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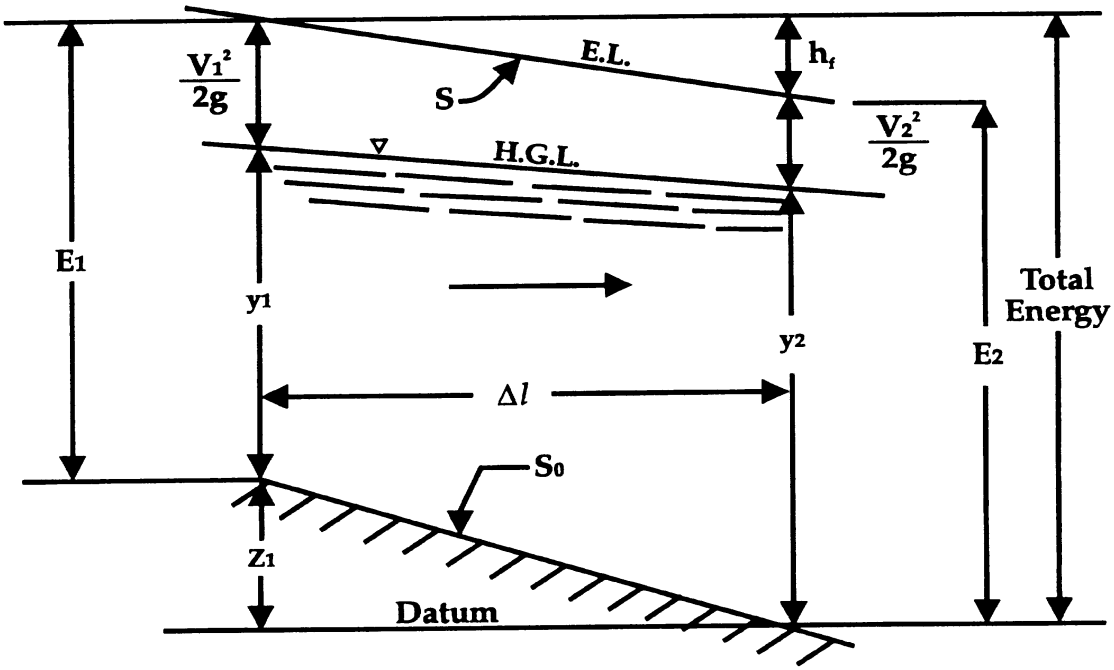
U.S. Department
of Transportation

**Federal Highway
Administration**

**Office of Engineering
Office of Technology Applications
400 Seventh Street, SW
Washington, DC 20590**

User's Manual for HYDRAIN

Integrated Drainage Design Computer System: Version 6.1



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Innovation Through Partnerships

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16. Abstract

This software documentation report, in six volumes, presents an integrated and metricated DOS-based system, HYDRAIN, of hydrology and hydraulic computer programs for drainage design and flood computations. Integration of programs is organized around consistent usage of command line input structure or interactive inputs. HYDRAIN is incorporated into the AASHTO Model Drainage Manual, by reference, using detailed example. HYDRAIN software is available through FHWA distribution agents including McTrans Center, University of Florida, Tallahassee, Florida, and PC Trans, University of Kansas, Lawrence, Kansas. This documentation presents technical details of computerized methods, examples, and complete command definitions. The software includes original logic for the programs: HYDRAIN, HYEDT, HYDRO, and HYCHL. The pre-existent programs, HY8, WSPRO, HYDRA, and NFF are enhanced and conformed to the HYDRAIN system. All component programs accept input and produce output in either SI (metric) or customary (English) units.

The six volumes in this report are:

I. HYDRAIN (system operation, editor usage, files)
II. HYDRO-HYDROLOGY (design flow and rainfall)
III. HYDRA-STORM Drains (gravity and pressure flow computations)
IV. WSPRO-STEP BACKWATER AND BRIDGE HYDRAULICS
V. HY8-CULVERTS (analysis and design)
VI. HYCHL-ROADSIDE CHANNELS (lining design)

Training on HYDRAIN is available from National Highway Institute Course No. 13057; training notebook provides supplementary documentation. Minimum equipment configuration: MS DOS 3.0 or better, IBM XT, 640K RAM, Hard Disk, Monochrome Monitor. Implementation requires 560K free RAM. Desirable additional equipment: math coprocessor, VGA monitor, printer.

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HYDRAIN - INTEGRATED DRAINAGE DESIGN COMPUTER SYSTEM

VOLUME I. HYDRAIN System

for:

Office of Technology Applications
Federal Highway Administration
Washington, DC

March 1999

(Metric Page)

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INTRODUCTION

This document reviews the capabilities of version 6.1 of the HYDRAIN application programs. These application programs perform a support function with respect to engineering programs. The documentation provides technical and operational information, and discusses user instructions. The HYDRAIN system integrates the application programs with existing and newly developed drainage programs to provide a modular, expandable, and comprehensive set of tools for the practicing engineer. The system objective is providing these tools to engineers in a form that will **enhance their productivity**.

The HYDRAIN application programs include the main HYDRAIN program and associated programs, such as editors and configuration software. The main HYDRAIN application program (HYDRAIN program) integrates and controls the entire system of Pooled Fund Project software. The HYDRAIN program supports engineering design and analysis programs and facilitates communication (data transfer) within the system. It provides a means of file and disk management. It contains tutorial capabilities and modules. The HYDRAIN program can review input, output, or other text files.

Each of the application programs are written in the C language. The language offers ease of portability, and is efficient for performing input/output operations. The C language enables software to more easily control other programs and hardware.

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 program or module in the HYDRAIN system that performs hydraulic or hydrologic computations.

- **Applications Program** - A program *wrapped around* another program to facilitate its use.

- **Input Program** - An application program built around one of the engineering programs.

- **HYDRAIN Program** - The main application program built around the *entire system* of engineering and application programs.

- **HYDRAIN Editor (HYEDT)** - A special input program that provides full screen text editing capability to command line engineering programs. HYEDT supplies an intermediate to high level of support (context-sensitive one line and extended

helps and word processing abilities) for creating or editing an input data set. Appendix A presents a description of the editor.

- **Interactive Programs -** This category of application program provides full screen, expert assistance in data creation/modification, range and error checks, and short and long help.

- **Program Module -** A combination of input and engineering programs.

- **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 program are:

- HYDRA - Storm Drain and Sanitary Sewer Design and Analysis.
- WSPRO - Open Channel Water Surface Analysis.
- HYDRO - Design Event versus Return Period.
- HY8 - FHWA Culvert Analysis and Design.
- HYCHL - Flexible & Rigid Channel Lining Design and Analysis.
- HYEQT - Flow Equation Program.
- NFF - USGS National Flood Frequency Program.
- HYEDT - 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 Utilities (Change drives, directories, devices, colors).
  - System Information.
- Future HYDRAIN Programs - other programs included as desired by the HYDRAIN user community.

Current operational software includes HYDRA, WSPRO, HYDRO, HY8, HYCHL, NFF, and HYEQT engineering programs, HYEDT, and support system modules. Figure 1 illustrates the logical layout of these program modules.

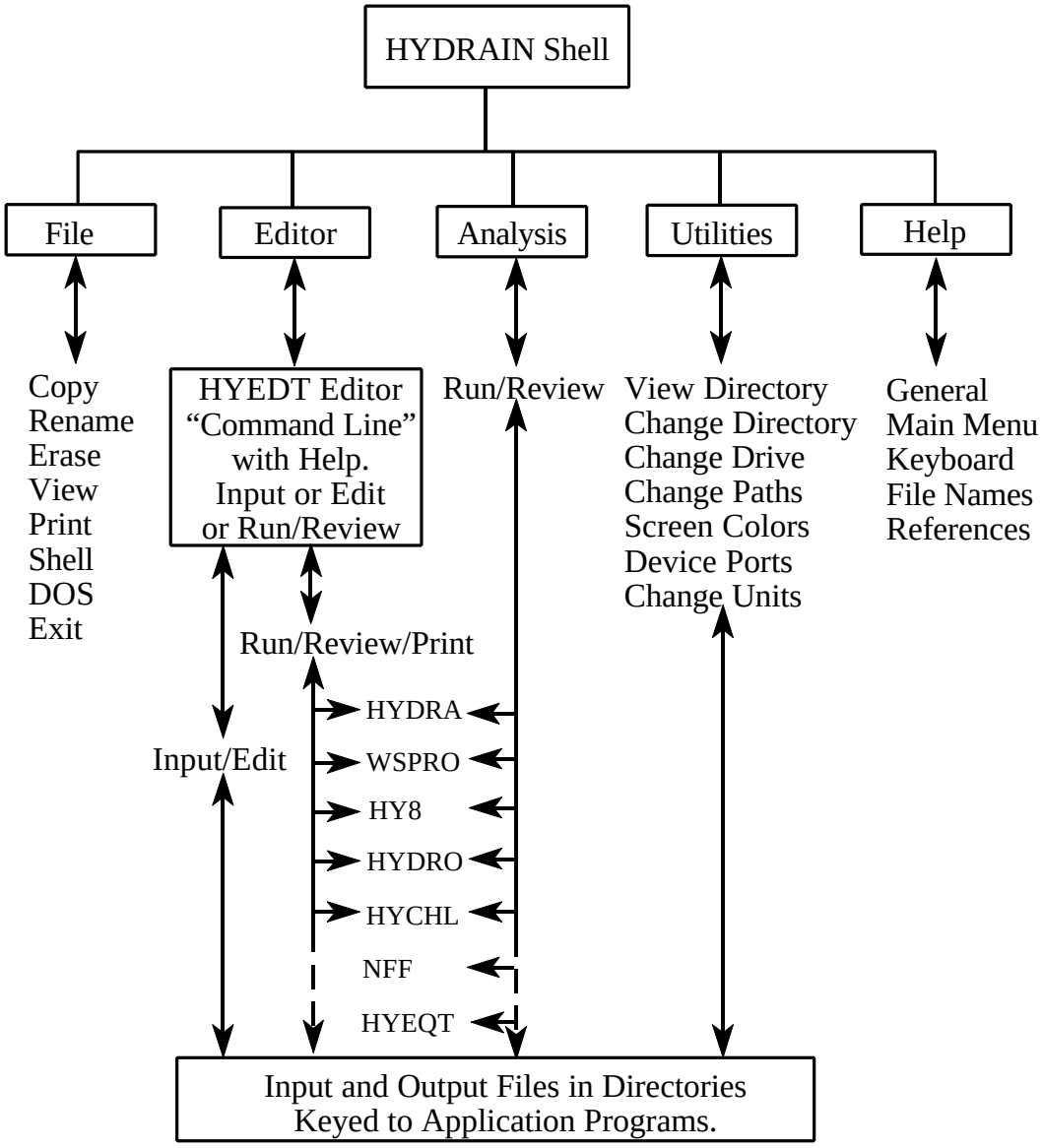

Figure 1. HYDRAIN layout.

The HYDRAIN program controls access to these modules by employing one of five primary options: **File**, **Editor**, **Analyze**, **Utilities**, and **Help**. Two options, **Editor** and **Analyze**, provide access to a corresponding engineering program by parallel branching to the design and analysis modules. The HYDRAIN program assists the user by ensuring that proper naming conventions are used and by providing on-line help upon request.

The **File** option performs many file management functions. These include the DOS equivalent activities of copying, deleting, renaming, printing or viewing files. It allows the user, through the **DOS Shell** option, to temporarily return to the DOS operating system. Finally, it allows the user to Exit the program.

Utilities allows changing and reviewing directories; switching the disk drives; and updating screen colors, default drives and directories, or device characteristics.

The **Help** option provides on-line documentation (a feature provided throughout the HYDRAIN system) for further explanation of a requested option as well as providing "how to" information and selected references.

TECHNICAL REFERENCE

SUMMARY OF FEATURES

The HYDRAIN program runs on DOS version 3.0 (or higher) on IBM-XT/PC or compatible microcomputers. It has the following capabilities:

- **Linkages to HYDRAIN Engineering Modules** - There are seven engineering programs: HYDRA, WSPRO, HYDRO, HY8, HYCHL, NFF, and HYEQT. Five of the seven are batch programs that can use the HYDRAIN editor to assist in entering/editing data. HY8 also has an internal routine that allow for the interactive input, editing, or execution of data. Likewise, HYCHL and WSPRO have interactive programs that assist in the creation, execution, and review 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 program ensures flexibility, allowing such modules to be easily "plugged in." The NFF program, a recent addition to HYDRAIN is such an example of open architecture.

- **Active Short Help Messages** - The HYDRAIN program (as well as other application programs) 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 field, 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 function key one (denoted as **<F1>** in the documentation). These messages range in length from a short paragraph to several pages.

- **DOS Shell** - This allows the user to temporarily leave the HYDRAIN program 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 HYDRAIN program to enter a word processor or text editor, or to execute a spreadsheet program. When selecting this option, HYDRAIN will remain resident in memory. For this reason it is important to always return to the HYDRAIN program (by typing **EXIT**) and leave HYDRAIN in a normal manner (through the **Exit** suboption under the **File** option).

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

- **File Review Module** - A file review option (in the Utilities pulldown menu) permits viewing of input, output, and other files found on the current directory. The review option uses the , , PgUp, PgDn, Home, and End keys to move vertically through a file. The option uses the and cursor keys to move horizontally in a file. This horizontal scrolling ability is useful for viewing documents wider than the computer's display screen; for example, a 132-character wide output file.

- **System Maintenance** - One system support module 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 can scan the files on any drive and directory.

- **Ring Menus** - The decision screens in the application programs 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 <Enter> in the documentation). In most areas of the system, the user can also choose an option by simply pressing a letter which is **h**ighlighted in the field.

- **Pulldown Menus** - These special ring menus present suboptions within the main menu options. Move any direction within pulldown menus by using the arrow keys. The advantage of pulldown 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 submenu they are in. That is, the user is able to follow a progression from entering the system to the most detailed submenu.

- **Popup Menus** - These ring menus present additional options, choices or information. Usually the up and down arrows keys to move within these menu types. Press <Esc> to move back to the previous menu level.

FILE MANAGEMENT STRUCTURE

The overall file management structure operates on a hard-disk drive. It is possible to create a multitude of file management structures on a system. (Appendix B discusses of the custom directory layout.) Normally, HYDRAIN uses the default hard disk file structure shown in figure 2. The main directory is **HYDRAIN**. This directory contains executable and help files used by the HYDRAIN program and HYEDT. The HYDRAIN directory has a subdirectory **ITM**, that contain files shared by engineering programs. Five level one directories, designated **HYDRA**, **WSPRO**, **HYDRO**, **HY8**, and **HYCHL**, contain all executable files, input files, output files, and help files used by each particular engineering program. (As a default, HYEQT files are placed on the **HYDRO** directory and NFF files are placed on the ITM directory.) The file management structure is transparent when running the HYDRAIN package.

```
ROOT        )),
              /) HYDRAIN )))) ITM  (Intermediate/Shared Files/NFF)
              /) HYDRA  (Storm Drains)
              /) WSPRO  (Bridge Waterways)
              /) HYDRO  (Hydrology)(Also HYEQT)
              /) HY8    (Culvert Analysis, Energy Dissipators)
              /) HYCHL  (Channel Stability and Design)
              *
              .) ETC... (other directories on the drive ...)
```

Figure 2. Default HYDRAIN directory structure.

Whether or not using the default or an alternative directory structure, the HYDRAIN program uses this structure when it passes information to an input program, engineering program, or applications program. For example, when the HYDRAIN program executes HYDRA, it takes the user-supplied filename, appends the appropriate drives and paths, and passes this information to the HYDRA program. Exactly how this is accomplished for a specific program depends on whether the program called by the HYDRAIN program performs input, output, or analysis functions.

FILE NAMING CONVENTIONS

The HYDRAIN system uses standardized input and output file extensions to further ensure compatibility and to prevent the passing of incorrect files. All HYDRAIN files must follow the convention **xxxxxxxx.zzz**. The file name node or prefix (i.e., xxxxxxxx) may have up to eight characters (conforming to DOS file naming conventions). The files also require an extension (i.e.,: zzz) of up to three characters.

Engineering Program Extensions

To assist application programs in distinguishing the input found from different engineering 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.**

- HYDRA - the storm drain and sanitary sewer analysis and design program uses an **HDA** extension for input data and executing the program.

- WSPRO - the bridge waterways (and open channel) analysis program uses a **WSP** extension for input data and executing the program.

- HYDRO - the hydrology program uses an **HDO** extension for input data and executing the program.

- HYCHL - the channel lining stability program uses a **CHL** extension for input data and executing the program.

- HY8 - the culvert analysis and design program uses a variety of extensions to support HY8's modular computations. The culvert analysis modules uses an **INP** extension for most input data.

Output File Extensions

- All output files will retain the input file name prefix (i.e. **xxxxxxxx**), but they will have **LST** extensions (HY8 output files have **PC** extensions).

Other File Extensions

- **QT** - This extension contains the ordinates of a hydrograph (i.e.: flow, **Q**, versus time, **T**). HYDRO, HY8, NFF, and HYCLV generate this type of file. Hydrograph files can be incorporated as input data in other engineering programs (for example, into HYCLV using the **HYD** command).

- **HYE** - This extension contains the ordinates of a hyetograph (i.e.: rainfall intensity, **I**, versus time, **T**). HYDRO generates the file, which, at user option, can be incorporated into the other engineering programs.

- **IDF** - This extension contains the ordinates of an Intensity-Duration-Frequency (IDF) curve (for a duration from 5 min to 24 h). HYDRO generates the file, which, at user option, can be incorporated into HYDRA or HYCLV using the **RAI** command.

- **Q** - This extension contains design flow values generated by a HYDRO analysis. In the future, other programs will read these values as input data.

- **HLP -** This extension indicates the file contains short and long help for the different application programs. There will be at least two help files for each engineering program.

- **CNF -** This extension indicates the file contains information used by the HYDRAIN system. **HYDRAIN.CNF** is the primary file using this extension. Appendix B contains more information on this file. This extension also indicates a file containing information used by the HY8 program. The HY8 information may consist of configuration, print, and setup data.

- **DAT -** This extension indicates that the file contains HY8 culvert information pertaining to industry's available sizes for different pipe culverts.

- **ERR -** This extension contains any system error messages. The HYDRAIN and editor programs capture the standard error output (if any) to assist in debugging.

The file conventions, when combined with the file management structure discussed earlier, provides a method of organizing HYDRAIN files within the DOS environment. HYDRAIN expects designated directories to contain specific files. 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. HYDRAIN placed files used by differing programs (such as files with **IDF**, **QT**, and **HYE** extensions) in a common subdirectory, **ITM**, where they too can be readily accessed by 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 appropriate documentation provides the specific meaning. This document normally indicates use of a key by enclosing it within the < and > characters. For example, <Enter> means "press the Enter key."

Cursor Keys

The cursor keys permit movement through the screens and windows found in the application programs. The active cursor keys are:

	-	Moves the cursor to the left one field or space.
	-	Moves the cursor to the right one field or space.
	-	Moves the cursor up one line.
	-	Moves the cursor down one line.
PgDn	-	Moves screen display forward one page.
PgUp	-	Moves screen display backwards one page.
Home	-	Moves to beginning of a field.
End	-	Moves to end of a field.
Crtl+Home	-	Moves to top of document displayed.
Crtl+End	-	Moves to bottom of document displayed.
Ins	-	Toggles between insert and replace modes.
Del	-	Deletes character at cursor location.
Backspace	-	Moves cursor left, deleting the character.

Function Keys

HYDRAIN uses function keys in different ways, depending on the application program. One primary function key (F1) is active throughout every application program. Secondary function keys are available in various regions of the system. **The current screen typically displays the function key(s) currently active in the module or program.)** Various function keys active in the HYDRAIN program are:

F1	-	Long (Extended) Help. This primary function key produces a window of long, context-sensitive help. This is always active in all application programs.
F3	-	Secondary function key used in the file erase section of the HYDRAIN program (one of the File suboptions).

Other Keys

Enter	-	Enter/Carriage Return - continue to the next screen.
Esc	-	Aborts an operation (escapes).

MINIMUM EQUIPMENT CONFIGURATION

The HYDRAIN system uses a minimum equipment configuration (MEC) to provide a fundamental, uniform hardware and software platform. The HYDRAIN system is upgradable; it will normally run on equipment that exceeds the MEC. A common problem is not enough memory to execute the programs. Try to maximize the available memory before starting the HYDRAIN system. (A suggested minimum quantity of memory is approximately 560 kB of RAM.)

Hardware

- IBM XT/PC (or 100 percent compatible) with 640 kB RAM.
- 360-kB (5¼-in) floppy diskette drive or 1.4-MB (3½-in) floppy diskette drive.
- Hard disk drive with a minimum storage capacity of 10 MB suggested. A minimum of 6.8 MB required for installation.
- Math coprocessor (8087, 80287, 80387) recommended.
- Monochrome monitor and adapter (24 × 80); VGA card and monitor recommended.
- Dot matrix printer.
- Surge/spike protector.

Graphical capabilities of the HY8, HYCHL, and WSPRO programs require a graphics card having, at least, Color Graphics Adapter (CGA) abilities. These programs can also run without a CGA card. Because of future HYDRAIN enhancements, a VGA card is recommended for all equipment.

Software

- DOS (version 3.0 or higher).

BASIC, FORTRAN, and C compilers are not required to run the HYDRAIN programs as supplied, but are the compilers used for HYDRAIN.

USER DOCUMENTATION

This section discusses how to install the HYDRAIN system and execute the HYDRAIN program. The installation assumes that there is a 3½- or 5¼-in floppy disk drive on the computer. Furthermore, it assumes that the computer designates the disk device as drive A.[1] The required hard disk drive should contain at least 6.8 MB of free storage space. The discussion on executing the HYDRAIN program provides an overview on the features present in the software. Experience serves to enhance proficiency.

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 (this is always diskette one) into the A drive. Change to the A drive. Type **INSTALL** and press <Enter> to begin the program.[2,3]

The first screen displayed provides the user with information about the 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. It is recommended that a math coprocessor be purchased and installed on the machine. The install program displays a prompt "To continue, press any key" that moves the program to the next screen. (Should the user need to leave the installation program, they can strike <Esc> when prompted by the program.)

If this is an initial installation of HYDRAIN, the next screen asks the user to choose the disk drive from which HYDRAIN will be run. The HYDRAIN system requires 6.8 MB of disk space, therefore, it is important to choose a drive with sufficient free space. To aid the user in

---

[1]HYDRAIN will install from either drive A or B. For the sake of clarity, the documentation assumes that the installation occurs on drive A. The installation diskette includes a README.1ST file to aid the user.

[2]To install on a gas plasma display computer, type **INSTALL P** and press <Enter>. The installation program will change internal defaults to display text in black and white.

[3]If a CD-ROM drive is installed on the system, ensure a disk is present in the drive.

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 next screen will either show the program creating the new directories or begin copying the files.

If the system detects an older version of HYDRAIN, it will then inform the user that HYDRAIN exists. Choosing "Stop" will allow the user to leave the Install program to back-up or remove the old files. Choosing "Continue" will result in a screen which gives explanations as to what (if any) new directories have been created.

Next, the user is asked whether Metric or English units are to be used as default units. To change default units requires reinstallation; however, the user may switch between units systems at will from within the HYDRAIN shell.

The program will then 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. To conserve space, most of the files have been compressed. Later in the installation procedure, these files will be unpacked.

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

Insert Disk 2 of 2 into disk drive

After the second distribution disk is properly inserted, the program will then copy all of the information from diskette 2 to the appropriate directories.

After the files have been copied to their respective directories, the installation program creates three files, **HYDRAIN.CNF**, **PRINT.CNF**, and **HY8.CNF**. These files contain information developed by the installation program. This file creation process is transparent to the user. If the **HYDRAIN.CNF** and **HY8.CNF** files are already present on the system, they will be modified to reflect changes in HYDRAIN. In this manner, previous settings will not be lost.

Upon completion of this file creation, the compressed files will be unpacked. Older versions of the programs and files, if they exist, will be overwritten. HYDRAIN is now installed on the computer. After deleting some older and unused files, the installation program will terminate, leaving the user in the HYDRAIN main directory.

The user should add the HYDRAIN and HY8 directories to the PATH statement in their AUTOEXEC.BAT file. After this is done, the HYDRAIN system is ready to be used.

USING THE HYDRAIN PROGRAM

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

C> CD HYDRAIN and press <Enter>
C> HYDRAIN and press <Enter>

The first HYDRAIN program screen, depicted below in figure 3, will appear on the monitor.[4] 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 31 sponsoring States in the Pooled Fund. Press any key to continue.

```
                    HYDRAIN - DRAINAGE DESIGN SYSTEM
                              Version 6.1

 Sponsored by the Pooled Fund Project States:

       Alabama       Arizona      Arkansas     California    Colorado
       Connecticut   Florida      Idaho        Illinois      Iowa
       Kansas        Louisiana    Maryland     Minnesota     Mississippi
       Montana       Nebraska     New Jersey   New York      N Carolina
       N Dakota      Oklahoma     Oregon       Pennsylvania  S Carolina
       Texas         Utah         Vermont      Virginia      Washington
       Wyoming
                  in cooperation with the Federal Highway Administration



                                 developed by:
                    GKY & Associates, Inc., Springfield, VA.


                                          To continue, press any key.
```

Figure 3. Initial screen for HYDRAIN program.

[4]This first screen will always appear unless using an **S** argument when running the program (i.e., **HYDRAIN S**). This is a feature for those who might call HYDRAIN from a menu or shell.

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

Main Menu

The next screen is the HYDRAIN **Main Menu**, illustrated in figure 4. The Main 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. The **Main Menu**, as well as several other menus in the HYDRAIN program, 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 **Help** option moves it back to the **File** option. Similarly, moving left of **File** places the cursor back at **Help**.

```
HYDRAIN   Version 6.1   METRIC
Thursday May 1, 1997  6:01:00 am          F1-Help | C:\HYDRAIN
   File        Editor    Analyze     Utilities              Help

              HYDRA
              WSPRO
              HYDRO
              HYCHL
               HY8
```

Figure 4. HYDRAIN main menu.

There are five options available in this menu, each having an associated pulldown menu. Each option provides some category of program operation. The **File** options perform file management operations, shell to DOS, or leave the program. The **Editor** options create or edit new and existing input files using the HYDRAIN editor. **Analyze** options execute engineering programs or, for some programs, the interactive editors. **Utilities** options change drives, directories, and update the system configuration. **Help** options access long help for selected HYDRAIN topics.

Two other forms of help are available throughout the HYDRAIN system. Context sensitive help provides the user with brief, but detailed information regarding functions and operations of the program. Active (short) help is constantly displayed at the bottom of the screen for the option on which the cursor is positioned. In addition, more detailed long help is available for many 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 program.

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

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

- If a letter in an option of a HYDRAIN menu (or submenu) is **highlighted**, pressing that letter will invoke the associated option. For example, notice that the main menu highlights the "**A**" in **A**nalyze. Pressing <**A**> will select the analyze option. It is equivalent to manually moving the cursor to **Analyze** and striking <Enter>.

The next section discusses the menu categories and options in more detail. The discussion provides an overview of the category (i.e., File, Editor, Analyze, Utilities, and Help). After each category discussion, the section provides information on each pulldown menu option.

File Menu Category

The HYDRAIN program uses the **File** menu category options to copy, rename, erase, view, & print files; shell to DOS; and leave the program. The options are: Copy, Rename, Erase, View, Print, DOS Shell, and Exit. Figure 5 depicts the menu options in the **File** menu category. Select the **File** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**F**> key.

```
HYDRAIN   Version 6.1   METRIC
Thursday May 1, 1997  6:01:00 am          F1-Help | C:\HYDRAIN
  File        Editor    Analyze    Utilities              Help

  Copy
 Rename
  Erase
  View
  Print
 DOS Shell
  Exit
```

Figure 5. File pulldown menu.

The pulldown menu system uses a subset of cursor keys to move and scroll through options. **Arrows** move cursor up, down, left, or right through the menus. Moving left or right automatically moves to the next pulldown menu. (In some other application programs, the cursor must first move to the top menu, over, and back down.) <Esc> cancels menu or dialog operations, returning to the active window. <Enter> selects and performs the current option (designated by the cursor). **H**ighlighted characters select an operation or option. Striking the highlighted character is equivalent to moving to the option and pressing <Enter>.

Copy pulldown option

The **Copy** function is used to copy a file located on the current drive and directory to a file found at any location. Select the **Copy** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**C**> key. After selecting this option, the HYDRAIN program displays the screen depicted in figure 6.

The screen lists all of the files in the current drive and directory. When presented with the list of files, such as the one in figure 6, choose the Source File by moving the cursor and pressing <Enter>. Should there be more files than can fit on the screen, use the cursor keys to scroll files into view. In this example, the file **YOUNG.LTR** was selected.

```
HYDRAIN   Version 6.1   METRIC
Thursday May 1, 1997  6:01:00 am          F1-Help | C:\HYDRAIN
   File        Editor    Analyze     Utilities             Help

  Copy
 Rename
  Erase
  View
  Print
 DOS Shell
  Exit

    - HYDRAIN System ??? File Catalog -

Status :    32 file(s) found

Current Path  : C:\HYDRAIN\__________
Current File  : _____________

HYDRAIN  EXE  148000  05/01/1997  06:01
ROUTE95  HDA    4108  05/01/1997  06:01
HYDRO1   HDO     722  05/01/1997  06:01
README   1ST    4546  05/01/1997  06:01
YOUNG    LTR   18885  05/01/1997  06:01
HYDRAIN  CNF     801  05/01/1997  06:01
```

Figure 6. Copy option source file menu.

As depicted in figure 7, a second screen appears with the selected name appearing in a field called *Copy Source File*. A second *Copy Target File* field is highlighted. This is where the user should type the filename to which the copied file should go. In figure 7, the file name **JONES.MEM** is in this second target field. This indicates that the user wishes to copy **YOUNG.LTR** (found in the HYDRAIN directory) to **JONES.MEM** (to be placed in the current working directory). When this information is entered, press <Enter> to execute the copy and return to the main menu. 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 <Enter>. The user can return to the HYDRAIN main menu by pressing <Esc>.

```
HYDRAIN   Version 6.1   METRIC
Thursday May 1, 1997  6:01:00 am          F1-Help | C:\HYDRAIN
   File        Editor    Analyze     Utilities              Help

  Copy
 Rename
  Erase
  View
  Print
 DOS Shell
  Exit

Copy Source File:  C:\HYDRAIN\YOUNG.LTR_
Copy Target File:  JONES.MEM____________
```

Figure 7. Entering target file in the copy option.

Rename pulldown option

The **Rename** function allows the user to rename any file in the current drive and directory. Select the **Rename** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**R**> key. The operation of the Rename function is parallel to the Copy function. A screen similar to the one depicted in figure 6 will appear. Select a file to be renamed by moving the cursor and pressing <Enter>. Then type a new name for the file and press <Enter> to enact the command. As before, the new name can be changed by reentering it before <Enter> is hit. Press <Esc> to return to the File pulldown menu.

Erase pulldown option

The **Erase** function allows the user to delete one or more files from the current drive and directory. Select the **Erase** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**E**> key. Once the option is activated, a listing of available files is given on the screen. To select a file to be deleted, move the cursor to the file and press <Enter>. The Erase function depicts selected (or marked) files by using reverse video or having the same features as the menu bar. A highlighted field locates the cursor position in the file listing.

The mark may be removed by moving the cursor to the file and pressing <Enter> again. More than one file may be marked for deletion at any time. Figure 8 shows a file listing with several files marked for deletion. The cursor is on the file **HYDRN.HLP**; the files *BADFILE.YUK*, *OOPSFILE.NO*, and *ERASE.ME* have all been marked for erasure.

```
HYDRAIN   Version 6.1   METRIC
Thursday May 1, 1997  6:01:00 am          F1-Help | C:\HYDRAIN
   File        Editor    Analyze    Utilities              Help

   Copy
 Rename
   Erase
   View
   Print
 DOS Shell
   Exit

Directory: D:\PPFP\HDOC\
Status: 34 file(s) found
Use ↑, ↓, PgUp, PgDn to View Directory
'Enter' Marks Files - F3 Deletes Files

HYDRAIN  EXE  148000  05/01/1997  06:01
HYDRNI   HLP    9108  05/01/1997  06:01
HYDRN    HLP   55722  05/01/1997  06:01
HYEDT    EXE  100383  05/01/1997  06:01
BADFILE  YUK   18885  05/01/1997  06:01
HYEXE    EXE   11801  05/01/1997  06:01
OOPSFILE NO    14285  05/01/1997  06:01
HYDRAIN  CNF     801  05/01/1997  06:01
ERASE    ME     1895  05/01/1997  06:01

     3 Files Marked For Deletion ...
```

Figure 8. Selecting files to be deleted.

To delete these files, press <F3>. The intent is to give the user ample opportunity to reconsider before deleting a group of files. 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. The fact that a file 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. To return to the File pulldown menu, press <Esc>.

View

The **View** option allows the user to look at the contents of any file on the current drive and directory. Select the **View** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**V**> key. After choosing View, the screen displays a listing of all the files in the specified directory. Choose the file to be viewed by moving the cursor and pressing <Enter>. 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 File pulldown menu, press <Esc>.

Print

The **Print** option allows the user to print the contents of a file on the current drive and directory. Select the **Print** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**P**> key. After choosing Print, the screen displays a listing all of the files in the specified directory. Choose the file to be viewed by moving the cursor and pressing <Enter>. Unlike the Review option, the contents of the file are printed rather than displayed on the screen. Before attempting to print a file, be sure that the printer is

attached to the system and is ON-LINE. Otherwise, the HYDRAIN program will "blow up." For instance, if there is no printer connected to the terminal, HYDRAIN will attempt to send data to this nonexistent device. The result is a program failure.

DOS Shell

The **DOS Shell** option reenters DOS while keeping the HYDRAIN program resident in memory. The option satisfies the requirement that sometimes arises to temporarily go to DOS, possibly to use a word processor or a spreadsheet. Select the **DOS Shell** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**D**> key. The user will be placed into DOS with the screen resembling that shown in figure 9.

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 Program.
C:\HYDRAIN>

Figure 9. DOS prompt.

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

Exit

The **Exit** option allows the user to leave the HYDRAIN program. This is the correct method to use to return to DOS. Select the **Exit** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**X**> key. To exit the program from anywhere in the pulldown menus, press <Ctrl+X>. This key combination automatically moves to this option and ends the program.

Editor Menu Category

The HYDRAIN program uses the **Editor** menu category options to access the HYDRAIN editor, HYEDT. The HYDRAIN 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 HYDRAIN editor program and its requirements. As seen in figure 4, the user can apply the editor to six engineering programs; HYDRA, WSPRO, HY8, HYDRO, and HYCHL. Each of these programs can operate in batch mode. (Details on the HYDRAIN 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.) Select the **Editor** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**E**> key.

Selecting the Editor menu moves the user to the pulldown menu. Select an option by using the arrow keys to move the cursor to the desired program. Once the cursor is in the correct position, pressing <Enter> will activate the selection. A popup file access menu, as seen in figure 10, will appear on the screen.

```
HYDRAIN   Version 6.1   METRIC
Thursday May 1, 1997  6:01:00 am          F1-Help | C:\HYDRAIN
   File        Editor    Analyze     Utilities              Help

                HYDRA
                WSPRO
                HY8
                HYDRO
                HYCHL

                - HYDRAIN System HDA File Catalog -

                Status :    28 file(s) found

                Current Path  : C:\HYDRA\___________
                Current File  : _______________

                HLPFS    HDA     628   05/01/1997  06:01
                ROUTE95  HDA     623   05/01/1997  06:01
                HYDRA1   HDA    3855   05/01/1997  06:01
                HYDRA2   HDA    1146   05/01/1997  06:01
                HYDRA3   HDA    5658   05/01/1997  06:01
                HYDRA4   HDA    1232   05/01/1997  06:01
```

Figure 10. File access screen.

The first field of the screen shows the path of the input files of the program selected. The HYDRAIN program only displays those files having the default extension (HDA, WSP, HDO, INP, or CHL) that is appropriate for the selected engineering program.

To create a new file (or use a file that does not use the default extension), enter the desired name and press <Enter>. This action activates the HYDRAIN editor. To select a file from those already existing, move the cursor to the appropriate name and press <Enter>. The default drive and path can be changed using the first field. After entering the name and pressing <Enter>, the files in that path, having the appropriate extension will appear. If no files exists, a

message to this effect will appear at the top of the window. Using default HYDRAIN extensions is not a requirement, but, as will become evident with continued use of HYDRAIN, doing so makes operations much easier. Return to the Editor pulldown menu at any time by pressing <Esc>.

Analyze Menu Category

The HYDRAIN program uses the **Analyze** menu category options to choose one of the eight engineering programs. These options are shown in figure 11. Select the **Analyze** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**A**> key. The Analyze menu categorizes engineering programs as being from one of two categories; batch or interactive execution.

- HYDRA, WSPRO, HYCHL, and HYDRO are known as **BATCH** programs (this is not to be 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. After program execution, the results calculated by the program are placed in a separate output file. This approach is similar to how mainframe programs process information.

- HY8, NFF, and HYEQT are **INTERACTIVE** programs.[5] Also, HYCHL and WSPRO are available in interactive form. Interactive means they combine data entry and program execution together. For example, HY8 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 any of the interactive programs will cause HYDRAIN to directly invoke the interaction execution process.

