharge (CFS); up to 6 values. If design command, PD, is used, first value is used for design. Otherwise it is a review discharge.

RCB - Reinforced Concrete Box

Purpose: Allows user to design or review several types of inlet geometric configurations common to reinforced concrete box culverts in frequent use.

Structure:

RCB inlet type

inlet type - a two digit code that describes one of seven inlet types. These inlet types have an associated entrance loss coefficient. Each code is provided below with an accompanying description.

11 - Wingwalls: alpha equals 30 to 75 degrees, square top edge (B/D = 0) - Wingwalls are desirable for their ability to protect embankments from scour and stabilizing eddies that may develop at the entrance. Alpha is measured from the plain parallel to the culvert axis. The wings are symmetrical. The flow path is probably normal to the embankments. The entrance loss, Ke, is equal to 0.4.

21 - Wingwalls: alpha equals 90 and 15 degrees, square top edge (B/D = 0) - Wingwalls are desirable for their ability to protect embankments from scour and stabilizing eddies that may develop at the entrance. Alpha is measured from the plain parallel to the culvert axis. The two angles, 90 and 15 degrees, indicate that the flow path is skewed to the embankment. The entrance loss, Ke, is equal to 0.5.

31 - Wingwalls: parallel, square top edge (B/D = 0) - Wingwalls are desirable for their ability to protect embankments from scour and stabilizing eddies that may develop at the entrance. The wingwalls are built parallel (alpha equals 0 degrees) to the axis of the culvert. Parallel wingwalls are less efficient than other type of wingwalls and are considered to be poor practice. The entrance loss, Ke, is equal to 0.7.

41 - Wingwalls: alpha equals 30 to 75 degrees, 1.5 to 1 top bevel (B/D=0.083) Wingwalls are desirable for their ability to protect embankments from scour and stabilizing eddies that may develop at the entrance. Alpha is measured from the plain parallel to the culvert axis. The wings are symmetrical. The flow path is probably normal to the embankments. The entrance loss, Ke (equal to 0.2), results from the beveled inlet, usually the most efficient standard type of inlet. The 1.5 to 1 value refers to the rise (1) to run (1.5) of the bevel (or a 33.7 degree angle). The R/D value refers to the radius of rounding (R) to the pipe diameter (D).

51 - Headwalls: square top edge (B/D = 0) - Headwalls are desirable for their ability to protect embankments from scour and stabilizing eddies that may develop at the entrance. The R/D

value refers to the radius of rounding (R) to the pipe diameter (D), in this case, the B/D is equal to zero. The entrance loss, Ke, is equal to 0.5.

61 - Headwalls: 1 to 1 top bevel - Headwalls are desirable for their ability to protect embankments from scour and stabilizing eddies that may develop at the entrance. The bevel on the top of the slab of the culvert will improve the hydraulic efficiency of the entrance. The 1 to 1 value refers to the rise (1) to run (1) of the bevel (or a 45 degree angle). The improved hydraulic efficiency of the inlet can be seen in the entrance loss, Ke, that is equal to 0.2.

71 - Headwalls: 1 to 1.5 top bevel - Headwalls are desirable for their ability to protect embankments from scour and stabilizing eddies that may develop at the entrance. The bevel on the top of the slab of the culvert will improve the hydraulic efficiency of the entrance. The 1.5 to 1 value refers to the rise (1) to run (1.5) of the bevel (or a 33.7 degree angle). This hydraulic improvement can be seen in the entrance loss, Ke, that is equal to 0.4.

Note: Only one inlet code can be used per command, although the command can be repeated several times in an input dataset. Each command would represent a different inlet type for a single culvert type.

RCP - Round Concrete Pipe

Purpose: Allows user to design or review several types of inlet geometric configurations common to circular reinforced concrete pipe culverts in frequent use.

Structure:

RCP inlet type

inlet type - a two digit code that describes one of seven inlet types. These inlet types have an associated entrance loss coefficient.

11 - Socket-end Projecting - The projecting inlet is the simplest form of culvert entrance. The socket end is the most hydraulically efficient type of projecting inlet. This is reflected in a small entrance loss coefficient (Ke) that is equal to 0.2.

21 - Square Edge Projecting - The square edge is not as hydraulically efficient as the socket-end. The entrance loss coeffi-cient, Ke = 0.5, reflects this effect.

31 - Socket-end Headwall - This is the most efficient of the sample headwall entrance types. It has a Ke value of 0.2.

41 - Square Edge Headwall - This inlet type is similar to the square edge projecting in terms of efficiency. The thick wall acts as a guide to flow and improves hydraulic performance. The Ke is 0.5.

51 - Flared End Section - This inlet type is similar to the square edge headwall in terms of efficiency. The flared entrance acts as a guide to flow and improves hydraulic performance. The Ke is 0.5.

61 - 0.067 Bevel - A beveled inlet usually results in the most efficient standard type of inlet. The R/D value (0.067) refers to the radius of rounding (R) to the pipe diameter (D). The entrance loss coefficient is 0.2.

71 - 0.033 Bevel - A beveled inlet usually results in the most efficient standard type of inlet. The R/D value is 0.033. The entrance loss coefficient is 0.2.

Note: Only one inlet code can be used per command, although the command can be repeated several times in an input dataset. Each command would represent a different inlet type for a single culvert type.

REM - Remark - Doesn't Influence Command String

Purpose: This command allows the user to place remakrs in his command string for reference.

Structure:

REM "Remark"

"Remark" - A line of text appearing in the command string that doesn't influence commands or appear in output.

RPD - Return Period(s) to Label Results (Optional)

<u>Purpose:</u> Provide a return period label to associate with values on Q command.

<u>Structure:</u>

RPD $r_1, r_2, \ldots, r_6$

r_i - return period (years)

RUN - Initiates Run

Purpose: This command executes the command string appearing above it.

Structure:

RUN

Note: A culvert type command (RCP, CMP, CPA, MPA, ECP, RCB) must follow the **RUN** command. Updated **Q**, **HYD**, and **SL** commands may follow a RUN which can, in turn, be followed by another RUN command. That is, RUNS can be "stacked."

SA - Friction Break Point Data (Flows N Command)

Purpose: Specify horizontal breakpoints for subdivision of cross section for roughness and/or geometry variations.

Structure: SA XSA(1), XSA(2),... (nsa-1)

Definition of variables:

xsa(i) - x-coordinate of the rightmost limit of the ith subdivision. The last XSA value to be coded is for the next-to-last subarea.

SDC - Tailwater Rating Data (Stage-Discharge)

Purpose: A user supplied table of existing stage discharge, stage storage, or overtopping rating curve values, overriding the internally computed relationship.

Structure:

```
SDC  depth(1), dschge(1), mxvlcty(1), ...
     depth(n), dschge(n), mxvlcty(n)
```

depth(i) - the flow depth of the tailwater rating curve, in feet. Natural flow depth and stage are often used synonymously. In the case of CDS, flow depth is measured above the streambed and stage is the corres-ponding elevation.

dschge(i)- discharge associated with the stage, in cubic feet per second.

mxvlcty(i)- maximum velocity associated with the flow depth and discharge, in feet per second.

SL - Essential Culvert Data (Slope, Length, Etc.)

Purpose: Provide data about culvert geometric setting.

Structure:

SL SLOPE, LENGTH, ELEVUP,ELEVDN, OH

SLOPE	-	culvert slope (f/f) barrel.
LENGTH	-	culvert length (ft)
ELEVUP	-	upstream invert elevation (ft)
ELEVDN	-	downstream invert elev (ft) - OPTIONAL
OH	-	vertical distance (ft) from upstream invert to minimum road elevation.

SOC - Overtopping Rating Data (Overtop Depth-Discharge)

Purpose: A user supplied table of existing stage discharge, stage storage, or overtopping rating curve values, overriding the internally computed relationship.

Structure:

```
SOC  depth(1), dschge(1), ...
     depth(n), dschge(n),
```

depth(i) - depth above the lowest overflow point, in feet.

dschge(i) - discharge associated with the stage, in cubic feet per second.

$n \geq 50$

SSA - Stage-Area Data

Purpose: A user supplied table of existing stage area values, used for the computation of storage volume for the flood routing analysis. Same as DT command except volume is computed using the average end area method.

Structure:

SSA depth(1), area(1), depth(2), area(2), ...
depth(n), area(n)

depth(i) - depth of the upstream storage curve, in feet. In the case of CDS, flow depth is measured above the streambed and stage is the corresponding elevation.

area(i) - pond surface area associated with the upstream depth or stage, in acres.

$n \geq 65$

Notes:

1) The parenthetical notation is for illustration purposes only.
2) The maximum number of coordinates that can be coded is 65 sets.

SSC - Stage-Storage Data

Purpose: A user supplied table of existing stage discharge, stage storage, or overtopping rating curve values, overriding the internally computed relationship.

Structure:

```
SSC   depth(1), area(1), volume(1), ...
      depth(n), area(n), volume(n)
```

depth(i)	-	depth of the upstream storage curve, in feet. Depth is measured above the streambed and stage is the corresponding elevation.
area(i)	-	pond surface area associated with the upstream depth or stage, in acres.
volume(i)	-	volume of pond associated with the depth.

USL - Upstream Slope Above Highest Cross Section

Purpose: This commands allows the user to provide the channel slope above the highest cross section to complete the upper segment of the volume prisms. The XS commands provide slope from the section downstream.

Structure: USL VSLOPE

VSLOPE - the slope in f/f above the highest cross section.

XR - Road Cross Section Header

Purpose: Header record for road grade cross section.

Structure: XR STA, EMBWID, IPAVE, USERCF, SKEW

Definition of variables:

STA - Section reference distance. Should represent the location of the centerline of the road near the center of the bridge. This will be negative and measured from the zero station which is the culvert inlet.

EMBWID- The top width, in feet, of the embankment. This distance should reflect the breadth (measured in the direction of flow) of the broad-crested weir that the embankment becomes when overtopped.

IPAVE - Code to indicate the road surface material. Default is paved (IPAVE = 1) and graveled (or otherwise non-smooth) can be indicated by IPAVE = 2.

USERCF- user-specified coefficient for unsubmerged weir flow. This value will override the coefficient computed by the model. The model will apply an adjustment factor for submerged weir flow for either a user-specified or computed coefficient.

SKEW - The acute angle that the road grade would have to be rotated to make the section normal to the direction of flow. The model will use the cosine of SKEW to adjust the horizontal dimensions for a weir length perpendicular to the flow. Users may simply allow the model to default to zero degrees if, in their judgment, the skewed length is the more appropriate weir length to be used.

XS - Analysis Cross Section Header

Purpose: Header record for unconstricted valley cross section.

Structure: XS STA, SKEW, VSLOPE

Definition of variables:

STA - Section reference distance (feet). Cumulative distance along the stream measured from culvert inlet zero reference point (STA is negative downstream of inlet). The difference between the SRA values of successive cross sections is assumed to represent the distance between those sections and is used to compute the prismatic volume.

SKEW - The acute angle, in degrees, that the cross section would have to be rotated to orient it normal to the flow direction. The model applies the cosine of skew angle to the horizontal dimensions of the cross section to compute the appropriate cross-section properties. Default is zero degrees.

VSLOPE- Valley slope, in feet/foot, used for adjusting cross-section elevations when the geometry data for the section are being propagated from a template section or a previously input section. Default value is zero or the last VSLOPE value input on a previous section.

XT - Template Cross Section Header

Purpose: Header record for template cross section.

Structure: XT STA, VSLOPE

Definition of variables:

STA - Section reference distance, in feet, measured from the culvert inlet zero reference point (STA is negative downstream of inlet). This provides the reference point for elevation adjustments by valley slope.

VSLOPE- Valley slope, in feet/foot. Alternatively, the valley slope may be specified on the header card of the cross section being synthesized.

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HYDRAIN - INTEGRATED DRAINAGE DESIGN COMPUTER SYSTEM

VOLUME V. WSPRO - STEP BACKWATER AND BRIDGE HYDRAULICS

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Federal Highway Administration

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TABLE OF CONTENTS

TABLE OF CONTENTS
(continued)

List of Figures

List of Tables

Preface

This report presents documentation for the HYDRAIN system. HYDRO, HYDRA, CDS, WSPRO and HY8 are five nonproprietary hydrology and hydraulic engineering programs incorporated in the HYDRAIN system. The HYDRAIN personal computer oriented system operates these engineering applications with programs written in the C language. The system is designed with an open architecture for expansion. HYDRAIN is sponsored as a Pooled Fund Project (PFP) of 29 State highway departments and is managed by the Federal Highway Administration (FHWA). The system is expanding with flexible lining design logic and integrated culvert analysis logic under development. Graphic output options are also under development and are available in some areas already.

Within the HYDRAIN concept, the HYDRO, HYDRA, CDS, and WSPRO allow the user to consistently input, edit and run relevant input data files and to scroll through output files. With these applications "short", one-line, and "long", multiple line, help is provided within an editor that services all applications.

HYDRAIN integrates hydraulic and hydrology programs into a unified system. The intent of the integration is to enable users to then learn basic principles of how to operate an application and file manipulation and then be able to apply the same principles to other applications and files within the system. One guiding principle is a **command land input format**. This trend in hydraulic programs is typified by HEC-2 and HYDRA. It is very pragmatic. WSPRO also adopted the command line method. Another guiding principle is a **generic input editor** that works the same for each integrated program--HYDRO, HYDRA, CDS, and WSPRO. The input file for each integrated program is a line by line command language that identifies the computation and/or provides the required data. Each line of data is preceded with a two or three-letter command. A typical command is **XS**, indicating a cross section; both WSPRO and CDS read this command. Another typical command is **PDA**, indicating the line contains the design parameters for pipe analysis (PIPE DATA); HYDRA reads this command.

A strength and a weakness of HYDRAIN is the need to know beforehand the sequence of commands that will result in making an application work. The commands are, of course, the batch input file. The user needs to know a proper sequence or know how to put one together. The sequences are termed "footprints." Given the right "footprint," an application will work; note that footprints are not necessarily unique, in that there may be several ways to get a job done. This documentation includes footprints to get users started and user support will aid in proper "footprint" design. Once a user has a library of footprints for his applications, the use of HYDRAIN should save considerable time and money. HY8 is a stand-alone interactive BASIC program that accepts inputs during processing; HY8 does not require footprints and leads the unfamiliar user through input preparation. All engineering programs but HY8 are batch oriented, and three steps are built into the process of using them: input file generation, programs execution, and output file screen review or listing. HY8 accepts inputs and generates outputs as the engineering program logic is executing.

HYDRO Program

HYDRO is a command line hydrology program. FORTRAN code for HYDRO was developed to combine existing approaches for rainfall and runoff analyses into one computerized program. Within the HYDRAIN system, it can be used independently or it can be used to generate input data for other engineering programs within the system.

HYDRO offers many hydrologic analysis options to the engineer. Each is site specific based on user inputs.

- Design Rain Using Digitized NWS Information or State-Supplied Files - Calculates the rainfall intensity for a specific return period, duration, and site.
- Design Hyetograph using Yen and Chow's method - Calculates the rain versus time plot for a return period, duration and site.
- Intensity-Duration-Frequency Curve Using Either the NWS Information or State-Supplied Files - Analyzes a specific site and creates two graphs: a plot of points for durations up to 24 hours, and a detail graph of the first two hours. Can be input to HYDRA.
- Design Flow by Rational Method - Uses a specific return period, duration and intensity to determine the peak flow for the site.
- Design Flow by USGS Regression Method - Uses USGS log-log regression equations with user-supplied parameters to determine design flow.
- Design Flow by log Pearson type III - Calculates the peak flow for given data.
- Design Hydrograph by USGS Dimensionless Hydrograph - Calculates a hydrograph to support storage routing within HYDRA or CDS.
- Maximum Observable Flood - estimates the largest flow at a site based on the envelope of all floods in a region.

HYDRA Program

HYDRA is a command line gravity pipe network hydraulics program. FORTRAN code for HYDRA previously existed and the Pooled Fund work effort included substantial improvements. HYDRA is a storm and sanitary sewer system analysis and design program. It can be used either to model an existing sewer system or to design a new system.

HYDRA generates storm flows by using either the Rational Method technique, hydrologic simulation techniques, or accepting a hydrograph generated by a HYDRO analysis. It can be used to design or analyze storm, sanitary or combined collection systems. HYDRA can handle up to 1,000 contributing drainage areas and 2,000 pipes. Additionally, HYDRA can be used for cost estimating. The Rational

Method approximates the peak rate of runoff from a basin resulting from storms of a given return period. HYDRA's hydrologic simulation models the natural rainfall-runoff process. In the simulation, runoff hydrographs are generated, merged together, and routed through the collection system. Inlet limitations can be analyzed: inlet overflow can be passed down a gutter system, while inlets in sumps can store water in ponds.

In the HYDRA design process, the program will select the pipe size, slope and invert elevations given certain design criteria. Additionally, HYDRA will perform analyses on a existing system of pipes (and/or ditches). When an existing system of pipes is overloaded, HYDRA will show suggested flow removal quantities as well as an increased pipe diameter size as an alternative remedy. HYDRA includes HEC-12 inlet theory hydraulic gradeline calculations, and an ability to route flow through internal storage sites using a storage-indication method.

HYDRA requires the forming of an input file of commands to describe the sewer system. Commands for HYDRA are placed in a logical sequence usually from upper to lower elevation. Is it possible that several command sequences can produce the same result. An input file is established for a particular collection system by the engineer and then the HYDRA program is executed. To change the characteristics of the collection system, the input file can be edited.

The HYDRA program requires design criteria for the pipes: friction factor (Manning's "n"), minimum diameter, ideal depth, minimum ground cover, minimum velocity (full flow), minimum slope, and maximum diameter. The friction factor is necessary for both analysis and design, while the remaining values are needed only for design. In the case of a design, the program selects invert elevations and slope as well as the physical sizing of each link given certain design criteria, whereas in the analysis mode, pipe alignment and sizing are predetermined and the impact of proposed flows are analyzed. Design criteria can be changed for each pipe if so desired. HYDRA is not an optimization program, thus individual case studies need to be run and analyzed by the engineer.

CDS Program

CDS is a command line culvert program. The Culvert Design System provides the user with two broad options for investigating culvert characteristics. CDS can either (1) hydraulically design a culvert or (2) analyze an existing or proposed culvert. CDS has capabilities for investigating a variety of hydrograph relationships, culvert shapes, materials, and inlet types. With CDS, the engineer can request any of six culvert types: round concrete, round metal, arch concrete, arch metal, oval concrete, and concrete box. CDS routes hydrographs, considers ponding, and overtopping.

The Design option selects a culvert size and number of barrels that are compatible with engineering data, environmental constraints, and site geometry. In this option, hydraulic performance data are calculated for each new culvert system design. The Review option provides hydraulic performance data for any preselected combination of culvert type and size, inlet type, slope, and number of barrels. The initial design and analysis options may be followed by up to five

additional culvert types or flow frequencies so that a full spectrum of risk scenarios or economic considerations can be simulated at the same time.

Two possible flow scenario methods can be selected: (1) steady state or irrigation, that assumes constant flow through the culvert, or (2) dynamic, that simulates drainage flow conditions. The dynamic option can route a hydrograph through the culvert system using three hydrograph alternatives: a user input hydrograph, a hydrograph produced by the HYDRO program, or the use of an internally produced default hydrograph (simulating semi-arid, high plains conditions). Additionally, the dynamic flow scenario can accommodate upstream pond storage.

CDS will determine culvert size based on the design headwater, headwater/diameter ratio, inundation, outlet velocity, cover limitations, or any combination of these parameters. The program will automatically increase the number of barrels when the upper limit for the greatest vertical dimension is exceeded. There is a limit of six barrels for commercial size culverts and five for concrete box culverts. The program can also be used to assess flood hazards, environmental assessments of upstream pond coverage, downstream flooding, channel impact, inlet type and beveled inlet evaluations, and reservoir facilities which use a culvert type structure for the spillway. Based on these data the program will proceed to identify the flow type and the outlet conditions for velocity, Froude number, and brink depth.

WSPRO Program

WSPRO is a command line step backwater program for natural channels with an orientation to bridge construction. The Water Surface Profile Computation Model Microcomputer Program has been designed to provide a water-surface profile for six major types of open channel flow situations:

- Unconstricted flow.
- Single opening bridge.
- Bridge opening(s) with spur dikes.
- Single opening embankment overflow.
- Multiple alternatives for a single job.
- Multiple openings.

WSPRO was originally developed by the United States Geologic Survey (USGS) for the Federal Highway Administration. The model was a batch mode mainframe program, written in FORTRAN. The members of the Pooled Fund Project decided to use WSPRO as the bridge waterways analysis element of the Integrated Computerized Drainage Design System. WSPRO was downloaded to the microcomputer by the USGS and FHWA. The microcomputer version of WSPRO, is dated August 1987.

The command input file forms a logical description of the physical characteristics of a waterway. Once the user is comfortable with this method of data setup, the program provides a step backwater method for determining water surface profiles. The scheme is similar to the Corps of Engineers HEC-2 program. Both WSPRO and HEC-2 are acceptable to the Federal Emergency Management Agency. WSPRO has the advantage that it utilizes more recent approximation techniques for the backwater effects associated with bridge constrictions.

HY8 Program

HY8 is an interactive culvert analysis basic program that utilizes the FHWA analysis methods and information published by pipe manufacturers. The program includes modules to allow the user to interactively enter, save, and edit data. HY8 will compute the culvert hydraulics for circular, rectangular, elliptical, arch, and user defined geometry. Additionally, improved inlets can be specified and the user can; analyze inlet and outlet control for full and partially full culverts, analyze the tailwater in trapezoidal and coordinate defined downstream channels, analyze flow over the roadway embankment, and balance flows through multiple parallel culverts. A hydrograph can be produced and routed.

The initial logic involves calculating the inlet control and outlet control headwater elevations for the given flow. These elevations are compared and the larger of the two is used as the controlling headwater elevation. Tailwater effects are taken into consideration when calculating these elevations. If the controlling headwater elevation overtops the roadway embankment, an overtopping analysis is done in which flow is balanced between the culvert discharge and the surcharge over the roadway. A balancing technique is also used in the case of multiple barrels. If the culvert is less than full for all or part of its length open channel computations are performed.

A series of data menus, data screens, summary screens, and output screens guides the user through the program. Each menu contains several options to match the desired culvert configuration, while the data screens prompt the user for specific dimensions and coordinates. Summary screens allow the user to edit entered data or change menu selections. Output screens display the output as calculations proceed; hard copy is only obtained using the "print screen" key.

There are three main groups of data to be entered into the program: initial culvert data, downstream channel data, and roadway data. Within the program, the user is sequentially led from one group to the next. From these sets of data, the program develops culvert performance data with or without overtopping. A performance curve can be plotted on a computer with graphics capabilities. For a given flow, HY8 can design a culvert. In addition to developing performance curves, the program generates rating curves for uniform flow, velocity, and maximum shear for the downstream channel. Culvert outlet velocities, inlet control head, and outlet control head are also calculated; energy dissipator design is possible.

HYCHL and HYCULV Programs

HYCHL and HYCULV are command line, flexible channel and culvert programs that are under development. HYCHL will solve for fixed and flexible lined channels. HYCULV will integrate state-of-the-art culvert flow methods and utilize features of both CDS and HY8.

Operation

To allow the software to be used by a wide audience, HYDRAIN operates on an IBM XT/PC or equivalent microcomputer with 640 K RAM, a hard disk, and a monochrome monitor. A math coprocessor is needed. Engineering programs are in Fortran 77. The utility software and editor is in C. The HYDRO, HYDRA, CDS, and WSPRO programs have command line input with are "short" and "long" help files available through the same editor that operates any of them. HY8 has also been integrated into the HYDRAIN system and is available as an interactive BASIC culvert program.

Report Contents

The remaining section of this volume provides technical reference and user instructions for the WSPRO program. There are a total of 6 such volumes for HYDRAIN.

Disclaimer

FHWA, the pooled fund States and their agents have, within the limits of their resources, tested and debugged the HYDRAIN shells. The engineering programs derive from several varied sources and were adapted to HYDRAIN and also underwent testing and debugging. However, this is a very large and somewhat complicated system of logic and coded implementation and errors and omissions may yet remain in the software. Therefore, use at your own risk. Please document problems and errors and report to FHWA. User support and technical assistance will be provided to pooled fund States. Agents of these States using the system should channel their requests for support or assistance through their sponsor State.

1. Introduction

The Water-Surface Profile Computation Model Microcomputer Program (WSPRO) has been designed to provide a water-surface profile for six major types of flow situations: 1) unconstricted flow, 2) single-opening bridge, 3) bridge opening(s) with spur dikes, 4) single-opening, embankment overflow, 5) multiple alternatives for a single job, and 6) multiple openings. This report is intended to introduce WSPRO and guide the user through the necessary steps toward the determination of water-surface profiles for the above mentioned types. Additional information can be found in other documents.[(1),(2)]

WSPRO was originally developed by the United States Geologic Survey (USGS) for the Federal Highway Administration (FHWA). The original model was a batch mode mainframe program, written in FORTRAN. Members of the Pooled Fund Project (PFP) decided to use WSPRO as the bridge waterways analysis element of the Integrated Computerized Drainage Design System. WSPRO was downloaded to the microcomputer by the USGS and FHWA. The microcomputer version of WSPRO, referenced in this document, is dated August 1988.

WSPRO requires the creation of an input file, consisting of commands to describe the physical characteristics of a waterway. The program shell facilitates this activity. The commands are placed in a logical sequence, usually from downstream section to upstream to facilitate a step-backwater computation methodology. The input file, established for a specific stream reach pattern by the user, is then executed using the WSPRO program.

This documentation consists of three major sections. The first section provides the user with an overview of the components that form the WSPRO program. The second section deals specifically with the technical methodologies used by WSPRO, beginning with a general description of topics, followed by narratives on methodologies and a discussion of relevant formulas and commands. The topics include: a general discussion of water-surface profile computation theory, single opening bridge hydraulics, multiple waterway opening hydraulics, and culvert analysis using the WSPRO program. The third section provides the user with instruction on how to apply WSPRO within the HYDRAIN system.

2. System Overview

This documentation is aimed at providing information to new users (as well as infrequent or "rusty" users) of WSPRO to bring them to a level of ability sufficient for them to utilize any feature that WSPRO offers. It is not meant to show every possible type of situation that WSPRO can handle (however examples of several types of situation are demonstrated).

This section will provide an overview of WSPRO by briefly describing its purpose, capabilities and structure. A key to some of the more frequently used terms and concepts is included at the end of this section. The following sections provide more detailed information to help the user make the most of WSPRO. The user is advised to scan the "Table of Contents" of this document to see exactly what this text offers, how it is arranged and where to turn for specific information.

Capabilities and Limitations

In this section of the applications guide, several of WSPRO's capabilities and limitations will be briefly discussed. The capabilities of WSPRO are:

- Water-surface profile computations in the absence of bridges are generally consistent with the methods used in other models such as the Corps of Engineers HEC-2.
- Any combination of subcritical, critical, and supercritical flow profiles may be analyzed for one dimensional, gradually varied, steady flow.
- Discharge may be varied from cross section to cross section to account for tributary and lateral flow gains or losses.
- Up to 20 profiles for different discharges and/or initial water surface elevations may be computed at one time.
- Initial water-surface elevations for each profile may be specified by the user or computed by the model.
- Variable Manning's roughness coefficients may be specified for any cross section to reflect roughness changes both horizontally and vertically in the cross section.
- Up to three different flow lengths for left, central and right portions of a valley may be specified between any two valley cross sections.
- Users may select the friction-slope averaging technique to be used in the friction loss computations.

- Users may specify the coefficients used to compute energy losses associated with expansion or contraction of flow.
- The model will compute backwater for both free-surface and pressure flow situations at a bridge.
- The model can compute water-surface profiles through bridges for cases where road overflow occurs in conjunction with flow through the bridge opening.
- The effects of spur dikes on the water-surface profile is estimated when spur dike data are entered.
- The model can analyze multiple waterway openings for a cross section, including culverts when used as one of the multiple openings.

Structure of WSPRO

The structure and organization of the WSPRO program is similar to many other computer programs. The program reads data, analyzes it, and outputs information for the user's review. Unlike many other hydraulic analysis programs, WSPRO requires only a single input data file. This data file is made up of a list of user-supplied **commands** that specify (describe) the waterway. All internal analysis by WSPRO is performed according to these commands. Once the commands are assembled into a final working data set, they are collectively called a **command string**. (These concepts are explored in more detail in the following section.) During analysis (program execution), the command string is checked for proper format and executability. Output is generated according to the user-supplied instructions of the command string and sent to a separate output file which the user may in turn send to either a printer or screen display. If a run aborts prematurely (before intended analysis is completed), appropriate descriptive error messages are then sent to the output file. There is also a "status report" feature within WSPRO itself that displays (on the user's screen) when each command in the command string is being executed, in "echo" format. This allows the user to trace program progress.

Key to WSPRO Terms

To use WSPRO, an understanding of how to prepare a program data file is central. For this reason, it is important to have a clear grasp of the more fundamental modeling terms as they are used in this documentation. The more comfortable the user is with the following terms (and their associated concepts), the easier it will be to put this documentation to use.

- **Command** - A one or two-letter user-supplied "key word" and its associated completed data field, that WSPRO recognizes and accepts as input data for performing a specific task. The user selects these commands according to the function(s) that WSPRO is to perform. Each command must be listed (entered) on a separate line of data. These data lines make up the user's input data set, which is collectively referred to as a **command string** (See entry below.) Command names are one or two-letter "descriptors" (often abbreviations or acronyms) of the tasks that the commands perform. For example, **WS** is the command name for "starting Water-Surface elevation." This command allows for user-provided specifications to initialize water-surface profile computations. A complete listing and explanation of available commands is provided in Appendix B.

- **Command string** - An arrangement of **commands** that describes a given system. A command string is the fundamental user-provided data set that allows WSPRO to analyze a site. This data set may be edited to adjust for modifications to the system without having to build a new command string from scratch. Commands and command strings are further discussed in the next section.

3. Technical Information

Bridge waterway design normally requires determination of: a) the amount of backwater due to the encroachment of the flood plain, and b) the upstream extent of the bridge-affected water-surface elevations relative to the unconstricted flow elevations. Capabilities of the model must therefore include the ability to compute water-surface profiles through unconstricted valley reaches in addition to profiles through bridges or culverts.

Water-Surface Profile Computation Theory

WSPRO uses a standard step method similar to that described by Chow to compute backwater in unconstricted valley reaches.[3] This method requires description of a series of cross sections which segment the valley reach into relatively short subreaches. Subreaches should be sufficiently short so that the assumption of gradually varied, steady flow is valid within each subreach.

The standard step method is based upon the principle of conservation of energy, i.e., the total energy head at an upstream section must be equal to the total energy head at a downstream section plus any energy losses that occur between the two sections. Thus, the energy equation between two adjacent cross sections may be written:

$$h_1 + h_{v1} = h_0 + h_{v0} + h_f + h_e \qquad (1)$$

where

$h_{1,0}$ = water-surface elevation (feet); 0=downstream, 1=upstream,
$h_{v1,v0}$ = velocity head (feet),
h_f = friction loss (feet), and
h_e = expansion/contraction loss (feet).

Each component of the energy equation is dependent upon physical data specific to the site. The velocity head components are derived as a function of conveyance, roughness, flow area, and discharge. Friction losses are also determined as a function of the above parameters, in the form of friction slope calculations, with the addition of a length parameter. Friction slope (or conveyance) may be calculated in any of the following four ways: geometric mean of conveyance, arithmatic average of conveyance, arithmatic average of friction slope, or harmonic mean of friction slope. The contraction and expansion losses are determined as a function of the velocity head differential and a user-specified contraction or expansion coefficient.

A direct solution of the energy equation is not possible when either h_0 or h_1 is unknown, since the associated velocity head and energy loss terms are then also unknown. The model therefore computes the difference in total energy between the sections using an iterative procedure. Successive estimates of the unknown elevation are used to compute the unknown velocity head and loss terms until an absolute value of the energy difference is achieved which is within an acceptable tolerance. Generally the user specified tolerance (given in the J1 - Job Parameter command) is on the order of 0.01 to 0.05 feet. The default value is 0.02. Should a tolerance exceeding 0.1 be needed to obtain a solution there may be reason to suspect data inadequacies such as an insufficient number of cross sections.

The model does not provide the capability to obtain a direct solution for a water-surface profile that represents a combination of supercritical and subcritical flow at adjacent cross-sections. However, it is possible that a critical water-surface elevation at one cross-section and either a sub- or supercritical water-surface elevation will satisfy the energy equation. If the appropriate control parameters and cross-sectional information have been specified, and computations have proceeded in the appropriate direction, such a combination represents a correct, acceptable solution for a water-surface profile.

WSPRO is designed, to the greatest extent possible, to reject computed water-surface elevations which are in the incorrect flow regime. Subcritical flow at any point is controlled by downstream flow conditions. Conversely, supercritical flow is controlled by upstream flow conditions. Therefore, subcritical profile computational direction is from downstream to upstream, while for supercritical flow the convention for computational direction is from upstream to downstream.

The water-surface elevation for critical flow is computed on the basis of minimum specific energy for each cross-section. Each trial water-surface elevation is constrained to be greater than minimum ground elevation and less than or equal to the critical water-surface elevation. Thus, any trial value satisfying the energy balance equation is automatically in the correct flow regime.

Most of the subcritical profile computations are for flow conditions significantly higher than critical flow making the determination of the elevation of minimum specific energy a much more time-consuming iterative process. Therefore, an attempt is made to avoid computation of critical water-surface elevation for a cross-section unless the flow is near critical flow. A Froude number test is a good alternative method of assuring that a trial elevation that satisfies the energy balance criteria is also in the subcritical flow range. If the computed Froude number is less than a user-specified Froude number test value the trial water-surface elevation will be accepted as a valid subcritical solution.

Since the computed Froude number is only an approximation, at a cross-section where flow is nearly critical, the possibility exists that a valid solution will be rejected. WSPRO therefore determines the critical water-surface elevation to establish the lower bound of the subcritical flow regime. Any trial elevation at or higher than the critical will be acceptable because the computed critical water-surface elevation is based on minimum specific energy.

At any cross-section where an acceptable solution is not found, in both subcritical and supercritical computations, WSPRO assumes critical flow exists at that cross-section. The model then uses the critical water-surface elevation at that cross-section as the "known" elevation for computing the water-surface profile through the next subreach.

Single-opening Bridge Hydraulics

Computation of the water-surface profile through a stream crossing having a single waterway opening requires definition of a minimum of four cross sections. In situations where uniformity of channel shape and valley slope permit, it is possible to provide this definition on the basis of a single surveyed cross section because the model provides fairly flexible data propagation capabilities. These cross-sections are the three unconstricted valley sections, exit, full-valley, and approach, and the bridge opening section as shown in Figure 1. A more complicated situation is observed for the single opening case if spur dikes are present. An additional cross section describing the spur dike is required, as shown in Figure 2.

The flow situation at a single bridge opening depends upon the relative elevations of the water surface both upstream and downstream of the bridge with respect to the elevations of the top of the bridge opening (referred to as low steel) and the top of the road grade. Free-water surface flow occurs when there is insignificant or no contact of water surface and low steel. Pressure flow through the bridge opening occurs as either submerged orifice flow (the water surface is in contact with the low steel for the full flow length of the bridge) or orifice flow (only the upstream water surface is in contact with low steel). Any of these conditions can exist in conjunction with road overflow. Flow classes are designated by number to provide a convenient means of directing computational sequences and identifying output. The flow classes are dependent upon the elevation of the water surface relative to the elevation of the low steel, which will determine whether free flow or pressure flow exists, and the minimum elevation along the top of the embankment, which determines whether road overflow occurs. Table 1 summarizes the flow classes and the governing elevation relationships.

Table 1. Summary of Flow Classes for a Single Bridge Opening.

Class No.	Flow Class	Road Overflow	Relative Elevations $h_{ds}<y_{ls}$	$h_{ds}>y_{ls}$	$h_{us}<y_{ls}$	$h_{us}>y_{ls}$	$h_{us}<y_{min}$	$h_{us}>y_{min}$
1	free-surface		X		X		X	
2	orifice		X			X	X	
3	submerged			X		X	X	
4	free-surface	X	X		X			X
5	orifice	X	X			X		X
6	submerged	X		X		X		X

h_{ds} = water surface elevation immediately downstream of the bridge,
h_{us} = water surface elevation immediately upstream of the bridge,
y_{ls} = low steel elevation, and
y_{min} = minimum embankment elevation.

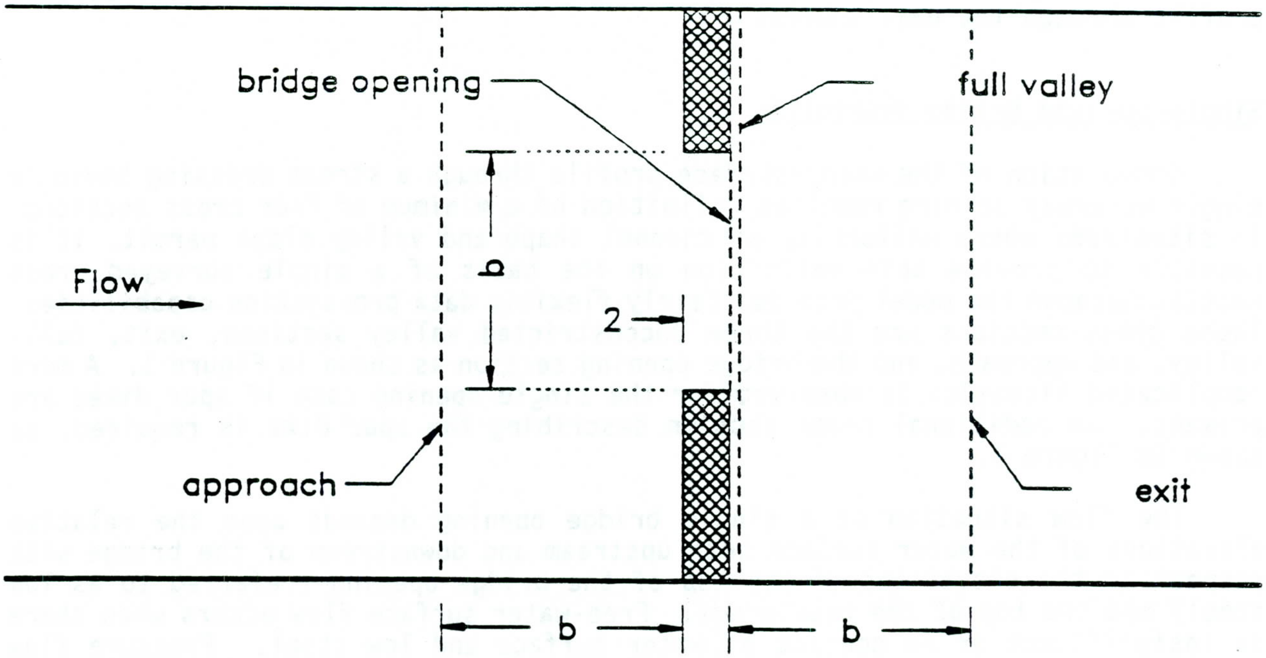

Figure 1. Schematic of Single Bridge Opening

source: (2)

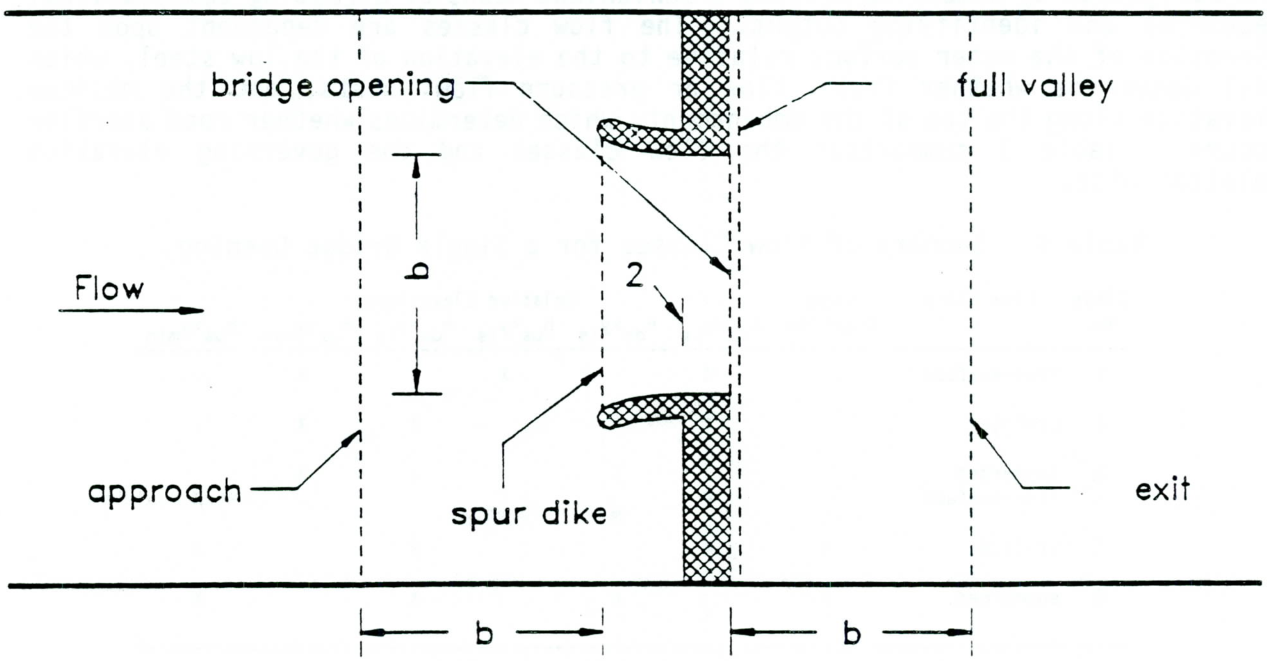

Figure 2. Schematic of Single Bridge Opening with Spur Dikes

source: (2)

WSPRO precedes each single-opening bridge analysis with computation of the natural profile from the exit section to the full-valley and approach sections. These data permit determination of the amount of backwater caused by constriction and are also used as the initial trial elevations in the iterative solution for the water-surface profile through the bridge.

Free Surface Flow

Water-surface profile computations for free-surface bridge flow situations are performed in accordance with the methods outlined by Schneider et al.[4] Improved computed results are attributed primarily to revisions in the computation of friction losses in the vicinity of the bridge. These revisions include use of an effective flow length from the approach section to the bridge opening section and use of a selected minimum conveyance for the subreaches both upstream and downstream of the bridge opening. Another minor improvement is attributed to the use of an expansion loss between the bridge-opening section and the exit section.

Friction losses depend upon conveyance, discharge, and effective flow length. Since these losses are directly proportional to flow length, it becomes imperative to obtain the best possible estimate of flow length, especially for those cases where the friction loss is a significant component of the energy balance between two sections. Previous computational methods that did compute friction loss components estimated the approach reach friction loss on the basis of the straight-line distance between the approach section and a reference point at the bridge opening. For minor degrees of constriction, this was usually adequate. However, for more significant constrictions, this straight-line distance is representative only of that portion of flow that is generally in direct line with the opening. Flow further away from the opening must flow not only downstream, but also across the valley to reach the opening, thus traveling much farther than the straight-line distance. Therefore, a simplified computational technique was developed and incorporated into WSPRO to compute average streamline length.

Pressure Flow

Free-surface flow cannot exist if there is significant contact of the water surface with the bridge superstructure. Instead, pressure flow, which is proportional to the square root of the head differential, is established. WSPRO analyzes pressure flow as either orifice or submerged orifice flow depending on the degree of contact between the water surface and the superstructure. Detailed discussion of the determination of discharge coefficients for each of these cases are found in the Bridge Waterways Analysis Model: Research Report (FHWA, 1986).

Multiple Waterway Opening Computation Theory

At some stream crossings, especially those across very wide flood plains, waterway openings in addition to the bridge spanning the main flow channel may be either economically and/or hydraulically justified. Various combinations of culverts and/or bridges may be used.

Data requirements for multiple opening situations are similar, but more extensive than those for the single-opening case. One of the basic assumptions in the multiple opening analysis is that the valley can be rationally divided into strips, one strip for each opening, in proportion to the distribution of discharge through the openings and across the valley. Figure 3 represents a typical situation with a centrally located main-channel opening and relief openings on both the left and right flood plains. Unconstricted valley cross-sections are required at the locations indicated by D and U , as well as immediately downstream of the openings at 3F. Section 3F is totally analogous to the full-valley section of the single-opening case. Section D serves as the starting point for analysis of each of the individual openings with a common water-surface elevation and is referred to as the downstream match section. Section U, referred to as the upstream match section, serves as the termination point for the analysis of each individual opening. These match sections must be located such that they satisfy the maximum distance requirements of exit and approach section location for single-opening analysis of each opening. Definition of each opening is also required. Each bridge opening is described as discussed for single-opening situations, that is, with a bridge opening section and, when necessary, a dike section.

The portion of the total discharge that will flow through each individual opening is dependent upon both the relative size of each opening and the flow distribution in the appropriate reach. Stagnation points, which are the location of flow division along the interior embankment between adjacent openings, are located in direct proportion to the total flow area of adjacent openings. That is, the distance between the right edge of the left opening and the stagnation point is computed by multiplying the length of embankment between two adjacent openings by the ratio of the left flow opening area to the total flow area of both openings. Boundaries parallel to the flow extended from the stagnation points to both upstream and downstream match sections define the valley strips for each of the openings. Discharge apportionment uses a channel resistance ratio[2] to define the flow capabilities of each valley strip.

Culvert Analysis

At many bridge sites, culverts are used to carry the flow of secondary stream channels and drainage swales through a roadway embankment. These culvert openings are usually designed to pass only low-water flows and, therefore, usually have negligible effect on the overall pattern of flow and backwater at the flood flows considered in most bridge waterway analyses. In some cases, however, small bridges in submerged flow under wide roadways may become more hydraulically like culverts than like bridges. In other cases, large culverts may carry significant fractions of the total flow and may have significant effects on the backwater pattern.

In WSPRO, culverts are considered only in the context of multiple opening bridge situations. The general plan of the culvert computations is to compute the headwater elevation corresponding to a given discharge and given tailwater elevation for a culvert of given dimensions and material. The culvert dimensions and material are specified by the user in the **CG** and **CV** commands.

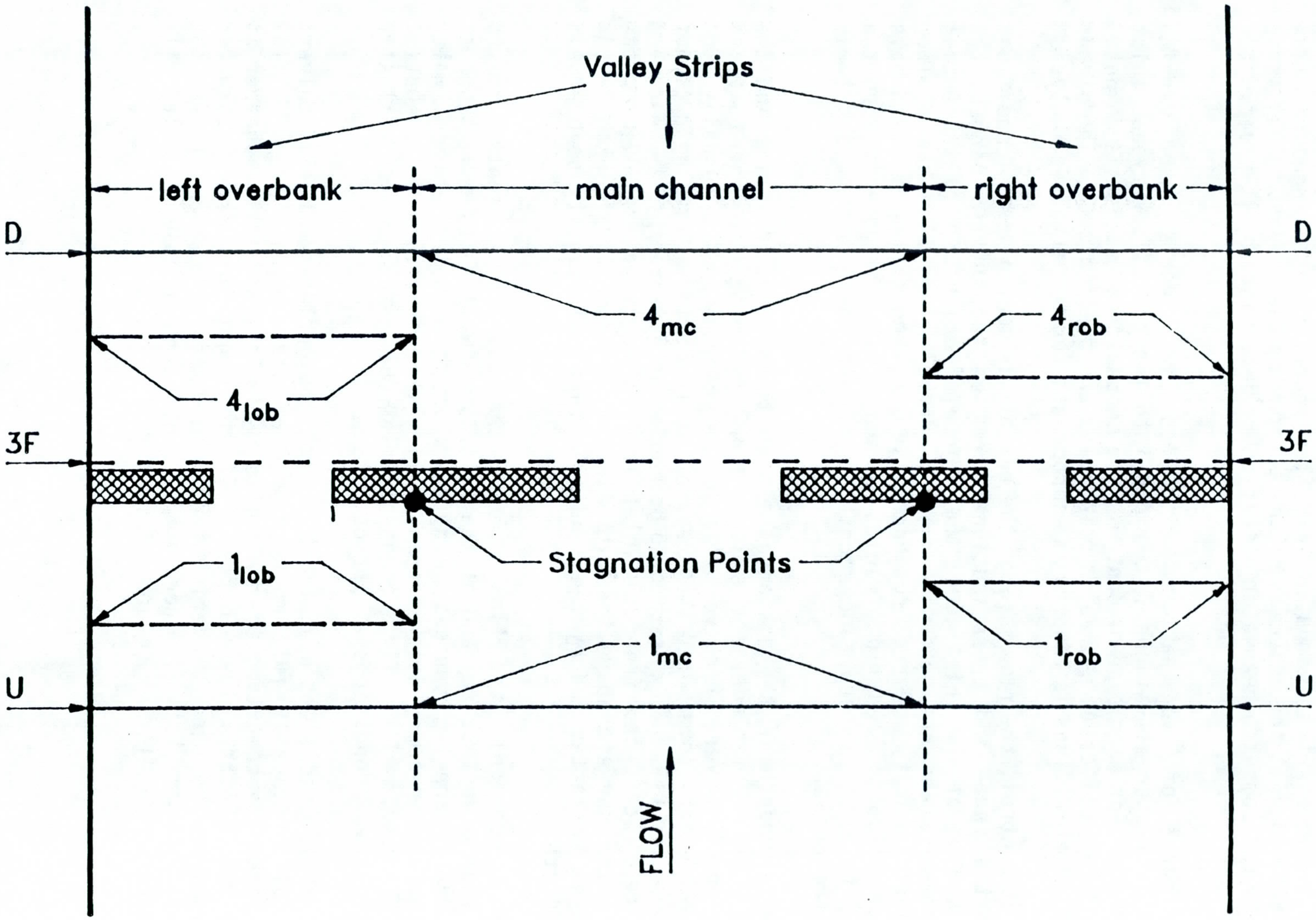

Figure 3. Sketch of typical multiple bridge opening situation illustrating valley strips and cross-section locations
source: (2)

The tailwater elevation is the result of step-backwater computations in the reach downstream of the culvert. The portion of the total discharge that is to be conveyed by the culvert is computed by a flow-apportionment procedure. The water-surface elevation at the upstream match section for the culvert valley strip corresponding to the computed headwater elevation is determined by step-backwater computations.

The wide range of flow patterns exhibited by culverts under varying discharges and tailwater elevations is divided into two broad flow types, inlet and outlet control. For each type of control, the headwater elevation is computed independently, using different hydraulic principles and coefficients. The higher of these headwater elevations is adopted as appropriate for conservative analysis.

Under inlet control, the flow through the culvert is controlled by conditions at the inlet: the shape and cross-sectional area of the culvert barrel, the beveling or rounding of the inlet edge, the degree of projection of the barrel from the embankment, and the headwater depth. Barrel slope also has a minor effect on culvert capacity. Barrel roughness, length, and tailwater depth have no effect on inlet controlled flow. Inlet control typically governs when the culvert barrel is short, steep, and smooth, and when there are good getaway conditions at the outlet.

The headwater depth is the distance between the energy gradeline and the inlet invert. Thus it includes the contribution of the velocity head at the headwater section. However, in culvert design the velocity head is usually such a small component of the total head that separating it from the total head is not justified. Headwater is usually assumed to be ponded with zero velocity head, and the headwater depth computed from the inlet control equation is taken as the height of the water surface above the inlet invert. The critical depth in the culvert barrel is characterized by the condition that the velocity head equals half the mean depth.

Under outlet control, the flow through the culvert is controlled by conditions in the culvert barrel and at the outlet, as well as by conditions at the inlet, Thus, barrel roughness, length, slope, headwater and tailwater elevations become the primary determinants of flow through the culvert. Outlet control typically governs long, flat, rough-barreled culverts with high tailwater and obstructed getaway conditions at the outlet.

Under the usual conditions of culvert design, the outlet-controlled culvert barrel flows full or nearly full most or all of its length. The full flow condition is checked by computing the hydraulic grade line and noting whether it intersects the top of the culvert barrel. If it is not full flow, backwater calculations have to be used to define the water-surface profile through the culvert barrel. Supercritical flow need not be considered because the inlet will control when supercritical flow occurs in the barrel.

4. User Documentation

Effective use of WSPRO requires an understanding of the interaction between user and software. While the previous chapter described what WSPRO does, this chapter explains how to interact with the software to achieve desired results.

The Command Approach - Organizing the Data

WSPRO operates through the command language concept. This means that data entry and data analysis are all dictated by user-supplied commands. A command is a very specific entity that describes one basic task that WSPRO can recognize. There is only a set number of commands in WSPRO's vocabulary and they must each follow a specific format. Currently there are 41 commands that WSPRO can recognize, although this number is subject to change as long as improvements are being added to WSPRO. A complete list, to date, of these commands along with their definitions and format specifications is included in Appendix B.

A brief glossary of all the commands is shown in Table 2. Detailed descriptions, formatting templates and special notes for each command are provided by the software as long helps (obtained by using the F1 key) and are also reproduced in Appendix B. Commands operate in "free format" fashion; that is, a space [ ], a comma [,] or a slash [/] are parameter subfield separators that may be used in any amount between each parameter value (spacing between subfields is not critical). All commands must be expressed in upper case letters. Continuation of a command with many or extremely lengthy variables is achieved by entering a plus sign [+] before the eightieth column and entering subsequent data into the next line.

Commands are the data that a user must specify to describe a system for analysis. These commands may be arranged in almost any order, provided they follow a few, simple guidelines. These guidelines ensure that the user' site is described appropriately and logically, and will become more clear as the user gains familiarity with this section and the examples provided in the appendix. Once these commands are arranged in their final working order, they are collectively referred to as a command string. The command string is what WSPRO needs to define a system model for analysis.

The output provides detailed information on the resulting calculations using keywords. Table 3 presents the keywords and their definitions.

Table 2. Input record types.

TITLE INFORMATION

T1, T2, T3 - alphanumeric data for identification of output

JOB PARAMETERS

J1 - error tolerances, test values, etc.
J2 - input and output control parameters
J3 - special tabling parameters

PROFILE CONTROL DATA

Q - discharge(s) for profile computation(s)
WS - starting water-surface elevation(s)
SK - energy gradient(s) for slope-conveyance computation of starting water-surface elevation(s)
EX - execution instruction and computation direction(s)
ER - indicates end of input (End of Run)

CROSS-SECTION DEFINITION

(Header Records)

XS - regular valley section
BR - bridge-opening section
SD - spur dike section
XR - road grade section
AS - approach section
CV - culvert section
XT - template section

(Cross-sectional Geometry Data)

GR - x,y-coordinates of ground points in a cross section (some exceptions at bridges, spur dikes, roads, and culverts, and in data propagation)

(Roughness Data)

N - roughness coefficients ('n' -values)
SA - x-coordinates of subarea breakpoints in cross section roughness
ND - depth breakpoints for vertical variation of roughness

(Flow Length Data)

FL - flow lengths and/or friction slope averaging technique

Table 2. Input record types (continued).

BRIDGE SECTION DATA

(Design Mode)

BL - bridge length and location (M)
BD - bridge deck parameters (M)
AB - abutment slopes (M)
CD - opening type and configuration (M)
PW - pier or pile data (O)
KD - conveyance breakpoints (O)

(Fixed Geometry Mode)

CD - opening type and configuration (M)
AB - abutment toe elevations (M)
PW - pier or pile data (O)
KD - conveyance breakpoints (O)

APPROACH SECTION DATA

BP - horizontal datum correction between bridge and approach sections

ROAD GRADE SECTION DATA

RG - vertical curve data
BP - horizontal datum correction between bridge and road grade sections

CULVERT SECTION DATA

CG - culvert geometry
CC - culvert coefficients

TEMPLATE GEOMETRY PROPAGATION

GT - replaces GR data when propagating template section geometry

DATA DISPLAY COMMANDS

HP - compute and print table of hydraulic properties of cross section
PX - produce printer plot of cross section

Note: (M)andatory / (O)ptional designations apply only where these routines are used.

Table 3. Output record types

WSEL	- Water-surface elevation	BLEN	- Bridge opening length
VHD	- Velocity head	XLAB	- Abutment station, left toe
Q	- Discharge	XRAB	- Abutment station, right toe
SRD	- Section reference distance	LSEL	- Low steel elevation
EGL	- Energy grade line	FLOW	- Flow classification code
ERR	- Error in energy/discharge balance	TYPE	- Bridge opening type
FLEN	- Flow distance	C	- Coefficient of discharge
SLEN	- Straight-line (SRD) distance	PPCD	- Pier or pile code
HF	- Friction loss	P/A	- Pier area ratio
HO	- Other losses	Q	- Flow over road
VEL	- Velocity	WLEN	- Weir length
FR#	- Froude number	LEW	- Left edge of weir
CRWS	- Critical water-surface elevation	REW	- Right edge of weir
K	- Cross-section conveyance	DMAX	- Maximum depth of flow
AREA	- Cross-section area	CAVG	- Average weir coefficient
ALPHA	- Velocity head correction factor	HAVG	- Average total head
BETA	- Momentum correction factor	DAVG	- Average depth of flow
XMAX	- Maximum station in cross section	VMAX	- Maximum velocity
YMAX	- Maximum elevation in cross section	VAVG	- Average velocity
XMIN	- Minimum station in cross section	M(K)	- Flow contraction ratio
		KQ	- Conveyance of Kq-section
YMIN	- Minimum elevation in cross section	XLKQ	- Left edge of Kq-section
SPLT	- Stagnation point, left	XRKQ	- Right edge of Kq-section
SPRT	- Stagnation point, right	M(G)	- Geometric contraction ratio
SKEW	- Skew of cross section	OTEL	- Road overtopping elevation
XSWP	- Cross section wetted perimeter		
XSTW	- Cross section top width		
LEW	- Left edge of water		
REW	- Right edge of water		
EX	- Expansion loss coefficient		
CK	- Contraction loss coefficient		

The HYDRAIN Environment

For those users who have obtained WSPRO as part of the Federal Highway Administration's **HYDRAIN** package, additional information is required to run WSPRO within that system. HYDRAIN documentation should be consulted for instructions. The following sections discuss the procedures for operating the HYDRAIN System Shell and using the Generic Editor to create WSPRO input data sets. Users not desiring to operate in the HYDRAIN environment can skip this section.