If selecting one of the batch programs, the user must choose an input file before execution can commence. Similar to the Editor option, a popup file access menu assists in this selection process. The user may choose an already existing file from those displayed by moving the cursor and pressing <Enter>, or, they might enter a filename in the second field.

[5]When selecting WSPRO, HYCHL, or HY8 from the Editor menu, HYDRAIN treats them as a BATCH program. The INTERACTIVE modes of these programs are only active when accessed through the Analyze menu.

```
HYDRAIN   Version 6.1    METRIC
Thursday May 1, 1997  6:01:00 am          F1-Help | C:\HYDRAIN
   File        Editor    Analyze     Utilities              Help

                          HYDRA
                          WSPRO
                          HY8
                          HYDRO
                          HYCHL
                          NFF
                          HYEQT
```

Figure 11. Analyze option pulldown menu.

One reason the user might use this option is 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, this 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**.

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

Utilities Menu Category

The HYDRAIN program uses the **Utilities** menu category options to perform maintenance and configuration functions. Figure 12 displays the pulldown menu for this option. These functions are described below. Select the **Utilities** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**U**> key.

```
HYDRAIN   Version 6.1   METRIC
Thursday May 1, 1997  6:01:00 am          F1-Help | C:\HYDRAIN
   File        Editor    Analyze     Utilities              Help

                          View Directory
                         Change Directory
                           Change Drive
                           Change Paths
                          Screen Colors
                           Device Ports
                           Change Units
```

Figure 12. Utilities option pulldown menu.

View Directory

The **View Directory** option views a listing of all of the files on the current drive and directory. Select the **View Directory** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**V**> key. After selecting this option, all pertinent information about the files and the directory is given. Use the arrow, <PgUp>, and <PgDn> cursor keys to view additional files. The list of files shown are in no particular order, so if an expected file is not seen, scroll down the list until it is found.

Change Directory

The **Change Directory** option changes the directory used as a default throughout the HYDRAIN system. Select the **Change Directory** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**C**> key. After selecting this option, the HYDRAIN program displays a popup menu that displays the default directory. (The current default directory is always displayed in the upper right corner of the screen.) To change the default, move the cursor to **Prior Level** and press <Enter> or move to one of the listed subdirectories and press <Enter> (**Prior Level** and **Current Level** will not appear if the user is on the Root Directory). If the current directory was C:\HYDRAIN, selecting **Prior Level** 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 <Enter>. Once a first (or larger) level directory has been reached, selecting **Current Level** will return the user to the Utilities pulldown menu. Pressing <Esc> also returns control to the Utilities pulldown 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.

Change Drive

The **Change Drive** option changes the default disk drive. Select the **Change Drive** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**D**> key. After selecting this option, a popup menu displays the current default and other available drive on the system. To change the drive, move the cursor and press <Enter>. The display at the top of the popup menu and the current path in the upper right screen will change accordingly. After the desired drive is selected, use the<Esc> keys to return to the Utilities menu. If the selected drive is a floppy disk device, be sure to insert a diskette inside the drive before using this function!

Change Paths

The option **Change Paths** indicates where to find input, output, executable, and help files for the various HYDRAIN programs. Select the **Change Paths** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**h**> key. The resulting popup menu lists all current programs and module in HYDRAIN. To select an option, move the cursor and press <Enter>, or, type the letter which is highlighted for the desired option.

The HYDRAIN option lets the user tell the program where to find the HYDRAIN executable and help files. It is also the option that allows changes to the INTERMEDIATE PATH. (Recall that the intermediate path defines the directory to which shared files and output used by 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 that requires the input of a hydrograph. Use of the Intermediate Path option saves the user a great deal of time.)

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 ensure 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 Change Paths popup menu, press <Esc>.

If selecting the engineering program options (i.e., HYDRA, WSPRO, HYDRO, HYCHL, HY8, NFF, and HYEQT), the program displays a dialog menu having four lines for user input. The first asks the user to specify where the executable program file location. The second specifies where program input files can be found. The next provides a field for entering the output file destination. Finally, the last field specifies the location of help files for the given program. 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 <Enter>. When the proper path selections has been made, select **Update** to save the path changes. Select **Cancel** to return to the Utilities pulldown menu without affecting any path changes.

Screen Colors

The **Screen Colors** options allows changes to default colors schemes for the HYDRAIN system. Select the **Screen Colors** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**S**> key. The resulting Screen Colors popup menu, shown in figure 13, has seven available options and a matrix of 128 possible color combinations. (Hercules and monochrome graphic monitors will get the same matrix, although many combinations will appear the same.)

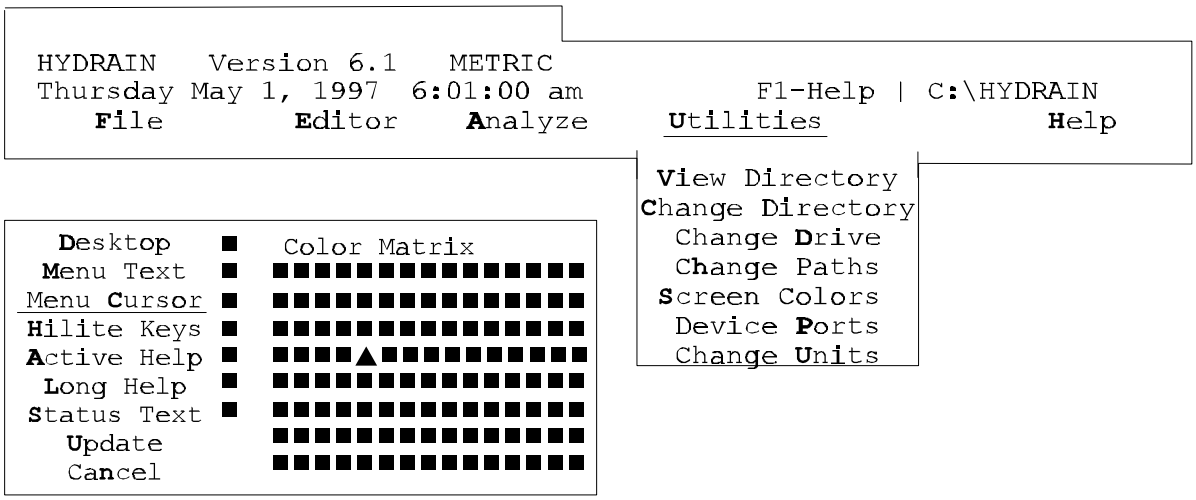

Figure 13. Screen colors matrix.

Choose the item for which the colors are to be changed by moving the cursor and pressing <Enter> or by pressing the highlighted letter in the desired option. When an item from the menu is chosen and the cursor is moved within the screen colors matrix, the corresponding part of the current display is changed.

If the option **Desktop** is chosen, moving the cursor in the matrix will change the background color of the display. Similarly, the cursor bar will change if the **Menu Cursor** option is selected. Manipulating the **Menu Text** option will affect the color of the menus, while selecting **Hilite Keys** will change the letter in each menu selection. Choosing **Active Help** and moving the cursor will affect the color of the short help at the bottom of the display. The **Long Help** option will allow the user to manipulate the color of the text in *Help Screens*, while choosing **Status Text** will allow the user to alter the color of messages at the top and the bottom of the screen.

From the color matrix, press <Enter> to return to the Screen Colors popup menu. The user may then choose to alter various other parts of the screen. Experiment with the different color combinations until finding one which is both practical and aesthetically pleasing. When all changes have been made, select **Update** to save the changes which have been made from the Screen Colors popup menu. Select **Cancel** to return to the original color combinations.

Device Ports

The **Device Ports** option allows changes to the hardware that is attached to the printer. Select the **Device Ports** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**P**> key. Appearing after either of these two actions occur, the Device Port popup menu provides a listing of parallel and serial ports common to most microcomputers. Also present is the option **None** which should be used if no printer is attached to the system. (This is the default option at installation.)

The popup menu displays both the existing device setting and any current selections made while in the menu. When the proper port selection has been made, select **Update** to save the port change. Select **Cancel** to return to the Utilities pulldown menu without affecting any port changes.

Change Units

The Change Units option allows either the metric unit system or English unit system to be chosen as the default unit for the engineering programs. (The default unit is selected at installation and can be changed with this option.)

Help Menu Category

The HYDRAIN program uses the **Help** menu category options to provide the user with six options that focus on specific HYDRAIN topics. Figure 14 displays the pulldown menu for this option. Select the **Help** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**H**> key.

```
HYDRAIN   Version 6.1   METRIC
Thursday May 1, 1997  6:01:00 am          F1-Help | C:\HYDRAIN
   File        Editor    Analyze    Utilities              Help
                                                          General
                                                         Main Menu
                                                          Keyboard
                                                         File Names
                                                         References
```

Figure 14. Help pulldown menu options.

SUMMARY OF OPERATIONS

Entry to engineering programs is via the HYDRAIN program. Table 1 lists other operations. The table reveals that for most of the programs, multiple methods exist to perform these system operations.

Table 1. HYDRAIN system operations.

Engineering Program	Input* Generation	Editing Input Data	Run* Control	Input & Output Review/Print
HYDRA	HYEDT or Editor**	HYEDT or Editor**	HYDRAIN Program or HYEDT	HYDRAIN Program or HYEDT
WSPRO	WSSHL or Editor**	HYEDT or Editor**	HYDRAIN Program or HYEDT	HYDRAIN Program or HYEDT
HYDRO	HYEDT or Editor**	HYEDT or Editor**	HYDRAIN Program or HYEDT	HYDRAIN Program or HYEDT
HY8	HY8 Program, HYEDT or Editor**	HYEDT or Editor**	HYDRAIN Program or HYEDT	HYDRAIN Program or HYEDT
HYCHL	CHSHL, HYEDT or Editor**	HYDRAIN Editor or Text Editor**	HYDRAIN Program or HYEDT	HYDRAIN Program or HYEDT
HYEQT	HYEQT Program	HYEQT Program	HYEQT Program	HYEQT Program
NFF	NFF Program	NFF Program	NFF Program	NFF Program

*All programs except NFF and HYEQT can use batch file operations. NFF and HYEQT secure data from the user as they are processing. HYCHL and HY8 can operate in either interactive or batch mode.

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

APPENDIX A: THE HYDRAIN EDITOR

The HYDRAIN editor (HYEDT) is an application program that provides a consistent means to add new or change existing data. The HYDRAIN editor uses the entire display screen and possesses advanced data manipulation abilities. The HYDRAIN editor orientation of HYEDT is towards command line input data sets, such as used by HYDRA, WSPRO, HYDRO, and HYCHL engineering programs. The editor allows review of output files and external files without leaving the program. It can process extended (long) context-sensitive help to assist in developing or debugging input data. The editor uses common user access (CUA) guidelines whenever possible to ensure consistency with other software products. The HYDRAIN editor achieves this mixture of features by dividing operations between data/text (windows) and menu/dialog portions. Figure 15 shows the editor screen containing input data and with a menu activated.

HY8 input files can also be viewed and edited directly using the HYDRAIN Editor. Care should be taken, however, when modifying HY8 input files, as many of the values are calculated by the HY8 interactive program. The facility to review and edit these files in the HYDRAIN Editor has been added to facilitate viewing and understanding the HY8 INP files. Changes to these files should usually be accomplished through the HY8 interactive program.

```
  File      Edit      Search      View      Help            WSPRO 6.1 Metric
                     +)))))))))))))),
*F *                 * Find...        *
T1 *       EXAMPLE O* Repeat Find    * FLOW
T2 *             HYD* Change...      *
T3 *                 .)))))))))))))))-
Q  *1423    3145   4207
WS *454.0   456.5  457.02
XT *SURVY  2500
GR *-90.0,465.0     0.0,461.0    45.0,457
GR *150.0,455.4   160.0,450.3   188.0,450
GR *276.0,458.0   344.0,458.0   430.0,461
XS *GAGE  1000
GT *-2.2
N  *0.110    0.080   0.040    0.065    0.
SA *     99      150     210       276
XS *XS2  1500  *  *  *  0.002
XS *XS3  2000  *  *  *  0.0012
XS *EXIT  2365
XS *FULLV  2485
XS *APPR 2635
XS *XS4  3000
XS *XS5  3500
Help: Search for specific data within the active window.
File: \WSPRO\UNC.WSP                              0002:00     Alt=Edit  F1=Help
```

Figure 15. Typical HYDRAIN editor screen.

WINDOWS

Three windows contain the input data, extended (long) help text, and output/file data. The use of the term "window" indicates that each data area "views" a separate aspect of the engineering problem. The input window contains the command line data and parameters. This window is the raw information required to perform an engineering analysis. The long help window contains detailed information on each command used in the input window. Analogous to a reference material or dictionary, use extended help to clarify a concept, or for deeper understanding of an issue. The output window contains analysis results or retrieves any additional data.

Moving Within Windows

The three windows use the same set of cursor keys to move or scroll the data. The keys and their respective actions are:

- **Arrows** - move cursor up, down, left, or right through a window. The editor will scroll, as needed, to display additional text or data within the window.

- **PgUp** - moves the cursor position up an entire screen of data (a screen is the quantity of data viewable in a window).

- **PgDn** - moves the cursor position down an entire screen of data.

- **Home** - moves cursor to the first column in the current row.

- **End** - moves cursor to the last column in the current row.

- **Ctrl+Home** - moves cursor to the top of the document. (In this documentation, the notation *Crtl+Home* means to simultaneously press the Crtl and Home keys.)

- **Ctrl+End** - moves cursor to the bottom of document.

- **Ctrl+Arrow** - moves cursor to next field or parameter.

- **Tab** - moves cursor to next field or parameter (identical to Crtl+Arrow operation).

As will be seen, many of these keys are active within other portions of the editor. The next section discusses each window in more detail.

Input Window

The input window is the primary data area in the HYDRAIN editor. It is the only window that permits creation, changes, or additions to a file. Oriented to command line input files, the input window contains two fields–one for commands and one for parameter data. The command field contains three spaces (reflecting the maximum command length in the engineering programs). The width of the second field equals 77 characters. The total width of the input window equals 80 characters. The input window may contain up to 1000 lines of input data.

The editor tracks movement and location by a cursor that appears in the window. Additionally, the lower right corner of the screen displays the current row and column. In the input window, this screen location also displays **CMD** when in the first (command) field, and the parameter count when in the second field. (The parameter count is useful in keeping track of recursive data.)

The cursor position also controls short (or active) help messages. Short helps are one-line, context-sensitive messages that provide information about input data. If the cursor is within the first field boundaries, the short help text corresponds to the last valid command entered in the field. If the input window is empty (or the command is invalid), the editor displays a message to that regard. If the cursor is within the second field (columns 4 through 80), the short help prompts for the parameter data. As mentioned earlier, the editor "counts" the number of parameters entered. HYEDT provides some checks for non-recursive commands. Should the parameter count exceed the maximum number of parameters for a given command, the editor provides a message to that effect. (This check does not occur for recursive command; for example, a listing of x and y coordinates.) The short help message location is at the bottom of the screen.

Besides the cursor keys used to move within the window, the input window uses additional editing keys. (These keys remain inactive in the other two windows.) The input window editing keys and their respective actions are:

- **Ins** - toggles between *insert* and *replace* modes. The editor indicates the insert mode with a blinking underline cursor and the message **Ins** in the lower right portion of the screen. The editor indicates the replace mode with a blinking box cursor and the message **Rep** in the lower right portion of the screen. (The **Ins** key may toggle in the other windows, but no editing activity takes place.)

- **Del** - deletes the character or space at the current cursor position.

- **Backspace** - moves cursor to left, deleting the character or space in the new cursor position.

- **Enter** - adds a row below the current cursor position.

- **Alt+D** - deletes row at current cursor position.

- **Space Bar** - adds "hard spaces" to a data field. The editor distinguishes between hard spaces and moving across the input window with the arrow keys. (Just like any other text editor or word processor, there are no implicit spaces added until done so by the user.)

The editor recognizes only two characters as valid delimiters. These delimiters are the hard space "_" and the comma "," characters. The editor considers consecutive occurrences of either delimiter as equivalent to a single delimiter. This is important in keeping track of the current parameter and the context-sensitive short help. A consequence of this feature is that the editor considers a blank, enclosed by commas (i.e., ",_,_,") as the same as a series of spaces. This affects engineering programs that use such a scheme in their input data sets. (Sometimes programs consider a blank surrounded by commands to equal a zero--HYEDT does not.)

The input window has automatic "wrap around" (or continuation) capabilities for command strings greater than 80 columns. HYDRAIN input conventions denote continuation of lines by leaving the subsequent command field blank and placing the additional data on the parameter field. Figure 16 depicts an example of command data continuing to the next row. (Notice the cursor is on row 5, column 61.) The editor attempts to preserve hard spaces when the data wraps. The wrap around feature does not reset the parameter counter. (The parameter counter indicates that the cursor is on the eighteenth parameter.)

```
 File      Edit      Search      View      Help
rem*Downstream Channel Data
XS *0.0  0.0  0.0025
GR *0.0,  106.5    25.0, 104.4    45.0, 102.0     55.0, 100.0    62.0, 98.0
   *70.0, 100.0    80.0, 102.0    100.0 105.0     125.0, 106.5
   *
   *
   *
   *
   *
   *
   *
   *
   *
   *
   *
   *
   *
   *
Help: y-coordinate distance above common elevation datum, in feet.
File: C:\WSPRO\EX1.WSP                                    Ins    0005:061:018
```

Figure 16. Automatic continuation of input data to next row.

Some engineering programs designate continuation by repeating the command in subsequent command fields. The editor considers these commands as new commands.[1] One result is the parameter counter resets to one. If parameter sets remain in order, this type of continuation should not affect the parameter short helps.

If retrieving input files with character width greater than 80 columns, the editor does not "cut off" the extra columns. Instead it attempts to continue these excess columns on the next row. Since no present engineering program allows input widths greater than 80 characters, this feature will not often occur.

Extended Help Window

The extended (long) help window provides additional on-line documentation for commands used to create input data sets. The long help window does not have the same extensive abilities as the input window. None of the editing keys are active within the window. (The **Ins** key does toggle between insert and replace modes, but the editor does not alter any help text.)

The help window contents are reproductions of the command documentation for each specific engineering program. The help window format begins with general command information and becomes progressively more specific when moving deeper into the text. The beginning of the help text consists of the command name and a short description. (This short description is often the same as the command short help.) Next, the text provides the command purpose and typical structure or parameter layouts. After the parameter layout, the help text includes detailed information regarding each parameter. This information includes units, if appropriate. (Consider this detailed parameter information to be more insightful than the parameter short helps.) The final portion of the extended long help text usually contains notes on the proper usage and requirements of the specific command. In the extended help window, the editor displays the last short help message produced by the input window (or menu option). In this case, the short help serves as an index to the parameter or command at which queries began.

Unlike the input window, there is only a single field. The field in the extended help window contains text that is 78 characters wide. The help text length may extend for several hundred rows, depending on the complexity of the command. (Most of the help text lengths are much less.) The editor reads the long help text from the hard disk, as necessary. (This saves memory.)

Output/File Window

The output window provides the editor with three specific functions. First, this window displays the results of an engineering analysis. (The editor executes the engineering program,

---

[1]It is not feasible for the editor to distinguish between a continuing command, using this format, and a series of commands, having the same name, ordered sequentially, but being independent of each other.

finds the output file, and reads it in.) The output window also displays any error or system messages that occur during engineering program execution. The final function allows the editor to retrieve text files. These text files may contain information useful for creating an input data file, for example, hydrograph ordinates.

The editor allows the output window to retrieve files up to 127 characters wide and 1,000 lines in length. Larger files may be viewed in another text editor. The fourth example in Volume III illustrates this issue.

The output window uses a temporary default output file name called **UNTITLED.LST**. The editor creates this file when called by the HYDRAIN program and deletes **UNTITLED.LST** when the editor terminates. The editor places the file on the default HYDRAIN directory. Still, it is a good idea not to give any input data set the prefix **UNTITLED** (i.e., **UNTITLED.HDA** for HYDRA) as unforeseen effects may occur during analysis. The editor uses **UNTITLED.LST** to store screen directed messages that occur during engineering program execution. These screen directed output include run-time error messages. After creating an output file (or retrieving a text file), the editor replaces **UNTITLED.LST** with this other file.

Full- and Split-Screen Modes

Each window can operate in full- or split-screen mode. The full-screen mode only displays the current (or active) window. Twenty-one rows of information are available for viewing within full-screen mode. Figure 16 depicted the input window in full-screen mode. The split-screen mode displays two windows simultaneously on the monitor. Each window reveals 10 rows of information for viewing. (In split-screen mode, the editor uses the extra row to display information about the bottom window. This row effectively separates the two windows.)

In both full- and split-screen modes, the windows act as a viewport of the document within. The viewport size is 21 by 80 characters in the full-screen mode and 10 by 80 characters in the split-screen mode. The window display does not change when moving from one window to another unless a change in cursor position has occurred. The next section discusses moving from one screen to another and selecting full- or split-screen modes.

Moving Between Windows

Moving from the active window to another window takes place by using function keys (or, as will be seen later, menu options). The function keys and their actions are:

- **F1** - display extended (long) help. The display becomes split-screen (if not already). The extended help window becomes the active window.

- **F2** - display input window. The input window becomes active. Total editing capability is present.

- **F3** - display output window. The output window becomes active. If no output available for display, empty file "UNTITLED.LST" displayed.

- **F4** - switch control between windows. This function key only works when in split-screen mode. Only affects windows displayed in split-screen mode.

- **F5** - display active window in full-screen mode.

By default, the HYDRAIN editor always starts by displaying the input window in full-screen mode. In this case, the input window is the active window. To activate the extended help window, press the F1 function key. This action automatically changes the editor into split-screen mode and makes the extended help window the active window. The input window remains the top window and the help window becomes the bottom window. The active key message (second line from the top of the display) changes to reflect that the extended help window is active. (The F1 ceases to be highlighted, and the F2 becomes highlighted. This means "you can go to the input window (F2) from the help window. You cannot go to the help window (F1) since you are already there.") Figure 17 illustrates the input and extended (active) windows in the split-screen mode.

```
 _File_     Edit      Search      View      Help
JOB*HYDRA McTrans Problem
SWI*1
HGL*1
NEW*Link One ...
rem*Add flow into system one ....
FLO*0.51
PDA*0.024 12 10 0 0 .001
rem*Assume that all ground elevations are 620.00 feet
PIP*10_620 620 601.45 601.35 -15
PNC*1 2 3 90 0 0

 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, plot

     1) length  - the length of the link or pipe, in feet.
Help:  The length of the link or pipe (feet).
File: "PIP" COMMAND                                                0001:001
```

Figure 17. Editor in split-screen mode.

There is a visual hierarchy (of sorts) that occurs when switching between windows. The input window always appears as the top window. The output window appears below the input window. If the output window is active and a switch is made to the long help window (using

F1), the output window becomes the top window and the help window moves to the bottom. In other words, the input window "outranks" the output window which "outranks" the help window.

The active split-screen window becomes full-screen mode by pressing the <F5> key. The contents of the "non-active" windows are not lost. The editor considers the other window(s) present, but hidden "behind" the active window.

As an example, suppose the input window is empty (or new). Entering the command **JOB** in the first field activates the active short help line (at the bottom of the screen). The active key(s) message depicts that, at least, <F1> has information (since <F1> is highlighted). Pressing <F1> moves to the extended help window (seen in figure 22). Pressing <F5> provides full-screen help. Pressing <F2> returns to the input window (making it active), but makes the display split-screen. The editor still displays the long help, but given the hierarchial nature of the windows, it is on the bottom.

MENUS AND DIALOGS

The editor uses a series of menus and dialog windows to provide additional and advanced options when creating or editing a file. The editor has five menu categories; each pertains to some general operation. The menu categories are: **File**, **Edit**, **Search**, **View**, and **Help**. (Users of CUA based programs will recognize these menu options.) All have pulldown menus that provide specific options for each category.

The menu system is separate from the three windows. The editor toggles between the window and menu systems. The <Alt> key provides this toggling capability. The menu system activates by pressing <Alt> from any of the three data windows. Pulldown menu options associated with editing functions are not available if the active windows are either the long or output windows.

Each menu option has associated short and long (extended) helps. These helps provide guidance in applying the menu features. (Using the extended help feature (F1) in the menu system returns to the help window with menu option specific text. The display switches to split-screen mode if necessary. To return to the menu, use the <Alt> key.)

Moving Within Menus

The menu system uses a subset of cursor keys to move and scroll through options. The keys and their respective actions are:

- **Arrows -** move cursor up, down, left, or right through the menus. In a pulldown menu, moving left or right automatically moves to the next pulldown menu. (In other application programs, the cursor must first move to the top menu, over, and back down.) The editor menus are not ring menus. (This means that moving right at the **Help** field does not circle back to the **File** field.)

- **Ctrl+Arrows** - moves the cursor to the next field or menu option. These keys are more useful in the dialog windows.

- **Tab** - moves the cursor right to the next field or menu option. (Identical to the **Ctrl+** operation.) This key is more useful in the dialog windows.

- **Shift+Tab** - moves the cursor left to the next field or menu option. (Identical to the **Ctrl+** operation.) This key is more useful in the dialog windows.

- **Esc** - cancels menu or dialog operations, returning to the active window.

- **Enter** - selects and performs the current option (designated by the cursor).

- **H**ighlighted characters - select an operation or option. Striking the **h**ighlighted character is equivalent to moving to the option and pressing <Enter>.

The next section discusses the menu categories and options in more detail. The discussion provides an overview of the category (i.e., File, Edit, Search, View, and Help). After each category discussion, the section provides information on each pulldown menu option, including any special keys or procedures.

File Menu Category

The editor uses the **File** menu category options to create, retrieve, save, & print files; run engineering programs; and leave the editor. The options are: New, Open, Save, Save as, Analyze, Print, and Exit. Figure 18 depicts the menu options in the **File** category. Use the **New** option to create a new file. The **Open** option retrieves an existing file to edit or view. The **Save** option will save the current working file (that is, the file in the input window) under the same name. To save a file under a different name (or for the first time after using the **New** option to create a working file), use the **Save as** option. The editor executes (runs) engineering programs with the **Analyze** option. The **Print** option sends contents of the current window to an output device. The final option, **Exit**, ends the editor program. Select the **File** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**E**> key.

New pulldown option

The **New** pulldown option clears the input window of any existing file and creates a untitled input file. The new file has the temporary name of **UNTITLED.EXT** (where **EXT** is the default extension for the current active engineering program). The newly created file is available to develop a command string for use in analyses. Use the **Save as** option to preserve the file. This allows changing the default file name to a more descriptive (and permanent) file name. Without using the **Save as** option, the editor will not preserve data before selecting succeeding **New** options or when leaving the program. Select the **New** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**N**> key. The option becomes inaccessible depending on the current active window. (For example, when the long command long help is the active window.)

```
 File      Edit      Search      View      Help
+)))))))))))))),
* New           *oblem
* Open...       *
* Save          *
* Save as...    *..
* Analyze       *nto system one ....
* Print         *
* DOS Shell     *0 0 0 .001
* Exit          *t all ground elevations are 620.00 feet
.))))))))))))))- 601.45 601.35 -15
PNC*1 2 3 90 0 0
FLO*1.02
PDA*0.024 12 10 0 0 .001
PIP*123.18 620 620 601.35 600.49 -15
PNC*2 4 3 90 0 0
HOL*1
NEW*Link Two ...
FLO*33.91
PDA*0.013 12 10 0 0 .001
PIP*63.75 620 620 599.0 598.74 -36
PNC*3 4 3 180 0 0
REC*1
Help: Create, retrieve, save, & print file; run analyses; exit editor.
File: C:\HYDRA\SAMPLE.HDA                                    Alt=Edit  F1=Help
```

Figure 18. File menu category options.

Open pulldown option

The **Open** pulldown option retrieves an existing file into the current window. When selecting this option, the next screen will be a file dialog box showing files on the directory. After selecting a file from the catalog, the editor replaces the existing file (located in the current window) with this newly selected file. The editor guards against accidental overwrites of edited files. If using the **Open** option will cause data loss, the editor provides a warning and allows cancellation of the operation. Select the **Open** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**O**> key. The option becomes inaccessible depending on the current active window. (For example, when the long command long help is the active window.)

Save pulldown option

The **Save** pulldown option writes the contents of the current window to the active file. The editor provides no opportunity to change the file name when using the **Save** option. (Use the **Save as** option to store the file under a different name.) The **Save** option writes over the existing file, destroying the prior data. The editor does not provide notice that this occurs.

The editor automatically saves an input file when using the **Analyze** option. Running a program results in the current input data overwriting the existing data file. Select the **Save** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the

highlighted <**S**> key. The option becomes inaccessible depending on the current active window. (For example, when the long command long help is the active window.)

Save as pulldown option

The **Save as** pulldown option writes the contents of the current window to a file whose name the user creates or selects. When selecting this option, the next screen will be a file dialog box showing files on the directory. The editor displays a field prompting for a file name. The editor guards against accidental file overwriting. If using the **Save as** option will cause data loss, the editor provides a warning and allows cancellation of the operation. Select the **Save as** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**V**> key. The option becomes inaccessible depending on the current active window. (For example, when the long help command is the active window.)

Analyze pulldown option

The **Analyze** pulldown option sends the current input file to the proper engineering program for execution. The editor automatically saves an input file will automatically run using the **Analyze** option. Running a program overwrites the contents of the current window to the data file.

During execution, some engineering programs create status information. The editor captures and displays the status in a window located below the input window. The editor stores status data in a temporary file (**UNTITLED.LST**). The temporary file also holds any compiler error messages that occur during execution. After completing the execution, the editor replaces the temporary file with the output file information. Select the **Analyze** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**A**> key. A third method is concurrently pressing the <**Ctrl**> and <**A**> keys <Ctrl+A> or <Alt+A> to select this option. The option becomes inaccessible depending on the current active window. (For example, when the file browser or command long help is the active window.)

Print pulldown option

The **Print** pulldown options sends the contents of the active window (input, file browser, or long help) to the printer. The editor assumes that the output device port location is LPT1. If errors occur during printing, the editor will try to determine the trouble and provide an applicable message. Select the **Print** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**P**> key.

DOS shell

The **DOS Shell** option reenters DOS while keeping the HYDRAIN program resident in memory. The option satisfies the requirement that sometimes the need arises to temporarily go to DOS, possibly to use a word processor or a spreadsheet. Select the **DOS Shell** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**D**> key. The user will be placed into DOS with the screen resembling that seen below in figure 19.

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 program.
C:\HYDRAIN>

Figure 19. DOS prompt.

Exit pulldown option

After completing all editing and saving all files, leave the HYDRAIN editor by using the **Exit** option. If file contents have changed but have not been saved, a warning screen will appear when leaving the editor. Proceeding with the exit option loses these changes. Canceling the exit allows use of the **Save** or **Save as** options (as appropriate) to preserve the changes. Select the **Exit** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**X**> key.

Edit Menu Category

The editor uses **Edit** pulldown menu options to **Mark** (block) and **Unmark** sections of data. The remaining **Edit** pulldown options act upon the marked information. These editing options include the ability to **Cut**, **Copy**, **Paste**, **Clear**, and **Delete** the marked (blocked) sections or window area. Figure 20 depicts the menu options in the **Edit** category. The editing options will not work unless marking has occurred sometime earlier in the editor session. Marked sections copied into memory allow repeated use of the paste option. This is useful for repeating similar sections of the command string. The cursor keys control the extent of the marked area. The editor can mark the entire contents of a window. Use the **Edit** pulldown menu options to copy data from one file to another. (The editor allows copied sections to transfer from one window to another. This is useful if using output from one program as input of another.) Select the **Edit** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**E**> key.

```
  File      Edit      Search      View      Help
          +)))))))))),
JOB*Sample* Mark    *
SWI*1     * Cut     *
HGL*1     * Copy    *
NEW*Link O* Paste   *
rem*Add fl* Unmark  *stem one ....
FLO*0.51  * Clear   *
PDA*0.024 * Delete  *.001
rem*Assume.)))))))))-ground elevations are 620.00 feet
PIP*10 620 620 601.45 601.35 -15
PNC*1 2 3 90 0 0
FLO*1.02
PDA*0.024 12 10 0 0 .001
PIP*123.18 620 620 601.35 600.49 -15
PNC*2 4 3 90 0 0
HOL*1
NEW*Link Two ...
FLO*33.91
PDA*0.013 12 10 0 0 .001
PIP*63.75 620 620 599.0 598.74 -36
PNC*3 4 3 180 0 0
REC*1
Help: Perform editing (mark, cut, copy, paste, clear & delete) operations.
File: C:\HYDRA\SAMPLE.HDA                                    Alt=Edit  F1=Help
```

Figure 20. Edit menu category options.

Mark pulldown option

The **Mark** pulldown option blocks sections of data in the active window. The initial cursor position (cursor location before the start of the mark process) becomes one corner of the marked area. Moving the cursor about the window (with the cursor keys) sets the opposite corner of a rectangular section. The marked area is inside the rectangle. Marking rows to copy and paste begins by positioning the cursor at column one of the first row to copy. Turn on the **Mark** option and move down to the last row to copy. Mark the entire set of rows by moving to the last column (use the <End> key). The marked section is ready for cut, copy, and pasting operations. Moving to the last column is important in this type of operation. The editor distinguishes between marking an entire row and marking only a portion of a row. The **Mark** option uses the cursor color scheme to distinguish it from the regular text window. Select the **Mark** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**M**> key. A third method is to concurrently press the <**Ctrl**> and <**B**> keys <Ctrl+B> or <Alt+B> to select this option. The third method works from anywhere within the editor.

Cut pulldown option

The **Cut** pulldown option removes marked (blocked) sections from the input window. The cut section remains in memory. The **Paste** option inserts the section back into the input window. Use the **Cut** option for rearranging an input file layout. An alternative use is to delete a section of data. (Since the "deleted" section remains in memory, this action is not as final as using the **Delete** option.) Since it only operates in the input window, it is not as versatile as the **Copy** option. (The editor does not allow editing to occur to the output or help files.) The **Cut** option becomes inaccessible in these cases. Select the **Cut** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**T**> key from within the pulldown menu.

Copy pulldown option

The **Copy** pulldown option copies marked (blocked) sections from the active window. The copied section remains on the window and in memory. The **Paste** option inserts the section at a different active window location. The **Copy** option is useful for duplicating sections of input data. The **Copy** option also allows transfer of the copied section from the output window to the input window. (The editor does not allow editing to occur to the output or help files.) Marking rows to copy and paste begins by positioning the cursor at column one of the first row to copy. Turn on the **Mark** option and move down to the last row to copy. Mark the entire set of rows by moving to the last column (use the <End> key). The marked section is ready for cut, copy, and pasting operations. Moving to the last column is important in this type of operation. The editor distinguishes between marking an entire row and marking only a portion of a row. Select the **Copy** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**C**> key from within the pulldown menu.

Paste pulldown option

The **Paste** pulldown option inserts marked (blocked) sections into the input window. (The **Cut** or **Copy** options placed the marked sections into memory for the **Paste** option to access.) The insertion takes place immediately after the current cursor position. The **Paste** option will not overwrite existing data (it may move them around). Perform multiple insertions by repeated use of the **Paste** option. The **Paste** option is only active within the input window. The editor does not allow insertion to occur to the output or help files. Pasting entire rows involves properly marking and copying (or cutting) the desired rows. After completing this operation, move the cursor to the first column of the row immediately preceding the insertion point. Selecting the **Paste** option will place the rows between the cursor and the remaining data. Locating the cursor at the first column is important when pasting rows. The editor distinguishes between an entire row and only a portion of a row. Select the **Paste** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**P**> key from within the pulldown menu.

Unmark pulldown option

The **Unmark** pulldown option turns off the mark (block) option. Any marked section remain in memory for ensuing paste operations. Select the **Unmark** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**U**> key. A third method is concurrently pressing the <**Ctrl**> and <**U**> keys <Ctrl+U> or <Alt+U> to select this option. The third method works from anywhere within the editor.

Clear pulldown option

The **Clear** pulldown option erases marked (blocked) sections from the input window. The erased section retains spaces. The **Clear** option is useful to remove or clean-up input data. The **Clear** option is final -- no undo feature exists in the editor. The editor does not allow editing to occur to the output or help files. The **Clear** option becomes inaccessible in these cases. Select the **Clear** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**E**> key from within the pulldown menu.

Delete pulldown option

The **Delete** pulldown option removes marked (blocked) sections from the input window. The **Delete** option is useful to remove rows from the input window. The **Delete** option is final -- no undo feature exists in the editor. The editor does not allow editing to occur to the output or help files. The **Delete** option becomes inaccessible in these cases. The difference between **Delete** and **Clear** is important. **Clear** overwrites the data with spaces. **Deletes** removes the marked section. Select the **Delete** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**D**> key from within the pulldown menu.