Operating the HYDRAIN System Shell

WSPRO, as well as the other PFP software packages, is implemented through the use of what is known as the PFP "shell". This shell is a separate program that ties the HYDRAIN system together and allows individual components to be accessed. The following text deals specifically with the interaction between the HYDRAIN System Shell and WSPRO; the operation of the other packages will be dealt with separately in their respective documentation.

Before work on a specific WSPRO data set can begin, the HYDRAIN shell must first be entered and WSPRO accessed. This process is begun, from DOS by entering the C:\HYDRAIN directory, typing the command **HYDRAIN**, and striking a carriage return (denoted by <CR>). A screen will appear showing the member sponsors of the Pooled Fund Project. Another <CR> reveals a message (a PFP "disclaimer") to the PFP user. A third <CR> will place the user in the Main Menu.

Entering the Generic Editor

During initial session use of the generic editor, the user will be looking at a "blank" screen with a banner that will be displayed across the top. The cursor will be located on the start of the first command line, in the top left corner of the blank area; the blank area, itself, is the work area where the command line input file is located. The first action to take is to type the first command "**JOB**" in the first three spaces and then an optional line of text to the right to label the input/output. Type <CR> to enter the first line and then enter the second command line. The user may wish to have a footprint in mind to keep the input session productive. Help is available using the "F1" function key. Help consists of short command definitions and long text for each command. Furthermore, active help displayed as input is underway in one line messages that pertain to each command or to each data field that are on the line associated with the command.

After the introductory screens have been cleared the user enters the Main Menu which contains the following choices:

- Input/Edit - input or edit data for HYDRA, WSPRO, HYDRO, CDSV5, or HYCHL;

- Execute - run HYDRA, WSPRO, HYDRO, CDSV5, HY8V3, EQUAT, or HYCHL;
- Utilities - DOS commands, file operation, HYDRAIN setup;
- System Info - long help files for selected topics in HYDRAIN; and
- Quit - exit the HYDRAIN system.

Selection of an option within the Main Menu is accomplished by simply using the left and right ARROWS to move the cursor to the desired procedure or by striking the highlighted letter of the desired option. As each of the procedural options is highlighted by the cursor, a menu of the options within the specific procedural category are displayed. Movement in this field, as before, is accomplished with the ARROWS (in this case, up and down). Since a new file is to be created, place the cursor under the first choice, **Input / Edit** , then, using the down ARROW, highlight WSPRO and strike <CR>.

At this point, the user is asked if the Generic Editor or an Interactive Editor will be used to create/edit the data set. The generic editor allows the user almost complete freedom to edit command line input files. Use of this editor assumes that the user has a basic working knowledge of the generic editor program and its requirements.

To make a selection, move the cursor to the desired field and press <CR>, or, press G for generic or I for interactive. As it is still under development, currently, none of the HYDRAIN programs can access the interactive editor. Should the user select this option, they will be given a message to this effect.

The result of selecting an editor will be a prompt for the user to specify the name of a file to be edited. Pressing <Esc> or <F2> will return the user to the HYDRAIN main menu. Next, the user should select a file to be edited (or created). The bottom of the screen shows the path of the input files for the engineering program selected. It also displays the number of bytes free on the disk being used. Only those files having the .WSP extension will be displayed.

To select a file from those already existing, move the cursor and press <CR>. The file name selected will be moved to the field next to "File:". To begin editing, press <CR>. Should the user wish to change the file name selection, once the filename is in the "File:" field, they may type the name of the file desired (with a three-letter extension) and press <CR>. This newly entered file name will be sent to the editor.

To create a new file (or use a file that does not use the .WSP extension), move the cursor to [..EDIT..] and press <CR>. The cursor will move to the "File:" field. The user should type the name of the file and press <CR> twice to begin editing. After pressing <CR> the second time, the user is placed into the file which was chosen.

Using the Generic Editor

The generic editor provides the HYDRAIN user with a simple method of adding new data and changing existing data to create program input files for programs which have command line inputs, such as WSPRO. The editor itself is a full-screen editor with each line having two fields. The first field has space for three characters and is the location in which the user enters the command ID for a line of data. The cursor is moved to field two using the right arrow key. Field two is the location of the input data associated with a given command ID and consists of a maximum of 72 characters plus any continuation lines.

In addition to its basic editing capabilities, the generic editor relies on the usage of two function keys. The <F1> key allows the user to access Help while the <F2> key accesses special editing and word processing tools. These two functions act as on/off switches; pressing the key once activates the function, while pressing it a second time deactivates it, returning the screen to edit mode. In addition to the <F1> and <F2> keys, numerous other keys are active in the generic editor. Table 4 provides a listing of these keys and their functions. Appendix A of the HYDRAIN Manual Volume I presents a comprehensive explanation and "walk-through" on the use of the generic editor. This section is intended to provide an overview of the editor and its capabilities.

Table 4
Active Keys and Their Functions

Key	Function
F1 ("Help Key")	Access Long Help.
F2 ("Hot Key")	Access pull-down menus of editing options.
Ctrl End	Delete a line.
Carriage Return <CR>	Insert a line. Move to the next line.
Esc	Return to HYDRAIN main menu.
Arrow keys	Move the cursor throughout the document.
PgUp	View the previous screen of data.
PgDn	View the next screen of data.
Ctrl PgUp	Move to the top of the document.
Ctrl PgDn	Move to the bottom of the document.
Ins	Switch between Insert and Replace modes.
Home	Move to beginning of the field, of the line, of the screen, and then of the file.
End	Move to the end of the field, of the line, of the screen, and then of the file.
Backspace	Move back one space (or field in certain cases).

The generic editor is designed to provide continuous short help displayed at the bottom of the screen for each field. Entering a three character Command in field one triggers a short descriptive help message. Should a more detailed description of the Command ID and the structure of the data to be input into field two be desired, pressing the <F1> key will access a menu of all command IDs for the type of data set (in this case WSPRO). By highlighting the desired command ID and striking <CR>, long help on that command ID is displayed. A complete listing of the command ID long help messages is found in Appendix B.

Editing functions are accessed at any time during the editing process by pressing the <F2> key. These functions are organized in pull-down menus of editing options. Descriptions of the four menus, titled **Select, Search, Modify** and **Block**, follow.

Within the **Select** menu, there are six functions which are presented under two sub-headings. The "File Access" sub-heading has three functions which allow the user to execute basic file management procedures. The "Action" sub-heading has three functions, each of which allows the user to execute a specified procedure.

FILE ACCESS - allows the user to perform one of three operations: Retrieve, Save, and Switch.

Retrieve - In order to Retrieve a file, the following procedure is performed:

a. Select "Retrieve" by moving cursor and pressing <CR>.
b. If the current path, as indicated, is incorrect, enter the correct directory (Note: there must be a backslash (\) before and after the directory name).
c. Using the down arrow, move the highlight bar to the desired file and Press <CR>. Or, type the filename (with extension) in the space next to "Current File:".
d. An inset "Warning" screen will then appear. To retrieve the file and overwrite any text which is on the screen, select "Continue . . .". Or, to cancel the retrieval and return to the Select menu, choose "Abandon . . .".
e. When the text is retrieved and appears on the screen, press <Esc> or <F2> to remove the menu.

Save - In order to Save a file, the following procedure is performed:

a. Select "Save" by moving the cursor and pressing <CR>.
b. If necessary, change the path and directory in which the file will be saved.
c. Using the down arrow, move the highlight bar to the desired file and press <CR>. Or, type the filename (an extension will be assigned automatically) in the space next to "Current File:".
d. If the file being saved is new, it is automatically saved and the user is returned to the Select menu. If the file had already existed, a "Warning" screen will appear. Choose "Continue . . ." to overwrite the existing file or, choose "Abandon . . ." to cancel the save process and return to the Select menu.

It should be noted that an input file will automatically be saved if it is run. Therefore, running a program results in the input file overwriting the previously existing data file.

Switch - The "Switch" function allows the user to bring a new file onto the screen while keeping the original file open. The feature is especially useful for copying or moving a block of text from one file into another through use of the cut/paste option.

To utilize the Switch option, move the cursor to Switch and press <CR>. Proceed as before to retrieve another file. To switch back to the original file, select "Switch" again. In this manner, the user may move between the two files.

ACTION - The "Action" section of the Select menu also contains three functions: Run, DOS, and Quit.

Run - The "Run" option allows the user to run the data file which is displayed on-screen. After running, the screen automatically displays the output. It is important to note, however, that the Run command is only active when the editor is invoked from the HYDRAIN program. As previously mentioned, a program should first be saved before it can be run. In addition, running the program will automatically save the input file.[1]

DOS - The "DOS" option allows the user to return to MS-DOS without actually leaving the editor. Select DOS by moving the cursor and pressing <CR>. The user will then be placed at the DOS prompt and may operate within DOS in a normal fashion. To exit DOS and return to the editor, type EXIT at the DOS prompt. Because of the quantity of space used by the editor and files, there might not be enough memory to use this function.

Quit - After all editing is completed and all files are saved, the user may leave the generic editor by using the "Quit" option. To quit the system, move the cursor to "QUIT" and press <CR>. If all files to which changes were made have been saved, the DOS prompt will be revealed. If changes were made and the files aren't saved, a warning screen will appear. If the choice is made to continue with the exit, all changes will be lost. If the user chooses to abandon the exit, the program will return to the Select menu and the user should then save the file(s).

The **Search menu** is divided into two sections, each of which has five options from which the user may choose. The Search capabilities of the Generic Editor allow the user to quickly locate instances where certain pieces of text occur.

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[1]This feature of the generic editor is very powerful for a user. Use of the "Run" option initiates execution of the current data file and displays the resulting output file on the monitor for immediate review. After complete review of the output file, the input file is returned to the screen for additional runs, if desired.

SEARCH - The "Search" section of the Search menu has five available options. The first four options specify the range of a search while the fifth executes the command. First, the user should select the range to be searched (block, row(s), column(s), global) by moving the cursor to the desired choice and pressing <CR>. Note that the "Block" option is not available unless there is already text which is marked as a block. Similarly, the "Continue" option is not made available until one search has already been performed. Each selection displays a screen in which the user will specify the exact text to be found. In the field next to "Pattern to Match", enter the string of characters to be located. Next, select "Floating" for "Pattern Position". Finally, choose "Yes" to begin the search. Choosing "No" will return the program to the Search menu.

The program then highlights the first instance in which the desired pattern is found. There may, however, be more matches. To check for additional matches, move the cursor to "Continue" in the "Search" section of the Search menu and press <CR>. Selecting "Continue" will result in the next instance in which a match occurs being highlighted. This procedure may be repeated as many times as desired until the end of the file is reached.

TRANSLATE - The "Translate" section of the Search menu has the same five options as the "Search" section. Once again, however, the "Block" and "Continue" options are not always available. The purpose of the translate function is to search for a given pattern and then automatically replace or amend it. The translate input screen requires the same information as search. In addition, the user must enter the new pattern which will replace or be added to the old one. This string is entered in the "Translate to pattern" field. Also, the user must specify whether the new pattern is to overwrite the old one or be inserted after it. This is done by moving the cursor to <Overwrite> or <Insert> and pressing <CR>. Again, choosing "Yes" executes the translate command, while choosing "No" returns the program to the Search menu.

Whenever the program locates the pattern to be translated, a prompt screen is displayed which asks the user whether or not that occurrence should be translated. Choosing "Yes" will perform the translation and move on to the next occurrence. Selecting "No" will move to the next occurrence without changing the previous instance. The "Global" option will automatically translate all of the matches and will return to the Search menu. "Quit" will abandon the translate procedure and return to the Search menu. The final option, "Continue", allows the user to continue the most recent translate procedure, even if the Search menu has been exited and normal editing has been resumed.

The **Modify menu** is divided into three sections: Cut, Paste, and Clear. All of the functions allow the user to move or delete text from the current file.

CUT - There are three options in the "Cut" section of the Modify menu. The user is able to cut a block of one or more columns, and one or more rows. In order to select the Block, Row(s), or Column(s) option, move the cursor to the selection and press <CR>. The "Cut" command deletes the specified portion of the text, but keeps it in memory for a short period of time. In order to cut text which has already been blocked from within the Block menu, select "Block". There is no further prompt, so the block is immediately deleted.

In order to cut one or more rows, select "Row(s)". An inset screen titled "Cut Rows from Sheet" will appear. Move to the field for "Number of rows to cut" and enter the desired number. Then, specify the row at which the cut should start. Note that the default row is the row the cursor was in and the default number of rows is one. The area to be cut is now highlighted. To execute the cut, select "Yes". Selecting "No" will abort the process and return the program to the Modify menu. In addition, pressing <Esc> or <F2> at any time will return the screen to edit mode.

In order to cut one or more column(s) from the text, select "Column(s)" and follow the procedure described for cutting rows.

PASTE - The paste function adds to the text a section which has just been cut. This section can be a block, row(s), or column(s). After selecting "Paste", the Paste Block menu will appear and the program will automatically highlight as much text as was previously cut. For instance, if four rows had been cut, four rows would be highlighted, beginning at the location of the cursor.

Several choices are then made. First, choose whether the new text is to be inserted or is to overwrite existing text. As mentioned, a section of the text is highlighted on the screen. If "overwrite" is selected, the highlighted section is where the new text will be displayed. If "insert" is chosen, the new text will be added above the highlighted area in the case of rows, and left of the highlighted area for columns. If the text to be pasted is a block, it will be inserted above the position of the cursor for rows and left of the cursor for columns.

The second choice, where to start the paste, depends on whether rows or columns are being pasted. For rows, the user specifies the row and column at which the paste is to begin. Keep in mind that for "overwrite", the new text will replace the old text beginning at the specified line number, while for "insert", the new text will go above the specified line. For columns, the choices are the same as those for rows, with one addition; the user specifies the character at which the paste should start. "Overwrite" works in the same manner as for rows, while "Insert" will add the column(s) to the left of the highlighted text.

After the paste is completed, select "Deactivate" in the Block menu (by moving the cursor and pressing <CR>) to remove the block notation.

CLEAR - The "Clear" section of the Modify menu also has three options. For each of these options, block, column(s), and row(s), the text in the specified (highlighted) area is erased. The block, columns, or rows remain in the text but are blank (contain no characters). If the "Block" option is chosen, all text in any area marked as a block is erased. If columns or rows are being cleared, the user specifies the number to clear and the starting location. This information is entered on the prompt screen which is displayed after the user has selected the "Clear" option. To execute the "Clear" command, select "Yes". Once again, pressing <Esc> or <F2> will return the program to edit mode while selecting "No" will display the Modify menu.

The **Block function** is used throughout the generic editor to perform a variety of editing tasks. These tasks include: cut/paste, search, clear, and translate. Each of these tasks are presented in detail in their own long helps. Furthermore, the block function allows the user to specify the exact area of the text where the task is to be performed. There are five options available in the Block menu. The first three, "Characters", "Rows", and "Columns", allow the user to block one or more of the chosen item. To use any of these options, select it (by moving the cursor to the desired choice and pressing <CR>) and use the arrow keys to highlight the block area. When the desired area is highlighted, press <CR> to mark it. The "Global" option automatically blocks the entire document. Finally, the "Deactivate" option removes the block notation from all blocked areas and returns it to standard text.

Executing WSPRO

There are two methods by which WSPRO can be run within the HYDRAIN environment. One method is to run WSPRO from the generic editor. This allows the user the option of immediate review, editing capabilities. The second method is to run WSPRO from the HYDRAIN shell using the **Execute** option.

WSPRO can be run from the generic editor by using the "Hot Key" (<F2>) and moving to the **Select** Action option, Run, and pressing <CR>. As the input file executes, the commands in the file will appear sequentially on the terminal screen. The user can "observe" the progress of the WSPRO run by observing which commands are being processed.

Upon completion of the run, the output file, which is automatically assigned an .LST filename extension, will be displayed on the screen. Movement through this screen can be accomplished with the cursor, PgUp, PgDn, Home and End keys. After reviewing the file, pressing F2 will return the user to the generic editor. From here, the user can once again edit the same file and rerun it.

After saving the data set in the generic editor, WSPRO can be run from the HYDRAIN shell by exiting the editor. This is accomplished by pressing <F2>, selecting the **Selection** Action option, Quit, and striking <CR>. The HYDRAIN main menu screen appears. By selecting the **Execute** procedure, WSPRO may be run by selecting the Run option. Prompts for the data set type and name allow the user to select the appropriate data set. As that with the generic editor while the input file executes, the commands in the file will appear sequentially on the terminal screen. The user can "observe" the progress of the WSPRO run by observing which commands are being processed.

Upon completion of the run, the output file, which is automatically assigned an .LST filename extension, will be displayed on the screen. Movement through this screen can be accomplished with the cursor, PgUp, PgDn, Home and End keys. After reviewing the file, pressing F2 will return the user to the HYDRAIN main menu. From this menu, editing of the input data set is accomplished through reentry of the generic editor.

Appendix A: Benchmark Examples

The following examples serve to illustrate the types of analyses that WSPRO can perform. While these examples are not intended to illustrate all of the options within WSPRO, they are intended to satisfy the following four objectives:

(1) provide guidance for creating command strings,
(2) demonstrate uses for many of the commands,
(3) provide information on how to set up a problem, and
(4) demonstrate what to expect for output.

In particular, the examples are used to illustrate three flow situations: unconstricted flow, a single-opening bridge, and a single-opening bridge with spur dikes. Effort will be made to "build" on each previous example so that the user may get a "feel" for the necessary data required to create a more and more complicated waterway.

Example 1: Water surface profile computations without considering bridges

I. Problem Statement: Given the following site conditions, for a proposed bridge site, determine the water surface profile for the unconstricted valley. The stream reach is 3/4 mile long; is relatively straight; cross section geometry remains the same throughout; bed slope varies along the reach. Due to the uniformity of the reach, only one cross section will be required. The section is located at the center of the proposed bridge site at a section reference distance (SRD) of 2500 feet. A gauging station is located at SRD 1000 feet, providing a stage-discharge relation at that location. Figures 4 and 5 illustrate the cross sectional and channel profiles.

II. Setting Up Data Input: Input data is organized into five general groups: 1) title information; 2) job parameters; 3) profile control data; 4) cross-section definition (that includes cross-section coordinate, roughness data and cross-section information subgroups); and 5) display and execution commands. Each group may be further broken down into subgroups. The record types are defined by a one or two character identifier. Example one will be input in the following manner. The input data set will follow the group descriptions.

A. Title Information: Identifiers T1, T2, T3 provide the user with an area in which output identification information is entered. This information can be site location data, comments, report names, etc.

B. Job Parameters: Three data records (with identifiers J1, J2, J3) are available to define parameters pertaining to the profile computations in their entirety.

A J1 record is used to specify the computational control parameters shown below:

- **DELTAY** - An elevation stepping increment, with a default value of 1.0,
- **YTOL** - an allowable error tolerance between elevations, with a default value of 0.02,
- **QTOL** - an allowable error tolerance between input and computed discharges, having a default value of 0.02,
- **FNTEST** - a Froude number test value, having a 0.8 default value,

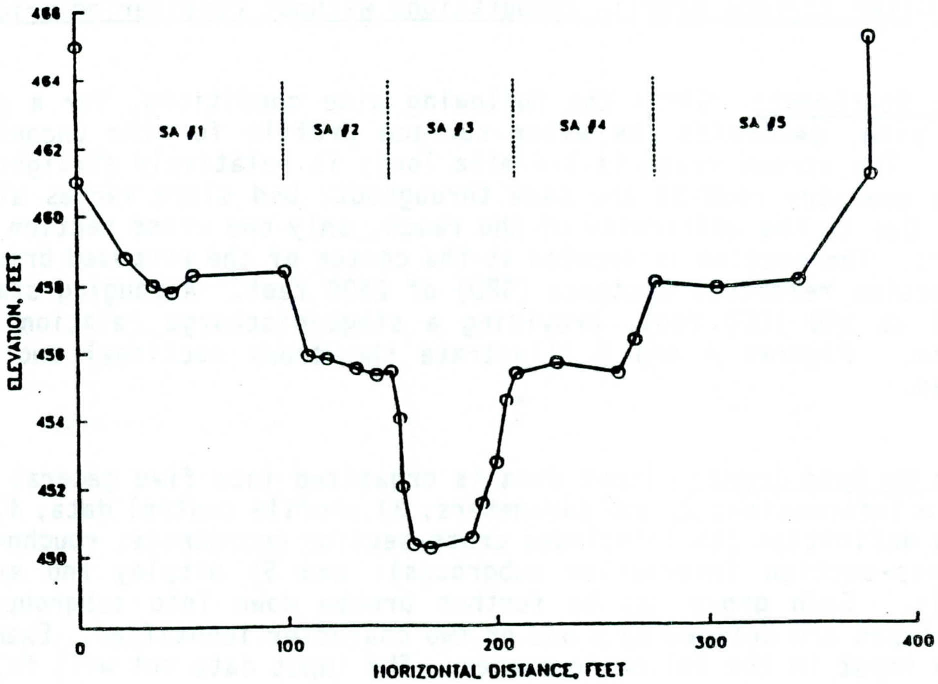

Figure 4. Example cross section.[1]

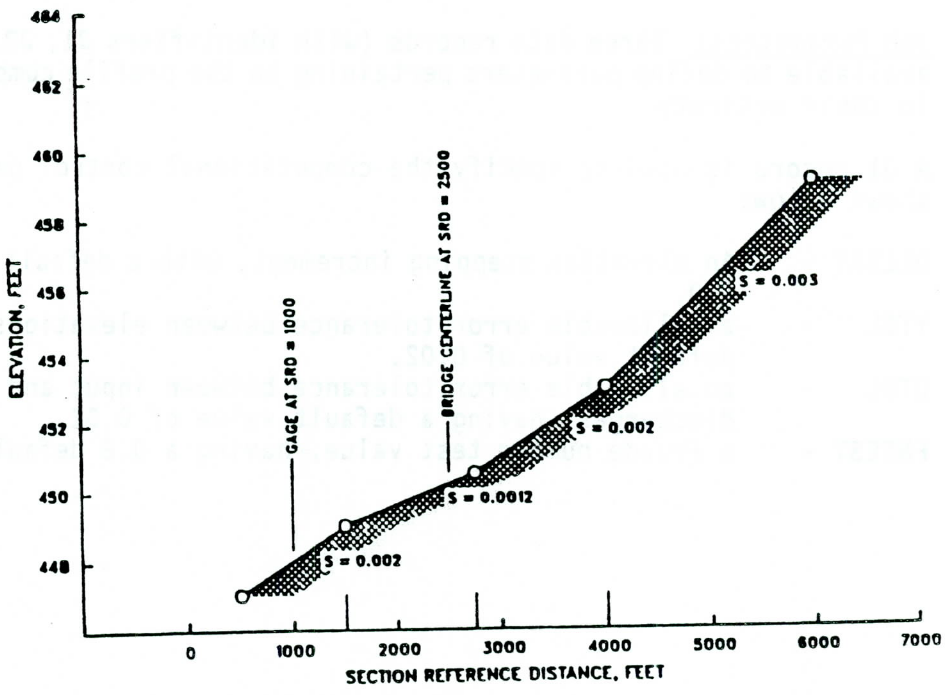

Figure 5. Example channel profile.[1]

IHFNOJ - a flag to select friction slope for <u>all</u> subreaches, a zero or blank is the default value.

If these values are acceptable, then ignore **J1**. Likewise, the **J2** and **J3** records are not used if using default values. Specifically, the **J2** record is designed for input controls, but has not been fully implemented and should be ignored. The **J3** record can specify parameters for special output tables. Default values for **J3** indicate that no special output tables are desired. In this case, default values are used.

C. <u>Profile Control Data:</u> For each water surface profile to be computed the following information is required: a) discharge - **Q**; b) starting elevation - **WS**, or energy slope - **SK**; and c) computation direction - **EX**. After identifying the type of data, the values may be input in a free format. Attention to spacing may make it easier for the user to re-interpret the data later on.

In the first example, five different profiles will be considered. Each profile will contain a value of discharge with its respective starting water surface elevation. For each entry on the **Q** record there must be a corresponding entry on a **WS** or **SK** and an **EX** identifier. The profile control data is shown below:

Q (in ft^3/s)	**WS** (in feet)
3000	456.22
3500	456.63
4500	457.33
5500	457.92
7500	458.92

D. <u>Cross-Section Definition:</u> This data group will be separated into three subgroups: cross-section coordinates, roughness coefficients, and cross-section information.

1. <u>Cross-Section Coordinates:</u> Assuming a uniform nature of the reach lends itself readily to the use of template sections, horizontal geometry may be: a) used without any adjustment, b) expanded or contracted by a scale factor, c) partially used by using selected portions of the section. Vertical geometry may also be: a) used without adjustment, b) shifted by a constant, c) shifted by a product of valley slope and SRD difference. These parameters are entered using a **XT** record and the corresponding SRD; then, **GR** records define the horizontal and vertical cross-section data. To fabricate a particular cross section, such as that at the gauging station, a **GT** record introduces the necessary scaling and shifting parameters. In this case, -2.2 is the shift that the Y coordinate makes from the original streambed elevation to this particular cross section.

2. **Roughness Data:** Figure 5 shows that a cross section may be made up of several subareas characterized by different geometry or roughness. Values of Manning's n may be specified in **N** records for each of these subareas. An n value is entered for the bottom of the subarea as well as the top. The hydraulic depths associated with these values of n are coded in **ND** records specifying first the bottom depth at and below which the bottom n is applicable. Between these depths a linear interpolation determines n. The **SA** records provide the right most X ordinate of each subarea.

3. **Cross-Section Information:** The user may consider unique cross sections by using the **XS** record and providing data pertinent to that particular cross section. In the example, this means entering information for a cross section at SRD 1500 and at SRD 2000 to reflect bottom slope, at SRD 2365 and SRD 2485, just prior to the bridge site, and at 2635, after the bridge site.

The values defining the cross section illustrated in figure 5 are provided below:

Subarea	Horizontal Distance (in ft)	Vertical Elevation (in ft)	Manning's Coefficient Range & Depth
#1	0.0	461.0	0.055 at the
	23.0	458.8	top (≥1) and
	36.0	458.0	0.050 at the
	45.0	457.8	bottom (≤3).
	55.0	458.3	
	99.0	458.4	
#2	110.0	455.9	0.065 at the
	119.0	455.8	top (≥2) and
	133.0	455.5	0.060 at the
	143.0	455.3	bottom (≤5).
	150.0	455.4	
#3	154.0	454.0	0.040 at the
	155.0	452.0	top (≥0) and
	160.0	450.3	0.040 at the
	168.0	450.2	bottom (≤1).
	188.0	450.5	
	193.0	451.5	
	200.0	452.7	
	205.0	454.5	
	210.0	455.3	
#4	229.0	455.6	0.065 at the
	258.0	455.3	top (≥1) and
	266.0	456.3	0.060 at the
	276.0	458.0	bottom (≤4).
#5	305.0	457.8	0.055 at the
	344.0	458.0	top (≥1) and
	380.0	461.0	0.050 at the
	380.0	465.0	bottom (≤3).

E. **Execution Commands:** Finally, the **EX** record, corresponding to the Q and **WS** records, instructs the model to begin execution of the profile computations. The default direction of computation is upstream (for subcritical and/or critical flow), which is the case in this example. The **ER** record indicates the end of the run.

III. <u>Complete Model Input Sequence:</u> The complete input sequence is shown below. Any comments or notes to the user are in bold and should not be used in the model execution.

```
T1        EXAMPLES OF INPUT AND OUTPUT FOR COMPUTER PROGRAM WSPRO
T2        FHWA/USGS MODEL FOR WATER-SURFACE PROFILE COMPUTATIONS
T3        <<<<< EXAMPLE PROBLEM ONE - SIMPLE UNCONSTRICTED FLOW
J1        1.0  0.02  0.02  0.80  0          - note: default values
J2        data input control - should be left out of input data set
J3        data output control - blank is default
Q           3000     3500     4500     5500     7500
WS        456.22  456.63  457.33  457.92  458.92
XT   SURVY  2500
GR            0.0,465.0       0.0,461.0      23.0,458.8      36.0,458.0      45.0,457.8
GR           55.0,458.3      99.0,458.4     110.0,455.9     119.0,455.8     133.0,455.5
GR          143.0,455.3     150.0,455.4     154.0,454.0     155.0,452.0     160.0,450.3
GR          168.0,450.2     188.0,450.5     193.0,451.5     200.0,452.7     205.0,454.5
GR          210.0,455.3     229.0,455.6     258.0,455.3     266.0,456.3     276.0,458.0
GR          305.0,457.8     344.0,458.0     380.0,461.0     380.0,465.0
XS    GAGE  1000
GT          -2.2
N                0.055,0.050        0.065,0.060        0.040,0.040
N                0.065,0.060        0.055,0.050
SA             99      150      210      276
ND            1,3      2,5      0,1      1,4      1,3
XS     XS2  1500     *    *    *      0.002
XS     XS3  2000     *    *    *     0.0012
XS    EXIT  2365
XS   FULLV  2485
XS    APPR  2635
EX
ER
```

The asterisks in the second and third **XS** records are used to indicate that default or previously coded values for the acute angle of rotation of the channel, the expansion and contraction loss components, respectively, are to be used. The only adjustment to be made is in the valley slope - note that the 0.0012 ft/ft is assumed to be the slope for these last three **XS** records since a new slope value was not entered after XS3.

IV. <u>Model Output:</u> Model output is extensive since five profiles are computed at seven cross sections. Only portions of the output are shown here, including the output for a discharge of 3000 ft^3/s and the echoed input and computations for SRD 2500 and "GAGE" SRD 1000. Dashed lines denote where sections of the complete output have been removed. The annotation refer to comments following the output.

```
------------------------------------------------------------------- A -------

WSPRO        FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
P061787          MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

           *** RUN DATE & TIME: 09-21-87  15:16

  T1         EXAMPLES OF INPUT AND OUTPUT FOR COMPUTER PROGRAM WSPRO
  T2         FHWA/USGS MODEL FOR WATER-SURFACE PROFILE COMPUTATIONS
  T3         <<<<< EXAMPLE PROBLEM ONE - SIMPLE UNCONSTRICTED FLOW
  Q            3000    3500    4500    5500    7500
*** Q-DATA FOR SEC-ID, ISEQ =                  1
  WS         456.22  456.63  457.33  457.92  458.92

WSPRO        FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
P061787          MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

       EXAMPLES OF INPUT AND OUTPUT FOR COMPUTER PROGRAM WSPRO
       FHWA/USGS MODEL FOR WATER-SURFACE PROFILE COMPUTATIONS
       <<<<< EXAMPLE PROBLEM ONE - SIMPLE UNCONSTRICTED FLOW
          *** RUN DATE & TIME: 09-21-87  15:16

*** START PROCESSING CROSS SECTION - "SURVY"
  XT   SURVY  2500
  GR          0.0,465.0    0.0,461.0   23.0,458.8   36.0,458.0   45.0,457.8
  GR         55.0,458.3   99.0,458.4  110.0,455.9  119.0,455.8  133.0,455.5
  GR        143.0,455.3  150.0,455.4  154.0,454.0  155.0,452.0  160.0,450.3
  GR        168.0,450.2  188.0,450.5  193.0,451.5  200.0,452.7  205.0,454.5
  GR        210.0,455.3  229.0,455.6  258.0,455.3  266.0,456.3  276.0,458.0
  GR        305.0,457.8  344.0,458.0  380.0,461.0  380.0,465.0

*** FINISH PROCESSING CROSS SECTION - "SURVY"
*** TEMPLATE CROSS SECTION "SURVY" SAVED INTERNALLY.

*** START PROCESSING CROSS SECTION - " GAGE"
  XS    GAGE  1000
  GT         -2.2
  N                0.055,0.050       0.065,0.060       0.040,0.040
  N                0.065,0.060       0.055,0.050
  SA            99       150      210       276
  ND           1,3       2,5      0,1       1,4       1,3

*** FINISH PROCESSING CROSS SECTION - " GAGE"
*** CROSS SECTION " GAGE" ADDED TO DAF, RECORD NO. =     1, IXTYPE =     1

--- DATA SUMMARY FOR SECID " GAGE" AT SRD =    1000.  ERR-CODE =       0

     SKEW      IHFNO    VSLOPE         EK         CK
       .0         0.     .0000        .50        .00
```

```
X-Y COORDINATE PAIRS  (NGP =  29):
        X       Y             X       Y             X       Y             X       Y
       .0  462.80            .0  458.80          23.0  456.60          36.0  455.80
     45.0  455.60          55.0  456.10          99.0  456.20         110.0  453.70
    119.0  453.60         133.0  453.30         143.0  453.10         150.0  453.20
    154.0  451.80         155.0  449.80         160.0  448.10         168.0  448.00
    188.0  448.30         193.0  449.30         200.0  450.50         205.0  452.30
    210.0  453.10         229.0  453.40         258.0  453.10         266.0  454.10
    276.0  455.80         305.0  455.60         344.0  455.80         380.0  458.80
    380.0  462.80

 X-Y MAX-MIN POINTS:
     XMIN       Y             X    YMIN          XMAX       Y             X    YMAX
       .0  462.80         168.0  448.00         380.0  458.80            .0  462.80

SUBAREA BREAKPOINTS (NSA =  5):
          99.      150.      210.      276.

ROUGHNESS DEPTHS (NRD =  2):
BOT:      1.00     2.00      .00      1.00     1.00
TOP:      3.00     5.00     1.00      4.00     3.00

ROUGHNESS COEFFICIENTS (NSA =  5):
BOT:      .055     .065     .040      .065     .055
TOP:      .050     .060     .040      .060     .050

-------------------------------------------------------------------------- A -------

-------------------------------------------------------------------------- B -------

WSPRO          FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
P061787             MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

        EXAMPLES OF INPUT AND OUTPUT FOR COMPUTER PROGRAM WSPRO
        FHWA/USGS MODEL FOR WATER-SURFACE PROFILE COMPUTATIONS
        <<<<< EXAMPLE PROBLEM ONE - SIMPLE UNCONSTRICTED FLOW
           *** RUN DATE & TIME: 09-21-87  15:16

 XSID:CODE    SRDL     LEW      AREA    VHD     HF      EGL     CRWS       Q     WSEL
       SRD    FLEN     REW         K   ALPH     HO      ERR      FR#     VEL

 GAGE:XS    ******     29.      760.    .43  *****   456.65   454.16   3000.   456.22
     1000.  ******    349.    67119.   1.76  ***** *******      .60    3.95

  XS2:XS      500.     29.      760.    .43   1.00   457.65  *******   3000.   457.22
     1500.    500.    349.    67183.   1.76    .00      .00      .60    3.95

  XS3:XS      500.     23.      880.    .33    .87   458.52  *******   3000.   458.19
     2000.    500.    353.    77037.   1.84    .00      .01      .50    3.41
```

EXIT:XS	365.	22.	918.	.31	.53	459.05	*******		3000.	458.74
2365.	365.	355.	80410.	1.86	.00	.00	.47		3.27	
FULLV:XS	120.	21.	932.	.30	.16	459.23	*******		3000.	458.93
2485.	120.	355.	81668.	1.87	.00	.01	.46		3.22	
APPR:XS	150.	21.	946.	.29	.20	459.44	*******		3000.	459.15
2635.	150.	356.	82880.	1.87	.00	.01	.46		3.17	

--- B -------

A. Input Echo: Initially, data in the input data file is echoed, processed and saved. The data for the cross section "SURVY" at SRD 2500 is used to compute the X, Y coordinate pairs for the remaining cross sections. The parameter in the GT record identifies the shift from SRD = 2500 to SRD = 1000. The "max - min" points are calculated and all data is summarized.

B. Profile Calculations: Upon completion of the input echo and data summary, the model calculates a water-surface profile for each of the coded discharges. The output for a discharge of 3000 ft^3/s for the indicated cross sections is presented below.

Example 2: Simple Single Opening Bridge

I. Problem Statement: At the same site described in the first example, we wish to construct a bridge at SRD 2485. The bridge length between the tops of the abutments will be 120 feet; depth of the bridge deck is 1 foot; elevation of the top of the bridge deck is 463.0 feet, bridge width is 30 feet. Abutments, in this case, are vertical (without wingwalls).

II. Setting up Data Input: Initially, the input for this example closely follows the input for example 1. The template section for SRD 2500 is unchanged. Data for gage cross-section stations at SRD 1000, 1500 and 2000 are not required since, from example one, we know the starting water-surface elevations at section "EXIT". The cross section at SRD 2365 (EXIT) has been fully described as SRD 1000 in example 1, the difference being that the slope is 0.0012 and there is no need of a Y-shifting factor in the **GT** record.

The user is familiar with all input coding up to the description of the bridge site; explanation of this section of input follows:

A. Cross-Section Description: The example two cross-section data will be the same as example one with the exception that only cross-section "EXIT" is considered. A slope of 0.012 ft/ft will be used as there were no earlier defined cross sections. A **GT** record without the shift parameter tells the program to use the template cross-section data without shifting the elevations. However, the template data will be adjusted based on the slope and the SRD of "EXIT". The channel roughness data will also be the same as used in example one.

B. Bridge Section: The **BR** record is the header for a bridge cross-section. The first entry in this record is a unique cross-section identification code that will be called "BRDGE". The second entry is the SRD of the cross section that in example two is equal to 2485.

A **BD** record specifies the bridge deck parameters. The first entry in this record is the depth of the bridge deck, in feet; the second is the elevation of the top of the bridge deck.

The **BL** record specifies the bridge length and the abutment constraints. The first entry for this example is a default value (blank or zero). This indicates that the bridge length is centered at the mid-point of the horizontal stations controlling the opening. The second entry in this record is the length of the bridge between the abutments, in feet. The third entry gives the right most horizontal location of the left boundary of the proposed opening; the fourth entry gives the left most location of the right boundary of the proposed opening.

The purpose of a **CD** record is to specify parameters used to compute the flow length and the coefficient of discharge for a bridge. The first of seven entries specifies the bridge opening type; A 1 (one) indicates vertical embankments and vertical abutments, with or without wingwalls. The second entry specifies the total width of the bridge deck in the direction of flow. Entry three describes the embankment side slope and the fourth entry codes the embankment elevation. Entries three and four are not applicable to a type 1 opening. Entry five is the wingwall angle - for this example, the default value of zero degrees is used. Wingwall width is the sixth entry; we will use the default value 0 for the example case. The seventh, and final **CD** entry gives the radius of the entrance rounding. Since we do not have a rounded entrance, the default value of zero is used.

Finally, the Manning's roughness values for the bridge surface are given. The records meaning are the same as were discussed earlier.

C. <u>Approach Section:</u> An **AS** identifier is the header record for an approach cross section. The first entry is a unique cross-section identity code; the second is the SRD of the section.

D. <u>Execution Commands:</u> Finally, the user codes the **EX** and **ER** records, indicating the start of calculation and end of run, respectively.

III. <u>Complete Model Input Sequence:</u> For example two, the complete input sequence is shown below. The * entered into the first column indicates a blank row, used for spacing of data.

```
T1        EXAMPLES OF INPUT AND OUTPUT FOR COMPUTER PROGRAM WSPRO
T2        FHWA/USGS MODEL FOR WATER-SURFACE PROFILE COMPUTATIONS
T3        <<<<< EXAMPLE PROBLEM TWO - SIMPLE BRIDGE OPENING FLOW
*
Q           3000     3500     4500     5500     7500
WS        458.74   459.16   459.87   460.48   461.50
*
XT   SURVY  2500
GR            0.0,465.0      0.0,461.0     23.0,458.8     36.0,458.0     45.0,457.8
GR           55.0,458.3     99.0,458.4    110.0,455.9    119.0,455.8    133.0,455.5
GR          143.0,455.3    150.0,455.4    154.0,454.0    155.0,452.0    160.0,450.3
GR          168.0,450.2    188.0,450.5    193.0,451.5    200.0,452.7    205.0,454.5
GR          210.0,455.3    229.0,455.6    258.0,455.3    266.0,456.3    276.0,458.0
GR          305.0,457.8    344.0,458.0    380.0,461.0    380.0,465.0
*
XS    EXIT  2365     *    *    *     0.0012
GT
*
N                0.055,0.050         0.065,0.060         0.040,0.040
N                0.065,0.060         0.055,0.050
SA            99       150       210       276
ND           1,3       2,5       0,1       1,4       1,3
*
```

```
XS   FULLV  2485
BR   BRDGE  2485
BD            1.0    463.0
BL            120      135      225
CD              1       30
N                  0.040,0.050
ND            3,5
SA
AS    APPR  2635
EX
ER
```

IV. Model Output: An abbriviated model output is given below. Dashed lines denote where sections of the complete output have been removed. The annotation refer to comments following the output.

```
------------------------------------------------------------------------ A1 ------

 *** START PROCESSING CROSS SECTION - "BRDGE"
     BR   BRDGE  2485
     BD            1.0    463.0
     BL            120      135      225
     CD              1       30
     N                  0.040,0.050
     ND            3,5
     SA

 *** FINISH PROCESSING CROSS SECTION - "BRDGE"
 *** CROSS SECTION "BRDGE" ADDED TO DAF, RECORD NO. =     3, IXTYPE =    2

 --- DATA SUMMARY FOR SECID "BRDGE" AT SRD =    2485.  ERR-CODE =      0

         SKEW      IHFNO     VSLOPE         EK         CK
           .0         0.      .0012        .50        .00

 X-Y COORDINATE PAIRS  (NGP =  18):
          X        Y          X        Y          X        Y          X        Y
        120.0  462.00       120.0  455.76       133.0  455.48       143.0  455.28
        150.0  455.38       154.0  453.98       155.0  451.98       160.0  450.28
        168.0  450.18       188.0  450.48       193.0  451.48       200.0  452.68
        205.0  454.48       210.0  455.28       229.0  455.58       240.0  455.47
        240.0  462.00       120.0  462.00

  X-Y MAX-MIN POINTS:
         XMIN        Y          X     YMIN       XMAX        Y          X     YMAX
        120.0  462.00       168.0  450.18       240.0  455.47       120.0  462.00

 ROUGHNESS DEPTHS (NRD =  2):
 BOT:       3.00
 TOP:       5.00
```

```
ROUGHNESS COEFFICIENTS (NSA =  1):
BOT:      .040
TOP:      .050

BRIDGE PARAMETERS:
 BRTYPE  BRWDTH      LSEL  USERCD  WWANGL  WWWID  CRRAD
    1      30.0   462.00 ******* ******* ****** ******

DESIGN DATA:     BRLEN   LOCOPT    XABLT    XABRT
                 120.0       0.    135.0    225.0

                GIRDEP   BDELEV    BDSLP    BDSTA
                  1.00   463.00 ******* *******

PIER DATA:  NPW =  0   PCODE = **

------------------------------------------------------------------------ A1 ------

------------------------------------------------------------------------ A2 ------

*** START PROCESSING CROSS SECTION - " APPR"
  AS    APPR  2635
  EX

*** FINISH PROCESSING CROSS SECTION - " APPR"
*** CROSS SECTION " APPR" ADDED TO DAF, RECORD NO. =    4, IXTYPE =    5

--- DATA SUMMARY FOR SECID " APPR" AT SRD =   2635.  ERR-CODE =      0

     SKEW      IHFNO     VSLOPE        EK        CK
       .0         0.      .0012       .50       .00

X-Y COORDINATE PAIRS  (NGP =  29):
       X      Y              X      Y              X      Y              X      Y
      .0  465.16            .0  461.16          23.0  458.96          36.0  458.16
    45.0  457.96          55.0  458.46          99.0  458.56         110.0  456.06
   119.0  455.96         133.0  455.66         143.0  455.46         150.0  455.56
   154.0  454.16         155.0  452.16         160.0  450.46         168.0  450.36
   188.0  450.66         193.0  451.66         200.0  452.86         205.0  454.66
   210.0  455.46         229.0  455.76         258.0  455.46         266.0  456.46
   276.0  458.16         305.0  457.96         344.0  458.16         380.0  461.16
   380.0  465.16

 X-Y MAX-MIN POINTS:
    XMIN       Y             X    YMIN        XMAX       Y             X    YMAX
      .0  465.16         168.0  450.36       380.0  461.16            .0  465.16

SUBAREA BREAKPOINTS (NSA =  5):
         99.     150.     210.     276.
```

```
ROUGHNESS DEPTHS (NRD =  2):
BOT:     1.00    2.00     .00    1.00    1.00
TOP:     3.00    5.00    1.00    4.00    3.00

ROUGHNESS COEFFICIENTS (NSA =  5):
BOT:     .055    .065    .040    .065    .055
TOP:     .050    .060    .040    .060    .050

BRIDGE PROJECTION DATA:  XREFLT  XREFRT  FDSTLT  FDSTRT
                        ******* ******* ******* *******

-------------------------------------------------------------------- A2 ------

-------------------------------------------------------------------- B -------

 XSID:CODE   SRDL    LEW     AREA    VHD     HF    EGL    CRWS      Q    WSEL
       SRD   FLEN    REW        K   ALPH     HO    ERR     FR#    VEL

 EXIT:XS   ******    22.     917.    .31  *****  459.05  456.20  3000.  458.74
     2365. ******   355.   80310.   1.86  ***** *******     .47   3.27

FULLV:FV     120.    21.     931.    .30    .16  459.23 *******  3000.  458.93
     2485.   120.   355.   81582.   1.87    .00     .01     .46   3.22
          <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 APPR:AS     150.    21.     945.    .29    .20  459.44 *******  3000.  459.15
     2635.   150.   356.   82808.   1.87    .00     .01     .46   3.18
          <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

             <<<<<RESULTS REFLECTING THE CONSTRICTED FLOW FOLLOW>>>>>

 XSID:CODE   SRDL    LEW     AREA    VHD     HF    EGL    CRWS      Q    WSEL
       SRD   FLEN    REW        K   ALPH     HO    ERR     FR#    VEL

BRDGE:BR     120.   120.     638.    .45    .24  459.31  456.24  3000.  458.87
     2485.   120.   240.   55250.   1.30    .02     .00     .41   4.70

      TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
        1. ****   1.   .877 ****** 462.00   120.   120.   240.

 XSID:CODE   SRDL    LEW     AREA    VHD     HF    EGL    CRWS      Q    WSEL
       SRD   FLEN    REW        K   ALPH     HO    ERR     FR#    VEL

 APPR:AS     120.    19.    1021.    .25    .22  459.62  456.53  3000.  459.37
     2635.   123.   359.   89862.   1.88    .09     .00     .41   2.94

       M(G)   M(K)      KQ   XLKQ   XRKQ   OTEL
       .642   .147  76494.   122.   242. 459.24

                    <<<<<END OF BRIDGE COMPUTATIONS>>>>>
-------------------------------------------------------------------- B -------
```

A. <u>Input Echo:</u> The input echo section of the output is very similar to that described in example 1 until the bridge section is echoed, the only difference resulting from the shifted starting elevations. A detailed explanation of the bridge and approach sections follow.

1) <u>Bridge Section:</u> As with the cross sections in example 1, the coded input is echoed and the cross section is processed and summarized. The cross-section information is summarized first. The skew angle, friction slope code (**IHFNO**), valley slope, expansion and contraction coefficient values were initially input at cross-section "exit" SRD 2365 and remain unchanged for the reach until a new value is coded in. The x,y - coordinate pairs are computed and displayed. X-Y maximum and minimum points are found and the roughness depths and Manning's coefficients are listed.

Finally, the bridge parameters, design data and pier data (input in records **BR**, **BD**, **BL** and **CD**) are echoed. A brief listing of data headings encountered in this example follows:

BRTYPE	-	Bridge opening type
BRWDTH	-	Bridge deck width
LSEL	-	Elevation of the low chord of the bridge opening, calculated by the model in design mode (feet)
USERCD	-	User specified discharge coefficient, calculated by the model if default option is used
WWANGL	-	Wingwall angle (degrees)
WWWID	-	Wingwall width (feet)
CRRAD	-	Radius of roundness of opening
BRLEN	-	Bridge length between abutment tops (feet)
LOCOPT	-	Bridge location with respect to horizontal stationing feet)
XCONLT	-	Horizontal stationing for left abutment constraint (feet)
XCONRT	-	Horizontal stationing for right abutment constraint (feet)
GIRDEP	-	Girder or deck depth (feet)
BDELEV	-	Deck elevation (feet)
BDSLP	-	Deck slope (ft/ft)
BDSTA	-	Deck slope station (feet)
NPW	-	Number of piers
PCODE	-	Pier code

2) <u>Approach Section:</u> The input echo for an approach station closely follows the format of a standard cross-section. The only "new" information is the bridge projection data, which is coded in the **BP** record. Since the approach is unskewed, default values are indicated. A full description of these variables is given in the users manual. The input echo for the approach section is displayed.

B. Profile Calculations: Upon completion of the input echoing and data summary, the model computes a water surface profile for each discharge. The profile for a discharge of 3000 ft^3/s is presented below.

The user may notice that the format is the same as the format encountered in example one. The flow which is now constricted, through addition of the single opening bridge, requires additional descriptors for computational results. An explanation of new output headings follows.

TYPE	-	Bridge Opening Type - Same as BRtype
PPCD	-	Pier or Pile Code
FLOW	-	Flow Classification Code
C	-	Coefficient of Discharge
P/A	-	Pier Area Ratio
LSEL	-	Low Steel (submergence) Elevation (feet)
BLEN	-	Bridge Opening Length (feet)
XLAB	-	Abutment Station. Left Toe (feet)
XRAB	-	Abutment Station, Right Toe
M(G)	-	Geometric Contraction Ratio (Width)
M(K)	-	Flow Contraction Ratio (conveyance)
KQ	-	Conveyance of Kq section. The Kq section is the portion of the approach section that conveys discharge that can flow through the bridge opening uncontracted. (ft^3/s)
XLKQ	-	Left Edge of Kq Section (feet)
XRKQ	-	Right Edge of Kq Section (feet)
OTEL	-	Road Overtopping Elevation (feet)

Comparison of the results for unconstricted flow and constricted flow at SRD 2485 point out the effects of constricting the channel: area is lessened; cross-section total conveyance is lessened; velocity head increases (the alpha velocity head correction factor decreased) friction loss increased; a critical water surface elevation is indicated; and velocity increases.

Comparing the flows at the approach section illustrates the effect of backwater occurrence resulting from the constriction of flow.

Example 3: Single Opening Bridge with Spur Dikes

I. Problem Statement: Building on examples one and two, the user may want to determine the effects of spur dikes on the water profile. The same reach will be considered, with a single opening bridge equipped with spur dikes. The spur dikes are offset 20 feet horizontally from the abutments and are elliptical, the center line is parallel to flow, and the length is 50 feet.

II. Setting up Data Input: The input data set for example two is used with the addition of four lines to describe the added spur dikes. Description of the spur dike information follows.

A. Cross-Section Information: The **SD** record is the header record for the spur dike cross-section. The first entry is a unique identification code, in this case "SDIKE". The second entry is the SRD. The third, indicates the type of spur dike, coded 1-4; type 1 an elliptical spur dike, no skew, type 2 - an elliptical spur dike skewed, type 3 - straight spur dike no offset, type 4 - straight spur dike, with offset. The fourth entry refers only to a type 4 dike, so the default is used. The fifth, the horizontal offset, is the distance between the abutment and the wall of the spur dike, measured normal to the flow at the mouth of the dikes. The user is familiar with the last four entries; skew, expansion and contraction coefficients, and valley slope.

III. Partial Model Input Sequence: For example three, a partial input sequence is shown below.

```
SD    SDIKE  2535  1  *  20  *  *  *  .0012
N            0.040,0.050
ND               3,5
SA
```

IV. Model Output: An abbriviated model output showing only the spur dike echo is given below. Dashed lines denote where sections of the complete output have been removed. The annotation refer to comments following the output.

```
----------------------------------------------------------------- A -------

 *** START PROCESSING CROSS SECTION - "SDIKE"
   SD   SDIKE  2535  1  *  20  *  *  *  .0012
   N           0.040,0.050
   ND              3,5
   SA

 *** FINISH PROCESSING CROSS SECTION - "SDIKE"
 *** CROSS SECTION "SDIKE" WRITTEN TO DISK, RECORD NO. =  4
```

```
--- DATA SUMMARY FOR SECID "SDIKE" AT SRD =    2535.  ERR-CODE =      0

     SKEW      IHFNO     VSLOPE        EK         CK
       .0         0.      .0012       .50        .00

X-Y COORDINATE PAIRS  (NGP =  20):
       X         Y           X         Y           X         Y           X         Y

    100.0   462.06       100.0   458.21       110.0   455.94       119.0   455.84
    133.0   455.54       143.0   455.34       150.0   455.44       154.0   454.04
    155.0   452.04       160.0   450.34       168.0   450.24       188.0   450.54
    193.0   451.54       200.0   452.74       205.0   454.54       210.0   455.34
    229.0   455.64       258.0   455.34       260.0   455.59       260.0   455.53

 X-Y MAX-MIN POINTS:
     XMIN        Y           X      YMIN        XMAX        Y           X      YMAX
    100.0   462.06       168.0   450.24       260.0   455.59       100.0   462.06

ROUGHNESS DEPTHS (NRD =  2):
BOT:       3.00
TOP:       5.00

ROUGHNESS COEFFICIENTS (NSA =  1):
BOT:       .040
TOP:       .050

SPUR DIKE DATA:  SDTYPE  OFFSET  DESOFF
                     1. *******   20.00

------------------------------------------------------------------- A -------


------------------------------------------------------------------- B -------

 XSID:CODE    SRDL      LEW      AREA    VHD      HF      EGL     CRWS        Q     WSEL
       SRD    FLEN      REW         K   ALPH      HO      ERR      FR#      VEL

 EXIT:XS    ******      22.      917.    .31   *****   459.05   456.20    3000.   458.74
     2365.  ******     355.    80310.   1.86   ***** *******      .47     3.27

FULLV:FV      120.      21.      931.    .30     .16   459.23  *******    3000.   458.93
     2485.    120.     355.    81582.   1.87     .00      .01      .46     3.22
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 APPR:AS      150.      21.      945.    .29     .20   459.44  *******    3000.   459.15
     2635.    150.     356.    82808.   1.87     .00      .01      .46     3.18
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

             <<<<<RESULTS REFLECTING THE CONSTRICTED FLOW FOLLOW>>>>>

 XSID:CODE    SRDL      LEW      AREA    VHD      HF      EGL     CRWS        Q     WSEL
       SRD    FLEN      REW         K   ALPH      HO      ERR      FR#      VEL
```

```
BRDGE:BR      120.    120.     649.    .33    .24  459.29  456.24   3000.  458.95
     2485.    120.    240.   56719.   1.00    .00     .00     .35    4.63

     TYPE PPCD FLOW       C     P/A     LSEL    BLEN    XLAB    XRAB
       1. ****   1.   1.000 ******  462.00    120.    120.    240.

===140 AT SECID "SDIKE":  END OF CROSS SECTION EXTENDED VERTICALLY.
                              WSEL,YLT,YRT =    459.20       462.1       455.5

 XSID:CODE    SRDL     LEW      AREA    VHD     HF      EGL    CRWS       Q    WSEL
       SRD    FLEN     REW         K   ALPH     HO      ERR     FR#     VEL

SDIKE:SD       20.    100.     800.    .22    .05  459.42  456.33   3000.  459.20
     2535.     20.    260.   67690.   1.00  *****     .01     .30    3.75

 XSID:CODE    SRDL     LEW      AREA    VHD     HF      EGL    CRWS       Q    WSEL
       SRD    FLEN     REW         K   ALPH     HO      ERR     FR#     VEL

 APPR:AS      100.     19.    1011.    .26    .19  459.60  456.53   3000.  459.34
     2635.    103.    358.   88947.   1.88    .08     .01     .42    2.97

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
       .642   .144   75756.   122.   242.  459.21

                        <<<<<END OF BRIDGE COMPUTATIONS>>>>>

----------------------------------------------------------------------- B -------
```

A. Input Echo: The input echo and data summary for cross section "SDIKE" is displayed below. It follows the same form as previously discussed with the addition of pertinent spur dike data: the type, straight dike offset and horizontal offset.

B. Profile Calculations; The addition of spur dikes to the example increased the conveyance through the Kq section, as expected, and also increased the approach area and the friction loss. Partial output is displayed.

One item of interest is the "=== 140" message. This message means that the water surface level at y left or y right is below the final computed water surface elevation. If vertical extension of the end of the cross section adequately describes the cross section, no action need be taken.

Appendix B: WSPRO Command Long Helps

This appendix details the meaning and syntax of each command available in WSPRO. The descriptions are ordered alphabetically and include information on the command name, its purpose, and its structure. Any important notes pertaining to the command are also included.

COMMAND AB - ABUTMENT PARAMETERS

Purpose: To specify abutment slopes (ONLY for Type 3 opening in DESIGN MODE) or abutment toe elevations (ONLY for Type 2 openings for FIXED-GEOMETRY MODE).

Structure:

AB abslpl, abslpr -- or --
AB yablt, yabrt

1) abslpl - slope (horizontal distance per foot of vertical distance) of left abutment. Required only for Type 3 opening DESIGN MODE.

2) abslpr - slope (horizontal distance per foot of vertical distance) of right abutment. Required only for Type 3 opening DESIGN MODE. (Note: this parameter not required if same as abslpl).

3) yablt - toe elevation at left abutment. Required only for Type 2 opening in FIXED-GEOMETRY MODE.

4) yabrt - toe elevation at right abutment. Required only for Type 2 opening in FIXED-GEOMETRY MODE. (Note: this parameter not required if same as yablt).

COMMAND AS - Approach Section

Purpose: To reference approach cross section.

Structure:

AS secid, srd, skew, ek, ck, vslope

1) secid - unique cross-section identification code.
2) srd - section reference distance. A cumulative distance, in feet, along the stream measured from any arbitrary zero reference point (srd may be negative).
3) skew - the acute angle (degrees) that the cross section must be rotated to orient it normal to the flow direction. (Default is 0.0 degrees).
4) ek - OPTIONAL - coefficient used for computing expansion losses in the energy equation. (Default value is 0.5).
5) ck - OPTIONAL - coefficient used for computing contraction losses in the energy equation. (Default value is 0.0).
6) vslope - valley slope in feet/foot. Used for adjusting elevations of propagated geometry data. (Default value is either 0.0 or the last valley slope that was input for a previous cross section)

COMMAND BD - Bridge Deck parameters

Purpose: To specify bridge deck parameters (DESIGN MODE ONLY).