Search Menu Category

The editor uses **Search** pulldown menu options to find the location of specific data within an active window. One of the options alters data involved in the search. The **Find** and **Repeat Find** options are available in all editor windows (input, output, and help). The **Change** option is only active within the input window. (The editor does not allow editing to occur to the output or help files.) Figure 21 depicts the menu options in the **Search** category. The range of **Search** options extends downward from the current cursor position. To globally locate data, use the cursor keys to move to the top of the file before beginning the **Search** operations. Select the **Search** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**S**> key.

```
  File      Edit      Search      View      Help
                     +)))))))))))))))),
JOB*Sample Problem   * Find...        *
SWI*1                * Repeat Find    *
HGL*1                * Change...      *
NEW*Link One ...     .)))))))))))))))-
rem*Add flow into system one ....
FLO*0.51
PDA*0.024 12 10 0 0 .001
rem*Assume that all ground elevations are 620.00 feet
PIP*10 620 620 601.45 601.35 -15
PNC*1 2 3 90 0 0
FLO*1.02
PDA*0.024 12 10 0 0 .001
PIP*123.18 620 620 601.35 600.49 -15
PNC*2 4 3 90 0 0
HOL*1
NEW*Link Two ...
FLO*33.91
PDA*0.013 12 10 0 0 .001
PIP*63.75 620 620 599.0 598.74 -36
PNC*3 4 3 180 0 0
REC*1
Help: Search for specific data within the active window.
File: C\HYDRA\SAMPLE.HDA                                    Alt=Edit  F1=Help
```

Figure 21. Search menu category options.

Find pulldown option

The **Find** pulldown option locates the occurrence of a character pattern (or string) in the active window. A dialog window prompts for the exact characters to use in the search. Upon finding the pattern, the editor moves the cursor to that location. To locate multiple occurrences of a string, use the **Find** option to initially define the characters. After locating the first occurrence, use the **Repeat** option to locate succeeding strings. The range of the **Find** option extends downward from the current cursor position. To globally locate data, use the cursor keys to move to the top of the file before starting the **Find** operation. Select the **Find** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**F**> key from within the pulldown menu.

Repeat pulldown option

After spotting the first occurrence of a pattern with the **Find** option, use the **Repeat** option to locate ensuing strings. The **Repeat** option is not available after performing one search. The **Repeat** option range extends downward from the current cursor position. Use the **Repeat** option (like the **Find** option) in any active window. Select the **Repeat** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**R**> key from within the pulldown menu.

Change pulldown option

The **Change** pulldown option allow the editor to perform search and replace operations within the input window. A dialog window prompts for both the search and replace characters. Upon encountering the pattern, the editor moves the cursor to that location. Inquiries prompt whether the editor should replace the pattern in this particular instance. This prevents accidental data changes. The range of the **Change** option extends downward from the current cursor position. To globally locate data, use the cursor keys to move to the top of the file before initiating the **Change** operation. The **Change** option is only active within the input window. (The editor does not allow editing to occur to the output or help files.) Select the **Change** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**C**> key from within the pulldown menu.

View Menu Category

The editor designates windows to contain either input data, output (file) data, or help data. Up to two windows may be visible in the editor at one time. The editor always appoints one window as the active window. (The active window is always the window in which the cursor is present.) Use **View** pulldown menu options to change from the input to output windows. The menu also changes the active window to full-screen mode. The **View** menu offers an alternative to using the function keys <F2>, <F3>, <F4>, and <F5>. The **Input** (F2) option always returns the active window to the input file. The **Output** (F3) option displays the last output or file read in the window. The **Output** options can browse any text file (not just output). The **Full** option (F5) changes the windows from split-screen to full-screen mode. This option is useful when desiring to concentrate on a complete screen of data. The **Switch** option (F4) moves between any two presently displayed windows. Figure 22 depicts the menu options in the **View** category. (Note that the **View** option does not provide a means to access long help. The **Help** menu option contains the means to select the **Extended Help** option.) Select the **View** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**V**> key.

```
  File      Edit      Search      View      Help
                                +))))))))),
JOB*Sample Problem              * Input   *
SWI*1                           * Output  *
HGL*1                           /))))))))))1
NEW*Link One ...                * Full    *
rem*Add flow into system one ...* Switch  *
FLO*0.51                        .))))))))))-
PDA*0.024 12 10 0 0 .001
rem*Assume that all ground elevations are 620.00 feet
PIP*10 620 620 601.45 601.35 -15
PNC*1 2 3 90 0 0
FLO*1.02
PDA*0.024 12 10 0 0 .001
PIP*123.18 620 620 601.35 600.49 -15
PNC*2 4 3 90 0 0
HOL*1
NEW*Link Two ...
FLO*33.91
PDA*0.013 12 10 0 0 .001
PIP*63.75 620 620 599.0 598.74 -36
PNC*3 4 3 180 0 0
REC*1
Help: Change active window between input/output; or return to full-screen mode.
File: HYDRA\SAMPLE.HDA                                          Alt=Edit  F1=Help
```

Figure 22. View menu category options.

Input pulldown option

The **Input** option always returns the active window to the input file. The editor calls the window that displays the input data file as the **input window.** The input window consists of two fields. The first field in the input window contains commands. The second field is for parameters associated with commands. The width of the two fields equals up to 80 characters. The input file is the only window in which editing operations can occur. Select the **Input** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**I**> key within the pulldown menu. A third method is pressing the <F2> function key. The third method works from anywhere within the editor.

Output pulldown option

The **Output** option returns the active window to the output or a user selected file. The editor calls the window that displays data files as the *output window* or *file browser*. Each row in the output window has a single field that holds data up to 127 characters wide. The **Open** pulldown option (under the **File** menu) can retrieve external text files. To take full advantage of the editor, place the data into the output window. Note that the input window is the only window in which editing operations can occur. If no output files yet exist, the default output window displays a temporary file (**UNTITLED.LST**). Select the **Output** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**O**> key within the pulldown menu. A third method is pressing the <F3> function key. The third method works from anywhere within the editor.

Full pulldown option

The **Full** option returns the active window to full-screen mode. When in split-screen mode, each window is 10 lines high. The full-screen window is 21 lines high. The extra 11 lines offers makes it easier to concentrate on the window contents (the split-screen can be distracting). When selecting the full-screen window, the other (nonactive) windows do not lose their contents. The editor considers these nonactive windows as hidden. Select the **Full** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**F**> key within the pulldown menu. A third method is pressing the <F5> function key. The third method works from anywhere within the editor.

Switch pulldown option

The **Switch** option moves control between windows. The option only affects the windows currently displayed in split-screen mode. The **Switch** option is an alternative to using the <F1>, <F2>, and <F3> keys. It is less flexible than these other methods. Select the **Switch** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**S**> key within the pulldown menu. A third method is pressing the <F4> function key.

Help Menu Category

The **Help** menu pulldown options provide a variety of options used to learn more about the editor. Use the **Extended Help** option to change to the long help window. This option offers an alternative to using the <F1> function key. The **Extended Help** option switches the active window to display help associated with the command currently in the input window. The **Command Index** option displays a listing of commands used by the active engineering program. Moving through the command matrix displays corresponding command short helps. Upon selecting a particular command, the editor displays corresponding extended help (long help). The **About** option provides basic information on the editor. Figure 23 depicts the menu options in the **Help** category. Select the **Help** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**H**> key.

Extended Help pulldown option

The **Extended Help** option displays long help for commands in the input window. Specifically, the help keys on the particular command associated with the input window cursor position. (The input window is the only window in which editing operations occur.) Select the **Extended Help** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**E**> key within the pulldown menu. A third method is pressing the <F1> function key. The third method works only within the input window. Otherwise, pressing <F1> activates context sensitive long help for menus or dialogs.

```
  File      Edit      Search      View      Help
                                        +))))))))))))))))),
JOB*Sample Problem                      * Command Index    *
SWI*1                                   * Extended Help... *
HGL*1                                   * About...         *
NEW*Link One ...                        .))))))))))))))))))-
rem*Add flow into system one ....
FLO*0.51
PDA*0.024 12 10 0 0 .001
rem*Assume that all ground elevations are 620.00 feet
PIP*10 620 620 601.45 601.35 -15
PNC*1 2 3 90 0 0
FLO*1.02
PDA*0.024 12 10 0 0 .001
PIP*123.18 620 620 601.35 600.49 -15
PNC*2 4 3 90 0 0
HOL*1
NEW*Link Two ...
FLO*33.91
PDA*0.013 12 10 0 0 .001
PIP*63.75 620 620 599.0 598.74 -36
PNC*3 4 3 180 0 0
REC*1
Help: Provides help on editor commands and operation.
File: C:\HYDRA\SAMPLE.HDA                                  Alt=Edit  F1=Help
```

Figure 23. Help menu category options.

Command Index pulldown option

The **Command Index** option displays the complete list of commands associated for an engineering program. Moving through the command matrix with the cursor keys displays corresponding command short help at the screen bottom. After pressing <Enter>, the long help window becomes active for the selected command. Use this option to help to remember a specific command name or command action.

If the extended help window is present on the screen when moving through the command index, the long help text automatically changes to reflect the highlighted command. This is a quick way to review the first 10 lines of the commands to glean purpose and structure information. Select the **Command Index** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**C**> key within the pulldown menu.

About pulldown option

The HYDRAIN editor assists in the creation and editing of command line input data sets. The editor program uses common user access (CUA) interfaces and standards whenever possible. In this manner, the editor is similar to commercially available text editors and word processors. The editor uses three windows to hold input, output, and help information. Context sensitive helps exists for all menu options and commands.

Dialog Windows

The editor uses dialog windows to receive information on files, paths, extensions, and character strings (for search and replace). Figure 24 depicts a dialog window used by the **Open** menu option. There is a series of fields within each dialog window. To move within a field (for example, moving through the list of files), use the arrow keys. To move between fields, use the <Tab> keys.

```
JOB Sample Problem
SWI 1 ┌──────────────────────────Open File──────────────────────────┐
HGL 1 │                                                              │
NEW L │   ┌──────────────────────────File Name──────────────────────┐
rem A │   │ *.HDA                                                    │
FLO 0 │   └──────────────────────────────────────────────────────────┘
PDA 0 │
rem A │  Directory:  C\HYDRA\
PIP 1 │
PNC 1 │   ┌──────────────────────────────────────────┐   ┌─Dirs/Drives─┐
FLO 1 │   │ EX1.HDA      EX2.HDA       EX3.HDA        │   │ ..          │
PDA 0 │   │ EX4.HDA      EX5.HDA       EX6.HDA        │   │ [-A-]       │
PIP 1 │   │ EX7.HDA      ROUTE95.HDA   OAKLND.HDA     │   │ [-B-]       │
PNC 2 │   │ SAMPLE.HDA                                │   │ [-C-]       │
HOL 1 │   └──────────────────────────────────────────┘   │ [-D-]       │
NEW L │                                                  └─────────────┘
FLO 3 │  < Ok >                    < Cancel >                 < Help >
PDA 0 └──────────────────────────────────────────────────────────────┘
PIP 6
PNC 3 4 3 180  0  0
REC 1
Help: First command in input dataset.
Enter=Execute  Esc=Cancel  Tab=Next Field   Arrow=Next Item
```

APPENDIX B: HYDRAIN DIRECTORY STRUCTURE

The standard HYDRAIN disk and directory layout places a series of directories on a single hard disk drive. With the exception of the Intermediate/Shared files path, this arrangement ensures that every program or file is one level from the root directory. The directory names 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 to run the engineering programs in batch mode. 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, for the HYDRAIN program, there is more than a single path required for each of the programs. In reality, each of the programs (HYDRAIN, HYDRA, WSPRO, HYDRO, HY8, HYCHL, and NFF) has at least two, and, in the case of HY8, possibly up to 11 distinct directories! For example, the five 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 by defining the layout and using a text editor to edit the contents of the **HYDRAIN.CNF** and **HY8.CNF** files. (These files are created at installation and are used by the HYDRAIN application programs and HY8, respectively.) After the desired layout has been placed in these files, use the DOS Copy command to redistribute the files. Since this will also involve potentially copying many files all over the system, this should be attempted only by experienced DOS users.

The easiest reconfiguration would be to select a single directory, say HYDRAIN, and copy all of the other directories to this directory. The only potential duplicate names are output files having the LST extension. The remainder of the HYDRAIN files have been named to prevent potential overwrites.

HYDRAIN executables are DOS batch programs. As such, command lines passed to them may not exceed 128 characters, a limitation of DOS. The default layout guarantees acceptable command lines. Should you NOT use the default or standard layout, the system will sometimes produce unpredictable results.

APPENDIX C: BATCH EXECUTION OF HYDRAIN

INTRODUCTION

The engineering programs that comprise the HYDRAIN system can be accessed in three methods: from the HYDRAIN program, from HYEDT, or from running them in DOS, without any application programs. The following material discusses how to proceed with the HYDRAIN programs using the third method.

ENGINEERING PROGRAMS

There are seven engineering programs currently in the HYDRAIN system: HYDRA, WSPRO, HYDRO, HY8, HYCHL, NFF and HYEQT. All programs (with the exception of HY8) consist of a single executable file. HY8 consists of several executable files. The five programs are seen below:

Engineering Program	Program Description
HYDRA.EXE	HYDRA executable program
WSPRO.EXE	WSPRO executable program
HYDRO.EXE	
HYDRO executable program	
HYCHL.EXE	HYCHL executable program
HY8.EXE	HY8 executable linker
NFF.EXE	NFF executable program
HYEQT.EXE	HYEQT executable program

HYDRA, WSPRO, HYDRO, HY8, and HYCHL are known as BATCH programs (this is not to be 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. After program execution, the results calculated by the program are placed in a separate output file. This approach is similar to how mainframe programs process information.

HY8 is also (and primarily) an INTERACTIVE program. That is, it combines data entry and program execution together. For example, HY8 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.

GENERATING INPUT FILES

Before running a program under DOS, an input file must be created. The versions of HYDRA, WSPRO, HYDRO, and HYCHL provided in the HYDRAIN system 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 or a text editor. If the file is created with the HYEDT, the format is predetermined.

RUNNING HYDRAIN PROGRAMS

HYDRA - To run HYDRA from DOS, at the prompt type "HYDRA" and strike <Enter>. Several blank lines will scroll across the screen. A message prompting the user for the required information will appear. When it does, enter the requested information. For example:

```
C>HYDRA<Enter>

- spaces -

Enter the name of the data file: ROUTE1.HDA<Enter>
Enter the name of the output file: ROUTE1.LST<Enter>
Enter the name of the drive and path
containing intermediate files - Press
<Enter> key if none or to use default
drive and path:<Enter>
Enter units, 0 (SI) or 1 (English): <Enter>
```