Structure:

BD girdep, bdelev, bdslp, bdsta

1) girdep - depth of bridge deck, in feet.
2) bdelev - elevation of the top of the bridge deck. If bridge deck is not horizontal, bdslp and bdsta are also required.
3) bdslp - slope (feet/foot) of the bridge deck (negative for left-to-right fall). Required only if bridge deck is not horizontal.
4) bdsta - x-coordinate corresponding to bdelev. Required only if bridge deck not horizontal.

Note: The above data provide the information necessary to connect the tops of the abutments and the low chord.

COMMAND BL - Bridge Length

Purpose: To specify bridge length and abutment location constraints (DESIGN MODE ONLY).

Structure:

```
BL  locopt, brlen, xconlt, xconrt
```

1) locopt - bridge-location option to specify location of the specified bridge length (brlen) with respect to the specified horizontal stationing (xconlt, xconrt). Three choices are available as follows:

   0 - brlen is centered at the midpoint of xconlt and xconrt. This is the default option and can also be left blank.

   1 - the toe of the right abutment is placed at the location specified by xconrt.

   2 - the toe of the left abutment is placed at the location specified by xconlt.

2) brlen - the length of the bridge (between the tops of the abutments), in feet.

3) xconlt - horizontal left station controlling the location of the bridge opening. These always serve as constraints on the abutment locations and bridge length.

4) xconrt - horizontal right station controlling right constraint of bridge opening.

COMMAND BP - Bridge oPening

Purpose: To relate bridge opening horizontal datum to the horizontal datum of road and/or approach section(s) (only applicable to single opening situations).

Structure:

BP xreflt, xrefrt, fdstlt, fdstrt

1) xreflt - horizontal station of the road grade or approach section which coincides with the projection of a reference point from the bridge section.

2) xrefrt - horizontal station of the approach section which coincides with the projection (parallel to the flow) of a right-hand reference point in the bridge section.

3) fdstlt - flow distance measured along the right projection lines, in feet.

4) fdstrt - flow distance measured along the right projection lines, in feet.

Notes:

1) The reference points mentioned above are either (1) xconrt and xconlt (from COMMAND BL) or (2) minimum and maximum x-coordinates of bridge section.

2) The three parameters, xrefrt, fdstlt, and fdstrt, are required to account for channel curvature between bridge and approach cross sections. The input data for the bridge and approach sections must be aligned normal to the flow.

COMMAND BR - BRidge section

Purpose: To establish bridge cross section.

Structure:

```
BR  secid, srd, lsel, skew, ek, ck, usercd
```

1) secid - unique cross section identification code.
2) srd - section reference distance. Should be assigned the same value as the full valley section.
3) lsel - elevation of the low chord of the bridge opening. (Can be omitted in DESIGN MODE).
4) skew - the acute angle (degrees) that the cross section must be rotated to orient it normal to the flow direction. (Default is 0.0 degrees).
5) ek - coefficient used for computing expansion losses in the energy equation. (Default value is 0.5).
6) ck - coefficient used for computing contraction losses in the energy equation. (Default value is 0.0).
7) usercd - user-specified coefficient of discharge for a bridge.

COMMAND CC - Culvert Coefficients

Purpose: To assign culvert coefficients. This command is not required if the default values are appropriate.

Structure:

CC ieqno, cke, cvalph, cn

1) ieqno - the inlet equation number.
2) cke - the culvert entrance loss coefficient, ke.
3) cvalph - the velocity head coefficient, a, for the culvert.
4) cn - Manning's roughness coefficient, n, for the culvert.

Note: Default values for cke, cvalph, and cn are provided on the basis of icode of the CG command.

COMMAND CD - Coefficient of Discharge

Purpose: To determine the coefficient of discharge for a bridge and the flow length.

Structure:

CD brtype, brwidth, embss, embelv, wwangl, wwwid, entrnd

1) brtype - indicates the type of bridge opening, as follows:

1 - vertical embankments and vertical abutments, with or without wingwalls.

2 - sloping embankments and vertical abutments.

3 - sloping embankments and sloping spill through abutments.

4 - sloping embankments and vertical abutments with wingwalls.

2) brwdth - total width (in direction of flow) of the bridge deck.

3) embss - embankment side slope, expressed in the horizontal change in feet per foot change of elevation. (Default value is 0.0) This parameter must be specified for brtype 2, 3, and 4.

4) embelv - elevation of top of embankment must be coded for brtype 2, 3, and 4. embel and embss are used to compute the x--component(s) of the flow length through the bridge.

5) wwangl - wingwall angle. Required only for type 1 and type 4 openings that have wingwalls. (Default value is 0 degrees).

6) wwwid - wingwall width, in feet. Required only for type 1 openings with wingwalls. (Default is 0.0).

7) entrnd - radius of entrance rounding, in feet. Required only for type 1 openings with rounded entrance corners. (Default is 0.0).

Notes:

1) brtype and brwdth must be coded for all opening types.

2) for brtype 1, optional parameters may be applicable as follows:
   (a) wwangl and wwwid (both parameters must be specified when wingwalls are present);
   (b) entrnd (if wingwalls are not present and entrance corners are rounded); or
   (c) no optional parameters when neither wingwalls nor entrance rounding exists.

3) when coding any of the above optional parameters, embss and embelv should be allowed to default.

COMMAND CG - Culvert section Geometry

Purpose: To establish culvert shape, geometry, material, and inlet type.

Structure:

CG icode, rise, [span, botrad, toprad, corrad]

1) icode - three digit culvert code in which the individual digits (e.g., IJK) are interpreted as follows:

I - shape code:
- 1 = box;
- 2 = circular;
- 3 = arch.

J - material code:
- 1 = concrete;
- 2 = corrugated metal pipe (steel);
- 3 = aluminum.

K - inlet control equation code.

2) rise - the maximum vertical dimension of the culvert barrel, in inches.

3) span - the maximum horizontal dimension of the culvert barrel, in inches. Span must be coded for box and pipe-arch culverts but should not be coded for circular culverts.

4) botrad - bottom radius of pipe-arch culvert barrel, in inches.

5) toprad - top radius of pipe-arch culvert barrel, in inches.

6) corrad - corner radius of pipe-arch culvert barrel, in inches.

Notes:

1) caution should be taken in selecting valid icode combinations.

2) if radius parameters are defaulted, approximate values will be computed on basis of icode, span, and rise.

COMMAND CV - CulVert cross section

Purpose: To designate culvert cross section parameters.

Structure:

```
CV  secid, srd, xctr, cvleng, dsinv, usinv, nbbl
```

1) secid - unique cross-section identification code.
2) srd - section reference distance (feet). The srd for the culvert should reflect the location of the downstream end of the barrel and should be the same as the srd of the full-valley cross section when none of sections are skewed to the flow.
3) xctr - horizontal stationing of the center of the culvert measured relative to an arbitrary origin on the left bank. This stationing must be consistent with GR command stationing.
4) cvleng - length of the culvert barrel (feet).
5) dsinv - elevation of downstream invert (feet above the common elevation datum).
6) usinv - elevation of upstream invert (feet above the common elevation datum).
7) nbbl - number of culvert barrels.

COMMAND ER - End of Run

Purpose: To signify end of run.

Structure:
    ER (no parameters)

Note: command indicates end of data input; if omitted, error message is generated.

COMMAND EX - EXecutive profile computations

Purpose: To instruct model to begin execution of profile computations and to specify computation direction.

Structure:

EX idir(1), idir(2), ..., idir(nprof)

nx) idir(i) - code indicating computational direction for the ith profile. idir = 0 for upstream computations and idir = 1 for downstream computations. (Can be left blank if all computations are to be done in upstream direction).

Note: when downstream computations are involved, idir should be specified for each discharge on Q command.

COMMAND FL - variable Flow Lengths

Purpose: To specify friction slope averaging technique and/or variable flow length(s) between sections.

Structure:

FL ihfno, flen

1) ihfno - code to select the friction slope (or conveyance) averaging technique in the friction loss computations. Valid entries are:

0 - uses of geometric mean of conveyance. This field can also be left blank.

1 - uses arithmetic average of conveyance.

2 - uses arithmetic average of friction slope.

3 - uses harmonic mean of friction slope.

2) flen - flow length between the current cross section and the adjacent downstream cross section, in feet. Up to three values may be specified, and these lengths override srd values except in bridge backwater computations.

3) xfl - x-coordinate of breakpoints between the segments of the cross section for which multiple flen values are to be applied.

Notes:

1) ihfno is propagated from section to section until a different value is introduced.
2) ihfno is overridden by ihfnoj if coded on J1 command.

COMMAND GR - cross-section GRound geometry

Purpose: To set x, y-coordinates defining cross-section geometry.

Structure:

GR x(1), y(1), x(2), y(2), ..., x(ngp), y(ngp)

1) x(i) - x-coordinate, distance from an arbitrary horizontal datum on the left bank, of the ith ground point, in feet.

2) y(i) - y-coordinate, distance above common elevation datum, of the ith ground point, in feet.

Notes:

1) The parenthetical notation is for illustration purposes only.
2) The maximum number of x, y-coordinates that can be coded is 100, with no limit on the number of GR commands used.
3) x, y-coordinates are oriented from left bank to right bank. (ngp is the total number of coordinates).

COMMAND GT - cross-section Ground geometry Template

Purpose: To replace GR data for cross sections with synthesized data from propagated template section.

Structure:

GT yshift, xliml, xlimr, scale, xorig

1) yshift - vertical distance, in feet, that the template section elevations are to be shifted to provide appropriate elevations for the propagated cross section.
2) xliml - x-coordinate of the left limit of the template cross section to be retained to represent the propagated section.
3) xlimr - x-coordinate of the right limit of the template cross--section be retained to represent the propagated section.
4) scale - a scaling factor to be used to stretching or shrinking the horizontal dimensions of the template section geometry.
5) xorig - an x-coordinate in the template section which will be held to its original value when the scale factor is used.

Note: Neither xliml nor xlimr must coincide with x-coordinates specified on GR command.

COMMAND HP - Hydraulic Properties

Purpose: To compute and output hydraulic properties of cross section.

Structure:

HP.isap, secid, elmin, yinc, elmax

1) isap - option code to output only the properties for the entire cross section (isap = 0 or blank) or to output properties for each subarea as well as the total section (isap = 1).
2) secid - the section identification code for the cross section for which properties are desired.
3) elmin - the minimum elevation in the cross section for which properties are to be computed. (Default value is one-fourth of the difference between the maximum and minimum ground elevations above channel bottom, rounded to the nearest whole foot).
4) yinc - the elevation increment between successive elevations for which properties are to be computed (feet). (Defaults to deltay on J1 command).
5) elmax - the maximum elevation for which properties are to be computed. (Default value is the maximum elevation in the cross section).

COMMAND J1 - Job computational parameters

Purpose: To set computational control parameters.

Structure:
J1 deltay, ytol, qtol fncrit, ihfnoj

1) deltay - elevation stepping increment, in feet, between successive assumptions of trail water-surface elevations when balancing the energy equation. (Default value is 1.0 foot).

2) ytol - allowable tolerance (error), in feet, between successive computed elevations for acceptable energy equation balance. (Default value is 0.02 feet).

3) qtol - allowable tolerance (error) between discharge specified on input (Q command) and discharge computed by model in combined bridge flow and road overflow situations. (Default value is 0.02).

4) fncrit - Froude number test value. Computed Froude numbers greater than fncrit are cause for rejecting a computed water-surface elevation as a valid solution. (Default value is 0.8).

5) ihfnoj - code to select the friction slope (or conveyance) averaging technique to be used in friction loss computations. (Default value for ihfnoj is 0.0). Valid entries are:

   0 - uses geometric mean of conveyance. This field can also be left blank.

   1 - uses arithmetic average of conveyance.

   2 - uses arithmetic average of friction slopes.

   3 - uses harmonic mean of friction slopes.

Note: ihfnoj is applicable for all subreaches (except for bridge backwater computations which always use geometric mean conveyances). To vary the averaging technique within a job requires use of FL commands.

COMMAND J2 - Job data parameters

Purpose: To specify input data control parameters.

Structure:
J2 lunit, ldc

1) lunit - Fortran logical unit number for reading subsequent input records from a secondary input file. The next input record and all subsequent records will be read from the secondary file unit until either lunit is reset by another J2 record in the secondary file or the end of the secondary file is reached. This facility enables the input file to be stored as several independent subfiles for convenience in input preparation. Usually the secondary file would contain fixed information on channel geometry, whereas the primary file would contain information that would vary from run to run, such as discharges and initial water-surface elevations for use in computing water-surface profiles under various flow conditions. An explicit null value (*) leaves the current value of lunit unchanged. If neither lunit nor ldc is specified, the J2 record causes the input to switch from primary input to secondary input on logical unit 10, or vice versa.

2) ldc - last data column, less than or equal to 80. The program stops scanning the free-format field on subsequent input records after column number ldc. Any remaining information (such as record-sequence numbers) will be ignored. ldc takes effect immediately following input of the J2 record and remains in effect until reset by a subsequent J2 record. The ldc value for the primary input remains in effect until reset explicitly by a J2 record in the primary input. ldc for secondary input is automatically reset by an end-of-file on that unit. (Default value is 80)

COMMAND J3 - Job parameters for risk analysis

Purpose: To specify input data control parameters.

Structure:

J3 iratbl varnos (list 1) * varnos (list 2) *
varnos (list 3) (up to 3 tables can be obtained)

1) iratbl - code to select one of two output tables specifically designed for risk analysis worksheets. These tables are described in the WSPRO documentation. Valid entries for iratbl are:

 0 - neither table will be output. This can also be left blank.

 1 - Output Risk Analysis Table #1 (for computing upstream flood damages).

 2 - Output Risk Analysis Table #2 (for computing damages for alternative bridge designs).

2) varnos - code numbers of stored output variables. The total number of variables in the three lists cannot exceed 50. The number of variables in each individual list is constrained only by printer line length (132 columns maximum). The model automatically uses 12 columns, thus leaving a maximum of 120 columns for the user.

COMMAND KD - conveyance, K, Distribution

Purpose: To designate user-defined breakpoints of conveyance distribution in bridge and approach sections.

Structure:

KD xltbr, xrtbr, xcntbr, xltkq, xrtkq, xcntkq

1) xltbr - x-coordinate of the left limit of conveyance (flow) distribution in the bridge section. These parameters affect only the projection of effective flow length.
2) xrtbr - x-coordinate of the right limit of conveyance (flow) distribution in the bridge section.
3) xcntbr - x-coordinate of the centroid of conveyance (flow) distribution in the bridge section.
4) xltkq - x-coordinate of the left limit of the conveyance (flow) distribution for the Kq-section.
5) xrtkq - x-coordinate of the right limit of conveyance (flow) distribution for the Kq-section.
6) xcntkq - x-coordinate of the centroid of conveyance (flow) distribution for the Kq-section.

Note: The model, unless overridden by some combination of xltkq, xrtkq and xcontkq, will place the kq-section based on the location of the computed centroid of conveyance. Literature suggests the Kq-section should generally include the low-water channel. The computed centroid of conveyance, especially in wide flood-plain situations, may thus lead to undesirable placement of the Kq-section.

COMMAND N - Manning's coefficient, N

Purpose: To specify values of Manning's "n" roughness coefficient.

Structure:

N botn(1), topn(1), botn(2), topn(2), ...,
botn(nsa), topn(nsa)

1) **botn(i)** - n-value for the ith subarea. In the absence of ND record data, this coefficient is applied over the entire range of depths. If NC command data are applicable, botn(i) is applied for the range of hydraulic depth, d of 0 < d botd(i).

2) **topn(i)** - when ND command data are applicable, topn(i) is applied for the range of hydraulic depth, d of d topd(i). topd(i) values must not be coded when ND command data are not applicable.

Note: nsa is the number of subareas in the channel cross section.

COMMAND ND - roughness coefficient, N, and hydraulic Depth

Purpose: To establish depth breakpoints for vertical roughness variation.

Structure:

```
ND  botd(1), topd(1), botd(2), botd(2), ...,
    botd(nsa), topd(nsa)
```

1) botd(i) - hydraulic depth of the ith subarea at and below which the n-value of botn(i) is applicable (feet).

2) topd(i) - hydraulic depth of the ith subarea at and above which the n-value of topn(i) is applicable (feet).

Notes:

1) Roughness coefficients for hydraulic depths between botd and topd are determined by straight-line interpolation.
2) Values of botd, topd, botn, and topn must be supplied for all subareas when an ND record is coded.
3) nsa is the number of subareas.

COMMAND PG - Parapet and Guardrail parameters

Purpose: To specify parapet and/or guardrail parameters (DESIGN MODE ONLY).

Structure:

PG parpht, parpx

1) parpht - the height of the parapet and/or guardrails above the road grade (feet).
2) parpx - the extent that the parapet and/or guardrails extend beyond the top of the bridge abutments (landward from the bridge opening) (feet).

Note: Road grade data between the point parpx feet to the left of the top of the left abutment and the point parpx to the right of the top of the right abutment are raised in elevation by parpht feet to prevent computation of weir flow through the parapets and/or guardrails.

COMMAND PW - Pier (or Pile) elevation-Width data

Purpose: To establish pier or pile data.

Structure:

```
PW  ppcd, pelv(1), pwdth(1), pelv(2), pwdth(2), ...,
    pelv(npw), pwdth (npw)
```

1) ppcd - code to indicate whether the obstruction is in the form of piers (ppcd = 0 or blank) or piles (ppcd = 1). The adjustment to the coefficient of discharge for piers requires this distinction.
2) pelv(i) - the elevation of the ith pair of elevation-width data (feet above datum).
3) pwdth(i) - the gross width of all piers (or pile bents) for the ith pair of elevation-width data, in feet.

Notes:

1) The model creates an elevation-area relationship from the elevation-width data. Straight-line interpolation is used to obtain pier (pier) area between specified elevations. A constant pier (pile) area is assumed between the highest elevation coded and the maximum bridge opening elevation.
2) The minimum pier (pile) data requirement is one elevation-width pair at the minimum elevation that pier (pile) area begins (this elevation cannot be less than the minimum ground elevation in the cross section).
3) If the gross pier (pile) width should happen to vary uniformly over the elevation range between minimum and maximum bridge-opening elevations, a second elevation-width pair at the maximum elevation will suffice.
4) For nonuniform variation of gross pier (pile) width, two elevation-width pairs are required at each elevation where there is an abrupt change in gross pier (pile) width.
5) An abrupt change can be: (1) additional piers coming into effect with increasing elevation; (2) changes in pier dimensions; and (3) loss of piers with increasing elevation (sloping low chord). The maximum number of elevation-width pairs is 50.

COMMAND PX - Plots X-section

Purpose: To plot cross section.

Structure:

PX secid, xrange, yrange

1) secid - section identification of cross section to be plotted. (Not required if PX record included with cross-section data.
2) xrange - horizontal distance range that the plot grid will encompass. (Default values are computed from the minimum and maximum x values of the cross section being plotted).
3) yrange - vertical distance range that plot grid will encompass. (Default values are computed from the minimum and maximum y values of the cross section being plotted).

Notes:

1) When plotting two or more sections, it may be desirable to specify the same range values for each section to obtain consistent scaling for cross-section comparisons.
2) The computed default values may result in "nonstandard" division of the axes (e.g., fractional and/or unwieldy increments). Therefore, the user may find it expedient to code ranges that best match the cross-section data to the six divisions of the X-axis and the four divisions of the Y-axis on the plot.

COMMAND Q - discharge, Q

Purpose: To specify discharge for each profile to be computed.

Structure:

Q q(1), q(2), ..., q(nprof)

q(i) - discharge for each water-surface profile to be computed. The maximum number of profiles which can be computed in a single job execution is 20.

Notes:

1) All entries on the Q record must be positive values (no default values are permitted).
2) nprof is the number of water-surface profiles (maximum equals 20)

COMMAND RG - Road Grade

Purpose: To establish road grade geometry in term of vertical curve data.

Structure:

```
RG  xpi(1), ypi(1), vcl(1), xpi(2), ypi(2), vcl(2), ...,
    xpi(npi), ypi(npi), vcl(npi)
```

1) xpi(i) - the x-coordinate of the ith pi (feet).
2) ypi(i) - the elevation of the ith pi (feet above datum).
3) vcl(i) - the vertical curvelength associated with the ith pi (feet).

Notes:

1) vcl must be specified as 0 or a null value (*) for the first and last triad of data (left and right limits of the road grade section, respectively). For intermediate triads, a specification of 0 for vcl(i) causes that pi to be simply used as a coordinate on the road grade section. Specifying a null value for vcl(i) for intermediate triads causes the model to use the AASHTO standard vertical curve length for 70 miles per hour (applicable grades are computed from the pi data).
2) pi is the point of intersection of vertical curve tangents.

COMMAND SA - SubAreal breakpoints

Purpose: To designate horizontal breakpoints for subdivision of cross section for roughness and/or geometry variations.

Structure:

SA xsa(1), xsa(2), xsa(nsa-1)

1) xsa(i) - x-coordinate of the rightmost limit of the ith subdivision. (The last xsa value to be coded is for the next-to-last subarea)

Note: nsa is the number of subareas.

COMMAND SD - Spur Dike data

Purpose: To reference spur dike cross section.

Structure:

SD secid, srd, sdtype, bsubd, sdoff, skew, ek, ck, vslope

1) secid - unique cross-section identification code.
2) srd - section reference distance (feet).
3) sdtype - code to indicate the type of spur dikes. Valid entries are:

   1 - elliptical spur dikes, no skew.
   2 - elliptical spur dikes, skewed.
   3 - straight spur dikes, no offset.
   4 - straight spur dikes, with offset.

4) bsubd - distance (feet) that straight dikes are offset from the abutments (at the bridge end of the dikes, not to be confused with sdoff below). (This parameter is only relevant for sdtype = 4).
5) sdoff - the horizontal distance (feet) measured normal to the flow at the mouth of the dikes between the bridge abutments and the dike wall. Use an average value if the distances on the left and right sides are different. The model will place the base of the dike. The side slope of the dike walls will be equal to the abutment slopes specified on the AB command.
6) skew - the acute angle (degrees) that the cross section must be rotated to orient it normal to the flow direction. (Default is 0.0 degrees).
7) ek - coefficient used for computing expansion losses in the energy equation. (Default value is 0.5).
8) ck - coefficient used for computing contraction losses in the energy equation. (Default value is 0.0).
9) vslope - valley slope in feet/foot. Used for adjusting elevations of propagated geometry data. (Default value is either 0.0 or the last valley slope that was input for a previous cross section).

COMMAND SK - Slope conveyance K

Purpose: To initialize slope(s) for computing starting water-surface elevation(s) by slope conveyance.

Structure:

SK sksl(1), sksl(2), ..., sksl(nprof)

1) sksl(i) - energy gradient for computing the initial water-surface elevation by slope conveyance for the ith profile (ft/ft).

Notes:

1) nprof is the number of water-surface profiles.
2) When an SK record is used, it must contain the same number of entries (specified or default) that are contained in the Q record. The last entry on an sk record must not be allowed to default. Instead, code a negative slope.

COMMAND T1

Purpose: To present the first line Title information for identification of model.

Structure:

T1 [up to 70 alphanumeric characters to state title]

Notes:

1) This command is used in conjuction with the T2 and T3 commands.
2) The information in the free-format area of the T1, T2, and T3 command are printed on essentially every page of printed output, along with the date and time of job execution. When analyzing a series of alternative designs, it is possible to change some of the title information for each alternative without recoding all three commands. Depending on the amount of information to be changed, the user may choose to provide a new T2 and T3 command or just a new T3 command for each alternative. If a new T2 command is coded without a new T3 command, a blank line is printed for T3 command information.

COMMAND T2

Purpose: To present the second line of Title information for identification of model.

Structure:

T2 [up to 70 alphanumeric characters to state title]

Notes:

1) This command is used in conjuction with the T1 and T3 commands.
2) The information in the free-format area of the T1, T2, and T3 command are printed on essentially every page of printed output, along with the date and time of job execution. When analyzing a series of alternative designs, it is possible to change some of the title information for each alternative without recoding all three commands. Depending on the amount of information to be changed, the user may choose to provide a new T2 and T3 command or just a new T3 command for each alternative. If a new T2 command is coded without a new T3 command, a blank line is printed for T3 command information.

COMMAND T3

Purpose: To present the third line Title information for identification of model.

Structure:

T3 [up to 70 alphanumeric characters to state title]

Notes:

1) This command is used in conjuction with the T1 and T2 commands.
2) The information in the free-format area of the T1, T2, and T3 command are printed on essentially every page of printed output, along with the date and time of job execution. When analyzing a series of alternative designs, it is possible to change some of the title information for each alternative without recoding all three commands. Depending on the amount of information to be changed, the user may choose to provide a new T2 and T3 command or just a new T3 command for each alternative. If a new T2 command is coded without a new T3 command, a blank line is printed for T3 command information.

COMMAND WS - Water-Surface elevations

Purpose: To initialize water-surface elevations for profile computations.

Structure:

```
WS  wsi(1), wsi(2), ..., wsi(nprof)
```

1) wsi(i) - elevation representing the water-surface elevation to be used at the first cross section of the ith profile computation (feet above datum).

Note: An actual elevation or null value (*) must be provided for each discharge specified on the Q command.

COMMAND XR - X-section for Road grade

Purpose: To establish road grade parameters.

Structure:

XR secid, srd, embwid, ipave, usercf, skew, ek, ck, vslope

1) secid - unique cross-section identification code.
2) srd - section reference distance, in feet. Should represent the location of the centerline of the road near the center of the bridge.
3) embwid - the top width (feet) of the embankment. This distance should reflect the breadth (measured in the direction of flow) of the broad-crested weir that the embankment becomes when overtopped.
4) ipave - code to indicate the road surface material. (Default is paved, ipave = 1, and graveled (or otherwise non-smooth) can be indicated by ipave = 2).
5) usercf - user-specified coefficient for unsubmerged weir flow. This value will override the coefficient computed by the model.
6) skew - the acute angle (degrees) that the cross section must be rotated to orient it normal to the flow direction. (Default is 0.0 degrees).
7) ek - coefficient used for computing expansion losses in the energy equation. (Default value is 0.5).
8) ck - coefficient used for computing contraction losses in the energy equation. (Default value is 0.0).
9) vslope - valley slope in feet/foot. Used for adjusting elevations of propagated geometry data. (Default value is either 0.0 or the last valley slope that was input for a previous cross section).

COMMAND XS - X-Section of unconstricted valley

Purpose: To reference unconstricted valley cross section (except for approach cross section).

Structure:

XS secid, srd, skew, ek, ck vslope

1) secid - unique cross-section identification code.

2) srd - section reference distance (feet). Cumulative distance along the streammeasured from an arbitrary zero reference point (srd may be negative). Unless overridden by FL command data, the difference between the srd values of successive cross sections is assumed to represent the flow distance between those sections and is used to compute the friction loss component in the energy equation.

3) skew - the acute angle (degrees) that the cross section must be rotated to orient it normal to the flow direction. (Default is 0.0 degrees).

4) ek - coefficient used for computing expansion losses in the energy equation. (Default value is 0.5 or the last value input on a previous section).

5) ck - coefficient used for computing contraction losses in the energy equation. (Default value is 0.0 or the last value input on a previous section).

6) vslope - valley slope in feet/foot. Used for adjusting elevations of propagated geometry data. (Default value is either 0.0 or the last valley slope that was input for a previous cross section).

COMMAND XT - X-section of Template

Purpose: To reference template cross section.

Structure:

XT secid, srd, vslope

1) secid - unique cross-section identification code.
2) srd - section reference distance (feet). This provides the reference point for elevation adjustments by valley slope.
3) vslope - valley slope in feet/foot. Used for adjusting elevations of propagated geometry data. (Default value is either 0.0 or the last valley slope that was input for a previous cross section).

COMMAND REM - comment or blank line

Purpose: To insert comments (or blank lines) in the input data sequence.
Structure:
REM [up to 70 alphanumeric characters to insert comments]

Note: **The free format area can be used to code notes that may help the user keep track of the input data, or simply left blank to separate different input daata (e.g., between cross sections) to improve** readability of printouts.

COMMAND * - comment or blank line

Purpose: To insert comments (or blank lines) in the input data sequence.

Structure:

```
 *  [up to 70 alphanumeric characters to insert comments]
```

Note: The free format area can be used to code notes that may help the user keep track of the input data, or simply left blank to separate different input data (e.g., between cross sections) to improve readability of printouts.

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HYDRAIN - INTEGRATED DRAINAGE DESIGN COMPUTER SYSTEM

VOLUME VI. HY8 - CULVERTS

by:

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Springfield, VA 22151
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for:

Structures Division, HNR-10
Federal Highway Administration

Under Contract #DTFH61-88-C-00083

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DRAFT

TABLE OF CONTENTS

List of Figures

List of Tables

Preface

This report presents documentation for the HYDRAIN system. HYDRO, HYDRA, CDS, WSPRO and HY8 are five nonproprietary hydrology and hydraulic engineering programs incorporated in the HYDRAIN system. The HYDRAIN personal computer oriented system operates these engineering applications with programs written in the C language. The system is designed with an open architecture for expansion. HYDRAIN is sponsored as a Pooled Fund Project (PFP) of 29 State highway departments and is managed by the Federal Highway Administration (FHWA). The system is expanding with flexible lining design logic and integrated culvert analysis logic under development. Graphic output options are also under development and are available in some areas already.