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 C:\ 0<Enter>
```

WSPRO - To run WSPRO from DOS, at the prompt type "WSPRO" and strike <Enter>. Similar to HYDRA, a message prompting the user for the input data file will appear. When it does, enter the requested information. For example:

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

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<Enter>

HYDRO - To run HYDRO from DOS, at the prompt type "HYDRO" and strike <Enter>. A message prompting the user for the input data file will appear. When it does, enter the requested information. For example:

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

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 C:\ 0<Enter>

HYCHL - To run HYCHL from DOS, at the prompt type "HYCHL" and strike <Enter>. A message prompting the user for the input data file will appear. When it does, enter the requested information. For example:

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

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>HYCHL ROUTE1.CHL ROUTE1.LST<Enter>

HY8 - To run HY8 from DOS, at the prompt type "HY8" and strike <Enter>. Since HY8 is Interactive, the user will be prompted for subsequent actions

by the program itself. It is a good idea to put the directory containing HY8 in the PATH found in the AUTOEXEC.BAT file.

APPENDIX D: NATIONAL FLOOD FREQUENCY PROGRAM

The United States Geological Survey (USGS), in cooperation with the Federal Highway Administration and the Federal Emergency Management Agency, has compiled all the **current** statewide and metropolitanwide regression equations into a microcomputer program entitled the National Flood Frequency (NFF) program. NFF summarizes techniques for estimating flood-peak discharges and associated flood hydrographs for a given recurrence interval or exceedance probability for unregulated rural and urban watersheds. These estimates should be useful to engineers and hydrologists for planning and design applications. NFF includes the statewide regression equations for rural watersheds in each State, includes the applicable metropolitanwide or Statewide regression equations for urban watersheds, and generates rural and urban frequency functions and hydrographs. The hydrographs are also written to the ITM directory as XXXXXXXX.QT files for use of other HYDRAIN programs.

More detailed NFF documentation is available from: Jennings, M.E., et al., Nationwide Summary of U.S. Geological Survey Regional Regression Equations for Estimating Magnitude and Frequency of Floods at Ungaged Sites, 1993, Water-Resources Investigations Report 94-4002, USGS, Reston, VA, 1994. The NFF is accessed through the HYDRAIN applications program and the user is prompted by the interactive program to provide appropriate input data. The version of the NFF program included in HYDRAIN 6.0 is substantially unchanged from that discussed in this report. The only change is the additional capability to perform calculations using SI units. Regardless of units selected by the user, NFF performs calculations using English units. In order to maintain consistency with existing units and the USGS Report, this discussion uses the English units involved. When SI units are selected, the program prompts the user for the appropriate SI values and reports output in SI units.

The rural regression equations in NFF are based on watershed and climatic characteristics that can be obtained from topographic maps or rainfall reports and atlases. The most frequently used watershed and climatic characteristics are drainage area, main-channel slope, and mean annual precipitation. The regression equations are generally reported in a multiplicative form where **a** is the multiplicative constant and **b, c, d**, etc., are exponents. The usual variations are where $\mathbf{RQ_T}$ is the T-yr rural flood-peak discharge, **A** is the drainage area, **S** is the channel slope, **P** is the mean annual precipitation, and **a**, **b**, **c**, and **d** are regression coefficients.

Seven-parameter urban equations are based on multiple regression analysis of urban flood frequency data from 199 urbanized basins. The variables are:

- **Q2**, **UQ5**, . . . **UQ500** are the urban peak discharges, in cubic feet per second, for the 2-, 5-, . . . 500-yr recurrence intervals.

- **A** is the contributing drainage area, in square miles, as determined from the best available topographic maps; in urban areas, drainage systems sometimes cross topographic divides. Such drainage changes should be accounted for when computing **a**.

- **SL** is the main channel slope, in feet per mile, measured between points which are 10 percent and 85 percent of the main channel length upstream from the study site (for sites where **SL** is greater than 70 ft/mi, 70 ft/mi is used in the equations.

- **RI2** is the rainfall, in inches, for the 2-h, 2-yr occurrence, determined from U.S. Weather Bureau (USWB) Technical Paper 40 (1961) (eastern USA), or from the National Oceanic and Atmospheric Administration (NOAA) Atlas 2 (Miller and others, 1973) (western USA); HYDRO can be used to estimate this value.

- **ST** is basin storage, the percentage of the drainage basin occupied by lakes, reservoirs, swamps, and wetlands; in-channel storage of a temporary nature, resulting from detention ponds or roadway embankments, should not be included in the computation of **ST**.

- **BDF** is the basin development factor, an index of the prevalence of the urban drainage improvement.

- **IA** is the percentage of the drainage basin occupied by impervious surfaces, such as houses, buildings, streets, and parking lots.

- **RQT** are the peak discharges, in cubic feet per second, for an equivalent rural drainage basin in the same hydrologic area as the urban basin, for a recurrence interval of **T** years; equivalent rural peak discharges are computed from the rural equations for the appropriate State, in the NFF program, and are automatically transferred to the urban computations.

The basin development factor (**BDF**) is a highly significant parameter in the equations, and provides a measure of the efficiency of the drainage basin. It can be determined from drainage maps and field inspections of the drainage basin. The basin is first divided into upper, middle, and lower thirds on a drainage map. Each third should contain approximately one-third of the contributing drainage area, and stream lengths of two or more streams should be approximately the same in each third. Within each third of the basin, four characteristics of the drainage system must be evaluated and assigned a code of 0 or 1. Summation of the 12 codes (four codes in each third of the basin) yields the **BDF**. Within each third, the codes are estimated as follows:

1. *Channel improvements*. If channel improvements such as straightening, enlarging, deepening, and clearing are prevalent for the main drainage channels and principal tributaries (those that drain directly into the main channel), then a code of 1 is assigned. To be considered prevalent, at least 50 percent of the main drainage channels and principal tributaries must be improved to some degree over natural

conditions. If channel improvements are not prevalent, then a code of zero is assigned.

2. *Channel linings*. If more than 50 percent of the length of the main channels and principal tributaries has been lined with an impervious surface, such as concrete, then a code of 1 is assigned to this characteristic. Otherwise, a code of zero is assigned. The presence of channel linings would obviously indicate the presence of channel improvements as well. Therefore, this is an added factor and indicates a more highly developed drainage system.

3. *Storm drains or storm sewers*. Storm drains are defined as those enclosed drainage structures (usually pipes), frequently used on the secondary tributaries where the drainage is received directly from streets or parking lots. Many of these drains empty into open channels; however, in some basins they empty into channels enclosed as box and pipe culverts. When more than 50 percent of the secondary tributaries within a subarea (third) consists of storm drains, then a code of 1 is assigned to this aspect, otherwise a code of zero is assigned.

4. *Curb-and-gutter streets*. If more than 50 percent of the subarea (third) is urbanized (covered with residential, commercial, and/or industrial development), and if more than 50 percent of the streets and highways in the subarea are constructed with curbs and gutters, then a code of 1 would be assigned to this aspect. Otherwise, a code of zero is assigned. Drainage from curb-and-gutter streets frequently empties into storm drains.

The procedure used in NFF to compute the average hydrograph is known as the dimensionless hydrograph method. There are three essential parts to the dimensionless hydrograph method: (1) the peak discharge for which a hydrograph is desired, (2) the basin lagtime, and (3) the dimensionless hydrograph ordinates. In order to compute the average, or design hydrograph using the NFF procedures, the user selects the peak discharge from the NFF frequency output. The user must also provide an estimate of the basin lagtime. The NFF program then computes the hydrograph using the dimensionless ordinates of the hydrograph which are stored in the NFF program.

A procedure is included in the NFF program for extrapolating the regional regression equations in any State to the 500-yr flood. The extrapolation procedure consists of fitting a Log Pearson Type III curve to the 2- to 100-yr flood discharges given by NFF and extrapolating this curve to the 500-yr flood discharge.

NFF methods are applicable and representative of data used to derive them. The user of NFF is responsible for the assessment and interpretation of the computed frequency results, the following limitations of NFF should be observed:

1. The rural equations in NFF should only be used for rural areas and should not be used in urban areas unless the effects of urbanization are insignificant.

2. NFF should not be used where dams, flood-detention structures, and other man-made works have a significant effect on peak discharges.

3. The user is cautioned that the magnitude of the standard errors may be larger than the reported errors if the equations in NFF are used to estimate flood magnitudes for streams with variables outside the ranges for the necessary variables as identified in NFF.

4. Drainage area must always be determined, as NFF requires a value. Although a hydrologic region may not include drainage area as a variable in its prediction equation in order to compute a frequency curve, NFF requires the use of a watershed's drainage area for other computations.

5. Frequency curves for watersheds contained in more than one region cannot be computed if the regions involved do not have corresponding T-yr equations. Failure to observe this limitation of NFF will lead to erroneous results. Frequency curves are weighted by the percentage of drainage area in each region. No provision is provided for weighting frequency curves for watersheds in two different States.

6. In some instances, the maximum flood envelope value may be less than some T-yr computed peak discharges for a given watershed. The user should carefully determine which maximum flood-region contains the watershed being analyzed.

7. NFF allows the weighting of estimated and observed peak discharges for frequency curve calculations. However, since very few 500-yr peak discharge estimates have been published, NFF does not allow the user to enter observed values for the 500-yr peak discharge. The user should evaluate the weighted curve thoroughly; it is possible for the 500-yr peak discharges to be less than some of the other less extreme T-yr peak discharges.

8. The user should be cautioned that some hydrologic regions do not have prediction equations for peak discharges as large as the 100-yr peak discharge. The user is responsible for the assessment and interpretation of any interpolated or any extrapolated T-peak discharges. Examination of plots of the frequency curves computed by NFF is strongly recommended.

9. Flood hydrographs, computed by procedures in NFF, are not applicable to watersheds whose flood hydrographs are typically from snowmelt runoff, or watersheds that typically experience double-peaked hydrographs. Furthermore, the flood hydrograph estimation procedures may not be applicable to watersheds in the semi-arid/arid regions of the Nation.

APPENDIX E: THE HYDRAIN EQUATION PROGRAM

The HYDRAIN equation program (HYEQT) is an application program that allows the user to create and solve regression equations for solving peak flow (or any other formula of interest). The NFF program already contains many USGS peak flow regression equations within its data base. The HYEQT program allows the user to supplement and modify these or other equations to reflect their specific needs. HYEQT uses the entire display screen and possesses advanced data manipulation abilities.

USING THE HYEQT PROGRAM

The HYEQT program is assessed from the HYDRAIN program, under the Analyze pull-down menu. Upon entering HYEQT, the initial screen displays either a series of blank fields, or the last series of equations solved.

The program groups a series of equations into an element designated a **Region**. A **Region** may consist of a watershed, hydrologic district, or some other unique division in a State. Each region can contain up to ten regression equations with a total of fifteen independent variables. All Regions are placed into a single ASCII data base file. There is no practical limit to the number of Regions that the program can access (the upper limit is a function of the available disk space).

The program uses cursor keys to move or scroll the data. The keys and their respective actions are:

- **Arrows** - move cursor up, down, left, or right through a screen or field. The program will scroll, as needed, to display additional text or data within a field.
- **PgUp** - moves the cursor position up an entire screen of data (a screen is the quantity of data viewable in a window).
- **PgDn** - moves the cursor position down to the bottom of the screen.
- **Home** - moves cursor to the first column in the current row or field.
- **End** - moves cursor to the last column in the current row or field.
- **Tab** - moves cursor to next field or parameter.

EDIT AND SOLVE MODE SCREENS

The program uses two screen modes; **Edit** and **Solve**; to create or process the equations. The **Edit** mode places the user into a screen with four sets of fields. The set of fields in the upper left section of the screen is where the equations can be entered or modified. (There are 10 rows in this section.) The equation format should contain dependent and independent variables, coefficients and appropriate arithmetic operators. The dependent variable and independent variables MUST be separated by an equal sign [=]. Valid arithmetic operators include: addition [+], subtraction [-], multiplication [*****], division [/], and exponentials [******]. The program allows use of parentheses [**(**] and [**)**] within the equation to group variables and coefficients. The program uses standard hierarchal operations for the application of these operators. An (imaginary) example of a valid equation is:

Q25 = 1.34 * Area ** 0.25 + Slope ** 0.112 / (Length - 10 ** Runoff)

Note that **Q25** is the dependent variable; **Area**, **Slope**, **Length**, and **Runoff** are the independent variables; and **1.34**, **0.25**, **0.112**, and **10** are coefficients. Spaces between the variables are not required, but aid in viewing and debugging.

The fields in the upper right section of the Edit mode screen contain areas for creating short helps for the dependent variables or the entire equation. (Once again, there are 10 rows or fields, each for the help of a possible formula.) The two fields in the bottom portion of the screen list the independent variables and short help associated with each of them.

The **Solve** mode screen shows the already-created equations in the top left section; the independent variables in the bottom portion; and the solutions in the top right screen section. The equations can not be modified within the Solve mode. The values for the independent variables can. After entering all values in the fields next to the independent variable, the program automatically "plugs" them into the equations and displays the solutions. The solution is dynamic. Changing any of the independent variable values instantly changes the solution. As the user moves from field to field, HYEQT displays the short helps (developed in the Edit mode) at the bottom of the screen.

MENUS AND DIALOGS

The editor uses a series of menus and dialog windows to provide additional options when creating or editing an equation. The editor has two menu categories: **Region** and **Edit**. Both have pulldown menus that provide specific options for the category.

The menu system is separate from the Edit and Solve screens. The editor toggles between these screens and menu systems. The <Alt> key provides this toggling capability. The menu system activates by pressing <Alt> from the Edit or Solve mode screens.

The menu system uses a subset of cursor keys to move and scroll through options. The keys and their respective actions are:

- **Arrows** - move cursor up, down, left, or right through the menus. In a pulldown menu, moving left or right automatically move to the next pulldown menu. (In other application programs, the cursor must first move to the top menu, over, and back down.) The menus are not ring menus. (This means that moving right at the **Edit** field does not circle back to the **File** field.)

- **Esc** - cancels menu or dialog operations, returning to the active window.

- **Enter** - selects and performs the current option (designated by the cursor).

- **H**ighlighted characters - select an operation or option. Striking the **h**ighlighted character is equivalent to moving to the option and pressing <Enter>.

Region Menu Category

The program uses the **Region** menu category options to create, retrieve, save, erase, & print regions; and to leave the editor. The options are: New, Open, Save, Save as, Delete, Print, and Exit. Use the **New** option to create a new region. The **Open** option retrieves an existing region to edit or view. The **Save** option will save the current working region (that is, the region in the input window) under the same name. To save a region under a different name (or for the first time after using the **New** option to create a working region), use the **Save as** option. Delete an old or erroneous region with the **Delete** option. The **Print** option sends contents of the current window to an output device. The final option, **Exit**, ends the HYEQT program. Select the **Region** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**R**> key.

New pulldown option

The **New** pulldown option clears the input window of any existing region and creates a blank, untitled screen in the Edit mode. The new region has the temporary name of **UNTITLED**. The newly created region is available to develop a set of equations. Use the **Save as** option to preserve the region. Select the **New** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**N**> key.

Open pulldown option

The **Open** pulldown option retrieves an existing region into the current window. When selecting this option, the next screen will be a dialog box showing regions in the data base file. After selecting a region from the catalog, the program replaces the existing region (located on the

screen) with this newly selected region. Select the **Open** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**O**> key.

Save pulldown option

The **Save** pulldown option writes the contents of the current screen to the active region. The program provides no opportunity to change the region name when using the **Save** option. (Use the **Save as** option to store the region under a different name.) The **Save** option writes over the existing region, destroying the prior data. Select the **Save** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**S**> key.

Save as pulldown option

The **Save as** pulldown option writes the contents of the current screen to a region whose name the user creates or selects. When selecting this option, the next screen will be a dialog box showing all current regions. The program displays a field prompting for a region name. This field is where an alternative name is entered. Select the **Save as** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**V**> key.

Delete pulldown option

The **Delete** pulldown options deletes the contents of a region and removes it from the data base. Select the specific region using a dialog box of current regions. Select the **Delete** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**D**> key.

Print pulldown option

The **Print** pulldown options sends the contents of the screen to the printer. The program assumes that the output device port location is LPT1. Select the **Print** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**P**> key.

Exit pulldown option

After completing all editing and saving all files, leave HYEQT by using the **Exit** option. If region contents have changed but have not been saved, a warning screen will appear when leaving the program. Proceeding with the exit option loses these changes. Canceling the exit allows use of the **Save** or **Save as** options (as appropriate) to preserve the changes. Select the **Exit** option by moving to the option with cursor keys and pressing <Enter>. Another method is to press the highlighted <**X**> key.

Edit Menu Category

The program uses the **Edit** menu category options to switch between the Edit and Solve screen modes. The options are: Solving Equation and Edit Equation. The actions of these options have been described earlier. Use the cursor keys and <Enter> to select a specific option, or press the highlighted letter.

HYDRAIN - INTEGRATED DRAINAGE DESIGN COMPUTER SYSTEM

VOLUME II. HYDRO - HYDROLOGY

for:

Office of Technology Applications
Federal Highway Administration
Washington, DC

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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 (HEC-19), and as such, is an effort to combine existing approaches for rainfall and runoff analyses into one system.[1] HYDRO generates point estimates for 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 HEC-19, with some areas of HEC-12 also included.[2] This documentation explains 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 user 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 section demonstrates how to apply the program, particularly as it pertains to the HYDRAIN microcomputer package.

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 HYDRAIN, 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.

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 gaged stream flow. As with the rainfall scenario, both steady-state (peak flow) and dynamic (hydrograph) flow conditions can be considered. Figure 1 shows the basic types of analysis available through HYDRO.

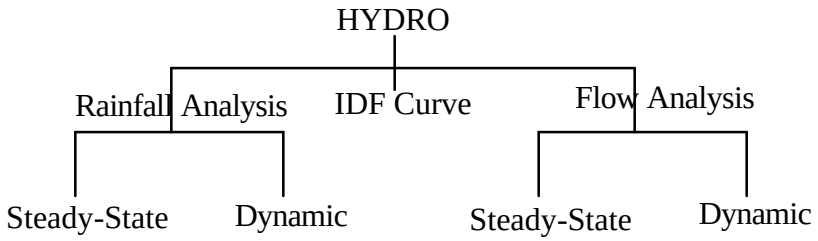


Figure 1. HYDRO flow chart.

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. HYDRO can be used to create a hyetograph (a plot of rainfall intensity versus time). A site-specific IDF curve can also be estimated.

Rainfall Data Bases

Rainfall intensities are generated from values provided in either the default, Pooled Fund data base (RAIN.PFP) or a State-supplied data base. The option to access a State-supplied data base 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 data base is too coarse for regions where the climate varies greatly over short distances. It would not be wise to use the Pooled Fund data base when the site is within mountain ranges or similar topographic features.

The default data base consists of the 1- and 24-h rain durations for 2- and 100-yr return periods for a total of 5597 latitude/longitude coordinate pairs. The data base was developed from three sources; the National Weather Service (NWS) technical memorandum, HYDRO-35, the Rainfall Frequency Atlas of the United States, Technical Paper 40 (TP-40), and the National Oceanic and Atmospheric Administration (NOAA) Atlas 2 documents.[3,4,5] The resolution of the data is as follows: 30 min for the eastern and midwest States covered by the HYDRO-35 and TP-40 documents, 20 min for the 11 western States covered by the NOAA Atlas 2, and 10 min for parts of Southern California.

The State-supplied data base must provide the intensities of 1-h 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. Data base format must conform to that specified in appendix D.

Peak Intensity

The manner in which HYDRO determines a rainfall intensity from the default data base follows. The program computes a weighted rainfall intensity averages of the points surrounding a user-supplied latitude and longitude. 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- and 24-h 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- and 24-h rainfall intensities are adjusted to a rainfall intensity associated with the duration using NWS and HYDRO rainfall intensity and frequency regression equations and logarithmic interpolation.[3,6,7]

In this manner, any rainfall with a frequency between 2 and 100 yr and duration between 5 min and 24 h can be considered for analysis. The user is freed from needing the HYDRO-35, TP-40, and Atlas 2 documents, as the intensity calculated by HYDRO represent the data used to create these documents and the accompanying maps.

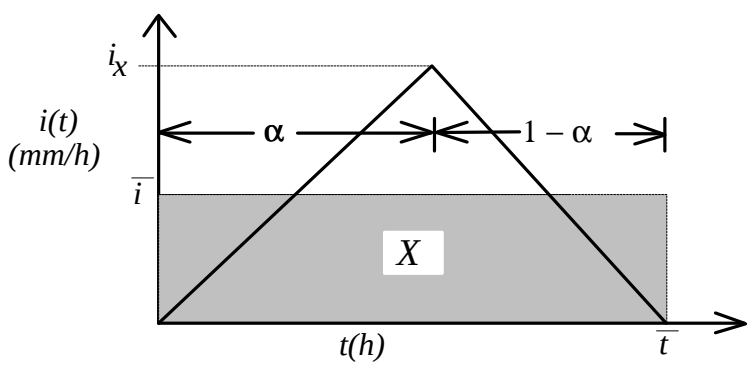
If the State-supplied data base option is exercised, HYDRO uses logic modeled after the CALTRANS program to compute the intensity for a given duration and return period using relationships described in the Technical Operation section.

Hyetographs

To apply the steady-state rainfall intensity to a dynamic condition, the triangular hyetograph method, developed by Yen and Chow is used.[8] This method, discussed in detail later, uses the rainfall intensity, the duration and a regional coefficient (α) to create the hyetograph seen in figure 2. Applications of the results can be as input for other programs that use hyetographs or for analyses such as a Least Total Economic Cost (LTEC) study for storm drain design.[9]

IDF Curves

HYDRO allows the user to create an IDF curve using either of the rainfall data bases 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 yr and the duration can extend from 5 min to 24 h of rainfall duration. Other HYDRAIN programs can apply these IDF curves as a portion of their input needs.



$$X = \text{AREA} = \text{TOTAL RAIN [mm/Event]} = \frac{i_X \bar{t}}{2}$$

- i_X = twice the average rainfall intensity
  $= 2\bar{i}$
- α tabulated in Yen & Chow, 1983

Figure 2. Yen and Chow's triangular hyetograph.

User-Supplied Rainfall Values

Should the user desire to implement a user-specified 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-h, **n** year intensity is adjusted for. A user- supplied rainfall intensity will cause HYDRO to override the data base 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 ungaged watersheds where runoff is the primary source of flow. The Log Pearson Type III method requires gaged 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 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 HYDRAIN 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 gaged 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.[10,11] 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, values derived from a nationwide urban hydrograph study, or use a semi-arid hydrograph relationship.[12] 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.

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

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 data bases, 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 DATA BASES

The default rainfall data base, created specifically for HYDRO, contains precipitation-frequency values for the continental United States. The values are for 2- and 100-yr return periods and 1- and 24-h rainfall durations.

The information used to create the data base came from:

1. The final base values used to compute isohyetal maps for 11 western States.[13] The 11 western States are: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington and Wyoming.

2. The tape E17383, obtained from the National Weather Service, contains data for the remaining 37 midwestern and eastern States and the District of Columbia. These are the data that were used to create the HYDRO-35 document.[13]

3. The TP-40 document was used to collect 24-h rainfall intensities for those States not covered by NOAA Atlas 2.

The data base resolution is a 30-min grid in the midwest and east and a 20-min grid in the west except in Southern California, where the resolution is a 10-min 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.

A State can choose to supply its own data base, consisting of 1-h 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 data base (default or State-supplied) to find the coordinates most closely associated with those of the site. For the default data base, 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-yr, 1- and 24-h 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-yr, 1- and 24-h duration, weighted average variables, the program will continue to the next module.

For the State-supplied data base, HYDRO identifies up to 50 stations within a 0.25-degree by 0.25-degree window. If a station is within 3 mi 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. If a user has identified specific stations for analysis, HYDRO allows selection of up to four stations to be used in calculating the weighted average. 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).

FREQUENCY ADJUSTMENT

If the default data base is to be accessed, the user can select any return period between 2 and 100 yr. Transforming the frequency of the rainfall intensity from the 2- and 100-yr 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 that was created especially for the HYDRO program.

5-Yr Equation[3]

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

10-Yr Equation[3]

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

25-Yr Equation[3]

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

50-Yr Equation[3]

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

General Equation[6]

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

Where:

A	=	The intensity for a 100-yr storm with a 1-h duration, mm/h.
B	=	The intensity for a 2-yr storm with a 1-h duration, mm/h.
C	=	The intensity for a user-defined return period with a 1-h duration, mm/h.
n	=	The user-defined frequency or return period, yr.

Equation 5 is used to adjust the frequency for both the 1- and 24-h duration intensities.

If the State data base is to be accessed, the user must either select one of the six "standard" return periods for which data are provided in the data base, or supply the mean 1-h storm, Log Pearson frequency factor, and coefficient of variation so that the 1-h intensity for the user-defined return period can be computed from the relationship:[14]

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

Where:

I_{mean}	=	The mean 1-h storm, mm.
K_j	=	The Log Pearson Type III frequency factor.
C_V	=	Coefficient of variation.

TIME OF CONCENTRATION

Having adjusted the rainfall intensity to the proper return period, the next logical step is to adjust the 1- and 24-h duration to the duration associated with watershed characteristics. The program assumes that this duration equals the time of concentration of the watershed. For IDF curves, pre-set durations are substituted for the time of concentration calculations.

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 as the sum of the two. 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.[15,16] This method is limited to small watersheds (≤ 800 ha) 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 8 to 11 mm/h.

B: A sand/loam soil, having a shallow loess/sandy loam with a moderate infiltration rate of 4 to 8 mm/h.

C: A clay/loam soil, having low organic content and usually high in clay. It has a slow infiltration rate of 1 to 4 mm/h.

D: A clay soil, having a mixture of heavy plastic clay (90 to 100 percent) and certain saline soils that swells significantly when wet. Clay has a very low infiltration rate of 0 to 1 mm/h.

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 rainfall from 0 to 635 mm/yr.
2: a TYPICAL soil, allowing a normal quantity of infiltration, associated with rainfall from 635 to 1270 mm/yr.
3: a WET soil, allowing a lower than normal quantity of infiltration, associated with rainfall greater than 1270 mm/yr.

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/Load			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
Residential	42	62	81	56	74	90	66	82	95	72	86	97
Urban	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:

$$CN = \frac{\sum \left[CN_i \times A_i \right]}{\sum A_i} \tag{7}$$

Where:

CN	=	The composite curve number for the watershed.
CN_i	=	The curve number associated with each subdivided land use, the watershed soil type and climate.
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:

$$S = \frac{1000}{CN} - 10 \tag{8}$$

Where:

S	=	An intermediate empirical value.
CN	=	The composite or user-defined curve number defined above.

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

$$t_{co} = \frac{L_o^{0.8} \times (S + 1)^{0.7}}{441 \times S_o^{0.5}} \tag{9}$$

Where:

t_{co}	=	The overland time of concentration, h.
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, m.
S	=	The intermediate empirical coefficient, defined above.
S_o	=	The average overland slope, 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 conducted for the Maryland State Highway Administration and the FHWA.[17] 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:

$$t_{co} = \frac{418 \times L_o^{0.6} \times n^{0.6}}{S_o^{0.3} \times i^{0.4}} \tag{10}$$

Where:

t_{co}	=	The overland time of concentration, s.
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, m.
n	=	Manning's friction value for a waterway.
S_o	=	The average overland slope, m/m.
i	=	The rainfall intensity, for a desired frequency or return period, mm/h.

Initially, HYDRO uses the 1-h rainfall intensity (already adjusted for the desired frequency) and will use equation (10) to compute an initial time of concentration. Should the initially calculated time of concentration equal one 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 substituted into equation (10), and a second estimate of time of concentration is calculated and compared to the initial estimate. If necessary, a third intensity is determined and substituted 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 1 percent different than the previous estimate; or select a minimum value of 5 min or a maximum value of 24 h. 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.[15] 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.[6] The SCS grassy waterway equation is given as:

$$V = 0.455 \times S_c^{0.504} \tag{11}$$

Where:

V	=	The channel velocity, m/s.
S_c	=	The average slope of the channel, percent.

Manning's Formula

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

$$V = \frac{1}{n} \times R_h^{0.67} \times S_c^{0.5} \tag{12}$$

Where:

V	=	The weighted average velocity occurring within a channel's cross sectional area, m/s.
R_h	=	The hydraulic radius of a channel (channel area divided by wetted parameter), m.
S_c	=	The friction slope (assumed to be the average channel slope), m/m.
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 3 is assumed.

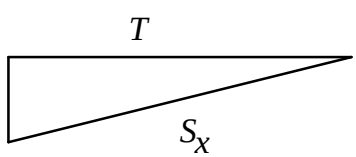


Figure 3. Triangular gutter section.

Substituting basic geometric relationships, derived from figure 3 into equation (12) yields:

$$V = \frac{0.75}{n} \times S_c^{0.5} \times S_x^{0.67} \times T^{0.67} \tag{13}$$

Where:

V	=	The velocity occurring within a gutter, m/s.
n	=	Manning's friction value for the channel.
S_c	=	The average channel slope, m/m.
S_x	=	The roadway cross slope, m/m.
T	=	The spread occurring in the gutter section, m.

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:

$$t_{cc} = \frac{L_c}{V \times 3600} \tag{14}$$

Where:

t_{cc}	=	The channel time of concentration, h.
L_c	=	The length of the channel, m.
V	=	The channel velocity, calculated using one the methods discussed above.

<u>Combining Overland and Channel Time of Concentrations</u>

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, h.
t_{co}	=	The overland time of concentration, h.
t_{cc}	=	The channel time of concentration, h.

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 is considered to be the duration by the program.

ADJUSTING RAINFALL INTENSITY FOR DURATION

If the default data base is used in the analysis, transformation of the 1- and 24-h rainfall intensities to the intensity associated with the time of concentration, just calculated, is achieved using NWS and HYDRO rainfall intensity and frequency regression equations and logarithmic interpolation. The NWS equations are from the HYDRO-35 memorandum.[3] There are four equations for transforming the 1-h intensity to rainfall intensities less than 1 h:

5-Min Equation[6]

$$i_{5\,\min} = 13.5 \times i_{1h}^{0.635} \tag{16}$$

10-Min Equation[3]

$$i_{10\,\min} = 0.59 \times i_{15\,\min} + 0.41 \times i_{5\,\min} \tag{17}$$

15-Min Equation[6]

$$i_{15\,\min} = 4.46 \times i_{1h}^{0.817} \tag{18}$$

30-Min Equation[3]

$$i_{30\,\min} = 0.49 \times i_{1h} + 0.51 \times i_{15\,\min} \tag{19}$$

Where:

$i_{5\,\min}$	=	The 5-min rainfall intensity derived from a 1-h rainfall intensity and having a user-defined return period, mm/h.
$i_{1\,h}$	=	The 1-h rainfall intensity having a user-defined return period, mm/h.
$i_{10\,\min}$	=	The 10-min rainfall intensity derived from the 5- and 15-min rainfall intensities and having a user-defined return period, mm/h.
$i_{15\,\min}$	=	The 15-min rainfall intensity derived from a 1-h rainfall intensity having a user-defined return period, mm/h.
$i_{30\,\min}$	=	The 30-min rainfall intensity derived from the 15-min and 1-h rainfall intensities and having a user-defined return period, mm/h.

If the duration is less than one 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 h, but less than 24 h in length, a general equation is used to transform the rainfall intensity. The equation uses a log-log interpolation between duration and intensity as follows:

$$i_{d,rp} = i_{1,rp} \times D^{\left[\log_{10}(i_{24,rp}) - \log_{10}(i_{1,rp})\right] / \log_{10}(24)} \tag{20}$$

Where:

$i_{d,rp}$	=	Intensity for a specified duration and return period, mm/h.
$i_{1,rp}$	=	Intensity for a 1-h storm and the specified return period, mm/h.
D	=	Duration, h.

$i_{24,rp}$ = Intensity for a 24-h storm and the specified return period, mm/h.

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

$$I_{d,rp} = I_{1,rp} \times D^{r} \tag{21}$$

Where:

$I_{d,\,rp}$ = Intensity mm/h for a specified duration and return period.
$I_{1,\,rp}$ = Intensity mm/h for a 1-h storm and the specified return period duration, h.
D = Duration, h.
r = 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.[8] 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 is shown earlier in figure 2.

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-min, and 1-, 2-, 4-, 8- and 24-h durations. Specifically, a location and the rainfall data base (default or State-supplied) are used to retrieve the appropriate 1- and 24-h 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:

$$Q = K \times C \times i \times A \tag{22}$$

Where:

Q	=	The peak flow, m^3/s.
K	=	Constant, 0.00276.
C	=	The runoff coefficient.
i	=	The rainfall intensity, mm/h.
A	=	The area of the watershed, ha.

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

Table 2. Default runoff coefficients.

Land Use	C Value	Land Use	C Value
Meadows	0.2	Residential	0.4
Woods	0.2	Urban & Hwy ROW	0.7
Pasture	0.3	Pavement	0.9
Crops	0.3		

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

$$C = \frac{\sum \left(C_i \times A_i \right)}{\sum A_i} \tag{23}$$

Where:

C	=	The weighted runoff coefficient for the entire watershed, having no dimension.
C_i	=	The runoff coefficient associated with each subarea.
A_i	=	The subarea associated with each subdivided land use, ha. 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 one-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 calculates the Rational method peak flow.

REGRESSION EQUATIONS

A more sophisticated analysis of flow at ungaged 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 equation is:

$$Q_p = a \times \prod_{i=1}^{n} X_i^{b_i} = a \times X_1^{b_1} \times X_2^{b_2} \cdot \cdot \cdot X_n^{b_n} \tag{24}$$

Where:

Q_p	=	The equation peak flow, m^3/s.
a	=	The constant, usually a translation factor.
X_i	=	The independent variables (parameters) for the watershed.
b_i	=	The exponential coefficients associated with each independent variable.
n	=	The number of independent variables.

The equation is usually developed by regression using logarithms of the dependent and independent variates 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-yr flood frequency and have 3, 5, or 7 independent variables. The United States Geological Survey (USGS) has conducted a nationwide study that developed three and seven parameter regression equations.[12] More recent work has concentrated on developing regional equations.[18] The interested reader is referred to the

literature for more information on typical coefficients and variables to be used with these equations.[1]

LOG PEARSON TYPE III FLOOD FREQUENCY

The Log Pearson Type III method is designed to be applied on watersheds with gaged 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.[10,11] Log Pearson Type III is the flood frequency standard for agencies of the Federal Government.

HYDRO applies Log Pearson Type III by first considering the relative location of the watershed outlet to that of the gaging station from where the peak stream flows were obtained. If the watershed outlet is at the same location as the gauging station, 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 4.

If the watershed outlet is not at the same location as the gaging station, the annual peak stream flows must be adjusted. In this case, the watershed outlet is either UPSTREAM or DOWNSTREAM from the gaging station and 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 4 and is described mathematically as:

$$Q_{ia} = Q_i \times \left[\frac{A_w}{A_g}\right]^{aexp} \tag{25}$$

Where:

Q_{ia}	=	The adjusted peak annual flow, m^3/s.
Q_i	=	The original peak annual flow, m^3/s, this is the flow obtained from the gauging station.
A_w	=	The area of the watershed, ha.
A_g	=	The area of the gauging station, ha.
aexp	=	Area adjustment exponent.

[1]The results of a nationwide compilation of USGS equations are found in the NFF program module accessible elsewhere within the HYDRAIN system.

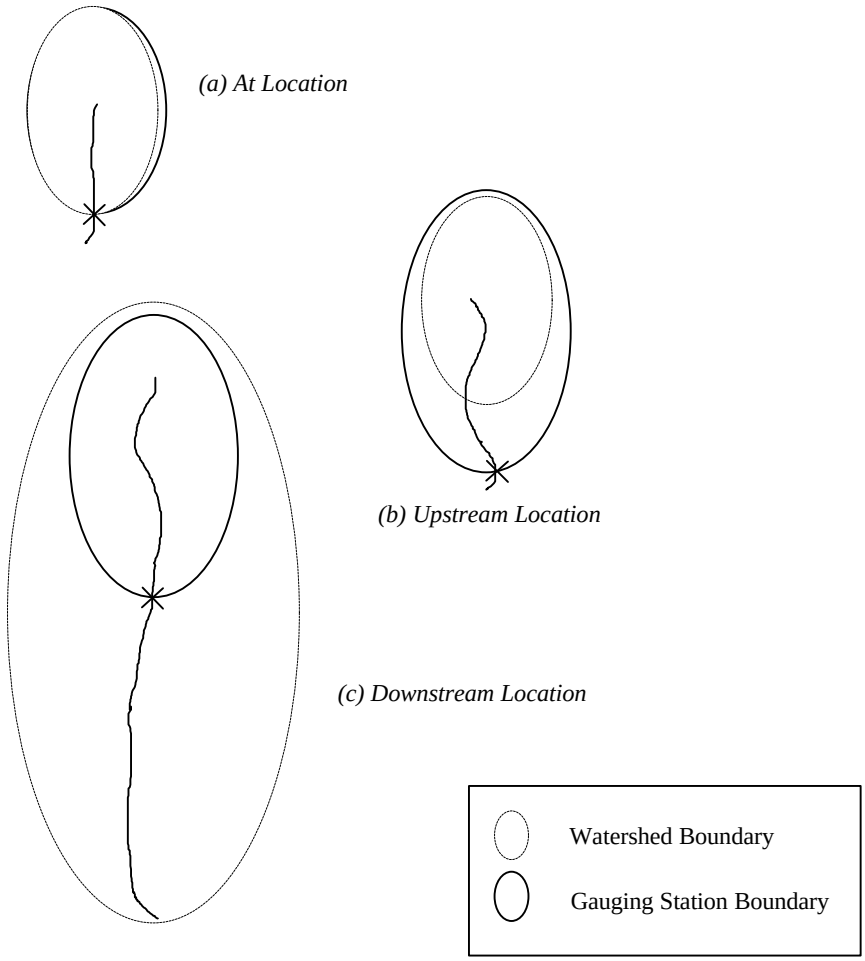


Figure 4. Relative watershed locations.

If the value of the area adjustment exponent is equal to 1.0, then the respective watersheds are topographically similar. 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).

$$\overline{Q_L} = \frac{\sum \log_{10}(Q_i)}{n} \tag{26}$$

Standard Deviation;

$$S_L = \sqrt{\frac{\sum_{i=1}^{n}\left[\log_{10}(Q_i) - \overline{Q_L}\right]^2}{n - 1}} \tag{27}$$

Skew Coefficient;

$$G_L = \frac{n \times \sum_{i=1}^{n}\left[\log_{10}(Q_i) - \overline{Q_L}\right]^3}{(n - 1) \times (n - 2) \times S_L^3} \tag{28}$$

Where:

G_L	=	The skew coefficient for the sample of peak annual stream flow values.
S_L	=	The standard deviation of the peak annual stream flow values, $\log_{10}m^3/s$.
$\overline{Q_L}$	=	The mean of the log transformed peak annual stream flows, $\log_{10}m^3/s$.
Q_i	=	The peak annual stream flow samples, $\log_{10}m^3/s$.
n	=	The period of record for the gaged stream flows, yr. 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.

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.[11]

HYDRO calculates a form of the Incomplete Gamma Function using the methodology outlined by Croley.[19] 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:

$$\alpha = \left[2 \times G_L\right]^2 \tag{29}$$

$$= \frac{\left[S_L \times G_L\right]}{2} \tag{30}$$

$$F = \overline{Q_L} - \frac{2 \times S_L}{G_L} \tag{31}$$

Where:

α	=	The first Croley translation coefficient, alpha.
ß	=	The second Croley translation coefficient, beta.
	=	The third Croley translation coefficient, delta.

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

$$t = \frac{\log_{10} Q \quad -}{} \tag{32}$$

Where:

t	=	The -quantile point for some logarithmic transformed stream flow, Q .
Q	=	A stream flow in the distribution defined by Q_L, S_L and G_L, m^3/s.
	=	The translation coefficient, delta, defined above.
ß	=	The translation coefficient, beta, defined above.

Pearson's integral, is defined as:

$$= \int_0^t \frac{1}{(\alpha)} \times t^{(\alpha - 1)} \times e^{-t} \times dt \approx P(Q \le Q) \tag{33}$$

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

$$P(Q \le Q) \approx \sqrt{\frac{\alpha + 5}{2 \times} \times \frac{(\alpha + 4)! \times \alpha}{\alpha!} \times \left[\frac{t}{\alpha + 5}\right]^{\alpha} \times \left[\frac{1}{\alpha + 5}\right]^{5} \times}$$

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

$$\sum_{j=0}^{14} \left[\frac{t^j}{\prod (\alpha + j)}\right] \tag{34}$$

Where:

$P(Q \leq Q)$	=	The probability that the flow Q is equal or greater than some flow, the inverse of which is that flow's return period.
α	=	Croley's translation coefficient, defined above.
	=	The value of pi, truncated in HYDRO to be 3.1415927.
t	=	The upper bounds of Pearson's integral, defined above.
j	=	An integer variable used in the summation.

HYDRO will enter two values for Q into equation (34) (with the two values of Q 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:

$$P(Q_p) = \frac{1}{n} \tag{35}$$

Where:

$P(Q_p)$	=	The probability associated with the user-defined return period, yr^{-1}.
n	=	The user-defined return period, yr.

The program uses an elimination scheme algorithm to 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 (34). First, the upper interval of the integral must satisfy the condition $0 \leq t \leq \infty$. 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 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 five percent of a value derived by a table.[11] The function relates the skew coefficient to the normal deviate, and produces a skew based on a user-defined probability:

$$K = \frac{2}{G_L} \times \left[\left[1 + \frac{G_L \times Z}{6} - \frac{G_L^2}{36}\right]^3 - 1\right] \tag{36}$$

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.
Z	=	The normal deviate, that is approximated by:

$$Z = 4.91 \times \left[(1 - P)^{0.14} - P^{0.14}\right] \tag{37}$$

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:

$$Q_p = 10^{\left(\overline{Q_L} + K \times S_L\right)} \tag{38}$$

Where:

Q_p	=	The peak flow for the stream, m^3/s, based on a user-defined return period.
$\overline{Q_L}$	=	The mean of the log transformed peak annual stream flows, $\log_{10}$ m^3/s.
K	=	The skew value based on a user-defined frequency.
S_L	=	The standard deviation of the peak annual stream flow values, $\log_{10}$ m^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 gaged stream.

HYDROGRAPH FORMATION

HYDRO uses two dimensionless hydrograph methods for generating a hydrograph representing the average runoff for a particular peak flow.[2] These methods are the USGS nationwide urban method and the semi-arid method. Within HYDRO, both are optional and require the user to access them using the **DHY** and **AHY** commands.

USGS Nationwide Urban Hydrograph

The nationwide urban method uses information developed by the USGS that approximates the shape and characteristics of hydrographs. Information required for using this method are: (1) dimensionless hydrograph ordinates; (2) time lag; and (3) peak flow. HYDRO can use either

[2]Hydrographs can also be generated using the NFF program module accessible elsewhere within the HYDRAIN system.

default dimensionless hydrograph coordinates or coordinates supplied by the user to define the shape of the hydrograph. Table 3 lists default values derived from the nationwide urban hydrograph study.[12]

Table 3. Default USGS dimensionless hydrograph coordinates.

Abscissa	Ordinate	:	Abscissa	Ordinate
0.0	0.00	:	1.3	0.65
0.1	0.04	:	1.4	0.54
0.2	0.08	:	1.5	0.44
0.3	0.14	:	1.6	0.36
0.4	0.21	:	1.7	0.30
0.5	0.37	:	1.8	0.25
0.6	0.56	:	1.9	0.21
0.7	0.76	:	2.0	0.17
0.8	0.92	:	2.1	0.13
0.9	1.00	:	2.2	0.10
1.0	0.98	:	2.3	0.06
1.1	0.90	:	2.4	0.03
1.2	0.78	:	2.5	0.00

The abscissae are multiplied by the time lag between the centroid of the rainfall and the centroid of the runoff which is either supplied by the user or computed in accordance with the following relationship:[12] [3]

$$TL = \frac{L^{0.62} \times (13 - BDF)^{0.47}}{1630 \times S^{0.31}} \tag{39}$$

Where:

TL	=	Time lag, h.
L	=	Main channel length, m.
S	=	Main channel slope, m/m.
BDF	=	Basin development factor (a value ranging from 0 to 12, where 0 represents an undeveloped basin and 12 represents a basin consisting 100 percent of storm sewers, lined channels, or curb and gutter streets).

[3]Typically, the time lag is about 60 percent of the time of concentration and this relationship can be used to estimate user-supplied TL values based on time of concentration.

The ordinates are multiplied by the peak flow which is calculated by HYDRO according to one of the previously described methods (i.e., Rational method, regression equations, or Log Pearson Type III) or with peak flows provided by the user.

Semi-Arid Hydrograph

The USGS developed the semi-arid method for sites that exhibit a single peak hydrograph shape that is common to small, drier watersheds under 39 km^2.[20] Information required for using this method are: (1) dimensionless hydrograph ordinates; (2) semi-arid volume; and (3) peak flow. HYDRO uses default dimensionless hydrograph to define the shape of the hydrograph. Table 4 lists these default values derived from the semi-arid hydrograph study.[20]

Table 4. Semi-arid dimensionless hydrograph coordinates.

Abscissa	Ordinate	:	Abscissa	Ordinate
0	0.0	:	14	55
3	5.6	:	18	38
5	13	:	23	23
7	25	:	30	23
10	49	:	40	12
11	57	:	50	5.2
12	60	:	60	2
13	59	:	70	0.5

To obtain a time value, the abscissae are multiplied equation by equation (40):

$$t_i = \frac{abscissa_i}{970} \times \left[\frac{V_n}{Q_p} \right] \tag{40}$$

Where:

t_i = The time value at abscissa i, min.
V_n = The volume of the hydrograph, based on the basin area and the return period, m^3.
Q_p = The peak flow, m^3/s.

The flows corresponding to these times are calculated using equation (41):

$$q_i = ordinate_i \times \left(\frac{Q_p}{60} \right) \tag{41}$$

Hydrographs developed with either method can generate HYDRO output that is available as input for HYDRA and HY8. These program use the hydrographs 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.

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 27 commands that HYDRO can recognize, although this number is subject to change as long as improvements are being made to HYDRO. Appendix C includes a complete list, to date, of these commands along with their definitions and format specifications.

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-**REM**ark 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 [ ] or a comma [,] 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 5. Appendix C provides detailed descriptions, formatting templates, and special notes for each command.

Table 5. Glossary of commands.

Command	Description
AHY	- signal use of semi-**A**rid **HY**drograph.
APM	- specify a user-supplied regional **A P**ri**M**e value for a hyetograph.
BAS	- specify **BAS**in land use areas.
CAL	- specify **CAL**ifornia (state) rainfall data base if NWS is not used.
CRP	- specify **C**alifornia (state) **R**eturn **P**eriod information.
DHY	- signal use of **D**imensionless **HY**drograph.
END	- signal the **END** of the command string.
FLW	- specify the method for determining peak **FL**o**W**.
GFL	- specify **G**age **FL**ow 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 **LOC**ation of a site using latitude and longitude.
LPA	- specify constants for **L**og **P**earson Type III **A**nalysis.
MOF	- signal computation of **M**aximum **O**bservable **F**lood.
QAA	- flow **A**rea **A**djustment for Log Pearson Type III.
QPK	- user-supplied **P**ea**K** flow, **Q**.
REM	- to provide **REM**arks or comments.
RFL	- specify computation of single **R**ain**F**al**L** intensity or hyetograph.
RGR	- specify **R**e**GR**ession coefficients for peak flow computations.
RPD	- specify **R**eturn **P**erio**D** for frequency-dependent calculations.
RTL	- specify **R**a**T**iona**L** method runoff coefficients.
STN	- retrieve rainfall data for a **ST**atio**N** from a state data base.
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-h storm.

Figure 5 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 value of one, used as the first parameter. 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 different land use areas. Site-specific data are entered in the **TCO** command to compute the overland time of concentration for a runoff length of 400 m, 0.02 m/m 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 150 m and a slope of 0.01 m/m. 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 data base. Finally, the return period of 50 yr is specified in the **RPD** command.

HYDRO Command	Data	Comments
JOB	Command Example	The title of the HYDRO job.
FLW	1	Use Rational method to compute peak flow.
RTL	* * * 0.35 * * 0.95	Set default runoff coefficients for meadows, woods, pasture, residential, and urban/highway right-of-way (land uses 1, 2, 3, 5, and 6). For the crops and pavement areas, override the defaults–entering user-supplied values of 0.35 and 0.95, respectively.
BAS	0 0 0 50 0 1.5 4.0	Specify areas associated with the land uses. (Note that the zeros serve as place holders for land uses not present in the data.)
TCO	400.0 0.02 B 3	Specify data to compute overland time of concentration.
TCC	150.0 0.01	Specify data to compute channel time of concentration.
LOC	35 14 80 50	Latitude and longitude of site.
RPD	50	50-yr return period.
END		Terminates the HYDRO run and prints the results.

Figure 5. Example of a command string.

Figure 6 shows the required and optional commands for each of the three analysis branches. The order of the individual commands is unimportant except for the first, second, and last non-**REM**ark command. A **REM**ark command can appear anywhere within a command string.

As shown in figure 6, 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** commands can be replaced with the **TCU** command if the user wishes to supply the combined overland and channel time of concentration. If the user supplies an intensity using the **UIT** command, then neither the time of concentration commands nor the **LOC**ation command need be used. The **CAL** command (with or without the **CRP** and **STN** commands) should appear in the command string if using the State rainfall data base.

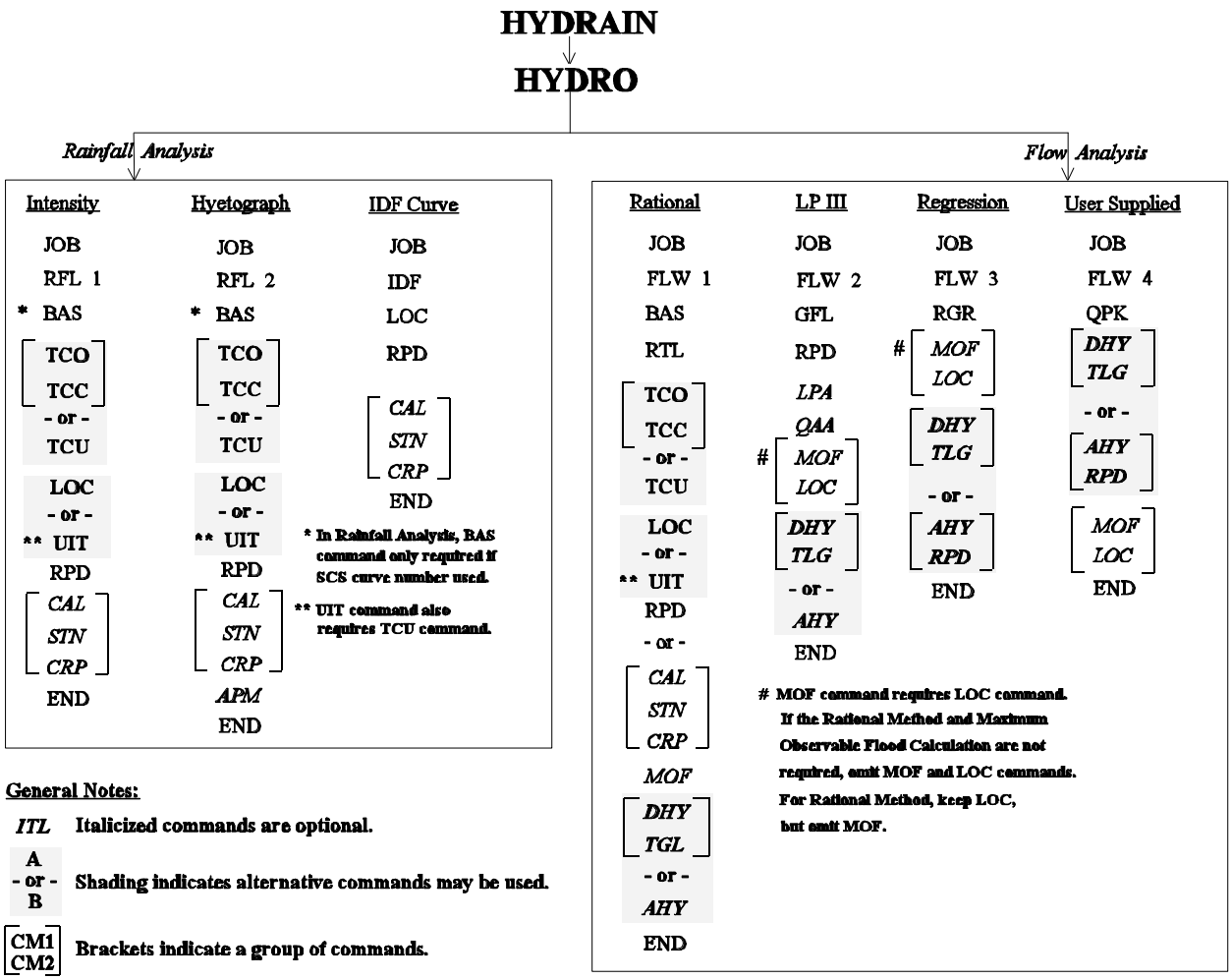


Figure 6. HYDRO footprints.

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

The Flow Analysis branch has four options, as indicated in figure 6. The user can indicate computation of peak flow using the Rational method, Log Pearson Type III analysis, or user-supplied regression equation by specifying the appropriate option number with the **FLW** branch command. HYDRO will compute a hydrograph if the **DHY** and **TLG** or the **AHY**

commands are present. Option 4 allows the user to supply the peak flow with the **QPK** command 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** command in the command string. The **MOF** command requires that the **LOC** and **BAS** commands also be present.

THE HYDRAIN ENVIRONMENT

For those users who have obtained HYDRO as part of the FHWA's **HYDRAIN** package, consult the HYDRAIN documentation for information on how to use the software system.

There are three methods by which HYDRO can be run. Two of these are within the HYDRAIN environment. The first method is to run HYDRO from the HYDRAIN 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. The third method is to execute HYDRO from the DOS prompt. Discussion of all three of these options is within the HYDRAIN documentation.

Upon completion of the run, the output file is automatically assigned an **.LST** filename extension. The output file contains an echo of the input data and the results. The output may contain messages describing warnings or errors encountered during execution. These messages are useful in debugging an input data set.

HYDRO produces four other output files 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 HYDRAIN Engineering programs (i.e., into HYDRA using the **UHY** command).

- IDF - This extension contains the ordinates of an Intensity-Duration-Frequency (IDF) curve (for a duration from 5 min to 24 h). The file is generated by HYDRO and, at user option, can be incorporated into the other HYDRAIN Engineering programs (i.e., into HYDRA using the **RAI** command).

- Q - This extension contains the ordinates of flow (Q) versus return period. It is created during Log Pearson Type III analysis.

- HYE - This extension contains the ordinates of a hyetograph (i.e., rainfall intensity (I) versus time (T)). The file is generated by HYDRO.

An additional program developed by the California Department of Transportation, IDF, can be used to analyze the state data base as an alternative to HYDRO. It can be accessed by

invoking the DOS SHELL option within HYEDT or HYDRAIN and typing IDF at the DOS prompt.

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

Example One: Rainfall Intensity & Duration

Problem:

Find the intensity and duration of a 50-yr storm using the kinematic wave method and the following data: overland runoff length equals 61 m, overland runoff slope equals 2 percent, basin Manning's coefficient equals 0.10, channel length equals 655 m, and channel slope equals 1 percent. Latitude equals 41 degrees 31 minutes and longitude equals 124 degrees 2 minutes.

Input File: HYDRO1.HDO

```
JOB Example One: Rainfall Intensity and Duration
RFL 1
TCO 61    0.02    0.1
TCC 655   0.01
LOC 41    31      124     2
RPD 50
END
```

Discussion of output:

The kinematic wave method is performed because only three parameters appear in the **TCO** command. Notice that we do not need the **BAS** command for the kinematic wave approach.

Output File: HYDRO1.LST

```
                ***************** HYDRO - Version 6.1 ***************
                *  HEC19 / Design Event vs Return Period Program  *
                *               Date of Run: 10-15-97              *
                                                                      Page No  1
                    Example One: Rainfall Intensity and Duration

--- Input File: \hydro\hydro1.hdo


 RFL  1

 === RAINFALL ANALYSIS (Intensity Suboption) Selected ...

 TCO  61    0.02    0.1
```

```
*** Notice:  Using Kinematic Wave Equation ...
--- Overland Runoff Length:    61.000 m.
    Overland Runoff Slope:    .020 m/m,
    Basin Mannings Coefficient:    .100

 TCC  655   0.01

*** Notice:  Using Grassy Waterway Equation ...
--- Channel Length:   655.000 m.
    Channel Slope:    .010 m/m.

 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 of Command File

--- Overland Time of Concentration:    .18 h
--- Channel Time of Concentration:     .40 h


                 ************************************************
                 *  Time of Concentration equals     .58 h       *
                 *        Intensity equals        49. mm/h       *
                 ************************************************


 +++ NORMAL END OF HYDRO
```

Example Two: Rainfall Intensity - State Data Base

Problem:

Find the intensity and duration of a 50-yr storm using the kinematic wave and the same data from example 1. Use the California State data base.

Input File: HYDRO2.HDO

```
JOB Example Two: Rainfall Intensity and Duration - State Database
RFL    1
TCO   61    0.02     0.1
TCC  655    0.01
LOC   41      31     124       2
RPD   50
CAL RAIN.ASC
END
```

Discussion of output:

The presence of the **CAL** command triggers the California State data base. The final answer is slightly different than example 1.

Output File: HYDRO2.LST

```
               *************** HYDRO - Version 6.1 ***************
               *  HEC19 / Design Event vs Return Period Program  *
               *              Date of Run: 10-15-97              *
                                                                  Page No  1
           Example Two: Rainfall Intensity and Duration - State Database

--- Input File: \hydro\hydro2.hdo


 RFL     1

 === RAINFALL ANALYSIS (Intensity Suboption) Selected ...

 TCO    61    0.02     0.1

*** Notice:  Using Kinematic Wave Equation ...
--- Overland Runoff Length:    61.000 m.
    Overland Runoff Slope:    .020 m/m,
    Basin Mannings Coefficient:    .100

 TCC   655    0.01

*** Notice:  Using Grassy Waterway Equation ...
--- Channel Length:   655.000 m.
    Channel Slope:    .010 m/m.

 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

 === File Read from Intermediate Directory: RAIN.ASC


*** End of Command File


--- The Following Station(s) Will Be Used in Determining the Sites Intensity:
    Station ID   Elev. (m)   Lat/Long (dec. deg.)  Distance from Site (km)

    F304577000      7           41.517  124.033                .000

    Notice:  A Station Elevation of -999 Indicates A Missing Value.


--- Overland Time of Concentration:    .21 h
--- Channel Time of Concentration:     .40 h


                 ************************************************
                 *  Time of Concentration equals     .61 h       *
                 *        Intensity equals        42. mm/h       *
                 ************************************************


 +++ NORMAL END OF HYDRO
```

Example Three: Rainfall Hyetograph

Problem:

Find the intensity, duration, and time to peak of a 50-yr storm using the kinematic wave method and the same data from example 1.

Input File: HYDRO3.HDO

```
JOB Example Three: Rainfall Hyetograph
RFL    2
TCO   61    0.02     0.1
TCC  655    0.01
LOC   41      31     124       2
RPD   50
END
```

Discussion of output:

Notice that the 50-yr hyetograph is plotted and tabulated.

Output File: HYDRO3.LST

```
                ***************** HYDRO - Version 6.1 ***************
                *  HEC19 / Design Event vs Return Period Program  *
                *              Date of Run: 10-15-97              *
                                                                   Page No  1
                         Example Three: Rainfall Hyetograph

--- Input File: \hydro\hydro3.hdo


 RFL     2

 === RAINFALL ANALYSIS (Hyetograph Suboption) Selected ...