Within the HYDRAIN concept, the HYDRO, HYDRA, CDS, and WSPRO allow the user to consistently input, edit and run relevant input data files and to scroll through output files. With these applications "short", one-line, and "long", multiple line, help is provided within an editor that services all applications.

HYDRAIN integrates hydraulic and hydrology programs into a unified system. The intent of the integration is to enable users to then learn basic principles of how to operate an application and file manipulation and then be able to apply the same principles to other applications and files within the system. One guiding principle is a **command land input format**. This trend in hydraulic programs is typified by HEC-2 and HYDRA. It is very pragmatic. WSPRO also adopted the command line method. Another guiding principle is a **generic input editor** that works the same for each integrated program--HYDRO, HYDRA, CDS, and WSPRO. The input file for each integrated program is a line by line command language that identifies the computation and/or provides the required data. Each line of data is preceded with a two or three-letter command. A typical command is **XS**, indicating a cross section; both WSPRO and CDS read this command. Another typical command is **PDA**, indicating the line contains the design parameters for pipe analysis (PIPE DATA); HYDRA reads this command.

A strength and a weakness of HYDRAIN is the need to know beforehand the sequence of commands that will result in making an application work. The commands are, of course, the batch input file. The user needs to know a proper sequence or know how to put one together. The sequences are termed "footprints." Given the right "footprint," an application will work; note that footprints are not necessarily unique, in that there may be several ways to get a job done. This documentation includes footprints to get users started and user support will aid in proper "footprint" design. Once a user has a library of footprints for his applications, the use of HYDRAIN should save considerable time and money. HY8 is a stand-alone interactive BASIC program that accepts inputs during processing; HY8 does not require footprints and leads the unfamiliar user through input preparation. All engineering programs but HY8 are batch oriented, and three steps are built into the process of using them: input file generation, programs execution, and output file screen review or listing. HY8 accepts inputs and generates outputs as the engineering program logic is executing.

HYDRO Program

HYDRO is a command line hydrology program. FORTRAN code for HYDRO was developed to combine existing approaches for rainfall and runoff analyses into one computerized program. Within the HYDRAIN system, it can be used independently or it can be used to generate input data for other engineering programs within the system.

HYDRO offers many hydrologic analysis options to the engineer. Each is site specific based on user inputs.

- Design Rain Using Digitized NWS Information or State-Supplied Files - Calculates the rainfall intensity for a specific return period, duration, and site.
- Design Hyetograph using Yen and Chow's method - Calculates the rain versus time plot for a return period, duration and site.
- Intensity-Duration-Frequency Curve Using Either the NWS Information or State-Supplied Files - Analyzes a specific site and creates two graphs: a plot of points for durations up to 24 hours, and a detail graph of the first two hours. Can be input to HYDRA.
- Design Flow by Rational Method - Uses a specific return period, duration and intensity to determine the peak flow for the site.
- Design Flow by USGS Regression Method - Uses USGS log-log regression equations with user-supplied parameters to determine design flow.
- Design Flow by log Pearson type III - Calculates the peak flow for given data.
- Design Hydrograph by USGS Dimensionless Hydrograph - Calculates a hydrograph to support storage routing within HYDRA or CDS.
- Maximum Observable Flood - estimates the largest flow at a site based on the envelope of all floods in a region.

PFP-HYDRA Program

HYDRA is a command line gravity pipe network hydraulics program. FORTRAN code for HYDRA previously existed and the Pooled Fund work effort included substantial improvements. HYDRA is a storm and sanitary sewer system analysis and design program. It can be used either to model an existing sewer system or to design a new system.

HYDRA generates storm flows by using either the Rational Method technique, hydrologic simulation techniques, or accepting a hydrograph generated by a HYDRO analysis. It can be used to design or analyze storm, sanitary or combined collection systems. HYDRA can handle up to 1,000 contributing drainage areas and 2,000 pipes. Additionally, HYDRA can be used for cost estimating. The Rational

Method approximates the peak rate of runoff from a basin resulting from storms of a given return period. HYDRA's hydrologic simulation models the natural rainfall-runoff process. In the simulation, runoff hydrographs are generated, merged together, and routed through the collection system. Inlet limitations can be analyzed: inlet overflow can be passed down a gutter system, while inlets in sumps can store water in ponds.

In the HYDRA design process, the program will select the pipe size, slope and invert elevations given certain design criteria. Additionally, HYDRA will perform analyses on a existing system of pipes (and/or ditches). When an existing system of pipes is overloaded, HYDRA will show suggested flow removal quantities as well as an increased pipe diameter size as an alternative remedy. HYDRA includes HEC-12 inlet theory hydraulic gradeline calculations, and an ability to route flow through internal storage sites using a storage-indication method.

HYDRA requires the forming of an input file of commands to describe the sewer system. Commands for HYDRA are placed in a logical sequence usually from upper to lower elevation. Is it possible that several command sequences can produce the same result. An input file is established for a particular collection system by the engineer and then the HYDRA program is executed. To change the characteristics of the collection system, the input file can be edited.

The HYDRA program requires design criteria for the pipes: friction factor (Manning's "n"), minimum diameter, ideal depth, minimum ground cover, minimum velocity (full flow), minimum slope, and maximum diameter. The friction factor is necessary for both analysis and design, while the remaining values are needed only for design. In the case of a design, the program selects invert elevations and slope as well as the physical sizing of each link given certain design criteria, whereas in the analysis mode, pipe alignment and sizing are predetermined and the impact of proposed flows are analyzed. Design criteria can be changed for each pipe if so desired. HYDRA is not an optimization program, thus individual case studies need to be run and analyzed by the engineer.

CDS Program

CDS is a command line culvert program. The Culvert Design System provides the user with two broad options for investigating culvert characteristics. CDS can either (1) hydraulically design a culvert or (2) analyze an existing or proposed culvert. CDS has capabilities for investigating a variety of hydrograph relationships, culvert shapes, materials, and inlet types. With CDS, the engineer can request any of six culvert types: round concrete, round metal, arch concrete, arch metal, oval concrete, and concrete box. CDS routes hydrographs, considers ponding, and overtopping.

The Design option selects a culvert size and number of barrels that are compatible with engineering data, environmental constraints, and site geometry. In this option, hydraulic performance data are calculated for each new culvert system design. The Review option provides hydraulic performance data for any preselected combination of culvert type and size, inlet type, slope, and number of barrels. The initial design and analysis options may be followed by up to five

additional culvert types or flow frequencies so that a full spectrum of risk scenarios or economic considerations can be simulated at the same time.

Two possible flow scenario methods can be selected: (1) steady state or irrigation, that assumes constant flow through the culvert, or (2) dynamic, that simulates drainage flow conditions. The dynamic option can route a hydrograph through the culvert system using three hydrograph alternatives: a user input hydrograph, a hydrograph produced by the HYDRO program, or the use of an internally produced default hydrograph (simulating semi-arid, high plains conditions). Additionally, the dynamic flow scenario can accommodate upstream pond storage.

CDS will determine culvert size based on the design headwater, headwater/diameter ratio, inundation, outlet velocity, cover limitations, or any combination of these parameters. The program will automatically increase the number of barrels when the upper limit for the greatest vertical dimension is exceeded. There is a limit of six barrels for commercial size culverts and five for concrete box culverts. The program can also be used to assess flood hazards, environmental assessments of upstream pond coverage, downstream flooding, channel impact, inlet type and beveled inlet evaluations, and reservoir facilities which use a culvert type structure for the spillway. Based on these data the program will proceed to identify the flow type and the outlet conditions for velocity, Froude number, and brink depth.

WSPRO Program

WSPRO is a command line step backwater program for natural channels with an orientation to bridge construction. The Water Surface Profile Computation Model Microcomputer Program has been designed to provide a water-surface profile for six major types of open channel flow situations:

- Unconstricted flow.
- Single opening bridge.
- Bridge opening(s) with spur dikes.
- Single opening embankment overflow.
- Multiple alternatives for a single job.
- Multiple openings.

WSPRO was originally developed by the United States Geologic Survey (USGS) for the Federal Highway Administration. The model was a batch mode mainframe program, written in FORTRAN. The members of the Pooled Fund Project decided to use WSPRO as the bridge waterways analysis element of the Integrated Computerized Drainage Design System. WSPRO was downloaded to the microcomputer by the USGS and FHWA. The microcomputer version of WSPRO, is dated August 1987.

The command input file forms a logical description of the physical characteristics of a waterway. Once the user is comfortable with this method of data setup, the program provides a step backwater method for determining water surface profiles. The scheme is similar to the Corps of Engineers HEC-2 program. Both WSPRO and HEC-2 are acceptable to the Federal Emergency Management Agency. WSPRO has the advantage that it utilizes more recent approximation techniques for the backwater effects associated with bridge constrictions.

HY8 Program

HY8 is an interactive culvert analysis basic program that utilizes the FHWA analysis methods and information published by pipe manufacturers. The program includes modules to allow the user to interactively enter, save, and edit data. HY8 will compute the culvert hydraulics for circular, rectangular, elliptical, arch, and user defined geometry. Additionally, improved inlets can be specified and the user can; analyze inlet and outlet control for full and partially full culverts, analyze the tailwater in trapezoidal and coordinate defined downstream channels, analyze flow over the roadway embankment, and balance flows through multiple parallel culverts. A hydrograph can be produced and routed.

The initial logic involves calculating the inlet control and outlet control headwater elevations for the given flow. These elevations are compared and the larger of the two is used as the controlling headwater elevation. Tailwater effects are taken into consideration when calculating these elevations. If the controlling headwater elevation overtops the roadway embankment, an overtopping analysis is done in which flow is balanced between the culvert discharge and the surcharge over the roadway. A balancing technique is also used in the case of multiple barrels. If the culvert is less than full for all or part of its length open channel computations are performed.

A series of data menus, data screens, summary screens, and output screens guides the user through the program. Each menu contains several options to match the desired culvert configuration, while the data screens prompt the user for specific dimensions and coordinates. Summary screens allow the user to edit entered data or change menu selections. Output screens display the output as calculations proceed; hard copy is only obtained using the "print screen" key.

There are three main groups of data to be entered into the program: initial culvert data, downstream channel data, and roadway data. Within the program, the user is sequentially led from one group to the next. From these sets of data, the program develops culvert performance data with or without overtopping. A performance curve can be plotted on a computer with graphics capabilities. For a given flow, HY8 can design a culvert. In addition to developing performance curves, the program generates rating curves for uniform flow, velocity, and maximum shear for the downstream channel. Culvert outlet velocities, inlet control head, and outlet control head are also calculated; energy dissipator design is possible.

HYCHL and HYCULV Programs

HYCHL and HYCULV are command line, flexible channel and culvert programs that are under development. HYCHL will solve for fixed and flexible lined channels. HYCULV will integrate state-of-the-art culvert flow methods and utilize features of both CDS and HY8.

Operation

To allow the software to be used by a wide audience, HYDRAIN operates on an IBM XT/PC or equivalent microcomputer with 640 K RAM, a hard disk, and a monochrome monitor. A math coprocessor is needed. Engineering programs are in Fortran 77. The utility software and editor is in C. The HYDRO, HYDRA, CDS, and WSPRO programs have command line input with are "short" and "long" help files available through the same editor that operates any of them. HY8 has also been integrated into the HYDRAIN system and is available as an interactive BASIC culvert program.

Report Contents

The remaining section of this volume provides technical reference and user instructions for the HY8 program. There are a total of 6 such volumes for HYDRAIN.

Disclaimer

FHWA, the pooled fund States and their agents have, within the limits of their resources, tested and debugged the HYDRAIN shells. The engineering programs derive from several varied sources and were adapted to HYDRAIN and also underwent testing and debugging. However, this is a very large and somewhat complicated system of logic and coded implementation and errors and omissions may yet remain in the software. Therefore, use at your own risk. Please document problems and errors and report to FHWA. User support and technical assistance will be provided to pooled fund States. Agents of these States using the system should channel their requests for support or assistance through their sponsor State.

1. Introduction

HY8 is an interactive program that allows the user to investigate the hydraulic performance of a culvert system. This culvert system is composed of the actual hydraulic structure, as well as hydrological inputs, storage and routing considerations, and energy dissipation devices and strategies. HY8 uses the logic presented in HDS 5, "Hydraulic Design of Highway Culverts"[1], HEC 14, "Hydraulic Design of Energy Dissipators for Culverts and Channels"[2], other Federal Highway Administration (FHWA) methods,[3],[4] and information published by pipe manufacturers pertaining to the culvert sizes and materials.[5] In this regard, HY8 should be considered as a computer based application of these documents. This volume of documentation describes the concepts and theories used within HY8, although the user should refer to the listed references for detailed explanations.

The documentation is divided into three sections: System operation, technical operation, and Users application. The first section, system operation, provides insight into the capabilities and hydrological aspects covered in the program. The technical operation section provides data on how the system operation is achieved. Specifically, it provides the user with equations and methodologies used by HY8 when performing a culvert analysis. The technical section does not discuss details of the hydrologic, routing, and energy dissipation analyses. These areas are adequately discussed in their respective references. The last chapter discusses how to apply the program, particularly as it pertains to the HYDRAIN microcomputer package.

Version 3.0 of the HY8 program runs on IBM PC/XT and compatible micro-computers. It is designed to run on MS-DOS version 3.0 (and higher). The program layout is a combination of executable files linked by a batch program. The source code is written in BASIC. Executable code is generated using the MS Quickbasic compiler. The source code is not available for distribution. Files created in Version 3.0 cannot be used by previous versions of HY8.

2. System Overview

The Federal Highway Administration has developed analytical and empirical techniques to aid in the hydraulic analysis and design of culverts. The design engineer can utilize the FHWA publications to analyze culverts for a single design discharge and, with some additional effort, develop a culvert performance curve. In addition, these techniques allow the consideration of inflow and outflow hydrographs, storage and routing, and energy dissipation. However, evaluating the performance of different culvert systems for several flow scenarios requires considerable effort. To take advantage of the microcomputer's ability to quickly and accurately solve these culvert system techniques, the HY8 program was developed.

HY8 is actually composed of four different programs, or modules. These four modules are: a culvert analysis module, a hydrograph generation module, a routing module, and an energy dissipation module. These are linked together as depicted in Figure 1. The capabilities of each of these modules are discussed below.

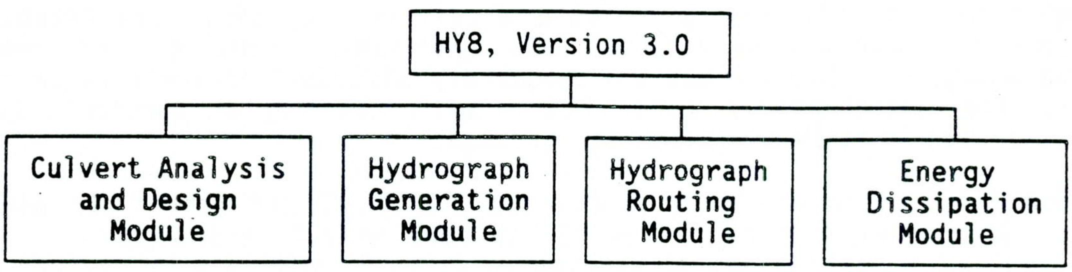


Figure 1. HY8 program modules.

Culvert Analysis and Design Module

The culvert analysis and design module allows the user to review the hydraulic characteristics of user supplied culvert data. This module also permits minimization of culvert size based on an allowable headwater elevation. The program will compute culvert hydraulics for circular, rectangular, elliptical, arch, and user defined geometry. Improved inlets can also be specified. The user will have the options of entering either a regular or an irregular cross-section for calculating tailwater, or a fixed tailwater may be specified.

A series of up to six parallel culvert systems, each having different inlets, inlet elevations, outlets, outlet elevations, and lengths, can be analyzed. (In the parlance of HY8, a single culvert system has only one shape and dimension, but can consist of several barrels. For example, a six by six foot box culvert that has three barrels is a single culvert system. A three barrel, six by six box culvert and a single barrel, two foot RCP culvert, set at a higher invert elevation, are considered as two culvert systems by HY8.) Overtopping can also be considered during the analysis process.

There are four main groups of data to be entered into the module: design flow data, initial culvert data, downstream channel data, and roadway data. These data are entered to the program through a series of data menus, and data screens. The data can be edited from a summary screen. Output screens contain computed culvert hydraulics, while help files guide the user through the program. Each screen menu contains several options to match the desired culvert configuration, while the data screens prompt the user for specific dimensions and coordinates.

From the data screens, the program calculates the inlet control and outlet control headwater elevations for a given flow. These elevations are compared and the larger of the two is used as the controlling headwater elevation. Tailwater effects are taken into consideration when calculating these elevations. The program develops culvert performance data with or without overtopping. If the controlling headwater elevation overtops the roadway embankment, an overtopping analysis is done in which flow is balanced between the culvert discharge and the discharge over the roadway. The technique used in this operation uses a parallel pipe solution to balance the flow.

The direct step method is used to calculate water surface profiles when open channel flow occurs in the culvert. Both the multiple culvert balancing technique and direct step method are exceptions to the procedures in the FHWA publications. That is, when a portion or all of the culvert is flowing less than full, water surface profile calculations are used to compute the friction losses in the open channel flow section. If the length of the full flow section is equal to the full length of the culvert, then pressure flow exists throughout the culvert. The pressure flow analysis is the same for steep and mild sloped culverts; however, the open channel flow analysis differs for steep and mild slopes. Three examples of the program's use are illustrated in the HY8 Culvert Analysis Microcomputer Program Applications Guide.

In addition to developing performance curves, the program generates rating curves for uniform flow, velocity, and maximum shear for the downstream channel. Culvert outlet velocities, inlet control head, and outlet control head are also calculated. Several of these curves can be placed on the screen for visual inspection of the results.

Finally, the culvert analysis module can assist in the design of a culvert through a "minimization" routine. The major constraints in this option are peak or design flow and allowable headwater. To design a culvert that passes the peak flow, the user enters an allowable headwater. The program will increase or decrease the culvert size so that a maximum headwater elevation that is less than the allowable headwater is calculated. Associated hydraulic parameters for the design discharge are recomputed when the minimization routine is activated.

Summary screens allow the user to edit entered data or change menu selections. Output screens display the output as calculations proceed; hard copy is obtained using the "print screen" key or by selecting a print-out of the culvert analysis summary from the performance curve output screen.

Hydrograph Generation Module

The hydrologic module of the HY8 program generates a storm hydrograph that can be used singly, or as input into culvert routing analyses. The hydrograph is generated using methods found in standard hydrology texts, including the FHWA HEC 19 document "Hydrology."[6]

Main input parameters in this module are watershed characteristics such as drainage area, slope, curve number, watershed distribution, coefficient of abstraction and base flow. From these parameters, a storm hyetograph and hydrograph are produced. An alternative option allows a user defined storm hyetograph to be entered. Based on this hyetograph, a hydrograph is then produced. As a final alternative, the user can enter a hydrograph.

Similar to the culvert analysis module, the hydrograph generation module uses full screen menus to guide the user through the input data options. Plots of hyetographs and hydrographs are generated in the screen while executing the hydrology section. Hard copies of plots can be obtained by pressing the print screen key. There are no help screens yet available for this module of HY8.

Hydrograph Routing Module

The routing module uses the culvert data collected in the first module and the hydrograph generated in the second module to calculate storage and outflow hydrograph characteristics. For this reason, it is necessary to have both an existing culvert analysis file and hydrograph file.

The routing is performed using the storage indication (modified Puls) method. Four options are available to determine the upstream stage storage relationships. These four options are: the prism method, entering a surface area versus elevation curve, entering a volume versus elevation curve, and stream cross-section data. The prism method uses the upstream channel slope and a rectangular or triangular shape to propagate a geometric shape (or prismatic section) upstream. In this manner, volumetric relationships can be calculated for a given elevation. The next two options employ user supplied data to determine the volumetric relationship. The final option uses actual upstream cross section profiles to calculate the storage relationship. Given some ingenuity, this option could be used to design a stormwater detention basin.

Output generated by the routing section of HY8 can be reviewed, and a plot of inflow, outflow, or both can be generated in the screen. A hard copy of the plot can be obtained by pressing the print screen key. There are no help screens yet available for this program in HY8.

Energy Dissipation Module

The final module in the HY8 program permits the design and analysis of an energy dissipator at the culvert outlet. It follows the design procedures used in FHWA publication HEC 14 "Hydraulic Design of Energy Dissipators for Culverts and Channels."[2] Similar to the routing module, the module needs a culvert analysis file to perform the energy dissipator design and analysis. If there is more than one culvert system in the culvert analysis file (recall the earlier discussion about how HY8 distinguishes number of barrels and the number of systems), the user has to specify which system they desire to use first for the design. The program will design a dissipator for only one culvert at a time.

The user can select several options from within this module. These options are: designing an external dissipator, designing an internal dissipator, estimating the scour hole geometry, and modifying hydraulic aspects of the culvert being analyzed.

The available external dissipator designs are: 1) Drop Structures (includes box drop-structures and straight drop-structures); 2) Stilling Basins (includes SAF, USBR-2, USBR-3, and USBR-4 basins); and 3) At-Streambed-Level Structures (includes Contra Costa, CSU, Hook, Riprap, and USBR-6 basins). The design of an internal dissipator is only available for box or circular culverts. The available internal dissipator designs are: 1) Increased Resistance and 2) Tumbling Flow. The type of dissipator available is based on the data obtained from the culvert file and other requirements needed for the available dissipators (Froude number, tailwater, and other special limitations). Where appropriate, these are shown in tables generated by the program.

Hydrologic data and soil type characteristics are used to estimate the scour hole geometry at the culvert outlet. The final option allows the user to change the culvert discharge, culvert outlet velocity and depth of water at culvert outlet. As mentioned before, the user can switch between the differing culvert systems if more than one was entered in the culvert analysis module.

The data created by HY8-Energy Dissipators is not stored as it is in the other modules within HY8. However, output of each dissipator design can be obtained by either pressing the print-screen key or by selecting the appropriate menu option after the energy dissipator is designed. Help files are available for this program module.

3. Technical / Operational Methods

This section investigates some of the technical and operational methods used by HY8 to analyze culvert systems. As mentioned earlier, this section will concentrate on the equations and methodologies used by HY8 when performing a culvert analysis. It will not discuss details of the hydrologic, routing, and energy dissipation analyses.

The culvert analysis involves calculating the inlet control and outlet control headwater elevations for the given flow. These elevations are compared and the larger of the two is used as the controlling headwater elevation. Tailwater effects are taken into consideration when calculating these elevations. If the controlling headwater elevation overtops the roadway embankment, an overtopping analysis is done in which flow is balanced between the culvert discharge and the surcharge over the roadway. An enhanced balancing technique is also used in the case of multiple barrels. A more detailed discussion of these calculations follows.

Inlet Control

By regression analysis, FHWA has produced fifth degree polynomial equations to model the inlet control headwater for a given flow. The regression equations have been developed for the range of inlet heads from one half to four times the diameter of the culvert. Analytical equations, based on minimum energy principles, are matched to the regression equations to model flows that create inlet control heads outside of the regression data range.

For culvert discharges within the range of the regression analysis, the FHWA equation gives a direct solution for inlet head. The regression equations are of the form:

$$H_{wi} = (A + B \cdot X + C \cdot X^2 + D \cdot X^3 + E \cdot X^4 + F \cdot X^5) \cdot D \qquad (1)$$

where:

H_{wi} = the inlet control headwater, in feet,

D = the height of the culvert barrel, in feet,

A to F = regression coefficients for each type of culvert, and

X = a function of the average outflow discharge being routed through a culvert, culvert barrel height and for box and pipe arch culverts, the width of the barrel.

For discharges that create inlet control heads above the regression equation limits, an orifice equation is used to model flows. The potential head for the orifice equation is given by the difference of the water surface elevation and the elevation of the center of the circular pipe. For non-circular culverts the potential head is determined to be from the center of the culvert, which is approximated by the sum of the invert elevation and one half the rise of the culvert. The orifice equation used in the program is of the form:

$$Q = k \cdot A \cdot h^{0.5} \tag{2}$$

where:

Q = the orifice equation discharge, in ft^3/s,

A = the cross sectional area of culvert, in ft^2,

k = the coefficient based on the headwater, outlet head and the coefficient of contraction, and

h = inlet control headwater, in feet.

The coefficient is determined by setting the orifice equation equal to the regression equation at the upper limit of the regression equation. The orifice equation is then used to determine inlet headwater for all flows exceeding the upper limit.

For discharges that create inlet control heads less than half the diameter of the culvert, an open channel flow minimum energy equation is used with the addition of a velocity head loss coefficient. Critical depth for the minimum energy equation is determined from the following condition:

$$F_r^2 = \frac{Q^2 \cdot T}{g \cdot A^3} = 1 \tag{3}$$

where:

F_r = the Froude number (equal to one in this case),

Q = the culvert flow rate, in ft^3/s,

A = the culvert's cross sectional flow area, in ft^2,

T = the culvert's cross section top width, in feet, and

g = the gravitational acceleration (32.2 ft/sec^2).

The coefficient is needed to match the minimum energy equation with the regression equation at one half the diameter of the culvert. The minimum energy equation is:

$$H_w = d_c + (1 + k_e) \frac{V^2}{2g} \tag{4}$$

where:

d_c = the critical depth at culvert entrance for given discharge, in feet, determined for the minimum energy condition above,

k_e = the entrance loss coefficient,

V = the velocity at critical depth, in ft/s, and

g = the gravitational acceleration (32.2 ft/sec^2).

The entrance coefficient is determined by setting the minimum energy equation equal to the regression equation at one half the rise, which is the lower limit of the regression equation.

The minimum energy equation with the additional velocity head loss would seem to describe the low flow portion of the inlet control headwater curve; however, numerical error in the calculation of flow are for very small depths tends to increase the velocity head as the flow approaches zero. This presents little or no problem in most practical cases since the flows that cause this are relatively small. In many of the calculations required for the solution of multiple culverts the inlet control curve must decrease continuously to zero for the iterative calculations to converge. Therefore modifications to this equation have been made to force the velocity head to continually decrease to zero as the flow approaches zero.

As the flow becomes very shallow in the culvert, the rate of width to depth of flow ratio increases greatly. As the flow approaches zero the culvert can be assumed to be very wide and the wide channel approximation of minimum energy is used.

$$E = 1.5 \cdot d_c \tag{5}$$

where:

E = the approximation of the minimum energy, and

d_c = the critical depth, in feet.

The critical depth is continuously decreasing and approaches zero as the flow approaches zero.

The inlet head calculation between flow at zero and half the depth must be a combination of the minimum energy calculation with the velocity head loss equation and the wide channel approximation minimum energy equation. This can be accomplished by a linear weighing of the equations in the low flow range.

In the range of flows between 15 percent of the flow that causes an inlet head elevation of one half the culvert diameter (denoted as $Q_{0.5} \cdot D$), to zero flow, the velocity head is gradually converted to one half the critical depth by using the following equations:

First, the fractional contribution of a given flow, Q, in relation with the 15 percent flow is calculated;

$$Q_{frac} = \frac{0.15 \cdot (Q_{0.5} \cdot D) + Q}{0.15 \cdot (Q_{0.5} \cdot D)} \quad (6)$$

where:

Q_{frac} = the fractional contribution of a given flow,

$Q_{0.5} \cdot D$ = the discharge that creates inlet control head of one half the diameter of the culvert, and

Q = a given discharge, between 0 and 15 percent flow, in ft^3/s.

Next, a velocity head coefficient, based on the fractional contribution and the velocity head is computed;

$$C_{vh} = \frac{1 - Q_{frac}}{1 + V_h \cdot Q_{frac}} \quad (7)$$

where:

C_{vh} = the velocity head coefficient,

Q_{frac} = the fractional contribution of a given flow, defined above, and

V_h = the velocity head calculated from average velocity, in feet.

Finally, the corrected velocity head can be calculated;

$$V_{hcorr} = Q_{frac} \cdot 0.5 \cdot d_c + V_h \cdot C_{vh} \quad (8)$$

where:

V_{hcorr} = the corrected velocity head, in feet,

Q_{frac} = the fractional contribution of a given flow, defined above,

d_c = the critical depth for given flow, in feet,

V_h = the velocity head calculated from average velocity, in feet, and

C_{vh} = the velocity head coefficient, defined above.

As the discharge, Q, approaches zero, Q_{frac} approaches unity and C_{vh} vanishes. Inversely, as Q approaches $Q_{0.5} \cdot D$, Q_{frac} vanishes and C_{vh} approaches unity.

From equation 8, it can be said that for very low flows, the inlet control equation becomes:

$$H_{wi} = d_c + (1 + C_{vh}) \cdot V_{hcorr} \quad (9)$$

where:

H_{wi} = the inlet control headwater, in feet,

d_c = the critical depth, in feet, for a given flow Q,

C_{vh} = the velocity head coefficient, and

V_{hcorr} = the corrected velocity head, in feet.

Outlet Control

Outlet control water surface elevation is determined by adding the friction losses in the pipe barrel and the entrance and exist losses to the tailwater elevation. For the losses to affect the headwater, the flow through the culvert must be subcritical. The program initially determines whether the culvert slope is mild or steep and then whether the culvert outlet crown is submerged or unsubmerged (whether the downstream water surface is above or below the outlet crown). The procedure for determining friction losses is decided from these two pieces of information.