 TCO    61    0.02     0.1

*** Notice:  Using Kinematic Wave Equation ...
--- Overland Runoff Length:    61.000 m.
    Overland Runoff Slope:    .020 m/m,
    Basin Mannings Coefficient:    .100

 TCC   655    0.01

*** Notice:  Using Grassy Waterway Equation ...
--- Channel Length:   655.000 m.
    Channel Slope:    .010 m/m.

 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 of Command File


--- Overland Time of Concentration:    .18 h
--- Channel Time of Concentration:     .40 h


                 ************************************************
                 *  Time of Concentration equals     .58 h       *
                 *        Intensity equals        49. mm/h       *
                 ************************************************


--- Internally supplied A-Prime value equals  .431


                    *****************************************
                    *   The time to peak equals   .25 h       *
                    *****************************************
```

```
          ***** HYDRO ***** (Version 6.1) *****          Date 10-15-97
                                                            Page No  2
                 Example Three: Rainfall Hyetograph


                     Graph of Triangular Hyetograph
                Rainfall Intensity (mm/h) versus Time (h)

99.............................*.....................................
   .                          *   *                                  .
   .                                *                               .
   .                        *         *                             .
74..                      *             *                           .
   .                    *                 *                         .
   .                  *                     *                       .
   .                                          *                     .
   .                *                            *                   .
49..              *                                *                 .
   .            *                                    *               .
   .           *                                       *             .
   .                                                     * *         .
   .         *                                                       .
25..       *                                                        .
   .     *                                                          .
   .   *                                                            .
   .                                                                .
   . *                                                              .
 0.*..............................................................*
   .00             .14             .29             .43            .58
```

```
***** HYDRO ***** (Version 6.1) *****          Date 10-15-97
                                                  Page No  3
       Example Three: Rainfall Hyetograph
```

Point	Time (h)	Intensity (mm/h)
1	.000	0.
2	.017	7.
3	.033	13.
4	.050	20.
5	.067	26.
6	.083	33.
7	.100	40.
8	.117	46.
9	.133	53.
10	.150	59.
11	.167	66.
12	.183	73.
13	.200	79.
14	.217	86.
15	.233	92.
16	.250	99.
17	.250	99.
18	.267	94.
19	.283	89.
20	.300	84.
21	.317	79.
22	.333	74.
23	.350	69.
24	.367	64.
25	.383	59.
26	.400	54.
27	.417	49.
28	.433	44.
29	.450	39.
30	.467	34.
31	.580	0.

```
+++ Notice:  Intermediate file has SI units.

=== File Created on Intermediate Directory: hydro3.HYE

+++ NORMAL END OF HYDRO
```

Intermediate File: HYDRO3.HYE

```
HYDRO HYETOGRAPH (SI) OUTPUT
  31
        .0        0.
       1.0        7.
       2.0       13.
       3.0       20.
       4.0       26.
       5.0       33.
       6.0       40.
       7.0       46.
       8.0       53.
       9.0       59.
      10.0       66.
      11.0       73.
      12.0       79.
      13.0       86.
      14.0       92.
      15.0       99.
      15.0       99.
      16.0       94.
      17.0       89.
      18.0       84.
      19.0       79.
      20.0       74.
      21.0       69.
      22.0       64.
      23.0       59.
      24.0       54.
      25.0       49.
      26.0       44.
      27.0       39.
      28.0       34.
      34.8        0.
```

Example Four: IDF Curve Generation

Problem:

Find the IDF curve for a 50-yr storm at the following location:

Latitude = 41 degrees 48 minutes
Longitude = 123 degrees 22 minutes

Input File: HYDRO4.HDO

```
JOB Example Four:  I-D-F Curve Generation
IDF Happy Camp Ranger Station
LOC   41     48    123     22
RPD   50
END
```

Discussion of output:

Notice that the 50-yr IDF curve is plotted and other intensities are tabulated for common frequencies.

Output File: HYDRO4.LST

```
                ***************** HYDRO - Version 6.1 ***************
                *  HEC19 / Design Event vs Return Period Program  *
                *               Date of Run: 10-15-97             *
                                                                     Page No  1
                        Example Four:  I-D-F Curve Generation

--- Input File: \hydro\hydro4.hdo


 IDF  Happy Camp Ranger Station

 === IDF CURVE Option 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 of Command File
```

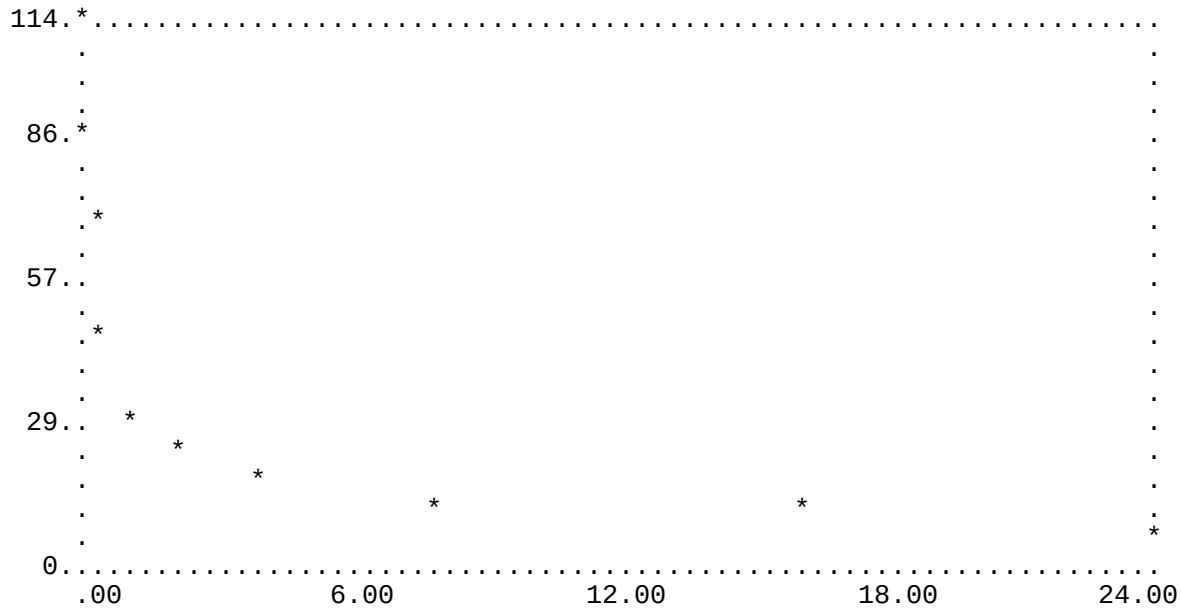
Example Four: I-D-F Curve Generation

IDF Curve for Various Return Periods

Intensities (mm/h)

Duration	50 Yr	2 Yr	5 Yr	10 Yr	25 Yr	100 Yr
5 min	114.	78.	89.	97.	107.	121.
10 min	88.	57.	66.	73.	81.	94.
15 min	70.	43.	51.	56.	64.	75.
30 min	47.	27.	33.	37.	42.	51.
60 min	29.	16.	20.	22.	26.	32.
120 min	22.	12.	15.	17.	20.	24.
4 h	17.	9.	11.	13.	15.	18.
8 h	13.	7.	9.	10.	11.	14.
16 h	10.	6.	7.	8.	9.	11.
24 h	8.	5.	6.	6.	7.	9.

Happy Camp Ranger Station
Intensity Curve for 50 Year Return Period
Rainfall Intensity (mm/h) versus Duration (h)



```
                ***** HYDRO ***** (Version 6.1) *****          Date 10-15-97
                                                                  Page No  3
                      Example Four:  I-D-F Curve Generation

+++ Notice:  Intermediate file has SI units.

=== File Created on Intermediate Directory: hydro4.IDF

+++ NORMAL END OF HYDRO
```

Intermediate File: HYDRO4.IDF

```
HYDRO IDF (SI) OUTPUT
  10
      5.0      114.
     10.0       88.
     15.0       70.
     30.0       47.
     60.0       29.
    120.0       22.
    240.0       17.
    480.0       13.
    960.0       10.
   1440.0        8.
```

Example Five: Peak Flow Using the Rational Method

Problem:

Find the peak flow of the subbasin in example 1, moved to latitude = 38 degrees 30 minutes and longitude = 80 degrees 50 minutes. The runoff coefficients are: meadow = 0.2, residential = 0.4, and pavement = 0.95. The land use areas are: meadow = 21.8 ha, residential = 20.4 ha; pavement = 1.5 ha.

Input File: HYDRO5.HDO

```
JOB Example Five: Rational Method Peak FLow
FLW    1
RTL    *       *       *       *       *       *    0.95
BAS 21.8       0       0       0    20.4       0     1.5
TCO 61      0.02       0.1
TCC 655     0.01
LOC 38      30      80      50
RPD 50
END
```

Discussion of output:

Notice that results include time of concentration, peak rainfall intensity, and peak flow.

Output File: HYDRO5.LST

```
                ***************** HYDRO - Version 6.1 ***************
                *  HEC19 / Design Event vs Return Period Program  *
                *              Date of Run: 10-15-97              *
                                                                     Page No  1
                       Example Five: Rational Method Peak FLow

--- Input File: \hydro\hydro5.hdo

 FLW     1

 === FLOW ANALYSIS (Rational Method Suboption) Selected ...

 RTL     *       *       *       *       *       *    0.95

 BAS  21.8       0       0       0    20.4       0     1.5

--- The Basin Area is      43.7 ha

 TCO  61      0.02       0.1

*** Notice:  Using Kinematic Wave Equation ...
--- Overland Runoff Length:    61.000 m.
    Overland Runoff Slope:    .020 m/m,
    Basin Mannings Coefficient:    .100

 TCC  655     0.01
```

```
*** Notice:  Using Grassy Waterway Equation ...
--- Channel Length:   655.000 m.
    Channel Slope:    .010 m/m.

 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 of Command File

          Subarea Drainage Area (ha) & Runoff Coefficients

                      Meadow ..........    21.8 C =  .200*
                      Woods ...........      .0 C =  .200*
                      Pasture .........      .0 C =  .300*
                      Crops ...........      .0 C =  .300*
                      Residential .....    20.4 C =  .400*
                      Urban/Highway ...      .0 C =  .700*
                      Pavement ........     1.5 C =  .950
                      - TOTAL Basin Area     43.7 ha -
                      Weighted runoff coefficient is .319

                      Notice: * indicates that a default
                                runoff coefficient used.

--- Overland Time of Concentration:    .15 h
--- Channel Time of Concentration:     .40 h

                 ************************************************
                 *  Time of Concentration equals     .55 h       *
                 *        Intensity equals        90. mm/h       *
                 ************************************************


                  ***** HYDRO ***** (Version 6.1) *****           Date 10-15-97
                                                                     Page No  2
                       Example Five: Rational Method Peak FLow

                      ************************************
                      * The Peak Flow is      3.447 m^3/s *
                      ************************************


 +++ NORMAL END OF HYDRO
```

Example Six: Peak Flow Using Log Pearson Type III

Problem:

Find the 500-yr flow at the same gauging station that recorded annual peak flows found in MEDINA.FLW. Use a skew coefficient of 0.236. Because the 500-yr flow is at the same gauging station, we do not need areas. Notice that the FLW command is set to 2.

Input File: HYDRO6.HDO

```
JOB Example Six:  Log Pearson Analysis for the Medina River
FLW 2
LPA 0.236     1
GFL MEDINA.FLW
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 D has further information on this and other command input formats and syntax.)

```
Annual Discharge - Medina River @ San Antonio, Texas: 1940-1982
   43
    71.925
   195.103
   495.545
   342.634
    56.334
   100.242
   900.476
    41.626
    58.050
   492.713
   160.273
    60.881
    22.682
   140.451
    24.494
    33.980
    49.554
   146.681
   261.081
    94.861
    90.614
    86.366
   112.135
    25.202
    60.598
   153.760
    61.164
   155.176
   370.951
    77.305
    95.145
    83.535
```

```
   180.095
   903.307
   274.107
   116.949
   212.660
   130.824
   267.311
   134.505
    56.067
   410.594
   231.065
```

Discussion of Output:

Because the 500-yr flow is at the same gauging station, we do not need basin areas. Notice that the **FLW** command is set to 2.

Output File: HYDRO6.LST

```
                 *************** HYDRO - Version 6.1 ***************
                 *  HEC19 / Design Event vs Return Period Program  *
                 *              Date of Run: 10-15-97              *
                                                                 Page No  1
               Example Six:  Log Pearson Analysis for the Medina River

--- Input File: \hydro\hydro6.hdo

 FLW  2

 === FLOW ANALYSIS (Log Pearson Type III Suboption) Selected ...

 LPA  0.236     1

--- The User-Supplied skew coefficient is  .236
 GFL  MEDINA.FLW

 === File Read from Intermediate Directory: MEDINA.FLW

 +++ Notice:  Intermediate file has SI units.

--- The Following Gage Flows were Entered:
   71.925  195.103  495.545  342.634   56.334  100.242  900.476   41.626
   58.050  492.713  160.273   60.881   22.682  140.451   24.494   33.980
   49.554  146.681  261.081   94.861   90.614   86.366  112.135   25.202
   60.598  153.760   61.164  155.176  370.951   77.305   95.145   83.535
  180.095  903.307  274.107  116.949  212.660  130.824  267.311  134.505
   56.067  410.594  231.065

 RPD  500

--- The Selected Return Period is  500 years.

*** End of Command File

--- Statistical Calculations:
    Mean of the Log Flow Values    2.091
    Computed Standard Deviation     .394
    Computed Skew Coefficient       .236
```

```
--- User-Supplied Skew Coefficient of   .23600
    used in place of the computed coefficient.

              ********************************************
              *  The  500 Year Flow Equals  2190.341 m^3/s *
              ********************************************
```

Peak Flows for Common Return Periods

	Return Period (Years)	Peak Flow (m^3/s)
Selected	500	2190.341
	2	119.035
	5	261.526
	10	402.843
	25	648.684
	50	890.813
	100	1191.815

```
                 ***** HYDRO ***** (Version 6.1) *****          Date 10-15-97
                                                                   Page No  2
              Example Six:  Log Pearson Analysis for the Medina River
                                Exceedence Probability
     (99.865)  (97.73)   (84.13)   (50.00)   (15.87)   (2.27)    (0.135)
    3.24+.........|.........|.........|.........|.........|.........+
        .         |         |         |         |         |        o.
        .  x - ACTUAL DATA  |         |         |         |         .
F       .  o - CALCULATED   |         |         |         |  o      .
L    .89+  * - BOTH         |         |         |         |*        +
O       .         |         |         |         |       o |         .
W       .         |         |         |         |  x x    |         .
        .         |         |         |         |xxo      |         .
1    .25+         |         |         |      x*x|         |         +
0       .         |         |         |  x xx   |         |         .
0       .         |         |        *xxx       |         |         .
0       .         |         |     xxxx|         |         |         .
     .07+         |         | x xx    |         |         |         +
C       .         |         xxx       |         |         |         .
M       .         |    x  x |         |         |         |         .
S       .         |xx       |         |         |         |         .
     .02+.........x.........|.........|.......|.|..|....|.||.|.....|+
                                      2       5   10   25 50 100  500
      (3.0)     (2.0)     (1.0)     (0.0)    (-1.0)    (-2.0)    (-3.0)
                      Return Period in Years, (Stand. Dev.)

+++ Notice:  Intermediate file has SI units.

=== File Created on Intermediate Directory: hydro6.Q

+++ NORMAL END OF HYDRO
```

Intermediate File: HYDRO6.Q

```
LOG PEARSON III (SI) OUTPUT
   7
       2.   119.035
       5.   261.526
      10.   402.843
      25.   648.684
      50.   890.813
     100.  1191.815
     500.  2190.341
```

APPENDIX B: FOOTPRINTS FOR TYPICAL APPLICATIONS

This section presents four basic HYDRO applications represented by an arrangement of command strings. These arrangements of command strings, or footprints, are provided for the following typical applications:

1. IDF curve.

2. Rainfall analysis (peak rainfall intensity).

3.* Flow analysis (Rational method).

4.* Flow analysis (Log Pearson Type III method).

* Note: This application has the option to generate a hydrograph from its peak flow.

These four footprints are contained in files on the HYDRAIN package diskettes. These files contain the footprint command lines with blank data fields for which the user can supply the appropriate data (the footprint files should be copied and renamed before any editing is done).

1. IDF Curve

Filename: IDF˜FP.HDO

The following command string is a typical footprint for an Intensity-Duration-Frequency (IDF) curve:

```
rem--->Intensity-Duration-Frequency (IDF) curve
rem--->REMOVE all unused command lines (Alt + D)
rem--->REQUIRED first command, JOB
JOB
IDF
rem--->OPTIONAL---UIT command
UIT
rem--->LOC command NOT necessary with UIT command
LOC
RPD
END
```

2. Rainfall Analysis

Filename: RAIN˜FP.HDO

The following command string is a typical rainfall analysis footprint for peak rainfall intensity:

```
rem--->Peak Rainfall Analysis
rem--->REMOVE all unused command lines (Alt + D)
rem--->REQUIRED first command, JOB
JOB
RFL 1
rem--->BAS command required only if SCS curve number is used.
BAS
rem--->USE: <TCO and TCC> or <TCU>
TCO
TCC
TCU
LOC
RPD
END
```

3. Flow Analysis - Rational Method

Filename: RATL˜FP.HDO

The following command string is a typical flow analysis footprint for the Rational method:

```
rem--->Rational Method Flow Analysis
rem--->REMOVE all unused command lines (Alt + D)
rem--->REQUIRED first command, JOB
JOB
FLW 1
rem--->RTL command required for Rational method
RTL
BAS
rem--->USE:  <TCO and TCC> OR <TCU> OR <TCU and UIT>
TCO
TCC
TCU
UIT
rem--->LOC command NOT necessary when both <TCU and UIT> are used
LOC
RPD
rem--->OPTIONAL---DHY and TLG commands are needed for a HYDROGRAPH
DHY
TLG
rem--->OPTIONAL---MOF command (requires LOC and BAS commands)
MOF
END
```

4. Flow Analysis - Log Pearson Type III Method

Filename: LPIII~FP.HDO

The following command string is a typical flow analysis footprint for the Log Pearson Type III method:

```
rem--->Log Pearson Type III Flow Analysis
rem--->REMOVE all unused command lines (Alt + D)
rem--->REQUIRED first command, JOB
JOB
FLW 2
GFL
RPD
rem--->OPTIONAL---LPA and QAA commands contain Log Pearson III parameters
LPA
QAA
rem--->OPTIONAL---DHY and TLG commands are needed for a HYDROGRAPH
DHY
TLG
rem--->OPTIONAL---Maximum Observable Flood:  MOF and LOC commands
MOF
LOC
END
```

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 AHY- semi-Arid HYdrograph

Purpose: To signal HYDRO to calculate a semi-arid hydrograph.

Structure:

AHY (aarea)

aarea - area of watershed, ha.

Notes:

1) If not already supplied to input file by the BAS or QAA commands.

2) The RPD and FLW commands must also appear in the input file when using AHY.

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

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 data base 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 - subBASin area information

Purpose: To specify subbasin sizes.

Structure:

BAS a_mdw, a_wds, a_pas, a_crps, a_res, a_urb, a_pav

1) a_mdw - area of land use that contains a meadow or open field, ha .
2) a_wds - area of land use that contains forests or woods, ha.
3) a_pas - area of land use that contains pasture, ha.
4) a_crps - area of land use that is composed of crops, ha.
5) a_res - area of land use that contains residential development, ha.
6) a_urb - area of land use that contains urban sections or highway right-of-way, ha.
7) a_pav - area of land use that contains pavement, ha.

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) The total of the subareas will be used as the total basin area.

3) The total basin area will be displayed.

4) 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 800 ha 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 120 ha.

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

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 D of the HYDRO documentation.)

Notes:

1) The CAL command 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.

COMMAND CRP - California (or state) Return Period information

Purpose: To specify the necessary data for redefining State rainfall data base statistical information.

Structure:

CRP dmean, pfact, cv

1)	dmean	-	mean 1-h storm, mm/25.4.
2)	pfact	-	Log-Pearson frequency factor.
3)	cv	-	coefficient of variation.

Note: The CAL command 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: (three options)

DHY (no parameters)

-- OR --

DHY dhydtd(1), dhydqd(1), dhydtd(2), dhydqd(2), ...dhydtd(n), dhydqd(n)

-- OR --

DHY filename

1)	dhydtd -	user-supplied abscissa value.
2)	dhydqd -	user-supplied ordinate value.

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 D 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 command must be present in a command string containing the DHY command.

COMMAND END - END of run

Purpose: To signal the end of the command string.

Structure:

END (no parameters)

Note: An END command 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

method - number indicating the method to be used in computing peak flow. These are:

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.

4 - User-supplied method. This option requires use of the QPK command to supply peak flow information.

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 cubic meters per second) 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 command. The area variable is developed using seven land use subareas (specified on the BAS command). Default runoff coefficients are provided (or can be replaced at the user's option) with the RTL command. 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 cubic meters per second) 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 commands can be used to develop a hydrograph from dimensionless hydrograph information. 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 flow records.

If option 3 is selected, a user-developed regression equation can be specified using the RGR command. This option allows users 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) .

3) Methods 1, 2 and 3 generate peak flows for hydrographs. The user supplies the peak flow for method 4. To activate the hydrograph computations:

a) The DHY command invokes the USGS urban hydrograph.
b) The AHY command invokes the semi-arid hydrograph.

COMMAND GFL - Gage FLow

Purpose: To specify gage flows for Log Pearson Type III analysis.

Structure: (2 options)

GFL q(1), q(2), ..., q(nyr)

-- OR --

GFL filename

OPTION 1:

q - gage flow for a particular water year, m^3/s.

OPTION 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 D 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 30 years of flow records be obtained for the Log Pearson Type III analysis to describe the probabilistic nature of streamflow. Contact a local USGS office or NAWDEX for more information.

2) 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

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 min up to 24 h. 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 per hour, and the x-axis is duration in hours. Two graphs are created: one plots all points for durations up to 24 h; the second details the first 2 h of the first curve.

COMMAND JOB - JOB start

Purpose: To initiate job and specify a job title.

Structure:

JOB jobtitle

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. The information in jobtitle becomes a header for the output file.

COMMAND LOC - LOCation of site

Purpose: To specify the latitude and longitude for use in computations requiring data base retrievals.

Structure:

LOC d_lat, m_lat, d_lng, m_lng

1) d_lat - degrees latitude of the site.
2) m_lat - minutes latitude of the site.
3) d_lng - degrees longitude of the site.
4) m_lng - minutes longitude of the site.

Notes:

1) 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.

2) The LOC command must be present when using the MOF command.

COMMAND LPA - Log Pearson type III Analysis

Purpose: To specify constants for Log Pearson Type III analysis.

Structure:

LPA skw, pflag

1) skw - skew coefficient. If an asterisk (*) 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. (default).
   - 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.

Note: To use the LPA command, the FLW method switch must be equal to 2.

COMMAND MOF - Maximum Observable Flood

Purpose: To signal computation of the maximum observable flood.

Structure:

MOF (abas)

abas - area of the basin, ha.

Note:

1) The parameter is not required if area supplied by some other command.

2) The LOC command must also appear in the command string when MOF is used.

COMMAND QAA - Flow Area Adjustment

Purpose: To specify adjustment parameters for Log Pearson Type III analysis.

Structure:

QAA abas ast aexp uni

1) abas - area of the basin, ha, ac, or mi^2.
2) ast - gauging station area, ha, ac, or mi^2a. 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 ha with limitation 405,000 ha on the total area.
3) aexp - area fraction coefficient having a value greater than or equal to 0 with a default value of 1.0. It is used in the following manner:

$$Q_{BASIN} = Q_{STATION} \times (A_{BASIN}/A_{STATION})^{aexp}$$

4) uni - units flag:
   - 0 or * - area of abas and ast, ac.
   - 1 - area of abas and ast, mi^2.
   - 2 - area of abas and ast, ha (default).

Notes:

1) To use the QAA command, the FLW method switch must be equal to 2.

2) The default units for abas and ast are ac but may be changed using the uni parameter.

3) 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.

4) If abas is equal to ast, then the watershed is assumed to be at the same location as the gage. If abas is less than ast, then the watershed is upstream of the gage. If abas is greater than ast, then the watershed is downstream of the gage.

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

qpu - user-supplied peak flow, m^3/s.

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

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 data base (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: (2 options)

RGR acof, x(1), b(1), ..., x(ncof), b(ncof)

-- OR --

RGR filename

OPTION 1:

1)	acof	-	intercept.
2)	x(j)	-	value of parameter.
3)	b(j)	-	value of exponent.

OPTION 2:

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 D of the HYDRO documentation.

COMMAND RPD - Return PerioD

Purpose: To specify the return period for frequency-dependent calculations.

Structure:

RPD rp

rp - return period, 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 data base 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.)

COMMAND RTL - RaTionaL method runoff coefficients

Purpose: To specify runoff coefficients for each of seven land use categories.

Structure: (2 options)

RTL (no parameters)

-- OR --

RTL C_mdw, C_wds, C_pas, C_crps, C_res, C_urb, C_pav

1)	C_mdw -	runoff coefficient for meadow. If an asterisk (*) is specified, C_mdw will be assumed to equal 0.2.
2)	C_wds -	runoff coefficient for woods. If an asterisk (*) is specified, C_wds will be assumed to equal 0.2.
3)	C_pas -	runoff coefficient for pasture. If an asterisk (*) is specified, C_pas will be assumed to equal 0.3.
4)	C_crps -	runoff coefficient for crops. If an asterisk (*) is specified, C_crps will be assumed to equal 0.3.
5)	C_res -	runoff coefficient for residential. If an asterisk (*) is specified, C_res will be assumed to equal 0.4.
6)	C_urb -	runoff coefficient for urban/highway right-of-way. If an asterisk (*) is specified, C_urb will be assumed to equal 0.7.
7)	C_pav -	runoff coefficient for pavement. If an asterisk (*) is specified, C_pav 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 an asterisk (*) 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

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 command. Up to four STN commands can be used per command chain. The CAL command must also be present in the input file.

2) Care should be used in selecting the stations which will be used for interpolating the 1-h intensity and log-log slope of the IDF curve. The following points should be kept in consideration:
   - If a station is within 5 km 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: (3 options)

TCC lchl, schl, smngs, sgtr, tgtr << HEC-12 Gutter Section

-- OR --

TCC lchl, schl, smngs, 0, hydr << Manning's Formula

-- OR --

TCC lchl, schl << SCS Grassy Waterway

OPTION ONE: HEC-12 Gutter Section:

1) lchl - channel length, m.
2) schl - channel slope, m/m. 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, m/m.
5) tgtr - gutter spread, m. The HEC-12 gutter equation will be used to compute channel velocity.

OPTION TWO: Manning's Formula:

1) lchl - channel length, m.
2) schl - channel slope, m/m. 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) 0 - enter zero as a placeholder.
5) hydr - hydraulic radius, m. Manning's formula will be used to compute channel velocity.

OPTION THREE: SCS Grassy Waterway:

1) lchl - channel length, m.
2) schl - channel slope, m/m. Channel slope refers to the average slope of the channel over its entire length.

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.[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. 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 is placed in the fifth field. Proper use of this alternative will require trial and error calculations to determine a proper hydraulic radius.

4) The SCS grassy waterway method 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. This alternative requires only the first two fields, channel flow length and channel slope.

5) Use only one TCC command per job. If channel has multiple hydraulic characteristics, attempt to develop a composite channel section.

COMMAND TCO - overland time of concentration

Purpose: To specify data for computing overland time of concentration by one of two methods.

Structure: (2 options)

TCO llnd, slnd, isoil, iclm (,cnmbr) << SCS Curve Number

-- OR --

TCO llnd, slnd, rmngs << Kinematic Wave

1) llnd - length of overland flow path, m. Overland length refers to the maximum length (m) 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, m/m. Overland slope refers to the average slope of the land draining to the channel or basin outlet. For example, an 8-m rise occurring over a 100-m length has a slope of 8/100 (rise/run) or 0.08 m/m.

OPTION ONE: SCS Curve Number

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 percent sand/gravel. There is a high infiltration rate of 8 to 11 mm/h.

B - mod. low runoff potential (sand/loam). Sand/loam is defined as shallow loess/sandy loam with a moderate infiltration rate of 4 to 8 mm/h.

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 1 to 4 mm/h.

D - high runoff potential (clay). Clay is defined as a mixture of heavy plastic clay (90 to 100 percent) and certain saline soils that swells significantly when wet. Clay has a very low infiltration rate of 0 to 1 mm/h.

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 635 mm of rain/year.
2 - typical. A typical climate receives 635 to 1270 mm of rain/year.
3 - wet. A wet climate experiences heavy rainfall and water-saturated soil. Over 1270 mm of rain fall each year.

5) cnmbr - OPTIONAL - 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.

OPTION TWO: Kinematic Wave

3) rmngs - Manning's coefficient for the basin. Sample ranges can be from 0.4 to 0.01. The user's best judgment is required to select a reasonable value. Use this parameter for kinematic wave method.

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.[14] This method is limited to watersheds less than or equal to 800 ha 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 and based on research conducted for the Maryland State Highway Administration and the FHWA.[(2)(16)] 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 BAS command is required if using the TCO command with the SCS option. The BAS command is not required if using the kinematic wave option.

5) 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

tc - time of concentration, h.

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: (2 options)

TLG tl << User-Supplied Time Lag

-- OR --

TLG bdf, dhsl, dhln << USGS Regression Formula

OPTION ONE: User-supplied Time Lag

tl - user-supplied time lag, h.

OPTION TWO: USGS Regression Formula

1) 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.
2) dhsl - main channel slope, m/m.
3) dhln - main channel length, m.

Notes:

1) The TLG command must be present in a command string containing the DHY command.

2) If used with FLW option 4, this command supplies the time lag method for deriving the hydrograph.

COMMAND UIT - User-supplied rainfall InTensity

Purpose: To specify the intensity of a 1-h storm of any return period.

Structure:

UIT itc

itc - user-supplied intensity, mm/h.

Notes:

1) The UIT command can be used in any command string in which the RFL command is used or in which the FLW switch is set equal to 1 (Rational method).

2) The TCU command must be used in conjunction with the UIT command.

3) HYDRO considers that the rainfall intensity associated with the UIT command has already been adjusted for return period.

4) The program adjusts the intensity from the 1-h duration to an intensity associated with the time of concentration specified in the TCU command.

5) Neither the RPD or LOC command are necessary in a command string that has the UIT command.

APPENDIX D: REQUIRED FORMAT FOR INTERMEDIATE 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 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
		2X
	Mean areal precipitation	F5.3
	Regional skew coefficient	F4.2
	Regional coefficient of variation	F5.3
	Distribution correction factor	F5.3
	Record length =	111

Required Format for Gage Flow Files (SI)

	VARIABLE DESCRIPTION	FORTRAN FORMAT
RECORD 1:	User's identification (not read)	A73
RECORD 2:	Number (NUM) of years of flow record (NUM)	I5
RECORDS 3-NUM:	Gage flow (m^3/s)	F10.3

Required Format for Gage Flow Files (English)

	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 (ft^3/s)	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

Required Format for Hydrograph Files (SI)

	VARIABLE DESCRIPTION	FORTRAN FORMAT
RECORD 1:	User's identification (not read)	A73
RECORD 2:	Number (NUM) of hydrograph coordinates, (time, flow pairs)	I5
RECORDS 3-NUM:	count, time, flow	F10.0, F10.1, F10.3

Required Format for Hydrograph Files (English)

	VARIABLE DESCRIPTION	FORTRAN FORMAT
RECORD 1:	User's identification (not read)	A73
RECORD 2:	Number (NUM) of hydrograph coordinates, (time, flow pairs)	I10
RECORDS 3-NUM:	count, time, flow	F10.0, F10.1, F10.3

Required Format for IDF Files (SI)

	VARIABLE DESCRIPTION	FORTRAN FORMAT
RECORD 1:	User's identification (not read)	A73
RECORD 2:	Number (NUM) of coordinates, (ret, intnsty pairs)	I5
RECORDS 3-NUM:	ret, intnsty	F10.1, F10.0

Required Format for IDF Files (English)

	VARIABLE DESCRIPTION	FORTRAN FORMAT
RECORD 1:	User's identification (not read)	A73
RECORD 2:	Number (NUM) of coordinates, (ret, intnsty pairs)	I10
RECORDS 3-NUM:	ret, intnsty	F10.1, F10.3

Required Format for Hyetograph Files (SI)

	VARIABLE DESCRIPTION	FORTRAN FORMAT
RECORD 1:	User's identification (not read)	A73
RECORD 2:	Number (NUM) of hyetograph coordinates, (time, intnsty pairs)	I5
RECORDS 3-NUM:	time, intnsty	F10.1 F10.0

Required Format for Hyetograph Files (English)

	VARIABLE DESCRIPTION	FORTRAN FORMAT
RECORD 1:	User's identification (not read)	A73
RECORD 2:	Number (NUM) of hyetograph coordinates, (time, intnsty pairs)	I10
RECORDS 3-NUM:	time, intnsty	F10.1 F10.3

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HYDRAIN - INTEGRATED DRAINAGE DESIGN COMPUTER SYSTEM

VOLUME III. HYDRA - STORM DRAINS

for:

Office of Technology Applications
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Washington, DC

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(Metric Conversion Sheet)

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Volume III, HYDRA

INTRODUCTION

HYDRA is a storm drain and sanitary sewer analysis and design program. This document describes HYDRA and guides the user through the necessary steps toward designing or analyzing stormwater drains and/or sanitary sewer systems. Originally designed and developed in 1975, the HYDRA program ran on mainframe computer systems. The objective of the HYDRA program was to provide hydraulic design engineers a means of accurately, easily and quickly designing and analyzing storm, sanitary or combined collection systems. HYDRA achieved these objectives with a high degree of success, and for this reason, selected for incorporation into the HYDRAIN system. The HYDRAIN version of HYDRA does everything its mainframe-oriented predecessor does, with the same accuracy, ease and quickness. In fact, it offers several improvements over the original version. 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. The user documentation section of this volume describes these interactions in more detail.

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 an 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 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 volume contains three major sections that provide details on HYDRA's methods and operation. The first section provides the user with an overview of HYDRA features and components. The second section deals specifically with the technical methods used 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 and pressure flow methodologies. The inlet routines, the hydraulic gradeline routines, and the pressure flow module were adapted to HYDRA from the stand-alone programs, PAVDRAIN, HGL, and PFSM, respectively.[1, 2, 3] Because the pressure flow module is derived from the EXTRAN module of SWMM, some of the pressurized flow discussion replicates the EXTRAN manual.[4]

The third section provides instruction on how to use HYDRA. The section describes the command line input scheme, and discusses the linkages with the HYDRAIN system and other programs. Three appendixes provide examples, commentary, and a listing of commands.

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 use any feature offered by HYDRA. It is not meant to show every possible type of analysis or situation that HYDRA can handle (however the document provides clear examples of several major types of applications).

This section provides an overview of HYDRA by briefly describing its capabilities and structure. The end of this section includes a key to some of the more frequently used terms and concepts. 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 on which HYDRA can work:

- Storm drain 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**.

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 using the program as a decision-making tool. *HYDRA is a design aid only and is not a substitute for sound engineering judgment.* This being mentioned, the following is a list of some of HYDRA's more useful features:

- *Cost estimation* - Capabilities that allow for consideration of de-watering, 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 the **Rational method** or modeling user-defined hydrographs in a **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.

- *Planning* - Use HYDRA 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.

- *Easy data input structure and quick editing capacity* - All data needed to run HYDRA is in one user-supplied input file, simplifying data editing operations. 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 User Documentation section describes the capabilities of this screen editor and provides instructions for its use.) 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.

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 criterion 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**. (The following section explores these concepts in more detail.) During analysis (program execution), HYDRA checks the command string 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 route to either a printer or screen display. If a run aborts prematurely (before intended analysis is completed), appropriate descriptive error messages are added 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 HYDRA 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 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 appendix C.

- *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 meters. 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. The maximum number of links that can be modeled in a single gravity flow or hydraulic gradeline application is 200 and 50 for a pressure-flow application.

- *Node* - A point where storm, sewage or combined flow can be either injected into or removed from the **system**. The maximum number of nodes that can be modeled in a single gravity flow or hydraulic gradeline application is 200 and 50 for a pressure-flow application.

- *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 storm drain 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.

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, calculating the hydraulic gradeline, and simulating pressure flow.

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:

$$Q = K \times C \times i \times A \tag{1}$$

Where:

Q	=	The peak flow, m^3/s.
K	=	Constant, 0.00276.
C	=	Runoff coefficient.
i	=	The rainfall intensity, mm/h.
A	=	The area of the watershed, ha.

Intended for determining runoff from <u>small</u>, <u>urban</u> 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-yr return period, generally cover a very small area. Applying the high intensity corresponding to a 100-yr 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 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 appendix C 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., $\Sigma\ C \times A$) 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 transport (e.g., **CHA**, **BOX**, **ELP**, **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**".

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 T_c 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.[1, 5] 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.[6]

$$T_c = \frac{3.26 \times (1.1 - C) \times L^{\frac{1}{2}}}{S^{\frac{1}{3}}} \tag{2}$$

Where:

T_c	=	Time of concentration, min.
C	=	The dimensionless runoff coefficient.
L	=	The distance traveled, m.
S	=	The slope, percent.

If the gutter time is to be calculated, a second formula is used:

$$T_c = \frac{L}{K \times S^{\frac{1}{2}}} \tag{3}$$

Where:

T_c	=	Time of concentration, s.
L	=	The distance traveled, m.
S	=	The slope, m/m.
K	=	An empirical coefficient equal to 9.81, m/s.