If the culvert exit is submerged then at least part of the barrel is flowing full and pressure flow computations are performed to determine the length of the full flow section. When only a portion of the culvert is flowing full water surface profile calculations are used to compute the friction losses in the open channel flow section. If the length of the full flow section is equal to the full length of the culvert, then pressure flow exists throughout the culvert. The pressure flow analysis is the same for steep and mild sloped culverts; however, the open channel flow analysis differs for steep and mild slopes.

On steep culverts, a hydraulic jump may form in the culvert if the flow depth is less than critical. If the jump is detected in the culvert then the culvert is controlled at the inlet. However, under this circumstance, the energy elevation at the jump is output for the outlet control elevation. If the tailwater is high enough, the jump may submerge the inlet causing the headwater elevation to be controlled by the outlet.

On mild slopes, a backwater routine is used to calculate friction losses through the culvert for low flows. If flow intersects the crown of the culvert, pressure flow is calculated for the remaining length of the culvert.

If the slope of the culvert is steep then a check is made to determine if the inlet is submerged by the tailwater. In most cases where the slope is supercritical the culvert is in inlet control. The program will proceed with head loss calculations from the outlet toward the inlet until either the entrance is reached or critical depth is reached suggesting that a hydraulic jump has formed in the culvert. If the entrance is reached before critical depth, then the inlet control point has been submerged by the tailwater and friction effects force outlet control. When critical depth is calculated in the culvert the flow is controlled at the inlet. The outlet control elevation output by the computer is the sum of minimum energy and an inlet loss at the location where the critical depth has been calculated. The program can display negative outlet control heads which mean that the outlet control effects only reach an elevation that is below the inlet invert.

Friction losses in the barrel are determined by algebraically manipulating Manning's formula to solve for friction slope:

$$S_f = \left[\frac{Q \cdot n}{1.486 \cdot A \cdot R_h^{0.67}} \right]^2 \qquad (10)$$

where:

S_f = the friction slope, in ft/ft,

Q = the culvert barrel discharge, in ft^3/s,

n = Manning's roughness coefficient,

A = the cross section flow area, in ft^2, and

R_h = the hydraulic radius of the culvert, in feet.

If the barrel is flowing full, the friction slope is constant over the length of the full flow section and frictional head loss can be computed by the following:

$$H_f = S_f \cdot L \tag{11}$$

where:

H_f = the head loss due to friction in the culvert barrel, in feet,

S_f = the friction slope, in ft/ft,

L = the length, in feet, of culvert containing full flow.

If open channel flow is occurring in the culvert, the hydraulic parameters are changing with flow depth along the length of the culvert. The friction losses are determined by summing the incremental changes in head loss using the direct step method. The incremental head loss is calculated by:

$$\delta H_f = S_f \;/\; \delta L \tag{12}$$

where:

δH_f = the incremental head loss,

S_f = the friction slope, in ft/ft, at δL, and

δL = the incremental change in length.

The open channel barrel loss calculations proceed as follows:

1. An increment of head loss is determined.
2. The friction slope is calculated at the outlet.
3. The length of culvert is calculated from the friction slope and the specified head loss.
4. A new friction slope is calculated at the distance computed in step three.
5. From the specified head loss and the friction slope determined in step four, an incremental length is calculated and added to the length calculated previously.
6. The incidental head losses are summed and steps four and five are repeated until the summed length from the outlet is greater than the length of the culvert or until the head losses in the culvert cause the

water surface to intersect the crown of the culvert (beginning of pressure flow section).

The sum of the incremental head losses computed is the frictional head loss through the open channel flow section of the culvert barrel. If a portion of the barrel is flowing full then the full flow head loss is computed and added to the open channel head loss for the total barrel friction loss.

Losses at the culvert entrance and exit are computed by the product of a loss coefficient and the velocity at the entrance and exit. The entrance loss equation used in the program is:

$$H_e = k_e \cdot \frac{V^2}{2g} \tag{13}$$

where:

H_e = the entrance head loss, in feet,

k_e = the entrance loss coefficient,

V = the flow velocity just inside culvert barrel, in ft/s, and

g = the gravitational acceleration (32.2 ft/sec^2).

Similarly, the exit loss equation is:

$$H_o = 1.0 \cdot \frac{V^2}{2g} \tag{14}$$

where:

H_o = the exit head loss, in feet,

V = the flow velocity just inside culvert barrel, in ft/s, and

g = the gravitational acceleration (32.2 ft/sec^2).

Downstream Channel

The water surface elevation in the downstream channel may influence the culvert discharge, therefore, it is important to have a reasonable estimate of the water surface elevation and the velocity in the downstream channel. The downstream water surface elevation is important in determining the effects of tailwater on culvert performance. Velocity, shear stress, and Froude number in the channel are important in determining channel stability. The program will calculate uniform flow elevation, velocity, shear, and Froude number values;

however, calculations for the culvert performance curve use only the elevation of the water surface.

The uniform flow calculations are performed using Manning's equation:

$$Q = \frac{1.486}{n} A \cdot R_h^{0.67} \cdot S_f^{0.5} \tag{15}$$

where:

Q = the uniform discharge, in ft^3/s, occurring within a waterway channel's cross sectional area,

A = the channel's waterway cross sectional area, in ft^2,

R_h = the hydraulic radius of a waterway (waterway area divided by wetted parameter), in feet,

S_f = the friction slope, in ft/ft, assumed to be equal to the downstream channel slope, and

n = Manning's friction value for a waterway.

Area and hydraulic radius are functions of water surface elevation and channel geometry. Since the determination of water surface elevation given flow is a direct solution in Manning's formula for only the simplest cases, an iterative technique is used to determine water surface elevation. For channels of simple cross-sectional geometry (trapezoidal, rectangular, and triangular) the area and hydraulic radius calculations are calculated by a single routine. The determination of the water surface elevation for an irregular shaped channel is more involved. A separate module was developed to perform uniform flow calculations in irregular shaped channels.

Under many flow conditions in natural channels, the flow is conveyed in subchannels and overbank regions that have significantly different hydraulic capacities than the main channel. The irregular channel module can calculate uniform flow water surface elevations with three separate subchannels using geometric principles to balance the conveyances in the subchannels.

Velocity calculations for the simple cross-sectional geometries are average velocities. Velocity calculations for the irregular shaped channels are average velocities for the main channel. Shear is calculated by the following equation:

$$Tau = \gamma \cdot S_f \cdot T_w \tag{16}$$

where:

Tau = the maximum shear, in psf,

γ = the specific weight of water, 62.4 lbs/ft^3,

S_f = the friction slope (equal to channel slope for uniform flow), in ft/ft, and

T_w = the tailwater depth, or the maximum depth of flow occurring in the natural channel just beyond the culvert outlet, in feet.

Froude number is determined from the following equation:

$$F_r^2 = \left[\frac{Q^2 \cdot T}{g \cdot A^3} \right] \tag{17}$$

where:

F_r = the Froude number,

Q = the discharge in the channel, in ft^3/s,

T = the channel cross section's top width, in feet,

A = the channel's waterway cross sectional area, in ft^2, and

g = the gravitational acceleration (32.2 ft/sec^2).

Roadway Overtopping

The flow that overtops an embankment is similar to that of a broad crested weir. The following weir equation is used by the program to determine flow over embankments:

$$Q_o = C_d \cdot L \cdot H_{wr}^{1.5} \tag{18}$$

where:

Q_o = the discharge over embankment, in ft^3/s,

C_d = the discharge coefficient (weir coefficient),

L = the length of weir crest, in feet, and

H_{wr} = the upstream head above embankment crest, in feet.

The program has two options for selection of the discharge coefficient. The user can specify the surface type and allow the program to determine the coefficient from internal tables or the user can input a discharge coefficient. Coefficients determined by the program are interpolated from data points taken from the FHWA discharge coefficient curves for paved and gravel roadway surfaces. The tables are based on the headwater elevation and the roadway width. The coefficients are modified for tailwater submergence by multiplying the coefficients by a submergence factor which is interpolated from data taken from the submergence factor curves for paved and gravel roadways. The coefficients entered by the user are also multiplied by a submergence factor that is interpolated from the data for the gravel roadway surfaces.

For convenience in computations an assumption of a constant roadway surface elevation for the crest of the weir is common, although the section of the roadway that becomes overtopped is usually the low portion of a vertical curve. With little additional computational effort, the calculation of flow can be integrated over the roadway profile described by several coordinates that more accurately define the roadway surface. If given a set of roadway profile coordinates and other data to describe headwater elevation and the coefficient of discharge, the program will integrate the weir equation to determine flow between each of the coordinates and sum the flows to give a total flow over the entire roadway profile.

A four point Gaussian quadrature routine is used to integrate between any two coordinate points. If the information for the roadway surface and tailwater is given, the weir coefficient and submergence reduction is computed at each integration point.

Multiple Barrel Analysis

In some cases an engineer may need to analyze flow through two or more barrels and/or over the roadway. If the tailwater effects are negligible, the determination of headwater elevation and flow conveyed through each of the conduits and over the roadway may be computed by adding performance curves. If each of the barrels is considered identical, the symmetry of the system can be used by dividing the flow by the number of barrels and proceeding with calculations as for a single barrel. However, if there is an effect on the conveyance by the tailwater and the culverts are different, then the simple addition of performance curves may be in considerable error. For a given flow the tailwater elevation can be approximated from normal depth or backwater calculations. Flows in each of the culverts must be such that the total head loss in each culvert is identical (the difference between headwater elevation and tailwater elevation) and the total flow conveyed must be equal to the sum of the flows through each of the culverts and over the roadway. The problem is similar to a parallel pipe problem.

The tailwater and headwater potential are identical for each of the culverts. Given the assumption of no interference of one culvert with another at the inlet or outlet, the head loss dissipated by each of the culverts must be the same. The total flow must be the sum of the flows through each culvert. Streeter and Wylie give an iterative procedure for solving the head loss and flow in similar parallel pipe systems.[7] With slight modification to the parallel pipe procedure, the following is the basis for the multiple barrel iterative solution technique.

1. Assume a flow through the control barrel, which is the barrel with the lowest invert.

2. Determine the head loss through the control barrel and the headwater elevation caused by that head loss.

3. Determine flow in the other barrel(s) based on the headwater elevation calculated from the control barrel.

4. Distribute flows by the following equation:

$$Q_i = \frac{Q_{ic}}{\Sigma Q_{ic}} \tag{19}$$

   where:

   Q_i = the adjusted flow through barrel i, in ft^3/s,

   Q_{ic} = the calculated flow through barrel i, in ft^3/s, and

   ΣQ_{ic} = the sum of the calculated flows, in ft^3/s.

5. Use the adjusted flow through the control barrel as the assumed flow in the control barrel and repeat the procedure until the difference in sum of the calculated flows and the given flow and the difference in the headwater elevations from successive iterations are within acceptable limits.

This technique converges rapidly and is stable if the rate of head loss change to discharge change is smaller for the controlling barrel than for the other barrels. In most cases, this translates to the controlling barrel diameter being larger than the diameter of the other barrels. When the controlling barrel diameter becomes much less than that of another barrel, the solution may oscillate. In most practical applications the barrel with the lowest invert is the largest or approximately the same size as the other barrels. However, it is desired that the same iterative procedure be used to balance flows if the roadway is overtopped. In most cases, because the conveyance of the roadway surface is so much larger than that of any culvert, the solution is unstable. Therefore some modifications must be made when the headwater elevation exceeds the roadway elevation.

If the flow that is conveyed over the roadway is treated as flow through another barrel, the above procedure can be used. To prevent oscillations, the overtopping flow must be the controlling flow.

Initial convergence limits, set on both headwater elevation and percent of total discharge, are well within the accuracy of the Manning's friction coefficient, n. The convergence limits are relaxed for the total number of barrels and for the number of iterations. In some flow situations, a slight change in flow will cause jumps in headwater elevation for a single barrel. This, in turn, will cause the oscillation of the multiple barrel solution.

A limit of 50 iterations is set to abort the process and go on to other calculations. A summary of iterative solution errors will show the error limits for the solution.

The greater the number of barrels in the solution the less stringent the convergence criteria must be for convergence. The criteria for terminating the successive headwater calculations is the iteration where the difference of the prior headwater and the newly computed headwater is less than the empirical value of 0.01 times the number of barrels.

Similarly, the criteria for convergence on percent total flow is when the ratio of total calculated flow to total flow is less than 1 percent times the number of barrels. A maximum of 50 iterations are run at which time the process is aborted.

After the tabulation of the performance curve for multiple culverts, a table of errors due to the iterative technique is given. This table includes error of percent total flow and headwater elevation error.

<u>Minimization of Culvert Size</u>

A culvert minimization routine permits a peak flow, culvert design calculation to be made. The minimization routine uses an allowable headwater elevation as the controlling hydraulic factor to adjust the culvert size. The culvert size that minimizes the difference between the maximum headwater calculation and the user supplied allowable headwater is the output. Hydraulic parameters are recomputed when the minimization routine is activated. These parameters include: allowable headwater elevation, controlling headwater elevation (which will be lower than the allowable headwater elevation), inlet and outlet control elevations, culvert flow velocity, channel flow velocity, design discharge, channel slope, culvert flow depth, channel flow depth, normal flow depth, and critical flow depth.

4. User Documentation

For those users who have obtained HY8 as part of the Federal Highway Administration's **HYDRAIN** package, the following section discusses the procedures for accessing HY8 through the HYDRAIN System Shell. In HYDRAIN, the HY8 program is referred to as Version 3.0 (or sometimes HY8V3) to reflect the current variant of the software. The user is referred to the HYDRAIN documentation if additional information is required on the working of the HYDRAIN System Shell.

Since HY8 is an interactive program, much of the procedure for performing an analysis is self contained within the menu screens and helps. This lessens the need for a users manual. Data entry is accomplished through the use of menus and prompts generated by the program. The program has some error and range checking capabilities for ensuring that only realistic values are entered by the user. Data is easily edited and summary tables of input data and output results are generated periodically throughout the data entry process.

Operating the HYDRAIN System Shell

HY8V3, as well as the other Pooled Fund Project (PFP) software packages, are activated through the use of what is known as the PFP "shell". This shell is a separate program that ties the above-mentioned packages together and allows them to be accessed. The following text deals specifically with the interaction between the HYDRAIN System Shell and HY8V3; the operation of the other packages will be dealt with separately in their respective documentation.

Before work on a specific HY8V3 example can begin, the HYDRAIN shell must first be entered and the desired package accessed. This process is begun, from DOS by entering the C:\HYDRAIN directory, typing the command **HYDRAIN**, and striking a carriage return (denoted by <CR>). A screen will appear showing the member sponsors of the Pooled Fund Project. Another <CR> reveals a message (a PFP "disclaimer") to the PFP user. A third <CR> will place the user in the Main Menu.

Executing HY8V3 in the HYDRAIN System Shell

After the introductory screens have been cleared the user enters the Main Menu which contains the following choices:

- Input/Edit - input or edit data for HYDRA, WSPRO, HYDRO, CDSV5, or HYCHL (note: this option WILL NOT be used in the case of HY8V3);
- Execute - run HYDRA, WSPRO, HYDRO, CDSV5, **HY8V3**, EQUAT, or HYCHL;
- Utilities - DOS commands, file operation, HYDRAIN setup;
- System Info - long help files for selected topics in HYDRAIN; and

- Quit - exit the HYDRAIN system.

Selection of an option within the Main Menu is accomplished by simply using the left and right ARROWS to move the cursor to the desired procedure or by striking the highlighted letter of the desired option. As each of the procedural options is highlighted by the cursor, a menu of the options within the specific procedural category are displayed. Movement in this field, as before, is accomplished with the ARROWS (in this case, up and down).

HY8 is an interactive program. This means that the input and editing of data takes place within the program. No programs need to be accessed to process input datasets. For this reason, the user will move the cursor to the EXECUTE option and strike <CR>. Once within the EXECUTE pulldown menu, move to the HY8V3 option with the "down" ARROW cursor key. Once the menu bar is over the **HY8V3** field, striking <CR> will initiate the HY8 program.

Executing HY8V3 without the HYDRAIN System Shell

Since HY8 has so many features, sometimes the program will require more memory than is available when using it in combination with the HYDRAIN System Shell. Should the user suspect that this is occurring, HY8V3 can be executed apart from the HYDRAIN System Shell by typing the command **PFPHY8** and striking <CR>. This activates the batch program **PFPHY8.BAT**, located in the HYDRAIN directory.

HY8 Program Menu

After viewing an introductory screen, the user will be placed in the HY8 program menu. It is at this juncture that the user has access to the four modules discussed earlier. Since the vast majority of the analyses are performed in the culvert analysis module, it will be discussed in more detail than the other modules. In the program menu, the culvert analysis option is denoted as CULVERT DESIGN so as to highlight the program's analysis and design capabilities.

Culvert Analysis (and Design) Module

The culvert analysis section of the program contains three main groups of data to be entered into the program; initial culvert data, downstream channel data, and roadway data. Within the program, the user is sequentially led from one group to the next. The user is provided with an understanding of the necessary procedures used in the analysis of a culvert.

The first type of information to be entered is the initial culvert data. When creating a new culvert file, the user is asked to enter a performance curve discharge range which consists of minimum, maximum, and design flows. The maximum discharge allows the user to enter a discharge consistent with the maximum probable storm event.

Next, data concerning the culvert site is entered. There are two possible options for entering this data, the culvert invert option and the embankment-toe option. With the culvert invert option, the stations and elevations of the inlet and outlet are entered. The other option is to enter embankment and toe data which is used by the program to generate invert data for the inlet and outlet. The program defaults one as the number of barrels to be used during the analysis at this point. This number can be edited to fit the user's desired number of barrels to be analyzed.

Following this series of screens, the culvert shape and dimensions are chosen along with the inlet type and culvert material. The program has a wide variety of shapes that can be used including, circular, box, elliptical, pipe arch, and irregular. Inlets can be conventional or improved with side tapering or slope tapering. Included in the inlet data is information on headwall and wingwall geometry. The culvert material data is used to determine a Manning's 'n' value. The culvert material option yields an 'n' value consistent with the culvert material chosen.

Downstream channel information is the next group of data to be entered. This information is used to generate a tailwater rating curve. First, a channel shape is chosen from one of the following possibilities; rectangular, trapezoidal, triangular, or irregular. The irregular channel can be described using a maximum of 15 coordinates. There are also options to enter the users own rating curve or a constant tailwater elevation. Two other pieces of information that are needed are the slope and Manning's 'n' value for the channel. Using all of this data, a tailwater rating curve is developed which is in table form and can be plotted if graphics capabilities are available.

After returning to the culvert portion of the program with the rating curve, the user will be prompted for roadway data to be used in the overtopping analysis. A constant roadway elevation can be entered or an irregular profile can be described using 3 to 15 coordinates. A weir coefficient and the embankment width are also needed to do the overtopping analysis. The analysis is similar to that of a broad crested weir and similar data is needed. With regard to weir coefficients, the user has the option to use the two preset coefficients for either paved or gravel roadway surfaces, or enter a user defined value between 2.5 and 3.095.

From these sets of data, the program develops culvert performance data with or without overtopping. A performance curve can be plotted on a computer with graphics capabilities by typing a V for view (note: this capability requires the presence of a <u>C</u>olor <u>G</u>raphics <u>A</u>daptor card or the equivalent in the host microcomputer).

A minimization routine has been added to the program which allows the user to enter an allowable headwater elevation. This routine is activated by selecting letter M from the summary table in the culvert analysis. The program will adjust the user defined culvert size based on the allowable headwater elevation and it will increase or decrease the culvert size to fit that allowable headwater elevation for the design discharge. Several hydraulic parameters will be recomputed while the routine is adjusting the culvert size. The final value for each one of the recomputed hydraulic parameters will be shown at the bottom of the summary table.

Help screens are operational throughout the culvert analysis module. A print-out of the summarized culvert analysis can be obtained by selecting the appropriate options depicted under the performance curve table for overtopping. Whenever possible, the SAVE option should be selected to insure that data is placed on a file for later reuse or editing.

Appendix A consists of a step-by-step example that will enable the user to enter data into the culvert analysis module. The results of the analysis are also depicted. In this manner, the user can follow along with the example and get a more concrete feel for the method in which HY8 can be used to analyze and design a culvert system. Three other examples of the program's use are illustrated in the "HY8 Culvert Analysis Microcomputer Program Applications Guide."[8]

Other HY8 Program Modules

Given the basics of using the culvert analysis program module, other HY8 modules (Hydrology, Routing, and Energy Dissipation) are accessed in a similar manner. At this level of development, some of these modules do not yet have long help. However, the modules will have the same full screen interactive ability as did the culvert analysis program. To leave the HY8 program, select the "RETURN TO DOS" option in the HY8 program menu. At this point, the user will be returned to either the HYDRAIN System Shell, or the DOS prompt, depending on the manner HY8V3 was initially accessed.

Returning to the HYDRAIN System Shell

After completion of the analyses, the user will be returned to the HYDRAIN System Shell. The user can then explore the other HYDRAIN system programs, or leave the program by moving the cursor to **QUIT** and striking <CR>, or alternatively, simply pressing **Q**.

Appendix A. Benchmark Example

This example demonstrates how culvert hydraulic analysis and design can be accomplished by using microcomputer program HY8 "Culvert Analysis Version 3.0" which is part of the HYDRAIN software. The screens shown may not match exactly the version of HY8 that is used since several changes were made to the screens of Version 3.0. What the example will do is provide a guideline on how to apply the HY8 program in a typical example.

The example assumes that the user has entered the HY8 program through the steps outlined in the earlier chapter. At the HY8 program menu, the user has selected the first option, "CULVERT DESIGN", to enter the culvert analysis and design module.. At the next screen, they have created a file to called **EXAMPLE1**. Note that no extension is required, as it is automatically appended by the program.

Data Input

After creating a file, the user will be prompted for discharge range, site data and culvert shape, size, material and inlet type.

Flow Data

As can be seen from the regression analysis, the discharge range for this example will be from 0 to 500 cfs. The design flow will equal 400 cfs and the maximum flow will equal to 500 cfs.

USGS Regression equations yield:

$$Q_{50} = 400 \text{ cfs}$$
$$Q_{100} = 500 \text{ cfs}$$

Site Data

The site data is entered by providing culvert invert data. This is depicted below in Figure 2. If embankment data points are input, the program will fit the culvert in the fill and subtract the appropriate length.

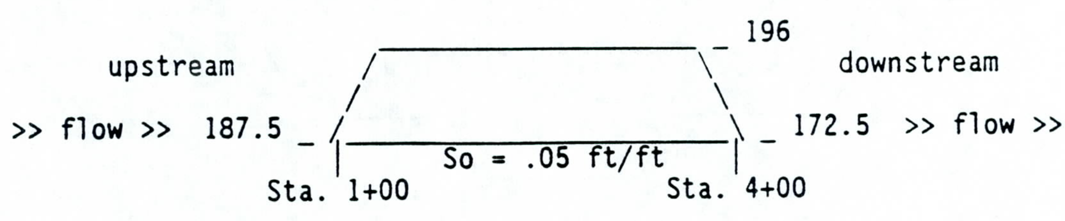


Figure 2. Culvert Invert data.

Culvert Data

As an initial size estimate, try a 5'x 5' concrete box culvert. For the culvert assume that a conventional inlet with 1:1 bevels and 45 degree wingwalls will be used.

As each group of data is entered the user is allowed to edit any incorrect entries. Figure 3 illustrates how the screen that summarizes the culvert information will appear.

```
CULVERT ANALYSIS 3.0                                        DATE:12-01-1989
CULVERT FILE:EXAMPLE1                                       CULVERT NO. 1

     ITEM                       SELECTED CULVERT

(1) BARREL SHAPE:           BOX
                            5.00 FT X  5.00 FT
(2) BARREL MATERIAL:        CONCRETE
(3) MANNING'S N:            .012
(4) INLET TYPE:             CONVENTIONAL
(5) INLET EDGE AND WALL:    1:1 BEVEL (45 DEG. FLARE)
(6) INLET DEPRESSION:       NONE
    TYPE ITEM NO. TO EDIT ITEM:
    <ENTER> TO CONTINUE DATA LISTING

1HELP   2     3     4     5END   6     7     8     9SHELL  10
```

Figure 3. Culvert data screen.

Channel Data

Next the program will prompt for data pertaining to the channel so that tailwater elevations can be determined. As can be seen below in Figure 4, the channel is irregularly shaped and can be described by the 8 coordinates listed in Table 1. After opening the irregular channel file the user will be prompted for channel slope (.05), number of cross-section coordinates (8) and subchannel option. The subchannel option in this case would be option (2), left and right overbanks (n =.08) and main channel (n =.03).

Cross section of channel (Slope = .05 ft/ft)

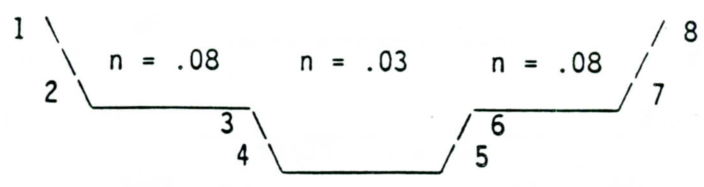


Figure 4. Irregular channel shape.

Table 1. Coordinates describing channel.

Point	Station, ft	Elevation, ft
1	12	180
2	22	175
3	32	174.5
4	34	172.5
5	39	172.5
6	41	174.5
7	51	175
8	61	180

After entering the last of the channel coordinates, the resulting screen similar to that depicted in Figure 5 below, will appear.

```
IRREGULAR CHANNEL CROSS-SECTION
CROSS-SECTION        X          Y
COORD. NO.         (FT)       (FT)
     1            12.00     180.00
     2            22.00     175.00
     3            32.00     174.50
     4            34.00     172.50
     5            39.00     172.50
     6            41.00     174.50
     7            51.00     175.00
     8            61.00     180.00
    TYPE COORD. NO. TO EDIT COORD.  *
    <I> OR <D> TO INSERT OR DELETE
    <ENTER> TO CONTINUE
    <P> TO PLOT CROSS-SECTION
1HELP   2     3     4     5END   6     7     8     9SHELL  10
```

Figure 5. Coordinates entered into screen.

The next prompt, for channel boundaries, refers to the number of the coordinate pair defining the left subchannel boundary and the number of the coordinate pair defining the right subchannel boundary. The boundaries for this example are the 3rd and 6th coordinates. After this is input, the program prompts for channel coordinates. Once these are entered, pressing (P) will cause the computer to display the channel cross-section. The user can easily identify any input errors by glancing at the plot. To return to the data input screens, press any key. If data is correct press <CR>. You can then enter the roughness data for the main channel and overbanks.

Tailwater Rating Curve

The program now has enough information to develop a uniform flow rating curve for the channel and provide the user with a list of options. Selecting option (T) on the Irregular Channel Data Menu will make the program compute the rating curve data, displayed below in Figure 6. Selecting option (I) will permit the user to interpolate data between calculated points.

CULVERT ANALYSIS 3.0 — DATE:12-01-89
CULVERT FILE:EXAMPLE1 — CULVERT NO. 1

TAILWATER RATING CURVE
IRREGULAR CHANNEL FILE: EXAMPLE1

NO.	FLOW(CFS)	T.W.E.(FT)	VEL.(FPS)	SHEAR(PSF)
1	0.00	172.50	0.00	0.00
2	50.00	173.45	9.02	2.29
3	100.00	173.91	11.13	3.14
4	150.00	174.28	12.52	3.75
5	200.00	174.57	13.70	4.29
6	250.00	174.80	14.93	4.88
7	300.00	174.99	15.94	5.39
8	350.00	175.15	16.77	5.81
9	400.00	175.30	17.51	6.20
10	450.00	175.44	18.18	6.56
11	500.00	175.56	18.80	6.90

TYPE:
<P> TO PLOT RATING CURVE
<ENTER> TO CONTINUE
<ESC> FOR TAILWATER MENU

1HELP 2 3 4 5END 6 7 8 9SHELL 10

Figure 6. Tailwater rating curve.

The Tailwater Rating Curve table consists of tailwater elevation (T.W.E.) at normal depth, natural channel velocity (Vel.) in feet per second, and the shear stress in pounds per square foot at the bottom of the channel for various flow rates. At the design flow rate of 400 cfs, the tailwater elevation will be 175.30 feet. The channel velocity will be 17.51 fps, and the shear will be 6.20 psf. This information will be useful in the design of channel linings if they are needed. Entering (P) will cause the computer to display the rating curve for the channel.

Roadway Data

The next prompts are for the roadway profile, so that an overtopping analysis can be performed. The roadway profile is a sag vertical curve, which will require the nine coordinates listed in Table 2 to define. Once these coordinates are input, the profile can be displayed when (P) is entered. The other data required for overtopping analysis are roadway surface or weir coefficient and the embankment top width. For this example, the roadway is paved with an embankment width of 50 feet.

Table 2. Roadway coordinate data.