STORM FLOW: HYDROGRAPHIC ANALYSIS

For situations where a system is to be analyzed or designed using hydrographs, HYDRA provides a means of incorporating one or more hydrographs. Through the use of the **UHY** command, a user may introduce a hydrograph to the drainage system. A single hydrograph may be used to represent runoff from multiple areas or different hydrographs may be employed for each land area. This ability is particularly important for analyzing the effects of storage and surcharging in a drainage system.

Several hydrograph generation techniques are available in the HYDRO program which is also a part of the HYDRAIN computer system. Hydrographs generated by HYDRO are automatically placed in the proper format to be read by HYDRA using the **UHY** command. Information about available hydrograph generation techniques can be found in volume II of this series.

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 liters produced per capita per day, (specified in the **GPC** command), by the number of people per hectares times the number of hectares, (specified in the **SAN** command). Therefore, flow in a given conveyance is calculated as follows:

$$Q_a = \sum (uflow \times pop \times area) \tag{4}$$

Where:

Q_a	=	The average flow, using the first combination, L/d.
uflow	=	The unit flow of generated wastewater, L/cap/d.
pop	=	The equivalent population density, cap/ha.
area	=	The area of sanitary collection, ha.

The flow is internally converted to m^3/s. In most circumstances, it will not be necessary to change the value of **uflow**, reducing the equation to:

$$Q_a = uflow \times \sum (pop \times area) \tag{5}$$

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 liters produced per capita per day. This is expressed as:

$$Q_a = uflow \times \sum (units \times ipu) \tag{6}$$

Where:

Q_a	=	The average flow, using the second combination, L/d.
uflow	=	The unit flow of generated wastewater, L/cap/d.
units	=	The number of dwelling units contributing to the system at each node.
ipu	=	The number of people per dwelling unit.

As with the first combination, flow is internally converted to cubic meters per second.

The decision to use 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 **adf**/**pf factor** ordered pairs.

Each time one of the transport commands, either **PIP**, **BOX**, **ELP**, 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:

$$Q_p = pkfctr \times Q_a \tag{7}$$

Where:

Q_p	=	The peak daily flow, L/d.
pkfctr	=	The peaking factor, resulting from the **flow** versus **factor** curve provided in the **PEA** command.
Q_a	=	The average daily flow, L/d.

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.

HYDRA uses Manning's formula and the continuity equation to evaluate the adequacy of an existing system to analyze imposed flows or to design a new system. Manning's formula empirically calculates open channel, gravity induced velocities:

$$V = \frac{1}{n} \times R_h^{\frac{2}{3}} \times S^{\frac{1}{2}} \tag{8}$$

Where:

V	=	The pipe velocity, m/s.
R_h	=	The hydraulic radius of the flow cross section, m.
S	=	The friction slope (assumed to equal the pipe slope), m/m.
n	=	Manning's friction coefficient for the pipe.

The continuity equation relates flow to velocity and flow area:

$$Q = V \times A \tag{9}$$

Merging equations (8) and (9) yields an equation that empirically calculates flow in an open channel or pipe:

$$Q = \frac{1}{n} \times A \times R_h^{\frac{2}{3}} \times S^{\frac{1}{2}} \tag{10}$$

Where:

Q	=	The pipe flow, m^3/s.
A	=	The area of the flow cross-section, m^2.
R_h	=	The hydraulic radius of the flow cross-section, m.
S	=	The pipe (friction) slope, m/m.
n	=	Manning's friction coefficient for the pipe.

In the design case, this equation is algebraically manipulated to solve for the circular pipe diameter necessary to handle the design flow. HYDRA uses ASTM standard metric sizes in increments of 75 mm for smaller pipes and 150 mm for larger pipes. When designing using English units, circular pipes are between 305 mm and 1220 mm in diameter, and the calculated diameter is rounded up to the nearest 76-mm increment. When the calculated pipe diameter is greater than 1220 mm, it is rounded up to the nearest 152-mm 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 305 mm in diameter for storm sewers and 152 mm for sanitary sewers. The **PSZ** command can be used to list a number of pipe diameters to which the pipe design process must be limited.

Since the hydraulic radius is a function of depth and in most cases the circular pipes will not be carrying capacity flows, this term is expressed as follows:

$$R_h = \frac{D}{4} \times \left[1 - \frac{\sin 2\theta}{2\theta}\right] \tag{11}$$

Where:

D	=	The diameter of the circular pipe, m.
θ	=	Theta, in radians, measured as shown in figure 1.

For horizontal elliptical, vertical elliptical, and box pipes (**ELP** and **BOX**, respectively), HYDRA has the capability of designing both the span and the rise. If the user specifies the span, HYDRA designs the rise.

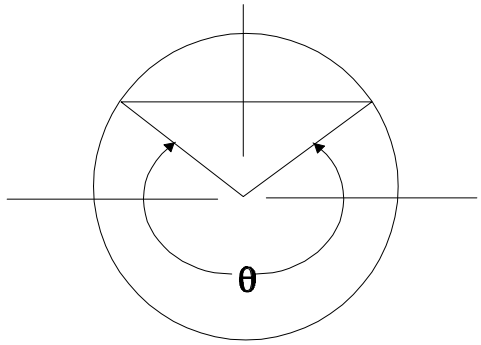

Figure 1. Measurement of θ.[8]

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.[1]

$$Q = \frac{0.38}{n} \times S_x^{\frac{5}{3}} \times S^{\frac{1}{2}} \times T^{\frac{8}{3}} \tag{12}$$

Where:

S_x	=	The roadway cross slope (vertical to horizontal), m/m.
S	=	The longitudinal slope of the gutter (vertical to horizontal), m/m.
T	=	The spread of flow in the gutter, m.
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:

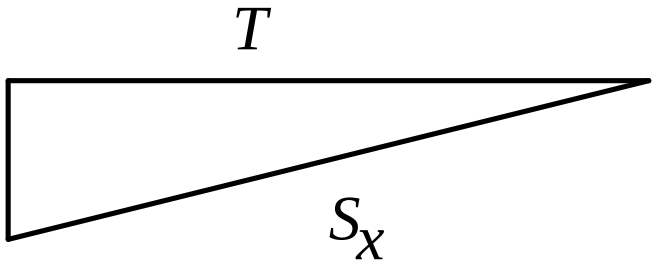

Figure 2. Triangular gutter shape.

The **GUT** command has the same two analysis options as that described for the **CHA** command, and an additional alternative of analyzing composite gutter sections, as shown in figure 3.

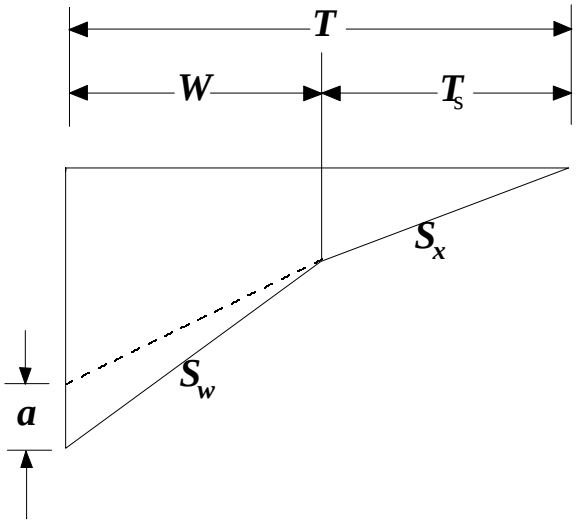

Figure 3. Composite gutter shape.

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 3 mm 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 meters horizontal to meters 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 steady-state (i.e., Rational method, sanitary, or constant flow) simulations. However, in steady-

state simulation runs, the **GUT** command is used only to provide spread, cross slope, velocity, and flow to the **INL** command, whereas, in the hydrographic simulation, the **GUT** command is required.

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**, **BOX**, **ELP**, 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 effect on system flows. It is, therefore, an option in steady-state runs.

The basis for the inlet calculations is the HEC-12 manual "Drainage of Highway Pavements."[(1)] 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 6:

- Grate inlets.
- Curb inlets.
- 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.

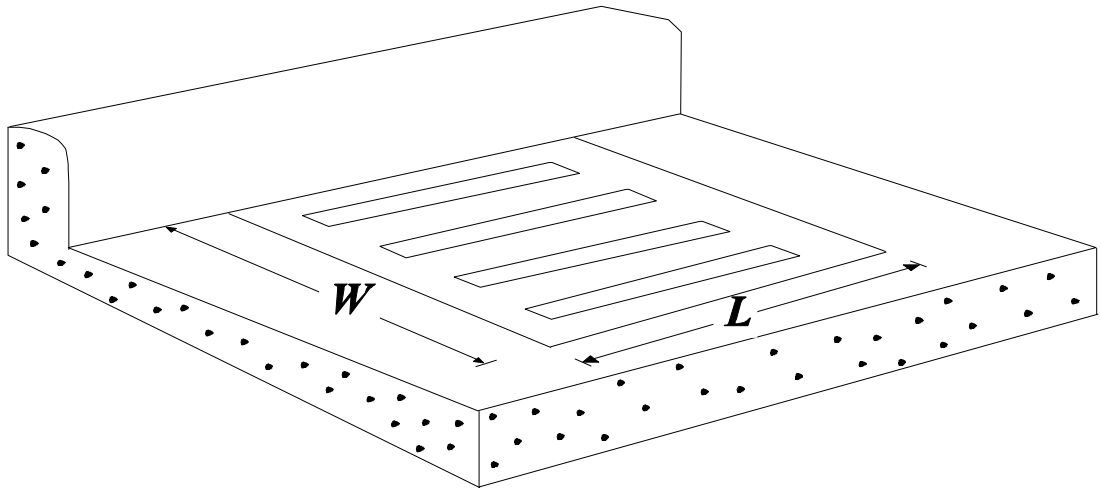

Figure 4. Perspective view of grate inlet.[1]

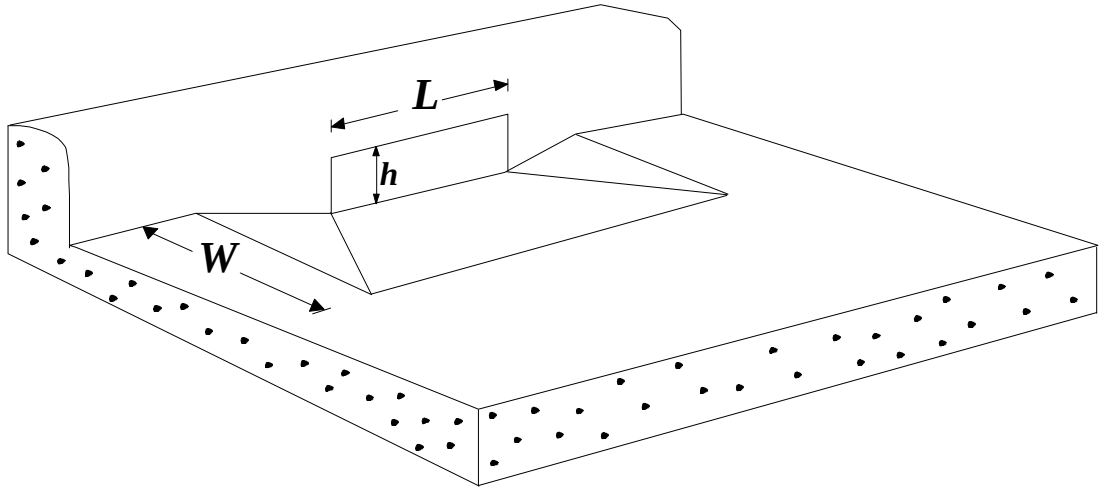

Figure 5. Perspective view of curb inlet.[1]

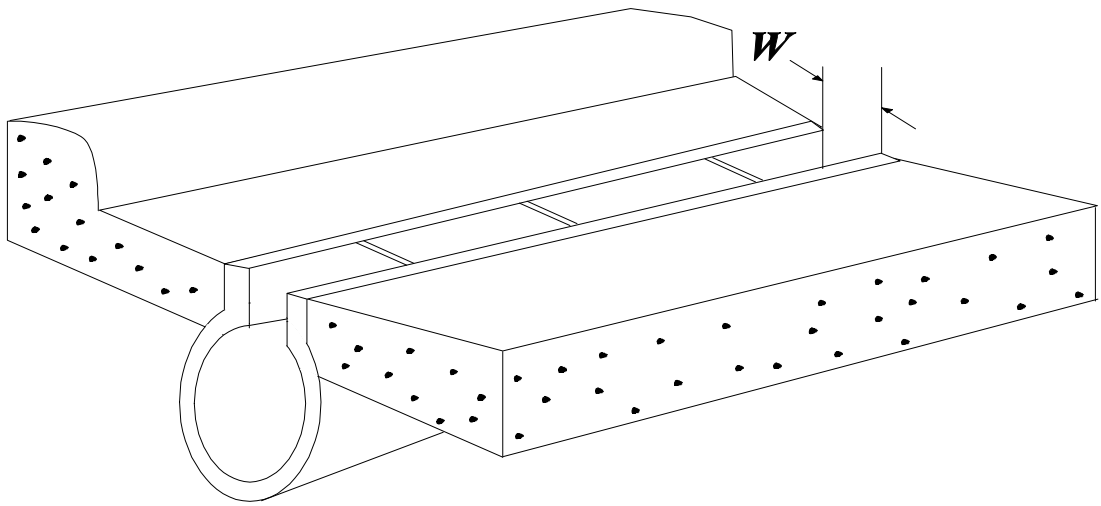

Figure 6. Perspective view of slotted drain inlet.[1]

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):

$$E_o = \frac{Q_w}{Q} = 1 - \left[1 - \frac{W}{T}\right]^{\frac{8}{3}} \tag{13}$$

Where:

Q	=	Total gutter flow, m^3/s.
Q_w	=	Flow in width W, m^3/s.
W	=	Width of depressed gutter or grate, m.
T	=	Total spread of water in the gutter, m.

The ratio of side flow, Q_s, to total gutter flow is:

$$\frac{Q_s}{Q} = 1 - \frac{Q_w}{Q} = 1 - E_o \tag{14}$$

The ratio of frontal flow intercepted to total frontal flow, R_f, or frontal flow efficiency, is calculated by equation (15):

$$R_f = 1 - 0.295 \times (V - V_o) \tag{15}$$

Where:

V	=	Velocity of flow in the gutter, m/s.
V_o	=	Gutter velocity where splash over first occurs, m/s.

The ratio of side flow intercepted to total side flow, R_s, or side flow interception efficiency, is calculated by equation (16):

$$R_s = \frac{1}{\left[1 + \frac{0.083 \times V^{1.8}}{S_x \times L^{2.3}}\right]} \tag{16}$$

Where:

L	=	Length of the grate, m.
S_x	=	Cross slope of pavement, m/m.
V	=	Velocity of flow in the gutter, m/s.

The efficiency, E, of a grate is calculated by equation (17):

$$E = R_f \times E_o + R_s \times (1 - E_o) \tag{17}$$

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:

$$Q_i = E \times Q = Q \times \left[R_f \times E_o + R_s \times (1 - E_o)\right] \tag{18}$$

For the analysis case, equations (13) through (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 length to accept a design flow, on grade, HYDRA iterates through equations (13) through (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 6.10 m. 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 6.10 m, is included as a practical limitation. The design equations are empirical in nature, based on experiments providing design guidance for grates up to 1.20 m in length. While there is no reason to doubt the validity of the design equations for lengths greater than 1.20 m, 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. HYDRA calculates the maximum depth at which weir flow will take place:

$$weir\ \ depth_{\max} = 0.08 + (0.02 \times P) \tag{19}$$

Where:

P = Perimeter of the grate, disregarding bars and the side against the curb, m.

Also calculated is the minimum depth at which orifice flow will occur:

$$orifice\ \ depth_{\min} = 0.265 + (0.013 \times A) \tag{20}$$

Where:

A = Clear opening area of the grate, m^2.

The inlet depth is then compared to the values computed above to determine the governing flow regime. Once this is established, the correct equation can be applied to calculate the capacity of the inlet. For cases where the flow is transitional, i.e., neither weir flow nor orifice flow clearly dominates, the minimum flow computed from the orifice and weir equations is selected.

In analyzing a grate inlet of given dimension, the capacity, assuming the inlet is operating as a weir, is computed as:

$$Q_i = C_w \times P \times d^{\frac{3}{2}} \tag{21}$$

Where:

C_w	=	The weir coefficient (equal to 1.66).
d	=	Depth of water, m.

Since the grate dimensions are known for the analysis condition, the perimeter is computed as 2 × grate width + grate length.

The capacity of a grate inlet operating as an orifice is computed as:

$$Q_i = C_o \times A \times \sqrt{2 \times g \times d} \tag{22}$$

Where:

C_o	=	Orifice coefficient equal to 0.67.
g	=	Acceleration due to gravity equal to 9.81 m/s^2.
d	=	Depth of water, m.

The depth, **d**, must be estimated to use equations (21) or (22). HYDRA assumes that **d** is approximated by the cross slope, $\mathbf{S_x}$, multiplied by the spread, **T**.

The clear opening area of the grate is calculated as the product of the grate width, the grate length, and the opening ratio. The clear opening area, as well as the perimeter, can be overridden 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-degree tilt bars would have a higher opening ratio than the same grate with 45-degree tilt bars. In fact, a 45-degree 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-degree tilt bar subtype is selected in a sump situation, the program uses the opening ratio for a 30-degree tilt bar. The opening ratios used in HYDRA are taken from HEC-12 and are shown in table 1.[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-degree Tilt-bar	0.34
45-degree Tilt-bar	0.00

To design the size of a grate inlet in a sump situation, HYDRA solves equation (21) for the required perimeter and equation (22) for the clear opening area. The type of flow regime is then computed, again by comparing the flow depth to equations (19) and (20), 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:

$$L_T = K \times Q^{\frac{5}{12}} \times S^{\frac{3}{10}} \left[\frac{1}{n \times S_e}\right]^{\frac{3}{5}} \tag{23}$$

Where:

K	=	Coefficient equal to 0.81.
Q	=	Gutter flow, m^3.
S	=	Longitudinal slope (vertical to horizontal), m/m.
n	=	Roughness coefficient.
S_e	=	Equivalent cross slope (vertical to horizontal), m/m.

The equivalent cross slope, S_e, is computed by the following equation:

$$S_e = S_x + S'_w \times E_o \tag{24}$$

Where:

S'_w	=	Cross slope of the gutter measured from the cross slope of the pavement, S_x, computed as a/w or S_w - S_x.
a	=	Inlet depression, m.
w	=	Width of depression, m.
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 or 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.

A weir equation is applicable to depths at the curb less than or equal to the height of the opening plus the depth of depression. HYDRA calculates the interception capacity of a depressed curb opening inlet in a sag or sump as:

$$Q_i = C_w \times (L + 1.8 \times W) \times d^{\frac{3}{2}} \tag{25}$$

Where:

C_w	=	Weir coefficient (equal to 1.27).
L	=	Length of curb opening, m.
W	=	Lateral width of depression, m.
d	=	Depth at curb measured from the normal cross slope, m.

Curb-opening inlets operate as orifices at depths greater than approximately 1.4 times the height of the curb opening. The orifice equation for curb-opening inlets is used for d greater than h and is calculated by:

$$Q_i = C_o \times h \times L \times \sqrt{2 \times g \times d_o} \tag{26}$$

Where:

C_o	=	Orifice coefficient (equal to 0.67).
h	=	Height of curb-opening inlet, m.
d_o	=	The effective head on the center of the orifice throat, m.
L	=	Curb-opening inlet length, m.

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 (25) or (26) as is appropriate.

Slotted Inlets

Slotted inlets, as shown in figure 6, 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 61 mm, depending on the slot width and length. For these, the following condition applies:

$$Q_i = C_w \times (L + 1.8 \times W_s) \times d^{\frac{3}{2}} \tag{27}$$

Slotted inlets in sag locations perform as orifices at depths greater than about 122 mm. The interception capacity of a slotted inlet operating as an orifice is computed by equation (28):

$$Q_i = C_o \times L \times W_s \times \sqrt{2 \times g \times d} \tag{28}$$

Where:

C_o	=	Orifice coefficient (equal to 0.8).
W_s	=	Width of slot, m.
L	=	Length of slot, m.
d	=	Depth of water at slot, m.

g = Acceleration due to gravity equal to 9.81 m/s^2.

For transitional flow depths (between 61 mm and 122 mm), equation (28) 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 three 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 nonstandard inlet type. This curve is consulted to determine what percentage of the flows generated by HYDRA are accepted into the inlet.

INLET BYPASS

When gutter flow arriving at the inlet exceeds the inlet capacity, there is an excess in flow, or bypass flow. This bypass flow can be captured at another point downstream in the system for both the hydrographic and peak flow simulations. The combination of the **store** parameter (**INL** command) and the **GET** command accomplish this application of storing the bypass flow to a register and retrieving the bypass flow, respectively. The **GUT** command must immediately follow the **GET** command in a bypass flow application. However, in the case of the peak flow analysis, the system flow is not affected by a bypass flow simulation (i.e., even though, theoretically, the inlet does not have the capacity to convey all of the gutter flow through the inlet and into the system transporter, the model assumes all of the flow does enter the system). In the context of the peak flow analysis, bypass flow is only an instrument to evaluate inlet efficiency.

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 **UHY**, **GET**, or **GUT** commands. The user has two options; to determine the:

1. Necessary pond capacity given a maximum outflow.
2. Maximum outflow given a pond capacity.

For option number 1, hydrographic flows exceeding the specified outflow are stored. These flows accumulate over the length of the hydrograph. The product of the excess flow and the time step yields the volume for each time step. The summation is equal to the required pond capacity. This approach assumes that all the excess flow volume can be stored.

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 effect on the hydrograph.

The **RES** command allows the user to study the effects 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.
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 (modified Puls) routing method.[9] 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:

$$\Delta s = \left[\frac{I_i + I_j}{2} - \frac{O_i + O_j}{2} \right] \times \Delta t \qquad (29)$$

Where:

Δs	=	The change in storage, m^3.
I_i	=	The inflow at the beginning of the time step, m^3/s.
I_j	=	The inflow at the end of the time step, m^3/s.
O_i	=	The outflow at the beginning of the time step, m^3/s.
O_j	=	The outflow at the end of the time step, m^3/s.
Δt	=	Time step, s.

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.
(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:

$$cost = \sum \left(X_i \times U_i \right) + lcost \tag{30}$$

Where:

cost	=	The cost associated with the sanitary sewer or storm drain project, 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, dollars per item or quantity.
lcost	=	Lump sum costs (e.g. inlets, pumps), 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**, **ELP**, and **BOX** commands 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**, **PIP**, **BOX**, and **ELP** 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** or node type of **2** in the relevant **PNC** command. If a node width of **0** or a node type of **2** 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.

Minor losses are calculated for both manholes and pipe junctions. A pipe junction is the connection of a lateral pipe to a larger trunk pipe without the use of a manhole structure. For adjoining pipes to be considered a pipe junction, the node type must be specified as **1** on the **PNC** command and only two inflow pipes (a lateral and a trunk) may enter the junction (for more than two pipes, the manhole loss equations are employed). The minor loss equation for a pipe junction is a form of the momentum equation:

$$H_j = \frac{Q_o \times V_o - Q_i \times V_i - Q_l \times V_l \times \cos\theta}{0.5 \times g \times (A_o + A_i)} + h_i - h_o \qquad (31)$$

Where:

H_j	=	Junction head loss, m.
Q_o, Q_i, Q_l	=	Outlet, inlet, and lateral flows, respectively, m^3/s.
V_o, V_i, V_l	=	Outlet, inlet, and lateral velocities, respectively, m/s.
h_o, h_i	=	Outlet and inlet velocity heads, m.
A_o, A_i	=	Outlet and inlet cross-sectional areas, m^2.
θ	=	Angle of lateral with respect to centerline of outlet pipe, degrees.
g	=	Gravitational acceleration, 9.81 m/s^2.

MINOR LOSS: HYDRAULIC GRADELINE ANALYSIS

The hydraulic gradeline analysis through a manhole focuses on the calculation of the energy loss from the inflow pipes to the outflow pipe.[12] A water depth in the manhole is estimated using an iterative procedure. Subsequently, the energy losses for each inflow pipe may be computed using the manhole depth and discharge.

The hydraulic gradeline methodology starts with equation (32) which describes the energy loss for an inflow pipe:

$$\Delta E = K_I \frac{V_o^2}{2g} \tag{32}$$

The methodology is completed by using the determining factors yielded from a dimensional analysis to predict K_I for a given physical configuration and hydraulic loading:

$$K_I = (C_1 \; C_2 \; C_3 + C_{4_i})\omega \tag{33}$$

Where:

K_I	=	Composite energy loss coefficient for an inflow pipe.
C_1	=	Coefficient related to relative manhole size.
C_2	=	Coefficient related to water depth in the manhole.
C_3	=	Coefficient related to lateral flow, lateral angle, and plunging flow.
C_{4_i}	=	Coefficient related to relative pipe diameters.
ω	=	Correction factor for benching.

Equations (32) and (33) are combined to yield the following equation:

$$\Delta E_I = (C_1 \; C_2 \; C_3 + C_{4_i})\omega \frac{V_o^2}{2g} \tag{34}$$

Determining Factors

Several determining factors affect the computation of the energy loss coefficient in the HGL methodology. They are the manhole size relative to the outlet pipe diameter, depth in the manhole, amount of inflow, inflow angle, plunge height, relative pipe diameter, and floor configuration. Empirical equations for each of these determining factors are developed from analysis of data collected by Chang.[12]

Relative manhole size

The role of relative manhole diameter (manhole diameter/outlet pipe diameter, b/D_o) is evaluated using data having a single inflow pipe at the same invert as the outflow pipe representing straight-through flow. The energy loss coefficient, in this case, increases with relative manhole size. The larger the manhole is relative to the outlet pipe, the greater the space and time are for the flow to expand and dissipate the velocity head. Similarly, the greater the expansion into the manhole, the greater the energy losses in contracting to leave through the outlet pipe. According to Marsalek, the energy loss coefficient is unaffected by changes in relative manhole diameter within the range of $2 \leq b/D_o \leq 6$. Sangster's study showed that the energy loss coefficient is more affected in the range of $b/D_o < 3$.[11,13] The proposed formulation for this methodology is that for b/D_o values up to 4.0, the coefficient related to manhole size, C_1, is calculated with the following equation:

$$C_1 = \frac{0.9\left[\frac{b}{D_o}\right]}{\left[6 + \frac{b}{D_o}\right]} \tag{35}$$

Where:

b = Manhole diameter, m.
D_o = Outflow pipe diameter, m.

The data from Sangster and Marsalek suggest that the relationship between the coefficient C_1 and the relative manhole diameter, b/D_o is nearly linear up to the point where b/D_o is approximately 4.0. Beyond this value, the relative manhole diameter has no effect on the head loss coefficient, C_1. Once the manhole diameter is four times the outlet pipe diameter, or larger, the manhole is "large" and the coefficient C_1 is assumed to be a constant equal to 0.36.

Water depth in the manhole

The coefficient, C_2, related to manhole water depth, increases rapidly with relative water depth, d_{mH}/D_o, up to 2. The rate of the increase slows when d_{mH}/D_o reaches approximately 3. This type of curve can be expressed as a third order polynomial. Equation (36) applies for $d_{mH}/D_o \leq 3$. When d_{mH}/D_o is greater than 3, C_2 is equal to 0.82. The following equation was found to fit the data reasonably well:

$$C_2 = 0.24 \left(\frac{d_{mH}}{D_o} \right)^2 - 0.05 \left(\frac{d_{mH}}{D_o} \right)^3 \tag{36}$$

Where:

d_{mH} = Depth in the manhole relative to the outlet pipe invert, m.

Multiple inflows

The coefficient related to multiple inflows, C_3, is the most complex term in the composite energy loss coefficient equation. The effect of lateral flows on the energy loss were studied with respect to three parameters: flow rate, connecting angle of the inflow pipe, and elevation of the inflow pipe. To select the form of the equation, the data were first plotted in groups according to the above three parameters to observe the variations in energy losses. The data are quite scattered because of air entrainment and turbulence. This was particularly true for plunging flows discharging into shallow water depths in the manhole. Based on the analysis, the following equation can be used to calculate the coefficient C_3.

$$C_3 = \text{Term 1} + \text{Term 2} + \text{Term 3} + \text{Term 4} + \text{Term 5} \tag{37}$$

Where:

Term 1 = 1

Term 2 = $$\sum_{i=1}^{4} \left(\frac{Q_i}{Q_0} \right)^{0.75} \left[1 + 2 \left(\frac{Z_i}{D_0} - \frac{d_{mH}}{D_0} \right)^{0.3} \left(\frac{Z_i}{D_0} \right)^{0.3} \right]$$

Term 3 = $$4 \sum_{i=1}^{3} \frac{(Cos\theta_i)(HMC_i)}{\left(\frac{d_{mH}}{D_0} \right)^{0.3}}$$

Term 4 = $$0.8 \left| \frac{Z_A}{D_0} - \frac{Z_B}{D_0} \right|$$

$$\text{Term 5} \quad = \quad \left| \left(\frac{Q_A}{Q_0} \right)^{0.75} Sin\theta_A + \left(\frac{Q_B}{Q_0} \right)^{0.75} Sin\theta_B \right|$$

$$HMC_i = \left[0.85 - \left(\frac{Z_i}{D_o} \right) \left(\frac{Q_i}{Q_o} \right)^{0.75} \right] \tag{38}$$

and:

Q_0	=	Total discharge in the outlet pipe, m^3/s.
Q_1, Q_2, Q_3	=	Pipe discharge in inflow pipes 1, 2 ,and 3, m^3/s.
Q_4	=	Discharge into manhole from the inlet, m^3/s.
Z_1, Z_2, Z_3	=	Invert elevation of inflow pipes 1, 2, and 3 relative to the outlet pipe invert, m.
Z_4	=	Elevation of the inlet relative to the outlet pipe invert, m.
D_0	=	Outlet pipe diameter, m.
b	=	Manhole diameter, m.
d_{mH}	=	Depth in the manhole relative to the outlet pipe invert, m.
$\theta_1, \theta_2, \theta_3$	=	Angle between the outlet main and inflow pipes 1, 2, and 3, degrees.
HMC_i	=	Horizontal momentum check for pipe i.
Q_A, Q_B	=	Pipe discharges for the pair of inflow pipes that produce the largest value for term 4, m^3/s.
Z_A, Z_B	=	Invert elevation, relative to outlet pipe invert, for the inflow pipes that produce the largest value for term 4, m.

The coefficient, C_3, takes into consideration losses due to inlet flow plunging by incrementing the number of inflows to four. The fourth inflow pipe is synthetic and accounts for inlet plunging. A corresponding angle is set to zero. Conceptually, as angles deviate from 180 degrees (straight-line flow) to 0 or 360 degrees, the associated loss increases because the skewed inflow prevents the main flow from smoothly transitioning to the outlet pipe. **All angles are represented between 0 and 360 degrees for this equation and are measured clockwise from the outlet pipe** as illustrated in Figure 7.

A pipe has plunging flow if the critical flow depth elevation ($y_c + Z_i$) in the pipe is higher than the manhole depth elevation ($d_{mH} + Z_o$). For a simple two-pipe system with no plunging flow, C_3 is assumed to be equal to 1.0.

The second term in equation (37) captures the energy losses from plunging inflows. This term reflects the fact that flows plunging from greater heights result in greater turbulence and, therefore, higher energy losses. As shown by the summation in the second term, the computation is valid for one to three inflow pipes and plunging flow from the inlet.

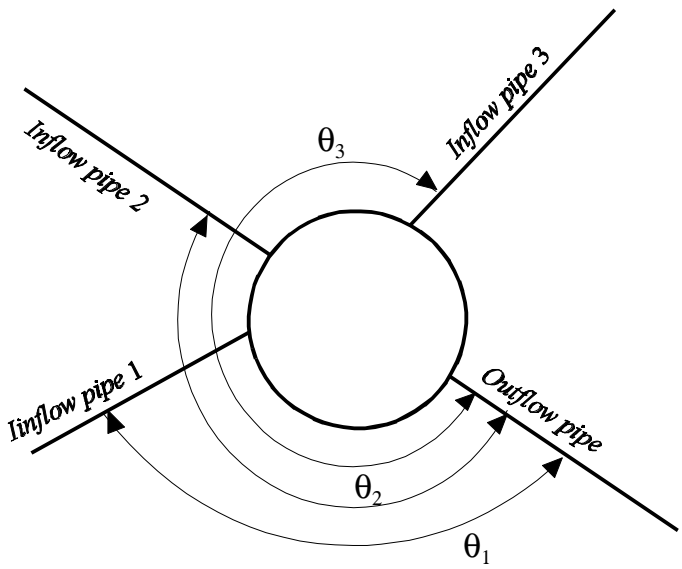

Figure 7. Convention of angle of deflection.

The third term reflects the effects the angle (with respect to the outflow pipe) has on energy losses. For inflows at a given invert (Z_i) and relative discharge (Q_i / Q_0), the cosine function provides for a higher energy loss coefficient when the inflow opposes ($\theta \leq 90$ degrees or $0 \geq 270$ degrees) the main inflow. If the horizontal momentum check (HMC_i) is less than 0, the flow is falling from a height such that the horizontal momentum is assumed to be negligible and term 3 is set to 0. Since surface flow is free-falling and has no horizontal momentum, it is not included in term 3 calculations.

The invert elevation, manhole depth, and relative inflow are also included in the third term to capture extremely complex interactions. For a 135-degree skewed plunging flow, for example, the velocity component of the flow in the main flow direction increases which results in lower energy losses because the momentum is predominantly in the direction of the outflow pipe. But, a higher flow velocity creates higher turbulence, thereby increasing the energy loss. If the skewed pipe is raised further so that the flow hits the opposite wall of the manhole during the fall, a different situation develops. The plunging flow dives along the manhole wall and moves in the opposite direction as the flow reaches the manhole bottom. The velocity component of the flow at the manhole bottom is then in the opposite direction it entered reversing the energy loss effect. In cases where water depth in the manhole is significant, the velocity of the diving flow will be reduced.

When more than one inflow pipe exists, HYDRA computes the fourth term for all combinations of inflow pipes that have an HMC_i greater than zero. HYDRA then uses the pipes that produce the highest fourth term value to calculate the fourth and fifth terms. If there are at

least two inflow pipes with positive HMC_i values, the third, fourth, and fifth terms are calculated; otherwise they are assumed to be zero.

Inspection of the fourth and fifth terms of equation (37) reveals that if two inflow pipes enter a junction manhole 180 degrees apart from one another, with equal discharges, and at the same invert elevation, they both reduce to zero. This means that opposing inflow pipes tend to neutralize, to a degree, the turbulence each would cause individually. For cases where discharge, angle, and/or elevation are different, additional energy losses occur.

Application limits for equation (37) with plunging flow ranges from 1.0 (no lateral flow) to 10.0. The predicted C_3 coefficient increases dramatically as the height of the plunging inflow increases.[12] In reality, the estimate of the C_3 coefficient from the empirical data does increase at higher plunge heights, but the data are very scattered. In other words, the empirical data does not support the dramatic upward trend that equation (37) predicts at higher plunge heights. Therefore, the chosen upper limit of 10.0 is a realistic ceiling for plunging flow.[14]

Relative pipe diameters

Although no experiments were performed with different pipe diameters in this study, a correction for such a case is required in the hydraulic gradeline analysis. Equation (39) was theoretically derived based on conservation of momentum and is proposed for this purpose. Since the C_4 term represents an exit loss from each inflow pipe, it is calculated for each pipe that does not have plunging flow. C_{4i} is assumed to be zero for pipes with plunging flow ($Z_i + yc_i > Z_o + d_{mH}$). Each loss is unique to each inflow pipe and does not affect any other inflow pipes.

$$C_{4i} = 1 + \left[\left(\frac{Q_i}{Q_o} + 2\,\frac{A_i}{A_o}\cos\theta_i\right)\frac{V_i^2}{V_o^2}\right] \tag{39}$$

Where:

A_i, A_o = Cross-sectional area of inflow and outflow pipes, m^2.
θ_i = Angle between outflow pipe and inflow pipe i, degrees.

If θ_i for any pipe is less than 90 degrees or greater than 270 degrees, ($\cos\theta_i$) is replaced with 0 in equation (39). This sets the maximum exit loss to be the incoming velocity head. The derivation of equation (39) followed theoretical derivation presented by Sangster, but Sangster's expression, which was used in earlier versions of HYDRA, was limited to a two-pipe system with pipes flowing full at 180-degree angles.

Equation (39) is consistent with Sangster's findings and is a more generalized form of the equation. A higher loss coefficient for pipe diameter reflects increasingly constricted flow in the

inlet pipe for a given outlet pipe diameter and velocity head. Energy lost as a result of differing pipe diameters is significant only in pressure flow situations when the depth in the manhole is greater than the outlet pipe diameter. The upper limit of C_4 used in HYDRA is 9.0.

Floor configuration

Manhole benching affects head loss because the bending channels guide the flow smoothly into the outlet pipe reducing disturbance in the flow. The reduction in the head loss is dictated by the type and extent of benching. The reduction of head loss is greater when all incoming flow is smoothly reflected by the benching facility.

Marsalek tested three types of benchings, exhibited in figure 8, that are commonly used in drainage practice. One type is a half benching for which the lower half of the pipe extends through the junction and horizontal benches are extended from the semi-circular channel to the junction wall. In the plan view, the channel axis follows a 90-degree segment of a circle with a radius equal to one half of the manhole diameter. The second type is a full benching which is an improved variation on the half benching obtained by extending the mold side wall to the pipe crown elevation. The third type is an improved variation of the full benching which adds smooth transition sections to the inflow and outflow pipes. The inflow was gradually enlarged 30 percent in diameter and then smoothly contracted into the outflow pipe.

His test data showed that the half and the full benchings reduced head losses by 5 percent and 25 percent, respectively, for pressure flows. For free-surface flows, the reductions were 85 percent and 93 percent, respectively. The improved full benching experienced a reduction rate of 60 percent for the pressurized flows and nearly 100 percent for the open-channel flows. It is no surprise that the reduction rates were different for these flows. The water depths were shallow for the free-surface flow, and thus, all or most of the flows were confined within and guided through the molded channel smoothly. For the pressure flow, the water in the manhole was deep, and the incoming flow was not totally confined and allowed to expand upward, causing agitation. Therefore, the energy-loss reductions were not as significant. The final selection of the type of benching depends on economics. There will be a substantial reduction in the head loss for the improved benching, however, a question of the additional cost required should be addressed in making the final decision. For half benching, or even for full benching, the improvement as related to the reduction in the head losses of 5 percent or 25 percent may not be sufficient to override the extra cost required to mold the bench.

In practice, the correction factors obtained from Marsalek's data and shown in table 2 may be used. The correction factors, ω, should be multiplied by the head-loss coefficient for a manhole with a flat floor. For conditions that are between clear pressure flow ($d_{mH} / D_o > 3.2$) and clear free-surface flow ($d_{mH} / D_o < 1.0$), a linear interpolation is an appropriate approximation.

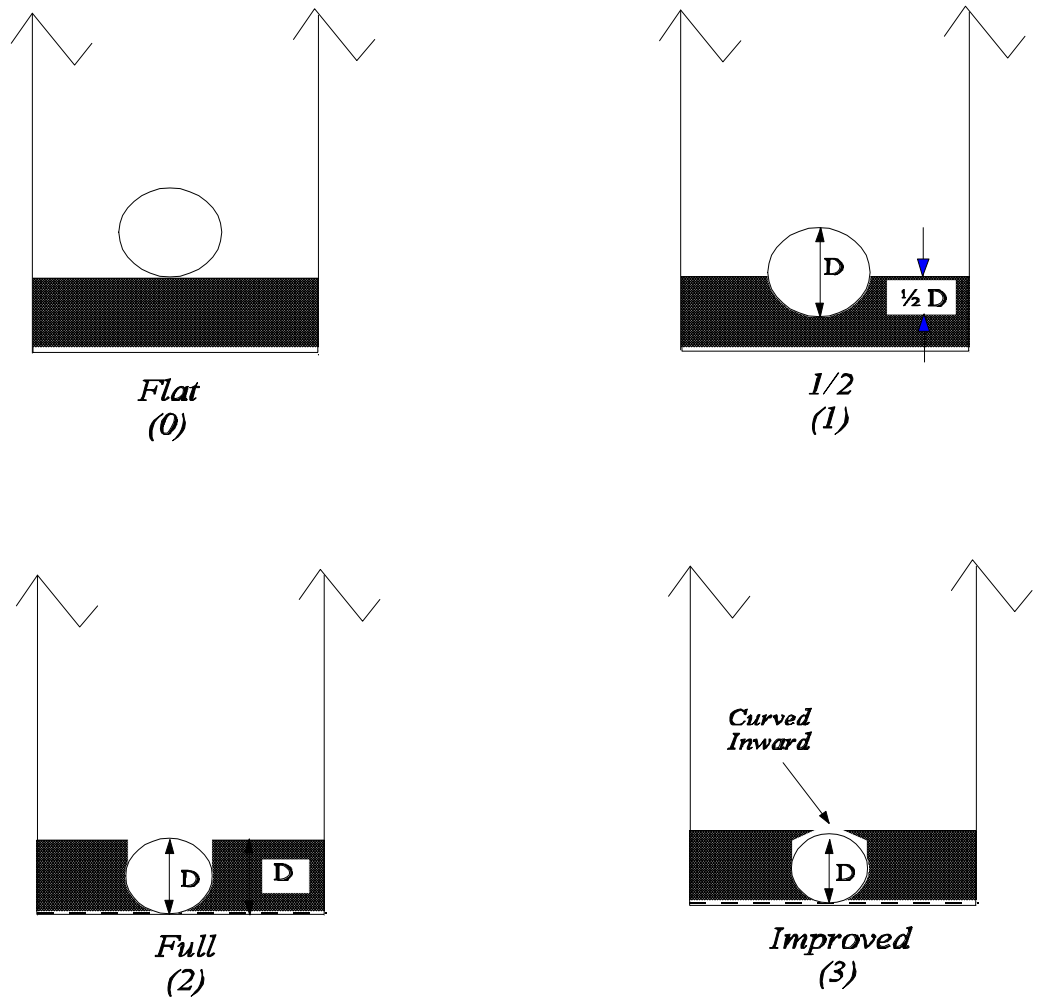

Figure 8. Schematic representation of benching types.

Table 2. Correction factors, ω, for benching.

	Bench Submerged*	Bench Unsubmerged**
Flat Floor	1.0	1.0
Benched one-half pipe diameter high	0.95	0.15
Benched one pipe diameter high	0.75	0.07
Improved	0.40	0.02

* pressure flow, $d_{mH} / D_0 > 3.2$

** free-surface flow, $d_{mH} / D_0 < 1.0$

APPLYING THE METHODOLOGY

The methodology developed can be applied by determining the estimated energy loss through a junction manhole given a set of physical and hydraulic parameters. Computation of the energy loss allows for the determination of the hydraulic gradeline upstream of the manhole to be analyzed. After the depth in the manhole is determined, the HGL for the inflow pipes are computed.

The user should note that this methodology applies to subcritical flow in pipes. When pipes are flowing supercritical, the HGL computations can be excessively high. This occurrence is due to the iterative solution of the depth in the manhole and the assumption that the downstream manhole depth is the hydraulic control. For pipes that are supercritical, the HGL computations assume critical depth in the pipe and the profile computations continue upstream.

Solving for Manhole Depth

To determine the depth in the manhole, an iterative procedure must be applied in computing the energy loss because the manhole depth is a function of C_2 and C_3, which, in turn, are functions of d_{mH} (which is unknown).

$$d_{mH} = HGL_o + \frac{V_o^2}{2g} + C_1 C_2 C_3 \, \omega \, \frac{V_o^2}{2g} - Z_o \tag{40}$$

Where:

HGL_o	=	Hydraulic gradeline at the upstream end of the outlet pipe, m.
Z_o	=	Invert elevation of outlet pipe at upstream end, m.

As an initial estimate of d_{mH}, the following equation is used:

$$d_{mH} = HGL_o + C_1 \omega \, \frac{V_o^2}{2g} - Z_o \tag{41}$$

Use of C_1 as that initial estimate is reasonable since it is independent of d_{mH}; calculation of C_2 and C_3 proceed according to the appropriate equations. Equation (40) is applied to determine a manhole depth. The computed d_{mH} value is compared to the prior estimate, and the procedure is repeated until these two values converge. If the junction manhole configuration has only one inflow pipe that is not plunging, d_{mH} may be directly calculated.

Computation of the HGL for inflow pipes

Once the manhole depth is calculated, the computed junction loss, ΔE, is applied so that the hydraulic gradeline in the inflow pipe(s) may be computed. The hydraulic gradeline at the downstream end of the inflow pipe is assumed to be the greatest value from equations (42), (43), and (44).

$$HGL_i = d_{mH} + Z_o \tag{42}$$

$$HGL_i = Z_i + d_i \tag{43}$$

$$HGL_i = HGL_o + \Delta E_i \tag{44}$$

Where:

HGL_I = Hydraulic gradeline at the outlet of inflow pipe, i, m.
Z_i = Invert elevation at the outlet of inflow pipe, i, m.
d_i = Normal depth (subcritical pipe) or critical depth (supercritical pipe) of pipe, i, m.

PRESSURE FLOW SIMULATION

Using HYDRA, a user may simulate performance of a system under pressurized (surcharged) flow conditions. This dynamic analysis methodology allows consideration of the effects of pipe storage and pressure surcharges in the system response to a hydrograph. Such a dynamic analysis requires additional information from the user, but for some drainage systems, may demonstrate that a system will perform adequately when more conservative steady-state approaches will not. The pressure flow computations, like the HGL computations, use a link-node description to represent the physical system.[4] Hence, the **PIP**, **ELP**, **BOX**, and **PNC** commands, once again, provide information concerning pipe-node connectivity and characteristics. The system's outfall assumes a tailwater elevation, either specified by the user on the **TWE** command or the default value, the downstream invert of the outlet pipe.

The pressure flow simulation can be initiated for systems modeled with hydrographic flow, using **UHY**, or steady-state flow, employing **STO**. Hydrographic flow is accepted into the system at a junction by way of an inlet using the **INL** command. However, the Rational method flow from the **STO** command can be introduced into the system at a junction with or without the use of the **INL** command.

Associated with the pressure flow computations are five additional commands: the pressure flow simulation command, **PFS**; the initial depth command, **IDY**; the initial flow and velocity command, **IQV**; the pipe flow print command, **PFP**; and the junction head print command, **PHJ**. The **PFS** command initiates the computations and establishes the flow control parameters. The optional initial condition commands, **IDY** and **IQV**, introduce the depths and flows and velocities, respectively, at the start of simulation. The print commands, **PFP** and **PHJ**, provide the user detailed output of specified pipe and junction results, respectively.

The pressure flow module recognizes the pipe-node connectivity of a system such that pipes transmit flow from one node to another node. These pipes have the following properties: roughness, length, cross-sectional area, hydraulic radius, and surface width. The last three properties are dependent on the instantaneous depth of flow.[4] The primary dependent variable in the pipes is the discharge, **Q**. It is assumed that **Q** is constant throughout the entire link during a computational time step, while velocity and the cross-sectional area of flow may vary within the link.

Nodes are the storage elements of the system and correspond to manholes or conduit junctions in the physical system. The variables associated with a node are volume, head, and surface area. The primary dependent variable is head, **H**, assumed to be constant within each node during a computational time step. Inflows, such as inlet hydrographs, and outflows take place at the nodes of the conveyance system. The volume of water in a node is the sum of the water volume in the half-pipe lengths connected to that node. The change in nodal volume during a given time step, Δt, is converted to a head change and is used to calculate new discharges in connected links.

Theory

The flow in a storm drain or sanitary sewer system follows the physical principles of conservation of mass, momentum, and energy. The basic differential equations for sewer flow are obtained from the gradually varied, unsteady flow equations for open channel flow:[4]

$$\frac{\partial Q}{\partial t} = -g \times A \times S_f + 2 \times V \times \frac{\partial A}{\partial t} + V^2 \times \frac{\partial A}{\partial x} - g \times A \times \frac{\partial H}{\partial x} \qquad (45)$$

Where:

Q	=	Discharge in pipe.
t	=	Time.
x	=	Longitudinal distance.
V	=	Velocity in pipe.
A	=	Cross-sectional flow area.
H	=	Hydraulic head.
S_f	=	Friction slope.

The friction slope is defined by Manning's equation:

$$S_f = \frac{n^2}{2.22 \times A \times R_h^{\frac{4}{3}}} \times Q \times |V| \tag{46}$$

Where:

R_h	=	Hydraulic radius.
n	=	Manning's roughness coefficient.

Use of the absolute value sign on the velocity term makes S_f a directional quantity and ensures that the frictional force always opposes the flow. The other quantities are as defined earlier.

HYDRA accounts for junction loss by modifying Manning's n. Sources have recommended the manipulation of Manning's **n** to correct the omission of junction losses. It would be erroneous for a user to estimate a single value of n for a junction because of the dynamic nature of the flows and losses. However, the program incorporates the instantaneous junction loss into Manning's n.[11]

Since the flows coming into a junction are known, the junction loss (H_{jl}) can be determined for that junction (the HGL routine is used here). The pipe friction losses (S_f) can be determined using the original value of Manning's n. These two losses can be combined and a new value of the friction slope, (S^*_f), can be found as shown in equation (47). Next, a new value of n* can be found for the pipe downstream of the junction using equation (48).[15]

$$S_f^* = \frac{S_f L + H_{jl}}{L} \tag{47}$$

$$n^* = \sqrt{\frac{Sf^* \times 2.22AR^{\frac{4}{3}}}{Q_{|}V_{|}}} \tag{48}$$

This scenario would have the junction loss spread across the length of the outflow pipe, instead of at the junctions. However, the junction elevations would be more accurately predicted than when junction loss is not included. Figure 9 illustrates how HYDRA with the modified **n** hydraulic gradeline would compare to the actual gradeline. One disadvantage to this method is that when the pipe is not flowing full, the water surface in the pipe will be predicted slightly higher than it actually is to account for junction loss. This would tend to add storage to the pipes and attenuate the peak flows. But this would not be so during pressurized flow. The amount of junction loss would not be as great during unpressurized flow; thus the overestimate of the water surface would be small, and therefore should not cause a problem.

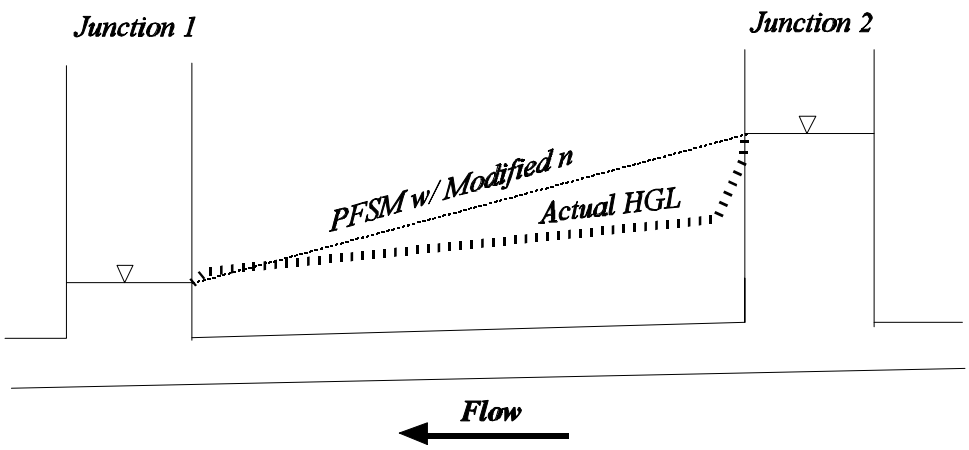

Figure 9. Sample comparison of actual HGL and modified PFSM gradeline.[15]

Considering the entire sewer length as a single computational reach allows derivation of the finite difference form of equation (46). The equation is written in backward time difference between time **n+1**, and time **n**, for the sewer. It is expressed explicitly as:

$$Q_{n+1} = \frac{\left[Q_n + 2 \times \overline{V_n} \times \left(\overline{A_{n+1}} - \overline{A_n}\right) \times \overline{V_n^2} \times \left[\frac{A_{u,n} - A_{d,n}}{L}\right] \times \Delta t - g \times \overline{A_n} \times \left[\frac{H_{u,n} - H_{d,n}}{L}\right] \times \Delta t \right]}{\left[1 + \frac{g \times n^2 \times \Delta t}{2.22 \times \overline{R_h}^{\frac{4}{3}}} \times |\overline{V_n}| \right]} \tag{49}$$

All the symbols above are as previously defined. The subscript **u** denotes the upstream end of a conduit (i.e., entrance) and **d** denotes the downstream end (i.e., exit). The values:

$\overline{V_n}$, $\overline{A_n}$, $\overline{A_{n+1}}$, and $\overline{R_h}$ represent average values at the entrance and exit.

The solution also requires specification of the continuity equation at each junction. The continuity equation for a constant cross-sectional storage junction is written as:

$$\sum Q_i + Q_j = A_j \times \frac{dH}{dt} \tag{50}$$

Where:

Q_i	=	Flow into or out of junction by pipe **i**.
Q_j	=	Time-varied inflow or overflow (outflow) at junction **j**.
A_j	=	Surface area of junction **j**.
H	=	Hydraulic head.

Within the pressure flow simulation, all storage is considered to take place at the junctions. Therefore, water physically located in a pipe must be allocated to the junction at either end. Therefore, the surface area, $\mathbf{A_j}$, of a junction is not the actual surface area of the manhole, **j**, but the surface area of half of the links connected at junction, **j**.

The continuity equation, equation (50), can be expressed in finite difference form in terms of head:

$$H_{n+1} = H_n + \frac{\Delta t}{A_j} \times \left[\Sigma Q_{i,n} + Q_{j,n}\right] \tag{51}$$

Equations (49) and (51) are solved alternately using a modified Euler method. The modified Euler method employs half-step and full-step calculations.

Time Step Selection

Accurate solution of equations (49) and (51) require proper selection of a time step, Δt. From a practical standpoint, pressure flow computations are numerically stable when stability criteria are met for all pipes and junction. The criteria are:

$$Pipe: \quad \Delta t \le \frac{L}{\sqrt{g \times D}} \tag{52}$$

$$Junction: \quad \Delta t \le \frac{C' \times A_s \times H_{\max}}{\Sigma Q_i + Q_j} \tag{53}$$

Where:

Δt	=	Time step.
L	=	Pipe length.
C'	=	Dimensionless constant (0.1).
D	=	Pipe diameter.
H_{max}	=	Maximum water-surface level.
A_s	=	Corresponding surface area of junction.
Q_i	=	Flow into or out of junction by pipe **i**.
Q_j	=	Time-varied inflow or overflow (outflow) at junction **j**.
g	=	Acceleration due to gravity.

Examination of equations (52) and (53) reveals that the maximum allowable time step, Δt, is determined by the shortest, smallest pipe having high inflows. In many applications, 15- to 30-s time-steps are numerically adequate. The user must carefully consider the link and junction geometry, the inflow hydrographs, and total simulation time in selecting time steps.

Surcharge and Flooding

The occurrence of surcharge and flooding in a system requires special treatment of the flow and continuity equations. Surcharge occurs when all pipes entering a node are full or when the water surface at the junction lies above the crown of the highest entering pipe, but below the ground surface. Flooding is a special case of surcharge which takes place when the hydraulic gradeline breaks the ground surface and water is lost from the junction to the overlying surface system. When flooding of a junction above the ground surface is detected, the program automatically resets the water surface at the ground elevation. Water rising above this level under flooding conditions is then lost from the system and the pressure flow simulation.

During surcharge, the head calculation in equation (51) is no longer possible because the surface area of the surcharged junction is zero. Thus, the continuity equation becomes:

$$\Sigma Q_i + Q_j = 0 \tag{54}$$

Since flow and continuity are not solved simultaneously in the model, flows computed in the links connected to junction **j** will not satisfy equation (54). By computing $\partial Q_i / \partial H_j$ for each pipe connected to junction **j** and $\partial Q_j / \partial H_j$, a head adjustment can be derived such that the continuity equation is satisfied. Rewriting equation (54) in terms of the adjusted head gives:

$$\sum \left[Q_i + \frac{\partial Q_i}{\partial H_j} \times \Delta H_j \right] + Q_j + \frac{\partial Q_j}{\partial H_j} \times \Delta H_j = 0 \tag{55}$$

By then rearranging terms, the head adjustment can be calculated as follows:

$$\Delta H_j = - \frac{\Sigma Q_i + Q_j}{\Sigma \left(\frac{\partial Q_i}{\partial H_j} \right) + \frac{\partial Q_j}{\partial H_j}} \tag{56}$$

This adjustment is made by half-steps during surcharge through the introduction of an adjustment factor. The model assumes that either the numerical iterations will reach a maximum number set by the user or the algebraic sum of the inflows and outflows of a junction will be less than tolerance. If the former occurs, results should be reviewed for adequacy.

Flow Conditions

The normal flow condition to which the methodology applies is labeled in figure 10. However, it must be modified in other cases. Four special scenarios are illustrated in figure 10.

The normal and special cases are summarized as follows:

1. Normal case - Flow computed from motion equation. Half of flow surface area in pipe assigned to each junction.
2. Critical depth downstream - Lesser of critical and normal depth used downstream. All surface area assigned to upstream junction.
3. Critical depth upstream - Critical depth used. All surface area assigned to downstream junction.
4. Supercritical - Flow set to normal value. Surface area assigned in usual manner as in (1).
5. Dry pipe - Flow set to zero. If any surface area exists, it is assigned to the downstream junction.

Rational Flow Hydrographs

Because the pressure flow module performs a dynamic simulation, the system flows must be dynamic as well. Therefore, for the case of a steady-state flow generated using the Rational method, a time-varied hydrograph must be developed. To develop a hydrograph from the rational peak flow, the following assumptions are made:

1. The rainfall duration, **D**, is equal to the time of concentration, $\mathbf{T_c}$, of the drainage area.
2. The time to peak, $\mathbf{T_p}$, is equal to the time of concentration.
3. The duration of runoff, $\mathbf{T_b}$, is equal to twice the time of concentration.

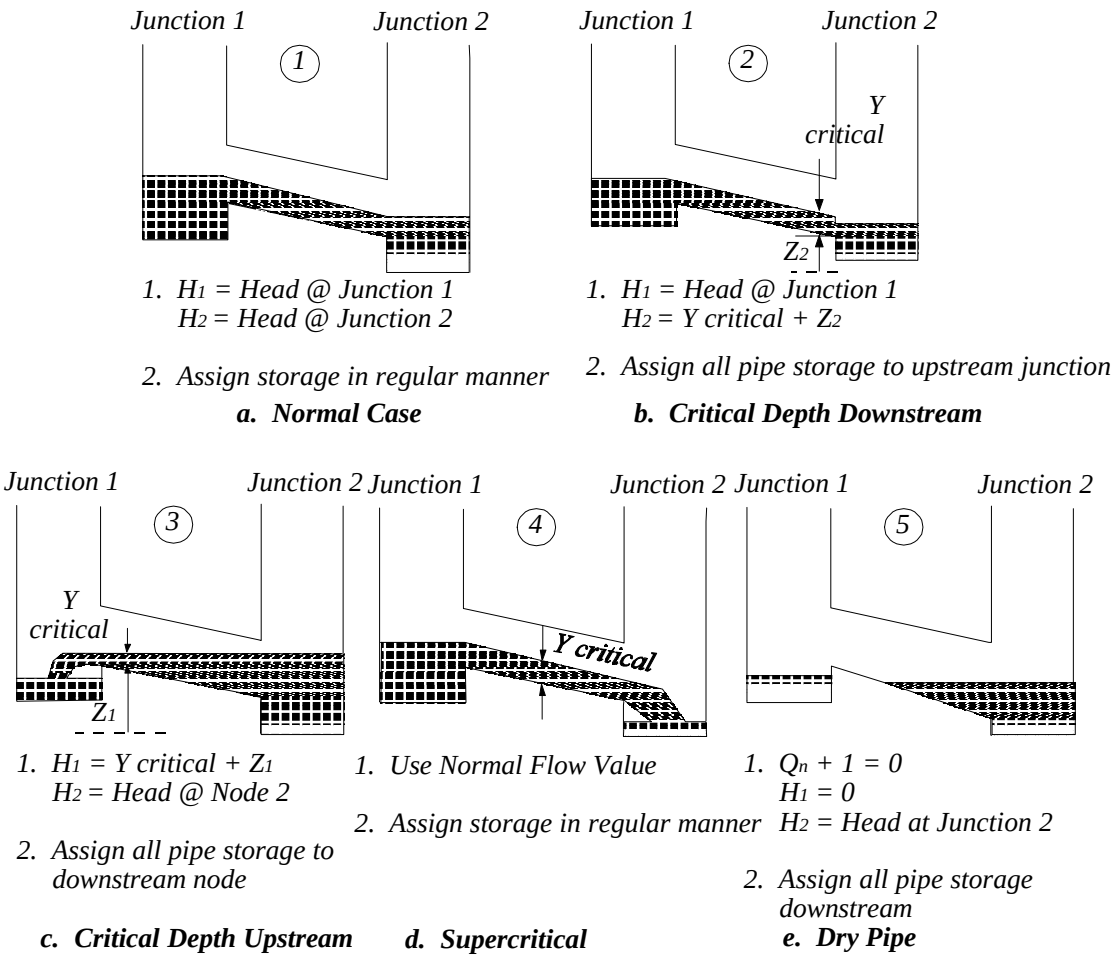

Figure 10. Special flow conditions.

From figure 11, the volume of rainfall excess, as represented by the lower portion of the hyetograph, must equal the volume of the triangular hydrograph. Therefore, CIAD = Q_pT_c and T_c = D; the peak flow, $\mathbf{Q_p}$, of this hydrograph is computed to be equal to CIA.

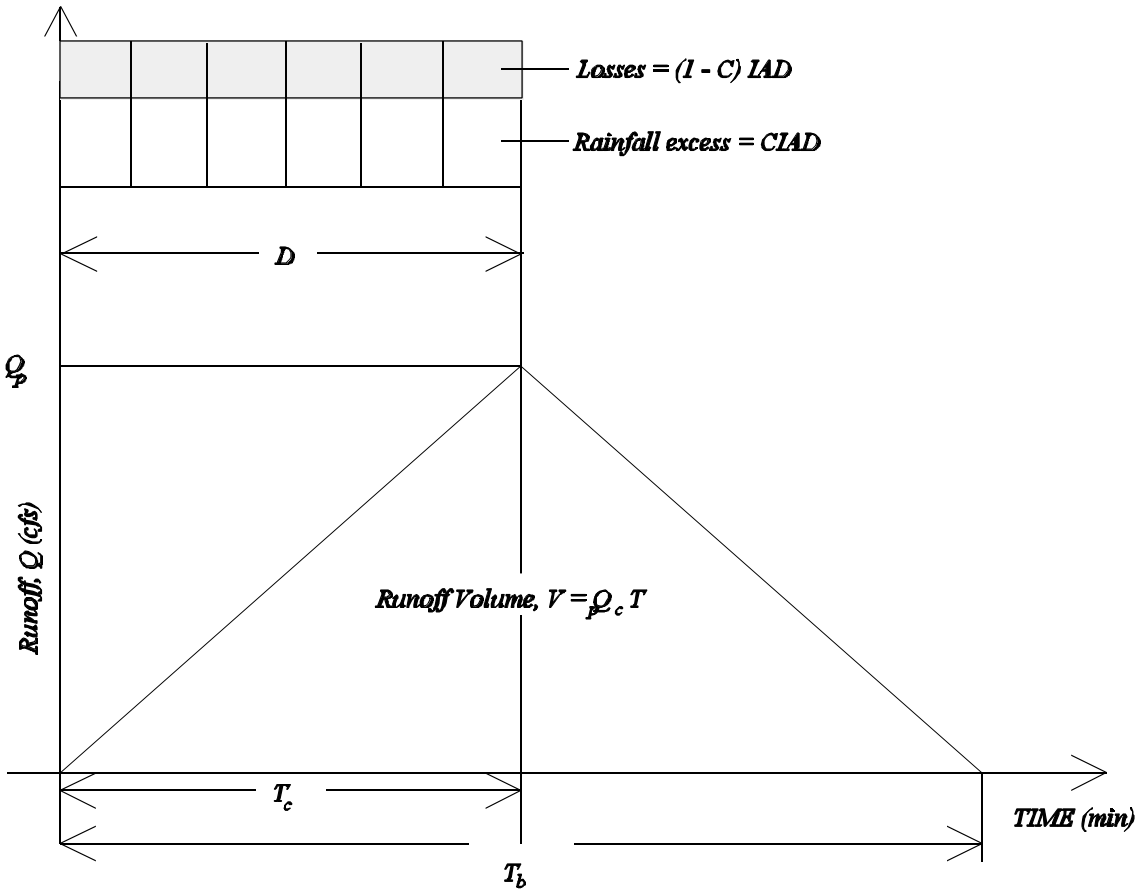

Figure 11. Rational hydrograph.

Limitations of the Pressure Flow Module

The pressure flow module has limitations which, if not appreciated, can result in improperly specified systems and the erroneous computation of heads and flow. The significant limitations are these:

1. Head loss at manholes, expansions, contractions, bends, etc, are estimated based on the hydraulic gradeline method. Minor losses are added by modifying the Manning's **n** specified for the pipes to include both friction and minor loss components.
2. Changes in hydraulic head due to rapid expansions or contractions are neglected. At expansions, the head loss will tend to equalize the heads; but at contractions, the head loss could aggravate the problem.
3. At a manhole where the invert of connecting pipes are different (e.g., a drop manhole), computational errors will occur during surcharge periods if the invert of

the highest pipe lies above the crown of the lowest pipe. The severity of the error increases as the separation increases.

Recommendations for Avoiding Difficulties

Most difficulties in using the Pressure Flow Module arise from three sources:

1. Numerical instability resulting from improper selection of time step and incorrect specification of the total simulation period.
2. Inappropriate iteration control specification.
3. Improper system connectivity.

Numerical stability constraints in the Pressure Flow Module require that **DELT**, the time-step, be no longer than the time it takes flow to travel the length of the shortest pipe in the transport system. A 10-s time-step is recommended for most wet-weather runs, while a 45-s step may be used satisfactorily for dry-weather flow conditions, depending on the system configuration.

Numerical instability in the Pressure Flow Module is signaled by the occurrence of one or more of the following hydraulic conditions:

1. Rapid oscillation of flow and water-surface elevation which is undampened in time: The unstable pipe usually is short relative to other adjacent pipes. The correction is a shorter time-step, a longer pipe length or combination of both. Neither of these should be applied until a careful check of system connections on all sides of the unstable pipe has been made.
2. Excessive velocities (over 6.1 m/s) and discharges which appear to grow without limit at some point in the simulation run: These are manifestations of an unstable pipe element in the system. The cause usually can be traced to the same short pipes or large time steps.
3. A node which continues to “dry up” on each time-step despite a constant or increasing inflow from upstream sources: The cause usually is too large a time-step and excessive discharges in adjacent downstream pipe elements which pull the upstream water surface down. The problem is related to items (1) and (2) and may usually be corrected by a smaller time-step.

4. A large continuity error: A continuity check, which sums the volumes of inflow, outflow, and storage at the beginning and end of the simulation, is found at the end of the intermediate printout. If the continuity error exceeds a reasonable value, the user should check the intermediate printout for pipes with zero flow or oscillating flow. These could be caused by stability or an improperly connected system.

Systems in surcharge may require a special iteration loop, allowing the explicit solution scheme to account for the rapid changes in flows and heads during surcharge conditions. This iteration loop is controlled by two variables on the **PFS** command, **ITMAX**, the maximum number of iterations, and **SURTOL**, a fraction of the flow through the surcharged area. It is recommended that **ITMAX** and **SURTOL** be set initially at 30 and 0.05, respectively. If **ITMAX** is exceeded many times, leaving relatively large flow differentials, the user should increase **ITMAX** to improve the accuracy of the surcharge computation. If, on the other hand, most or all of the iterations do converge, the user may decrease **ITMAX** or increase **SURTOL** to decrease the run time of the model and, consequently, the cost. The user should also keep an eye on the continuity error to ensure that a large loss of water is not caused by the iterations.

In some large systems, more than one area may be in surcharge at the same time. If this occurs and the flows in these areas differ appreciably, those areas with the smallest flows may not converge, while areas with large flows will. This is because both the tolerance and flow differential are computed as sums of all flows in surcharge. It is possible, therefore, for overall convergence to occur even when relatively large flow errors still exist in surcharge areas with small flows. To correct this, **SURTOL** can be decreased until the flow differential for the area in question decreases to a small value over time. It should be noted, however, that large flow differentials for a short period of time are not unusual providing they decrease to near or below the established tolerance for most of the simulation.

Prior to a lengthy run of the Pressure Flow Module for a new system, a short test run should be made to confirm that the link-node model is properly connected and correctly represents the prototype. This check should be made on the echo of the input data, which shows the connecting links at each junction. The geometric/hydraulic data for each pipe and junction should also be confirmed. Particular attention should be paid to the junction location of outfalls to ensure these conform to the prototype system. Using this short test run, the total number of pipes and junctions, including internal links and nodes created, can be determined from the junctions and pipe characteristic tables in the output. The length of all pipes in the system should be consistent. If possible, each pipe should be at least 30.5 m in length. This constraint may be difficult to meet in the vicinity of abrupt changes in pipe configurations which must be represented in the model. However, the length of the shortest pipe does directly determine the maximum time step.

SUMMARY

Methodologies used for the key features of HYDRA have been described including techniques for flow generation, flow conveyance, inlet computations, storage, cost estimation, hydraulic gradeline computations and pressure flow simulations. 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 ensure that appropriate application of the techniques is achieved.

USER DOCUMENTATION

Effective use of HYDRA requires an understanding of the interaction between the 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 each must follow a specific format. Currently there are 56 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. Appendix C includes a more detailed description, including format specifications.

Table 3. Glossary of commands.

Command		Description
BEN	-	specifies Pipe **BEN**d data such as angle and radius.
BOX	-	rectangular pipe that transport system flow from one point to another.
CHA	-	allows definition of an open **CHA**nnel or ditch.
CRI	-	determines whether inverts or crowns are to be matched (**CRI**teria).
CST	-	sets geometry factors and unit prices (**C**o**ST**s in place).
DIV	-	splits the system flow into two components (**DIV**erts flow).
ECF	-	allows **E**xtra **C**osts per linear meter to be added to the pipe cost.
EFF	-	describes inlet performance in ordered pairs of flow versus **EFF**iciency.
ELP	-	horizontal or vertical **El**li**P**se that transports system flow.
END	-	**END**s a command string.
EXC	-	establishes trench **EXC**avation costs.
FLO	-	adds or subtracts a constant **FLO**w to the system.
GET	-	**GET**s a gutter hydrograph from storage.
GPC	-	sets the **G**allons **P**er **C**apita per day for flow calculations.
GUT	-	establishes **GUT**ter characteristics.
HGL	-	signals that **H**ydraulic **G**rade**L**ine computations should be made.
HOL	-	**HOL**ds system flow at the lower end of a lateral.
IDY	-	**I**nitializes **D**epths for pressure flow.

Table 3. Glossary of commands (continued).

Command		Description
INF	-	inputs **INF**iltration flows by population or area.
INL	-	sets parameters for a storm water **INL**et.
IPU	-	establishes the number of **I**ndividuals **P**er sanitary **U**nit.
IQV	-	**I**nitializes flows and **V**elocities.
JOB	-	initiates **JOB** and enters **JOB** title.
LOS	-	allows input of additional pipe **LOS**ses.
LPC	-	calculates and **L**ists **P**ipe **C**osts in place.
MAP	-	establishes factor for converting in^2 on a **MAP** to ac.
NEW	-	clears some registers and loads **NEW** lateral name.
PCF	-	establishes a **P**ipe **C**ost **F**actor.
PCO	-	establishes **P**ipe **CO**sts per meter in place.
PDA	-	establishes **P**ipe design **DA**ta.
PEA	-	translates average daily flow into **PEA**k daily flow.
PFS	-	specifies **P**ressure **F**low **S**imulation parameters.
PFP	-	**P**rints **F**low in **P**ipes for pressure flow simulation.
PHJ	-	**P**rints **H**ead of **J**unctions for pressure flow simulation.
PIP	-	moves water from one point to another in a circular **PIP**e.
PNC	-	specifies **P**ipe-**N**ode **C**onnections for hydraulic gradeline computation.
PON	-	allows surface **PON**ding of flows **HYD**, **GUT**, **GET** commands.
PSZ	-	sets **P**ipe **S**i**Z**es for design.
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).
SAF	-	applies **SAF**ety factors to calculated flows.
SAN	-	enters **SAN**itary flow into the system.
SDI	-	allows input of **S**tage-**DI**scharge curve.
SST	-	allows input of **S**tage-**ST**orage curve.
STE	-	sets the length of time increments (**STE**ps).
STO	-	enters subbasin data for determining **STO**rm water design flow.
SUN	-	enters the number of contributing **S**anitary **UN**its.
SWI	-	sets **SWI**tch for determining method of storm/sanitary flow analysis.
TRA	-	**TRA**nsfer system flow to surface flow.
TSL	-	determines **T**rench side wall **SL**ope.
TWE	-	allows for the input of a **T**ail**W**ater **E**levation at the system outfall.
UHY	-	enables use of externally produced hydrographs (**U**ser **HY**drograph).

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 12 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 12 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 will have the criteria necessary to formulate a preliminary pipe design. The **PIP** command is the third command in the data set.

HYDRA Command	Data	Comments
JOB	Command Example	The title of the HYDRA job.
PDA	0.014 300 2.5 1.5 0.5 0.005	Sets initial design criteria, such as Manning's **n**, minimum diameter, etc.
NEW	Main Street	Starts a new lateral, providing it with a unique name.
FLO	0.500	Places a 0.500m^3/s FLOw into the system at this location.
PIP	100 33.500	Pipe parameters. (Transports the flow in a pipe 100-m long - ground elevation at both the upper and lower ends is 33.500 m.)
PIP	120 33.500 34.000	Continues to transport the flow into another pipe 120-m long. Notice that the ground elevation at the upstream end is 33.500 m and 34.000 m at the downstream end. HYDRA can model adverse ground elevations.
FLO	0.100	Adds another 0.100 m^3/s to the system at this point.
PDA	0.025 300 2.5 1.5 0.5 0.005	Change the pipe friction factor to 0.025 (corrugated metal pipe).
PIP	140 34.000 30.500	Transports the flow another 140 m.
END		Terminates the HYDRA run and prints the results.