Point	Station, ft	Elevation, ft
1	0	199.25
2	100	197.50
3	200	196.50
4	300	196.00
5	360	196.00
6	400	196.25
7	500	197.00
8	600	198.50
9	700	201.00

Data Summary

All the data has now been entered and the summary table is displayed as shown below in Figure 7. At this point any of the data could be changed or the user could continue by pressing <CR>, which will bring up the Culvert Program Options Menu. However, first a discussion of an interesting and powerful new feature of HY8 version 3.0 will be made.

```
CULVERT ANALYSIS 3.0                                          DATE:12-01-1989
CULVERT FILE:EXAMPLE1                                         SUMMARY TABLE
-------------------------------------------------------------------------------
| C |     A - SITE DATA              | B - CULVERT SHAPE, MATERIAL, INLET      |
| U |--------------------------------|------------------------------------------|
| L |  INLET   OUTLET   CULVERT      | BARRELS        SPAN   RISE   MANN.   INLET
| V |  ELEV.   ELEV.     LENGTH      | SHAPE                          N     TYPE
|NO.|  (FT)    (FT)       (FT)       | MATERIAL       (FT)   (FT)
| 1 |  187.50  172.50     300        | 1 - RCB        5.00   5.00   .012   CONVENTIONAL
| 2 |                                |
-------------------------------------------------------------------------------
TO REVIEW DATA PRESS <S> FOR SITE DATA
                     <C> FOR CULVERT SHAPE, MATERIAL, OR INLET DATA
                     <D> FOR DISCHARGE RANGE
                     <T> FOR TAILWATER RATING CURVE
                     <O> FOR OVERTOPPING DATA
                     <A> TO ADD OR DELETE CULVERTS
                     <M> TO MINIMIZE CULVERT SPAN
                     <ENTER> TO CONTINUE ANALYSIS
1HELP   2     3     4     5END    6     7     8     9SHELL   10
```

Figure 7. Summary Table.

Minimization Routine

A notable new feature of the program is intended to allow the designer to use HY8 version 3.0 as a tool to perform culvert design for circular culvert, box culvert, elliptical, and arch shape culverts based on a user's defined allowable headwater elevation. This feature, "Minimize Culvert Size" can be activated by selecting letter "M". Once this letter is selected it enables the user to input the allowable headwater elevation. That elevation will be the basis for adjusting the user's defined culvert size for the design discharge. The program will adjust the culvert span by increasing or decreasing it in 0.5 foot increments. It will compute the headwater elevation for that span, and compare it with the user's defined allowable headwater. If the computed headwater elevation is lower or equal than the defined allowable headwater elevation the minimization routine will stop, and the adjusted culvert can be used for the remainder of the program. Several hydraulic parameters are also computed while performing the minimization routine. These hydraulic parameters are part of the output of the minimization routine table, which is shown below in Figure 8. These results must be printed from this screen because they are not printed with the output listing routine. This feature should be a time saver for designers because it avoids the need for repetitively editing a culvert size to obtain a controlling headwater elevation.

```
CULVERT ANALYSIS 3.0                                              DATE:12-01-1989
CULVERT FILE:EXAMPLE1                                             SUMMARY TABLE
---------------------------------------------------------------------------------
| C |    A - SITE DATA               | B - CULVERT SHAPE, MATERIAL, INLET
| U |--------------------------------|--------------------------------------------
| L | INLET   OUTLET   CULVERT| BARRELS      SPAN    RISE    MANN.     INLET
| V | ELEV.   ELEV.     LENGTH| SHAPE                           N       TYPE
|NO.| (FT)    (FT)       (FT) | MATERIAL     (FT)    (FT)
| 1 | 187.50  172.50     300  | 1 - RCB      6.50    6.00    .012   CONVENTIONAL
| 2 |                         |
---------------------------------------------------------------------------------
      HEADWATER ELEVATION     |      FLOW VELOCITY      |       FLOW DEPTHS
ENTER ALLOWABLE    =  196.00  | CULVERT    =   31.71   | CULVERT    =    1.94
     CONTROLLING   =  195.50  | CHANNEL    =   17.51   | CHANNEL    =    2.80
   INLET CONTROL   =  195.50  | DISCHARGE  =  400.00   | NORMAL     =    1.94
  OUTLET CONTROL   =  180.32  | SLOPE      =  0.0500   | CRITICAL   =    4.91
MAXIMUM HEADWATER       <ENTER> TO CHANGE HEADWATER     <ANY KEY> TO CONTINUE
1HELP    2      3       4       5END      6        7        8       9SHELL   10
```

Figure 8. Minimization results.

For the sake of the example, DO NOT use this feature yet. If you have already done so, change the culvert size back to a 5' by 5' RCB using option (C); and edit the culvert shape.

Once you have returned to the Summary Screen, press <CR> to continue the example. The next screen will be entitled "Culvert Program Options."

Performance Curve (5x5)

At this point the data file can be saved or renamed by selecting option (S). The culvert performance curve table can be obtained by selecting option (N). If (N) is selected before (S) and an error occurs, the file can be retrieved by loading "current". When option (N) is selected, the program will compute the performance curve table without considering overtopping in the analysis. Since this 5'x 5' culvert is a preliminary estimate, the performance without considering overtopping is calculated and is shown below in Figure 9.

CULVERT # 1 PERFORMANCE CURVE
FOR 1 BARREL(S)

Q (cfs)	HWE (ft)	TWE (ft)	ICH (ft)	OCH (ft)	CCE (ft)	FCE (ft)	TCE (ft)	VO (fps)
0	187.50	172.50	0.00	-15.00	0.00	187.50	0.00	0.00
50	189.54	173.45	2.04	-12.67	0.00	0.00	0.00	17.29
100	190.91	173.91	3.41	-11.30	0.00	0.00	0.00	21.63
150	192.11	174.28	4.61	-10.15	0.00	0.00	0.00	24.57
200	193.30	174.57	5.80	-9.12	0.00	0.00	0.00	26.61
250	194.59	174.80	7.09	-8.18	0.00	0.00	0.00	28.45
300	196.04	174.99	8.54	-7.29	0.00	0.00	0.00	29.83
350	197.71	175.15	10.21	-6.35	0.00	0.00	0.00	31.11
400	199.62	175.30	12.12	-5.23	0.00	0.00	0.00	32.15
450	201.77	175.44	14.27	-3.96	0.00	0.00	0.00	33.12
500	204.16	175.56	16.66	-2.55	0.00	0.00	0.00	33.94

El. inlet face invert 187.50 ft El. outlet invert 172.50 ft
El. inlet throat invert 0.00 ft El. inlet crest 0.00 ft
PRESS <P> TO PLOT PRESS <ENTER> TO CONTINUE
1 2 3 4 5END 6 7 8 9 10

Figure 9. Non-overtopping performance curve.

This table indicates the controlling headwater elevation (HW), the tailwater elevation and the headwater elevations associated with all the possible control sections of the culvert. It is apparent from the table that 400 cfs the headwater (HW) is 199.62 ft, which exceeds the design headwater of 195 feet. Consequently, the 5'x 5' box culvert is inadequate for the site conditions. The following plot of inlet and outlet control headwaters can be obtained by entering (P). In this example, the culvert is operating in inlet control throughout the discharge range.

Performance Curve (6x6)

The user can easily modify the existing program file to analyze a larger barrel. Suppose a 6'x 6' culvert is tried. Hit any key to return to the Culvert Data Summary Table and enter (C) to modify culvert shape. The prompts will be the same as they were for the 5'x 5' culvert, and the user will be returned to the Culvert Data Summary Table directly without going through the tailwater and overtopping menus again. Pressing <CR> will bring up the Culvert Program Options menu, with which the file can be renamed and saved. The performance of this culvert can be checked by selecting option (N) for no overtopping. In this case, the table depicted in Figure 10 appears.

CULVERT # 1 PERFORMANCE CURVE
FOR 1 BARREL(S)

Q (cfs)	HWE (ft)	TWE (ft)	ICH (ft)	OCH (ft)	CCE (ft)	FCE (ft)	TCE (ft)	VO (fps)
0	187.50	172.50	0.00	-15.00	0.00	187.50	0.00	0.00
50	189.26	173.45	1.76	-12.93	0.00	0.00	0.00	17.48
100	190.42	173.91	2.92	-11.72	0.00	0.00	0.00	21.11
150	191.44	174.28	3.94	-10.70	0.00	0.00	0.00	23.92
200	192.37	174.57	4.87	-9.79	0.00	0.00	0.00	25.99
250	193.27	174.80	5.77	-8.96	0.00	0.00	0.00	27.95
300	194.18	174.99	6.68	-8.18	0.00	0.00	0.00	29.42
350	195.12	175.15	7.62	-7.44	0.00	0.00	0.00	30.75
400	196.12	175.30	8.62	-6.73	0.00	0.00	0.00	31.98
450	197.21	175.43	9.71	-6.06	0.00	0.00	0.00	33.01
500	198.40	175.56	10.90	-5.41	0.00	0.00	0.00	33.93

El. inlet face invert 187.50 ft El. outlet invert 172.50 ft
El. inlet throat invert 0.00 ft El. inlet crest 0.00 ft
PRESS <P> TO PLOT PRESS <ENTER> TO CONTINUE
1 2 3 4 5END 6 7 8 9 10

Figure 10. Non-overtopping, 6'x 6' culvert performance curve.

Performance Curve (7X6)

Since the design headwater criterion has still not been met, another size must be selected. Try a 7'x 6' culvert, and modify the file accordingly. The resulting performance table, shown in Figure 11, indicates that the design headwater will not be exceeded at 400 cfs. However, the headwater elevation of 196.74 feet at 500 cfs indicates that some overtopping will occur due to the 100-year storm.

Overtopping Performance Curve

To determine the amount of overtopping and the actual headwater, press <CR>, and then select (O) for overtopping. A Summary of Culvert Flows will appear on the screen, as shown in Figure 12.

CULVERT # 1 PERFORMANCE CURVE
FOR 1 BARREL(S)

Q (cfs)	HWE (ft)	TWE (ft)	ICH (ft)	OCH (ft)	CCE (ft)	FCE (ft)	TCE (ft)	VO (fps)
0	187.50	172.50	0.00	-15.00	0.00	187.50	0.00	0.00
50	189.08	173.45	1.58	-13.14	0.00	0.00	0.00	17.76
100	190.11	173.91	2.61	-12.04	0.00	0.00	0.00	20.19
150	191.02	174.28	3.52	-11.12	0.00	0.00	0.00	23.31
200	191.85	174.57	4.35	-10.30	0.00	0.00	0.00	25.26
250	192.63	174.80	5.13	-9.55	0.00	0.00	0.00	27.16
300	193.40	174.99	5.90	-8.84	0.00	0.00	0.00	28.85
350	194.18	175.15	6.68	-8.18	0.00	0.00	0.00	30.20
400	194.98	175.30	7.48	-7.54	0.00	0.00	0.00	31.34
450	195.83	175.43	8.33	-6.93	0.00	0.00	0.00	32.55
500	196.74	175.56	9.24	-6.34	0.00	0.00	0.00	33.58

El. inlet face invert 187.50 ft El. outlet invert 172.50 ft
El. inlet throat invert 0.00 ft El. inlet crest 0.00 ft
PRESS <P> TO PLOT PRESS <ENTER> TO CONTINUE
1 2 3 4 5END 6 7 8 9 10

Figure 11. Non-overtopping, 7'x 6' culvert performance curve.

SUMMARY OF CULVERT FLOWS (CFS) FILE: EXAMPLE1 DATE:12-01-1989

ELEV (FT)	TOTAL	1	2	3	4	5	6	OVERTOP	ITER
187.50	0	0	0	0	0	0	0	0	0
189.08	50	50	0	0	0	0	0	0	2
190.11	100	100	0	0	0	0	0	0	2
191.02	150	150	0	0	0	0	0	0	2
191.85	200	200	0	0	0	0	0	0	2
192.63	250	250	0	0	0	0	0	0	2
193.40	300	300	0	0	0	0	0	0	2
194.18	350	350	0	0	0	0	0	0	2
194.98	400	400	0	0	0	0	0	0	2
195.83	450	450	0	0	0	0	0	0	2
196.25	500	473	0	0	0	0	0	37	5

PRESS:
<1> TO PLOT TOTAL RATING CURVE
<2> TO DETERMINE SPECIFIC INFORMATION ABOUT EACH CULVERT
<3> TO SEE MULTIPLE CULVERT COMPUTATIONAL ERROR TABLE
<4> TO PRINT CULVERT SUMMARY
<ENTER> TO RETURN FOR NEW RUN OR EXIT

1HELP 2 3 4 5END 6 7 8 9SHELL 10

Figure 12. Overtopping performance curve.

This computation table shown in Figure 12 is used when overtopping and/or multiple culvert barrels are used. It shows the headwater, total flow rate, the flow through each barrel and overtopping flow, and the number of iterations it took to balance the flows. From this information a total (culvert and overtopping) performance curve, shown below, can be obtained by selecting option (1). The resulting curve is a plot of the headwater elevation versus the total flow rate which indicates how the culvert or group of culverts will perform over the selected range of discharges. It is especially useful for comparing the effects of various combinations of culverts.

From the Summary table, when the total flow is 500 cfs, 473 cfs passes through the culvert and 37 cfs flows over the road. The headwater elevation will be 196.25 feet. Assume that in this case overtopping at 100-year frequency can be tolerated, and the 7'x 6' culvert will be used. Referring back to the performance curve data, the outlet velocity at 400 cfs is 20.42 fps. Since the tailwater rating curve generated previously indicates that the natural channel velocity at 400 cfs is 17.51 fps, an energy dissipator will not be warranted.

When overtopping occurs, the performance of the culvert will differ from that without overtopping. By selecting option (2), the culvert performance data can be obtained. This is depicted in Figure 13. The user also has the option to plot this data.

CULVERT # 1 PERFORMANCE CURVE
FOR 1 BARREL(S)

Q (cfs)	HWE (ft)	TWE (ft)	ICH (ft)	OCH (ft)	CCE (ft)	FCE (ft)	TCE (ft)	VO (fps)
0	187.50	172.50	0.00	-15.00	0.00	187.50	0.00	0.00
50	189.08	173.45	1.58	-13.14	0.00	0.00	0.00	17.76
100	190.11	173.91	2.61	-12.04	0.00	0.00	0.00	20.19
150	191.02	174.28	3.52	-11.12	0.00	0.00	0.00	23.31
200	191.85	174.57	4.35	-10.30	0.00	0.00	0.00	25.26
250	192.63	174.80	5.13	-9.55	0.00	0.00	0.00	27.16
300	193.40	174.99	5.90	-8.84	0.00	0.00	0.00	28.85
350	194.18	175.15	6.68	-8.18	0.00	0.00	0.00	30.20
400	194.98	175.30	7.48	-7.54	0.00	0.00	0.00	31.34
450	195.83	175.43	8.33	-6.93	0.00	0.00	0.00	32.55
473	196.24	175.56	8.74	-6.66	0.00	0.00	0.00	33.05

El. inlet face invert 187.50 ft El. outlet invert 172.50 ft
El. inlet throat invert 0.00 ft El. inlet crest 0.00 ft
PRESS <P> TO PLOT PRESS <ENTER> TO CONTINUE
1HELP 2 3 4 5END 6 7 8 9SHELL 10

Figure 13. Specific culvert performance curve.

By pressing <CR> the program returns to the Summary of Culvert Flows menu. Selecting option (3), a Summary of Iterative Solution Errors is produced. This table, shown below in Figure 14, lists the amount of error present in the solution for a flow rate of 500 cfs as 10 cfs.

SUMMARY OF ITERATIVE SOLUTION ERRORS   FILE: EXAMPLE1   DATE: 12-01-1989

HEAD ELEV(FT)	HEAD ERROR(FT)	TOTAL FLOW(CFS)	FLOW ERROR(CFS)	% FLOW ERROR
187.50	0.00	0	0	0.00
189.08	0.00	50	0	0.00
190.11	0.00	100	0	0.00
191.02	0.00	150	0	0.00
191.85	0.00	200	0	0.00
192.63	0.00	250	0	0.00
193.40	0.00	300	0	0.00
194.18	0.00	350	0	0.00
194.98	0.00	400	0	0.00
195.83	0.00	450	0	0.00
196.25	0.00	500	10	1.96

PRESS <ENTER> TO CONTINUE

1HELP 2 3 4 5END 6 7 8 9SHELL 10

Figure 14. Iterative errors.

This concludes the benchmark example. The user should now have a fairly good understanding of the processes involved in using HY8 to analyze and design a culvert.

References

1) Normann, Jerome M., Robert J. Houghtalen, and William J. Johnston, "Hydraulic Design of Highway Culverts", FHWA Hydraulic Design Series No. 5, FHWA-IP-85-15, Washington D.C., September, 1985.

2) FHWA, "Hydraulic Design of Energy Dissipators for Culverts and Channels", FHWA Hydraulic Engineering Circular No. 14, Washington D.C., September, 1983.

3) Thompson, Phil, personal correspondence, April through December 1989.

4) Pagan, Jorge, personal correspondence, April 1989 through February 1990.

5) Parola Jr., A.C., "Hydraulic Analysis of Culverts by Microcomputers", a thesis submitted in partial fulfillment of the requirement for the degree of Master of Science, the Pennsylvania State University, 1987.

6) Masch, Frank D., "Hydrology", FHWA Hydraulic Engineering Circular Number 19, FHWA-IP-84-15, Washington, D.C., 1985.

7) Streeter, Victor L., and Wylie, E. Benjamin, Fluid Mechanics, NY, McGraw-Hill Book Company, 1979.

8) Ginsberg, Abigail, "HY8 Culvert Analysis Microcomputer Program Applications Guide", FHWA-EPD-87-101, Washington D.C., 1987.

November, 1990

********** HY8 VERSION 3.2 **********

CULVERT DESIGN
ENERGY DISSIPATOR DESIGN
HYDROGRAPH GENERATION
ROUTING

BACKGROUND:

HY8 Version 3.2 was developed by the Federal Highway Administration (FHWA), Bridge Division (HNG-31). HY8 Version 2.1 was produced by the Pennsylvania State University in cooperation with FHWA. The HY8 Version 2.1 software was sponsored by the Rural Technical Assistance Program (RTAP) of the National Highway Institute under Project 18B administered by the Pennsylvania Department of Transportation.

The software automates the design methods described in HDS No. 5, "Hydraulic Design of Highway Culverts" dated September 1985, FHWA-IP-85-15; HEC No. 14, "Hydraulic Design of Energy Dissipators for Culverts and Channels" dated September 1984; and HEC No. 19, "Hydrology" dated October 1984, FHWA-IP-84-15. These publications are available from the Government Printing Office, Washington, DC 20402, from NTIS, 5285 Port Royal Rd, Springfield, Virginia 22161, from the McTrans Center, 512 Weil Hall, Gainesville, Florida 32611, and from the PC-Trans, 2011 Learned Hall, Lawrence, Kansas 66045-2962.

The software has been structured to be self-contained and requires no users' manual. This facilitates its use by roadway design squads. However, the knowledgeable hydraulic engineer will also find the software package useful because it contains advanced features.

The software is designed to be self-explanatory. Help screens have been added to the Culvert Design and Energy Dissipator programs. However, some screens such as plots, do not tell you what your next action should be. In these cases, pressing enter will normally take you to the next screen or continue operation.

Some of the features such as improved inlets, hydrograph generation, routing, and design of energy dissipator require an experienced user who is familiar with these design methods. These options can be used by others, but uneconomical, hydraulically inadequate, or unpractical designs may result.

THE SOFTWARE FEATURES ARE AS FOLLOWS:

PROCEDURES - FHWA HDS No. 5, Hydraulic Design of Highway Culverts; FHWA HEC No. 14, Hydraulic Design of EnergyDissipators for Culverts and Channels; and HEC 19, Hydrology, are the references for the procedures used in the software package.

APPROACH - Programs analyze or review user selected variables. This approach is chosen so that the user is not constrained by the design philosophy of the software and can easily compare alternatives.

SHAPES - Circular, box, elliptical, and pipe-arch with constant "n" and user defined shape, arch, low-profile arch, high-profile arch and metal boxes with different "n" for top and bottom. Execution of user defined shape, arch, low-profile arch, high-profile arch and metal boxes is considerably slower than other shapes.

INLETS - The user selects inlet edge condition from a menu which is consistent with the selected culvert shape. An inlet depression may be provided. If a circular or box shape is selected, the user may select either a circular or rectangular side-tapered inlet or a slope-tapered inlet.

NUMBER - The user may choose any number of barrels with the same site conditions, shape configuration, inlet type, and "n" or up to 6 independent culverts. In both cases the culverts share the same headwaterpool, tailwater pool, and roadway characteristics.

SITE DATA - The station and elevation of the culvert inverts can be entered or will be computed if embankment slope and toe data are entered.

DISCHARGE - User chooses maximum discharge for 11 point performance (rating) curve. The minimum discharge default is 0, but can be changed. Design dischargeis one of points in the rating curve.

TAILWATER - The user can input a rectangular, or trapezoidal, or triangular channel, or up to 15 cross-section points for irregular channel; 11 rating curve points, or a constant tailwater elevation. A rating curve can be displayed.

MINIMIZATION-ROUTINE - This new feature in HY8 allows the designer to enter an allowable headwater elevation which will be used to adjust the culvert size. The program willincrease or decrease the culvert size until it computes a controlling headwater elevation lower than the defined allowable headwater for the design discharge. Several hydraulic parameters such as the controlling headwater elevation, inlet and outlet control elevation, culvert flow velocity, channel flow velocity, culvert flow depth, channel flow depth, and normal and critical depth will be recomputed when the minimization routine is activated. This routine is activated by selecting letter M from the options shown in the Summary Table screen. Only culvert no. 1 can be minimized.

OVERTOPPING - If a roadway profile cross-section is provided, flow over the roadway weir will be balanced with the flow through the culverts.

OUTPUT - (SCREEN 1)

A performance table for individual culverts in the roadway is provided so that culverts can be compared using plots.

- (SCREEN 2)

A performance table for multiple culverts is provided which contains for each total discharge and headwater: the discharge in each barrel and discharge over the roadway. The user can display a table for each culvert that contains: tailwater elevation, inlet and outlet control headwater depths, USGS flow types, flow profile types, crest control, throat control and face control elevations, and outlet velocity. The user can also choose to view the inlet and outlet control curves (plots) and computational error table or print a report. The summary of the culvert analysis can be printed to the screen, printed to the printer or stored in a diskette for both screens 1, and 2.

HYDROGRAPH - a program that generates a storm hydrograph based on watershed data, user's defined hydrograph points or user's input hyetograph.

ROUTING - A culvert file and an inflow hydrograph file name maybe provided with upstream topographic data and the software will provide both a table and a plot of the outflow hydrograph. If a hydrograph file is not available, it can be created if rainfall data is known.

ENERGY DISSIPATOR - This program follows the design procedures presented in HEC No. 14, Hydraulic Design of Energy Dissipatorsfor Culverts and Channels. Hydraulic parameters computed in the culvert design program are imported into this program. Therefore, a culvert file has to be created in order to use the energy dissipator program. The following categories of energy dissipators are available:

1) Internal Energy Dissipators:
   - Increased Resistance
   - Tumbling Flow

   These dissipators are only available for Box or Circular culverts.

2) External Energy Dissipators:
   A) Drop Structures
      - Box Drop-Structure
      - Straight Drop-Structure

   B) Stilling Basin:
      - USBR Type 2 Basin
      - USBR Type 3 Basin
      - USBR Type 4 Basin
      - S.A.F. Basin

   C) At-Streambed-Level Structures
      - CSU Basin
      - Riprap Basin
      - Contra Costa
      - USBR Type 6

Restrictions and special limitations on these dissipators are presented in a table format for each dissipator category in the screen.

FILES - Data files which are keyed to the MS-DOS name provided by the user are stored under the appropriate extension (described in SETUP.EXE) supplied by the software. The user has to create the subdirectories specified on SETUP.EXE so that the data files can be stored and retrieved by the software. The subdirectories specified on SETUP.EXE will be stored in DRIVE.DAT which should reside in the same directory as the *.EXE files.

EDITING CULVERT DESIGN FILES - Existing file data are loaded to a data summary screen and can be edited or run. If a change is desired, the user selects the data to revise: site, culvert, discharge, tailwater, or roadway. The existing data are then displayed in the data entry screens and can be edited.

*** INSTALLATION ***

The software is being provided to you in executable modules which are found on the distribution diskettes. The software can be adapted to your IBM or compatible system which has a Disk Operating System (PC/MS DOS) 2.1 or greater by following the instructions listed below.

CONTENT OF DISTRIBUTION DISKETTES:

C:\HY8	C:\HY8\DAT	C:\HY8\DATA
HY8.BAT	ELPC2.DAT	*.INP
SETUP.EXE	LSHPA.DAT	*.TW
BRT70ENR.EXE	LSLPA.DAT	*.PC
TITLE.EXE	PAC11.DAT	*.HYT
CULVERT.EXE	PAC12.DAT	*.QT
MULT.EXE	PAC21.DAT	*.SAR
HYD.EXE	PAC22.DAT	*.VOL
ROUTE.EXE	PAC23.DAT	*.CS
MSHERC.COM	PAC33.DAT	*.HLP
DRIVE.DAT	PAC44.DAT	
MULT.HLP	SPSA.DAT	
ENERGY.EXE	ELPC1.DAT	
ENERGY.HLP	CABC.DAT	
CULVERT.HLP	CSBC.DAT	
TWATER.EXE	PAC11H.DAT	
READ.ME	PAC12H.DAT	
	PAC33H.DAT	
	PRINT.DAT	

GENERAL

BEFORE USING THE HY8 SOFTWARE, DISKCOPY ALL DISTRIBUTION DISKETTES ONTO BLANK DISKETTES AND PUT THE DISTRIBUTION DISKETTES IN A SAFE PLACE.

The software can be executed only on microcomputers having the following configuration:

--single diskette drive high density (5-1/4" diskette);
--single diskette drive high density (3-1/2" diskette);
--hard disk

Prior to running the software, your system should be booted in DOS 2.1 or higher. Hercules Graphics Cards are now supported by Microsoft. Edit HY8.BAT so that either GRAPHIC.COM or MSHERC.COM are loaded before execution of any *.EXE modules. Within the plotting routine is the option to change scales of plots. This is accomplished by pressing "S" after the screen has been plotted. A new screen will appear that allows you to change screen coordinates and scaling parameters.

OPERATION WITH DISK DRIVE:

HY8 must have access to the COMMAND.COM file. This can be accomplished by using the PATH command to designate the location of COMMAND.COM or put COMMAND.COM with the *.EXE files. Therefore, before using the software on your system, you must copy the DOS COMMAND.COM file onto the disk that contains the *.EXE files or make sure that it is in your PATH.

Next, the SETUP.EXE program should be run to designate drives and paths of needed files. This program will use a DRIVE.DAT file, which is used by *.EXE files when they are executed. This DRIVE.DAT file must be in the default drive when running the software EXECUTABLE programs. Remember that you have to create the directories that you specified in SETUP.EXE and copy the appropriate files to these directories prior to running the software *.EXE files.
NOTE -- PRINT.DAT must be in the same subdirectory as the *.DAT files.

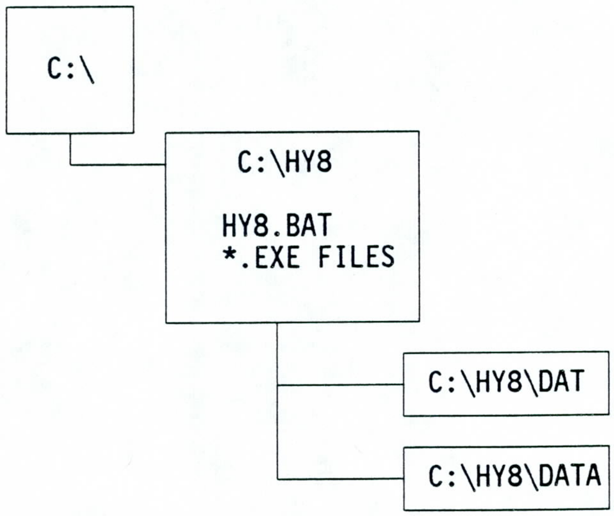
HY8.BAT file drives the HY8 program. This is accomplished by the creation of a temporary batch file (RUNFILE.BAT) which causes execution of SETUP, CULVERT, ROUTING, HYDROGRAPH, and ENERGY DISSIPATOR executables.

OPERATION WITH HARD DISK

HY8 can be operated totally on the hard disk. All *.EXE files and DRIVE.DAT must be in the default drive directory. The directories specified on SETUP.EXE must be created by the user prior to running the HY8.BAT file. Execution is the same as two drive system, otherwise.

STRUCTURE OF HY8 VERSION 3.2 FOR HARD DISK

We suggest that you use the following structure to install and run the software from your system hard disk:



```
****************************************************************************
*   Users who have older versions of HY8 (prior to Version 2.1) should not  *
*   attempt to run these data sets with this release.  These old data sets  *
*   will not correspond and will not be read by the current version.        *
****************************************************************************
```

We hope that you find this software to be a very useful tool for designing culverts. We would appreciate receiving your written comments on any errors identified in the software. Please send them to the following address:

Bridge Division (HNG-31)
Federal Highway Administration
400 Seventh St., SW, Room 3113
Washington, D.C. 20590

McTrans

Action Request

○ MALFUNCTION
○ SUGGESTION

Program ____________________ Version __________ Date __________

Description of Problem or Suggestion
(Attach program output or screen dump if possible)

(Do not write Below this line, use back if needed.)

Submitted By

Tel:
Fax:

Return To:
Mc*Trans* Center
University of Florida
512 Weil Hall
Gainesville, FL 32611-2083
Tel: (904) 392-0378
Fax: (904) 392-3224

Assessed By ____________________ Date __________

Comments

Completed By ____________________ Date __________

Comments