Figure 12. Example of a command string.

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 13 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 13. Commands operate in "free format" fashion; that is, a space [ ], or comma [,] 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 continuing the data onto the next line.

THE HYDRAIN ENVIRONMENT

For those users who have obtained HYDRA as part of the Federal Highway Administration's **HYDRAIN** package, consult the HYDRAIN documentation for information on how to use the software system.

There are three methods to execute the HYDRA program. Two of these are within the HYDRAIN environment. The first method is to run HYDRA from the HYDRAIN editor. This allows the user the option of immediate review and editing capabilities. The second method is to run HYDRA from the HYDRAIN shell using the **Analyze** option. The final method is to execute HYDRA from the DOS prompt. Detailed discussion of all three of these options is in the HYDRAIN portion of the documentation.

Upon completion of the run, HYDRA assigns the output file and an **.LST** filename extension. The output file contains an echo of the input data and the results. The output may contain message describing warnings or errors encountered during execution. These messages are useful in debugging an input data set.

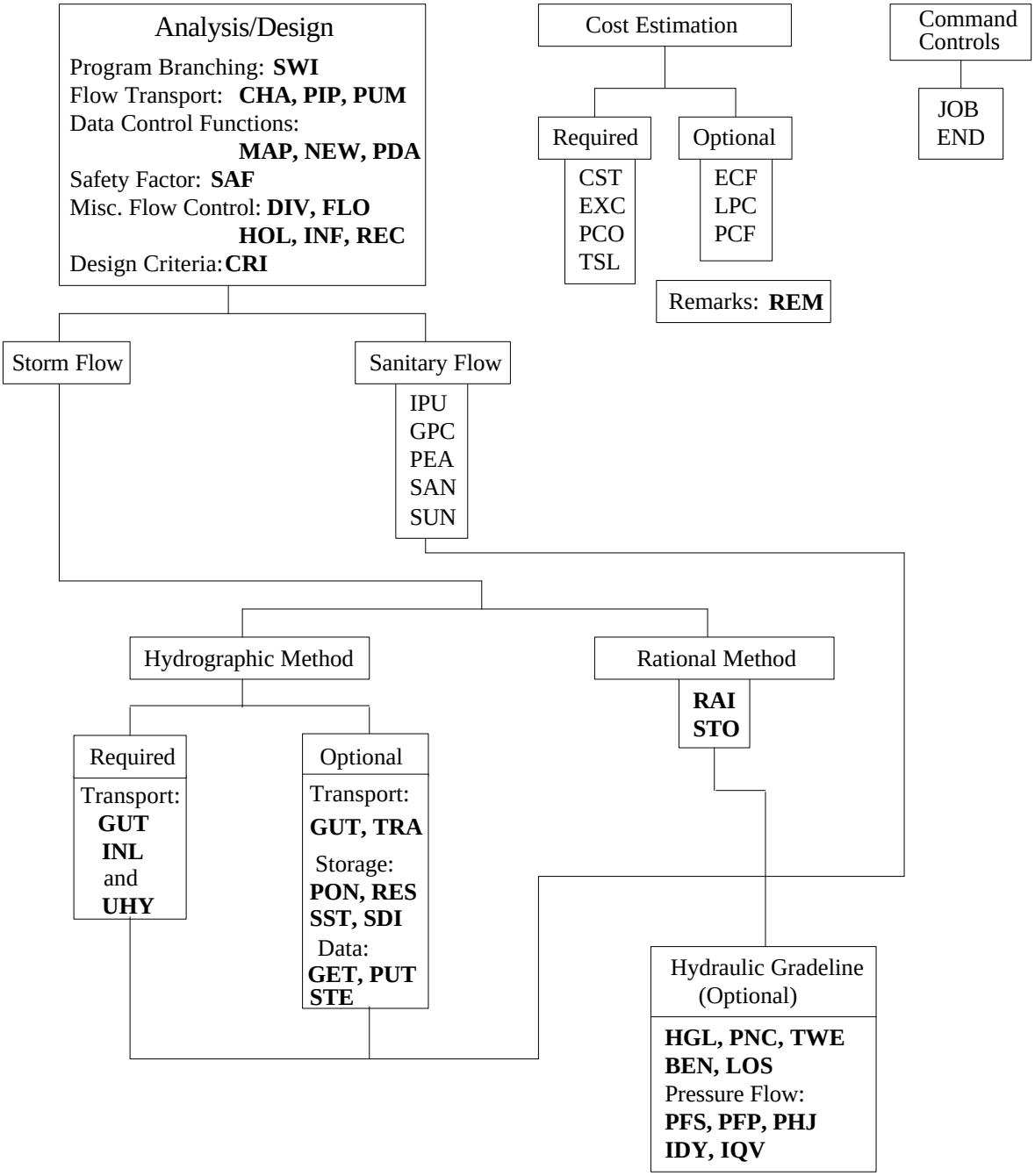

Figure 13. Organization of HYDRA commands.

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 C 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.
4. Demonstrate what to expect for output.

The 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 seven examples provides a different type of application of HYDRA. These are:

1. Rational method storm drain design with the hydraulic gradeline.
2. Rational method analysis with pressure flow.
3. Hydrographic simulation storm drain analysis/design.
4. Hydrographic analysis and pressure flow simulation.
5. Sanitary sewer design.
6. Sanitary sewer analysis.
7. Combined system analysis.

Example One: Rational Method Design with Hydraulic Gradeline

Problem:

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 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.

Data file: FOXHALL.IDF

```
FOXHALL CRESCENTS INTENSITY-DURATION-FREQUENCY
    8
         5    192.02
        10    160.02
        15    138.18
        30    100.33
        60     67.56
       100     48.77
       120     43.18
       360     19.81
```

Input file: HYDRA1.HDA

```
JOB Example One: Rational Method Design with Hydraulic Gradeline
SWI 2
PDA 0.013 300 1.22 0.914 0.61 0.001
RAI FOXHALL.IDF
EXC 1.52 0.94 7.62 1.48
TSL 0 0.25 3.05 0.15
PCO 300 15.03 900 81.50
CST 1.5 4.92 0 0 0 1.64 8.12 1 0 1.99 1.05 0.79 2.04 1.99 0
HGL 1
REM Begin Main Lateral
NEW MAIN STREET
REM Main Lateral: Junctions 1 to 2
STO 2.10 0.2 21
PIP 137.15 58.98 58.52
PNC 1 2 0.914 125 0 1
REM Main Lateral: Junctions 2 to 3
STO 1.62 0.5 28
STO 2.35 0.6 15
STO 1.05 0.6 15
PIP 228.59 58.52 56.17
PNC 2 3 1.52 180 0 0
REM Main Lateral: Junctions 3 to 7
```

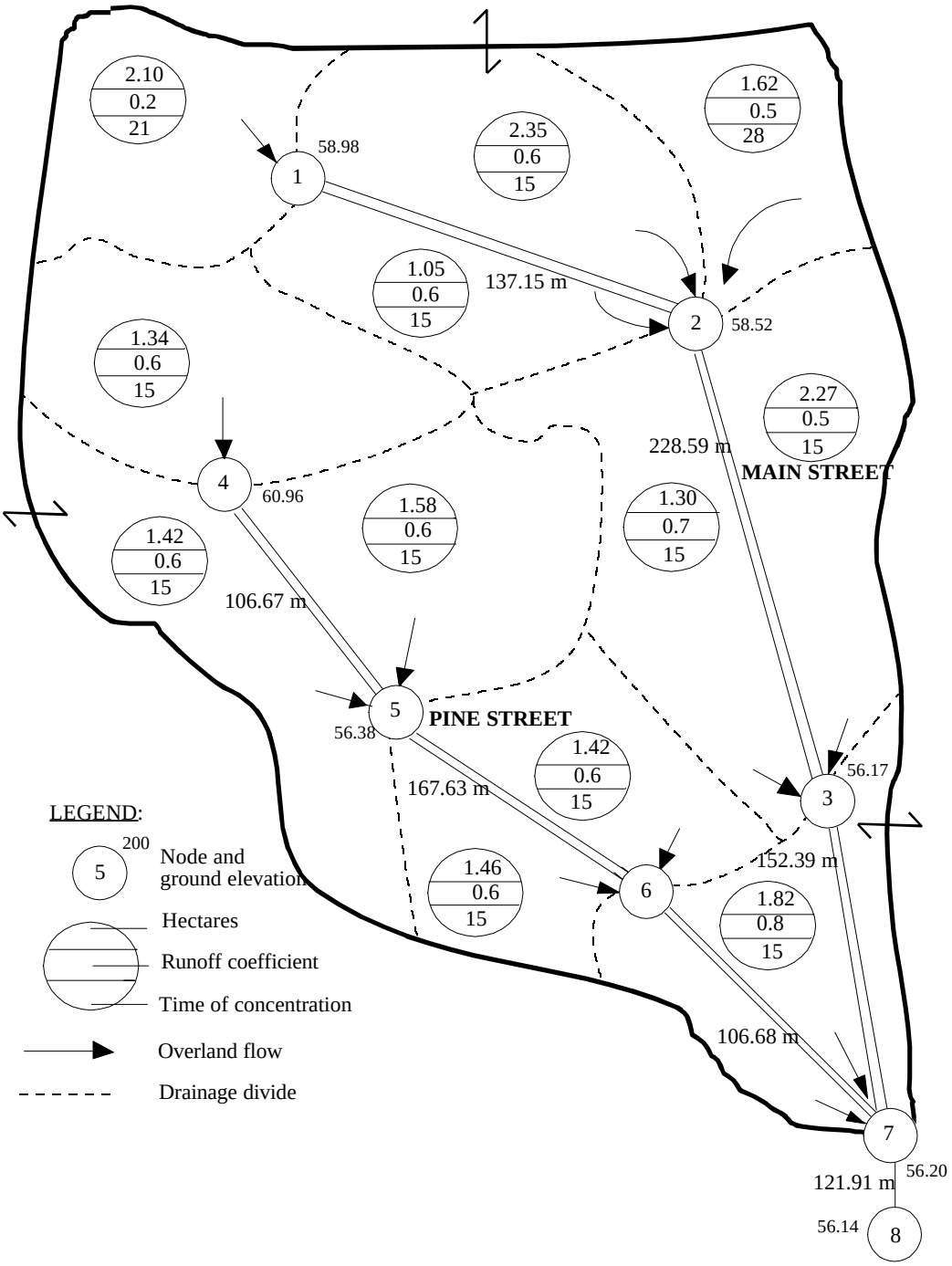

Figure 14. Rational method design.

```
STO 2.27 0.5 15
STO 1.30 0.7 15
PIP 152.39 56.17 56.20
PNC 3 7 2.13 180 0 3
HOL 1
REM Begin Second Lateral
NEW PINE STREET
REM Side Lateral: Junctions 4 to 5
STO 1.34 0.6 15
PIP 106.67 60.96 56.38
PNC 4 5 1.22 155 0 1
REM Side Lateral: Junctions 5 to 6
STO 1.42 0.6 15
STO 1.58 0.6 15
PIP 167.63 56.38 56.20
PNC 5 6 1.52 180 0 2
REM Side Lateral: Junctions 6 to 7
STO 1.46 0.6 15
STO 1.42 0.6 15
PIP 106.68 56.17 56.20
PNC 6 7 2.13 150 0 3
REC 1
STO 1.82 0.8 15
REM Outfall Link: Junctions 7 to 8
PIP 121.91 56.20 56.14
PNC 7 8 0 180 2
END
```

Discussion of output:

The gravity flow simulation portion of the results provides tables of designed pipe sizes, invert elevations, and costs. This pipe design scenario is then “sent” to the hydraulic gradeline component of the model. The hydraulic gradeline table indicates the pipe links that could possibly surcharge. However, since HGL is based on pipe full flow, the occurrence of super-critical flow in a surcharged pipe would be contradictory to the surcharged condition. In this case, it would be recommended to run the pressure flow simulation option.

Output file: HYDRA1.LST

```
        ******  HYDRA  ******* (Version 6.1) *****         Date 07-16-1998
                                                              Page No   1


  Example One: Rational Method Design with Hydraulic Gradeline


+++ Commands Read From File C:\HYDRA\HYDRA1.HDA
  JOB
  SWI 2
  PDA 0.013 300 1.22 0.914 0.61 0.001
  RAI FOXHALL.IDF
+++ Notice:  Intermediate file has data in SI units
```

IDF CURVE

```
192.*))))))))))))))))))3))))))))))))))))))3))))))))))))))))))3))))))))))),
         *                   .                   .                   .
*
 R       *                   .                   .                   .
*
 a       **                  .                   .                   .
*
 i   150.3                   .                   .                   .
3
 n       * *                 .                   .                   .
*
 f       *                   .                   .                   .
*
 a       *                   .                   .                   .
*
 l       *                   .                   .                   .
*
 l   100.3    *              .                   .                   .
3
         *                   .                   .                   .
*
 i       *                   .                   .                   .
*
 n       *          *        .                   .                   .
*
         *                   .                   .                   .
*
 m    50.3                   *                   .                   .
3
 m       *                   .   *               .                   .
*
 /       *                   .                   .                   .
*
 h       *                   .                   .                   .
*
         *                   .                   .                   .
*

0.*))))))))))))))))))3))))))))))))))))))3))))))))))))))))))3))))))))))-
       5.                 100.                 200.                 300.
360.
```

Duration, t (min)

PLOT-DATA (Time, t(min) vs. Intensity, i(mm/h))

t	i	t	i	t	i	t	i	t	i
5.	192.	60.	68.	0.	0.	0.	0.	0.	0.
10.	160.	100.	49.	0.	0.	0.	0.	0.	0.
15.	138.	120.	43.	0.	0.	0.	0.	0.	0.
30.	100.	360.	20.	0.	0.	0.	0.	0.	0.

```
EXC 1.52 0.94 7.62 1.48
TSL 0 0.25 3.05 0.15
PCO 300 15.03 900 81.50
CST 1.5 4.92 0 0 0 1.64 8.12 1 0 1.99 1.05 0.79 2.04 1.99 0
HGL 1
```

```
  Example One: Rational Method Design with Hydraulic Gradeline


  REM Begin Main Lateral
  NEW MAIN STREET
  REM Main Lateral: Junctions 1 to 2
  STO 2.10 0.2 21
  PIP 137.15 58.98 58.52
+++ Tc =  21.0 min
+++ CA =    .4
+++ Top width of trench ---> UP  1.5 m
                        ---> DN  1.5 m
+++ Link #  1,  Flow depth =    .324 m, Critical depth =    .264 m
  PNC 1 2 0.914 125 0 1
  REM Main Lateral: Junctions 2 to 3
  STO 1.62 0.5 28
  STO 2.35 0.6 15
  STO 1.05 0.6 15
  PIP 228.59 58.52 56.17
+++ Tc =  28.0 min
+++ CA =   3.3
*** WARNING: Pipe invert at D/S end dropped to meet minimum depth
    to invert criterion at D/S end
*** WARNING: Pipe invert at U/S dropped to meet cover criterion at U/S end
*** WARNING: Inverts at D/S & U/S dropped to meet cover criterion at D/S end
+++ Top width of trench ---> UP  2.0 m
                        ---> DN  1.9 m
+++ Link #  2,  Flow depth =    .547 m, Critical depth =    .602 m
  PNC 2 3 1.52 180 0 0
  REM Main Lateral: Junctions 3 to 7
  STO 2.27 0.5 15
  STO 1.30 0.7 15
  PIP 152.39 56.17 56.20
+++ Tc =  29.4 min
+++ CA =   5.3
*** WARNING: Pipe invert at U/S dropped to meet cover criterion at U/S end
+++ Top width of trench ---> UP  2.8 m
                        ---> DN  2.8 m
+++ Link #  3,  Flow depth =    .999 m, Critical depth =    .645 m
  PNC 3 7 2.13 180 0 3
  HOL 1
  REM Begin Second Lateral
  NEW PINE STREET
  REM Side Lateral: Junctions 4 to 5
  STO 1.34 0.6 15
  PIP 106.67 60.96 56.38
+++ Tc =  15.0 min
+++ CA =    .8
+++ Top width of trench ---> UP  1.4 m
                        ---> DN  1.4 m
+++ Link #  4,  Flow depth =    .266 m, Critical depth =    .362 m
  PNC 4 5 1.22 155 0 1
```

```
  Example One: Rational Method Design with Hydraulic Gradeline

  REM Side Lateral: Junctions 5 to 6
  STO 1.42 0.6 15
  STO 1.58 0.6 15
  PIP 167.63 56.38 56.20
+++ Tc =  15.5 min
+++ CA =   2.6
*** WARNING: Pipe invert at U/S dropped to meet cover criterion at U/S end
*** WARNING: Inverts at D/S & U/S dropped to meet cover criterion at D/S end
+++ Top width of trench ---> UP  2.6 m
                        ---> DN  2.6 m
+++ Link #  5,  Flow depth =    .816 m, Critical depth =    .537 m
  PNC 5 6 1.52 180 0 2
  REM Side Lateral: Junctions 6 to 7
  STO 1.46 0.6 15
  STO 1.42 0.6 15
  PIP 106.68 56.17 56.20
+++ Tc =  17.8 min
+++ CA =   4.3
*** WARNING: Pipe invert at U/S dropped to meet cover criterion at U/S end
+++ Top width of trench ---> UP  2.8 m
                        ---> DN  2.8 m
+++ Link #  6,  Flow depth =   1.040 m, Critical depth =    .661 m
  PNC 6 7 2.13 150 0 3
  REC 1
  STO 1.82 0.8 15
  REM Outfall Link: Junctions 7 to 8
  PIP 121.91 56.20 56.14
+++ Tc =  31.3 min
+++ CA =  11.1
*** WARNING: Pipe invert at U/S dropped to meet cover criterion at U/S end
+++ Top width of trench ---> UP  3.4 m
                        ---> DN  3.5 m
+++ Link #  7,  Flow depth =   1.260 m, Critical depth =    .852 m
  PNC 7 8 0 180 2
  END
 END OF INPUT DATA.
```

Example One: Rational Method Design with Hydraulic Gradeline

*** MAIN STREET Pipe Design

Link	Length (m)	Diam (mm)	Invert Up/Dn (m)	Slope (m/m)	Depth Up/Dn (m)	Min. Cover (m)	Velocity Act/Full (m/s)	--Flow-- Act/Full (m^3/s)	Estimated Cost ($)
1	137	450	57.579	.003	1.402	.914	1.166	.142	5206.
			57.118		1.402		1.038	.165	
2	229	750	56.612	.009	1.908	.914	2.763	.949	17385.
			54.444		1.726		2.455	1.084	
3	152	1350	53.793	.001	2.377	.914	1.330	1.492	23687.
			53.641		2.559		1.179	1.688	

Length = 518. m Total length = 518. m
Cost = 46279. Total Cost = 46279.

*** PINE STREET Pipe Design

Link	Length (m)	Diam (mm)	Invert Up/Dn (m)	Slope (m/m)	Depth Up/Dn (m)	Min. Cover (m)	Velocity Act/Full (m/s)	--Flow-- Act/Full (m^3/s)	Estimated Cost ($)
4	107	375	59.640	.043	1.320	.914	3.687	.306	3061.
			55.060		1.320		3.290	.363	
5	168	1200	54.154	.001	2.226	.914	1.209	.983	22588.
			53.986		2.214		1.090	1.233	
6	107	1350	53.793	.001	2.377	.914	1.338	1.565	16570.
			53.687		2.513		1.179	1.688	
7	122	1800	53.336	.001	2.864	.914	1.597	3.026	26560.
			53.214		2.926		1.429	3.636	

Length = 503. m Total length = 1021. m
Cost = 68780. Total Cost = 115058.

Example One: Rational Method Design with Hydraulic Gradeline

Hydraulic Gradeline Computations

Link #	Down-stream Node #	Hydraulic Gradeline Elevation	Crown Elev.	Possible Surcharge	Ground Elev.	Super-crit.?	Manhole Depth	Loss Coef
1	2	57.569	57.576	N	58.520	N	.957	.28
2	3	55.046	55.206	N	56.170	Y	1.090	.01
3	7	54.726	54.987	N	56.200	N	1.390	.08
4	5	55.422	55.441	N	56.380	Y	.891	.01
5	6	54.925	55.180	N	56.170	N	1.132	.07
6	7	54.726	55.033	N	56.200	N	1.390	.09
7	8	54.474	55.017	N	56.140	N	1.260	.00

Link #	Terminal Node #	Hydraulic Gradeline Elevation	Ground Elevation	Loss Coef.
1	1	58.007	58.980	1.50
4	4	60.946	60.960	1.50

NORMAL END OF HYDRA

Example Two: Rational Method Analysis with Pressure Flow

Problem:

HYDRA is a useful tool in analyzing existing systems. This example, shown in figure 14, demonstrates the use of HYDRA to analyze a storm drain system using the Rational method. For this example, the system suggested by HYDRA in example one is entered in the command string as an existing system and analyzed. (Note the extra parameters on the PIP commands.) The system is identical to that designed in example one except that a higher return period is employed (the intensity/duration values are hand entered). Note that the RAI command requires two lines. Continuation of a line is achieved by making the first three columns in the second line blank.

The commands that are introduced in this example are: **PFS**, **PFP**, **PHJ**, and **TWE**. The **PFS** command initiates the pressurized flow simulation by establishing the control parameters. Commands **PFP** and **PHJ** select the pipes and junctions, respectively, to be printed out for the detailed printout. The **TWE** command specifies the tailwater elevation at the outfall of the system which is necessary for the pressure flow simulation. The default tailwater elevation is the invert of the outfall pipe (in this example, 53.35 m). Just like the hydraulic gradeline computations, the **PNC** and **PIP** commands define the pipe-node connectivity for the entire system.

Input file: HYDRA2.HDA

```
JOB Example Two: Rational Method Analysis with Pressure Flow
SWI 2
PDA 0.013 300 1.22 0.914 0.61 0.001
RAI 5,223.77  10,197.61   15,168.91   30,140.72   60,102.87
    90,86.61   120,84.33   360,53.59
TWE 53.35
REM Begin Main Lateral
NEW MAIN STREET
REM Main Lateral: Junctions 1 to 2
STO 2.10 0.2 21
PIP 137.15 58.98 58.52 57.57 57.11 -450
PNC 1 2 0.914 125 0 1
REM Main Lateral: Junctions 2 to 3
STO 1.62 0.5 28
STO 2.35 0.6 15
STO 1.05 0.6 15
PIP 228.59 58.52 56.17 56.59 54.43 -750
PNC 2 3 1.52 180 0 0
REM Main Lateral: Junctions 3 to 7
STO 2.27 0.5 15
STO 10.50 0.7 15
PIP 152.39 56.17 56.20 53.77 53.62 -1350
PNC 3 7 2.13 180 0 3
HOL 1
REM Begin Second Lateral
NEW PINE STREET
REM Side Lateral: Junctions 4 to 5
STO 1.34 0.6 15
PIP 106.68 60.96 56.38 59.63 55.06 -375
PNC 4 5 1.22 155 0 1
REM Side Lateral: Junctions 5 to 6
STO 1.42 0.6 15
```

```
STO 1.58 0.6 15
PIP 167.63 56.38 56.20 54.22 54.05 -1200
PNC 5 6 1.52 180 0 2
REM Side Lateral: Junctions 6 to 7
STO 1.46 0.6 15
STO 1.42 0.6 15
PIP 106.67 56.17 56.20 53.77 53.66 -1350
PNC 6 7 2.13 150 0 3
REC 1
STO 1.82 0.8 15
REM Outfall Link: Junctions 7 to 8
PIP 121.91 56.20 56.14 53.31 53.18 -1800
PNC 7 8 0 180 2
PFS 0 60 10 10 1 3 2 30 0.05
PHJ 2 3 6
PFP 3 7
END
```

Discussion of output:

In the results of example two, the gravity flow simulation does suggest the possibility of surcharge. The gravity flow module notices which pipes have a design flow larger than the normal pipe capacity. The module then provides two alternatives (removing excess flow or adding additional pipe capacity) that would return the system to free surface flow conditions. In reality, the pipes would act under pressure. The second (and more substantive) output portion depicts results of the pressure flow simulation. Note that the pipe junction connectivity is reiterated, which is useful for debugging the network. Since the network in this example is the exact same as the previous example, the surcharging of the pressure flow simulation can be contrasted to that of the earlier HGL simulation.

Output file: HYDRA2.LST

```
          ******  HYDRA  ******* (Version 6.1) *****         Date 07-16-1998
                                                                Page No   1

   Example Two: Rational Method Analysis with Pressure Flow


 +++ Commands Read From File C:\HYDRA\HYDRA2.HDA
   JOB
   SWI 2
   PDA 0.013 300 1.22 0.914 0.61 0.001
   RAI 5,223.77  10,197.61   15,168.91   30,140.72   60,102.87
    90,86.61   120,84.33   360,53.59
```

IDF CURVE

```
     224.*)))))))))))))))))3)))))))))))))))))))3)))))))))))))))))))3)))))))))),
         *                 .                   .                   .          *
R        **                 .                   .                   .          *
a    200.3                  .                   .                   .          3
i        *                  .                   .                   .          *
n        * *                .                   .                   .          *
f        *                  .                   .                   .          *
a    150.3    *             .                   .                   .          3
l        *                  .                   .                   .          *
l        *                  .                   .                   .          *
         *          *       .                   .                   .          *
i    100.3                  .                   .                   .          3
n        *                * .   *               .                   .          *
         *                  .                   .                   .          *
m        *                  .                   .                   .          *
m     50.3                  .                   .                   .          3
/        *                  .                   .                   .          *
h        *                  .                   .                   .          *
         *                  .                   .                   .          *
       0.*)))))))))))))))))3)))))))))))))))))))3)))))))))))))))))))3)))))))))-
       5.                100.                200.                300.       360.

                          Duration, t (min)
```

PLOT-DATA (Time, t(min) vs. Intensity, i(mm/h))

t	i	t	i	t	i	t	i	t	i
5.	224.	60.	103.	0.	0.	0.	0.	0.	0.
10.	198.	90.	87.	0.	0.	0.	0.	0.	0.
15.	169.	120.	84.	0.	0.	0.	0.	0.	0.
30.	141.	360.	54.	0.	0.	0.	0.	0.	0.

```
TWE 53.35
REM Begin Main Lateral
NEW MAIN STREET
REM Main Lateral: Junctions 1 to 2
```

```
  Example Two: Rational Method Analysis with Pressure Flow

  STO 2.10 0.2 21
  PIP 137.15 58.98 58.52 57.57 57.11 -450
+++ Tc =  21.0 min
+++ CA =    .4
+++ Link #  1,  Flow depth =    .450 m, Critical depth =    .450 m
  PNC 1 2 0.914 125 0 1
  REM Main Lateral: Junctions 2 to 3
  STO 1.62 0.5 28
  STO 2.35 0.6 15
  STO 1.05 0.6 15
  PIP 228.59 58.52 56.17 56.59 54.43 -750
+++ Tc =  28.0 min
+++ CA =   3.3
+++ Link #  2,  Flow depth =    .750 m, Critical depth =    .750 m
  PNC 2 3 1.52 180 0 0
  REM Main Lateral: Junctions 3 to 7
  STO 2.27 0.5 15
  STO 10.50 0.7 15
  PIP 152.39 56.17 56.20 53.77 53.62 -1350
+++ Tc =  29.3 min
+++ CA =  11.8
+++ Link #  3,  Flow depth =   1.350 m, Critical depth =   1.350 m
  PNC 3 7 2.13 180 0 3
  HOL 1
  REM Begin Second Lateral
  NEW PINE STREET
  REM Side Lateral: Junctions 4 to 5
  STO 1.34 0.6 15
  PIP 106.68 60.96 56.38 59.63 55.06 -375
+++ Tc =  15.0 min
+++ CA =    .8
+++ Link #  4,  Flow depth =    .375 m, Critical depth =    .375 m
  PNC 4 5 1.22 155 0 1
  REM Side Lateral: Junctions 5 to 6
  STO 1.42 0.6 15
  STO 1.58 0.6 15
  PIP 167.63 56.38 56.20 54.22 54.05 -1200
+++ Tc =  15.5 min
+++ CA =   2.6
+++ Link #  5,  Flow depth =    .960 m, Critical depth =    .596 m
  PNC 5 6 1.52 180 0 2
  REM Side Lateral: Junctions 6 to 7
  STO 1.46 0.6 15
  STO 1.42 0.6 15
  PIP 106.67 56.17 56.20 53.77 53.66 -1350
+++ Tc =  17.8 min
+++ CA =   4.3
+++ Link #  6,  Flow depth =   1.350 m, Critical depth =   1.350 m
  PNC 6 7 2.13 150 0 3
```

```
  Example Two: Rational Method Analysis with Pressure Flow

  REC 1
  STO 1.82 0.8 15
  REM Outfall Link: Junctions 7 to 8
  PIP 121.91 56.20 56.14 53.31 53.18 -1800
+++ Tc =  30.1 min
+++ CA =  17.5
+++ Link #  7,  Flow depth =   1.800 m, Critical depth =   1.800 m
  PNC 7 8 0 180 2
  PFS 0 60 10 10 1 3 2 30 0.05
  PHJ 2 3 6
  PFP 3 7
  END
 END OF INPUT DATA.
```

Example Two: Rational Method Analysis with Pressure Flow

*** MAIN STREET Analysis of Existing Pipes

Link	Length (m)	Diam (mm)	Invert Up/Dn (m)	Slope (m/m)	Depth Up/Dn (m)	Cover Up/Dn (m)	Velocity Act/Full (m/s)	--Flow-- Act/Full (m^3/s)	Load (%)	-Solutions- Remove (m^3/s)	Diam (mm)
1	137	450	57.570	.003	1.410	.923	1.147	.182	110	.017	279
			57.110		1.410	.923	1.038	.165			
2	229	750	56.590	.009	1.930	1.117	2.946	1.302	120	.219	432
			54.430		1.740	.928	2.450	1.082			
3	152	1350	53.770	.001	2.400	.937	3.214	4.600	275	2.925	1778
			53.620		2.580	1.118	1.170	1.675			

Length = 518. m Total length = 518. m

*** PINE STREET Analysis of Existing Pipes

Link	Length (m)	Diam (mm)	Invert Up/Dn (m)	Slope (m/m)	Depth Up/Dn (m)	Cover Up/Dn (m)	Velocity Act/Full (m/s)	--Flow-- Act/Full (m^3/s)	Load (%)	-Solutions- Remove (m^3/s)	Diam (mm)
4	107	375	59.630	.043	1.330	.924	3.387	.374	103	.011	279
			55.060		1.320	.914	3.286	.363			
5	168	1200	54.220	.001	2.160	.860	1.250	1.205	97		
			54.050		2.150	.850	1.098	1.242			
6	107	1350	53.770	.001	2.400	.937	1.365	1.954	114	.240	660
			53.660		2.540	1.078	1.198	1.714			
7	122	1800	53.310	.001	2.890	.940	2.670	6.796	181	3.042	1778
			53.180		2.960	1.010	1.475	3.754			

Length = 503. m Total length = 1021. m

Example Two: Rational Method Analysis with Pressure Flow

Pressurized Flow Simulations

Total Simulation time: 60 min
Incremental time: 10 min
Length of integration step: 10 s
Initial time: .00 min
Surcharge variables: itMax 30 iterations
surTol .050

Printed output at the following 3 junctions

2 3 6

and for the following 2 pipes

3 7

Pipe Characteristics

Pipe Number	Length (m)	Area (m^2)	Manning "n"	Max. Width (m)	Depth (m)	Junctions at Ends		Invert Height above Junctions	
1	137.160	.164	.013	.457	.457	1	2	.000	.520
2	228.600	.456	.013	.762	.762	2	3	.000	.660
3	152.400	1.423	.013	1.346	1.346	3	7	.000	.310
4	106.680	.114	.013	.381	.381	4	5	.000	.840
5	167.640	1.119	.013	1.194	1.194	5	6	.000	.280
6	106.680	1.423	.013	1.346	1.346	6	7	.000	.350
7	121.920	2.554	.013	1.803	1.803	7	8	.000	.000

Junction Characteristics

Junction Number	Ground Elev.	Crown Elev.	Invert Elev.	Connecting Pipes	
1	58.980	58.027	57.570	1	
2	58.520	57.567	56.590	1	2
3	56.170	55.192	53.770	2	3
4	60.960	60.011	59.630	4	
5	56.380	55.441	54.220	4	5

Example Two: Rational Method Analysis with Pressure Flow

Junction Characteristics

Junction Number	Ground Elev.	Crown Elev.	Invert Elev.	Connecting Pipes		
6	56.170	55.244	53.770	5	6	
7	56.200	55.113	53.310	3	6	7
8	56.140	54.983	53.180	7		

+++ Outfall control water-surface elev = 53.350 m

Summary of initial heads, flows and velocities

Initial heads, flows and velocities are zero

Junction Hydrographs Obtained by Simplified Rational Formula

Junction Number	Triangle Hydrograph Time (min)/Inflow (m^3/s)		
1	.00/ .000	21.00/ .182	42.00/ .000
2	.00/ .000	28.00/ 1.134	56.00/ .000
3	.00/ .000	15.00/ 3.949	30.00/ .000
4	.00/ .000	15.00/ .374	30.00/ .000
5	.00/ .000	15.00/ .838	30.00/ .000
6	.00/ .000	15.00/ .804	30.00/ .000
7	.00/ .000	15.00/ .678	30.00/ .000

*** WARNING: iCyc = 113 zero surface area computed at junction 2
... Check input data for high pipe.

Time History of Hydraulic Gradeline

Time (h:min)	Junction 2 Grnd Elev (m)	Depth (m)	Junction 3 Grnd Elev (m)	Depth (m)	Junction 6 Grnd Elev (m)	Depth (m)
0:10	56.934	.344	55.702	1.932	55.624	1.854

Example Two: Rational Method Analysis with Pressure Flow

0:20	57.822	1.232	56.170	2.400	55.832	2.062
0:30	57.563	.973	54.841	1.071	54.740	.970
0:40	57.024	.434	54.402	.632	54.165	.395
0:50	56.842	.252	54.195	.425	53.895	.125
1: 0	56.620	.030	53.898	.128	53.804	.034

Summary of Junction Results

Junction Number	Ground /Invert Elev. (m)	Uppermost Pipe crown Elev. (m)	Maximum Computed Water Surface Elev	Time of Occurrence (h:min)	Surcharge at Max. Depth	Length of Surcharge (min)
1	58.980 57.570	58.027	58.980	0 : 19	.953	8.333
2	58.520 56.590	57.567	58.520	0 : 19	.953	11.000
3	56.170 53.770	55.192	56.170	0 : 11	.978	18.833
4	60.960 59.630	60.011	60.642	0 : 15	.631	1.000
5	56.380 54.220	55.441	56.380	0 : 10	.939	11.667
6	56.170 53.770	55.244	56.170	0 : 11	.926	14.333
7	56.200 53.310	55.113	56.200	0 : 11	1.087	14.833
8	56.140 53.180	54.983	53.180	0 : 0	.000	.000

Example Two: Rational Method Analysis with Pressure Flow

Time History of Flow and Velocity

Time (h:min)	Pipe 3 Flow m^3/s	Pipe 3 Vel m/s	Pipe 7 Flow m^3/s	Pipe 7 Vel m/s
0:10	3.130	2.062	2.034	3.028
0:20	2.409	1.620	2.259	2.159
0:30	1.382	1.137	2.228	2.244
0:40	.741	1.245	.855	1.627
0:50	.309	1.032	.373	1.243
1: 0	.021	.434	.049	.625

Summary of Pipe Results

Pipe Number	Design Flo/Vel m^3/s|m/s	Pipe Vertical Depth (mm)	Maximum Computed Flo/Vel m^3/s|m/s	Time of Occurrence (h:min)	Ratio of Max. to Design Flow	Max. Depth above Invert Pipe Ends Up (m)	Dn (m)
1	.172 1.049	458.	.182 1.239	0 : 21	1.1	1.410	1.410
2	1.129 2.476	763.	1.251 2.781	0 : 28	1.1	1.930	1.740
3	1.662 1.168	1347.	3.464 2.433	0 : 10	2.1	2.400	2.580
4	.379 3.321	382.	.378 3.313	0 : 15	1.0	1.012	1.320
5	1.225 1.094	1194.	1.202 1.240	0 : 15	1.0	2.160	2.120
6	1.701 1.195	1347.	2.554 1.794	0 : 18	1.5	2.400	2.540
7	3.773 1.477	1804.	4.836 3.028	0 : 11	1.3	2.890	.000

NORMAL END OF HYDRA

Example Three: Hydrographic Simulation and Design

Problem:

The site shown in figure 15 is a roadway section between two high points in the centerline profile. Six inlets are used to capture flow from eight identical pavement sections, each 0.20 ha 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 inlets, the flow goes through a feeder network of pipes to the main outfall pipe which, after passing through a pond, empties into a downstream channel.

The hydrographic commands featured in this example are **STE** (step), **UHY** (user-hydrograph), **GUT** (gutter), and **INL** (inlet). The **STE** command sets the time step for the analysis. In this example, it is set at 2 min which is relatively small for many analyses. The **UHY** command enables the user to employ either a user-defined hydrograph or a HYDRO-generated hydrograph (whose file name is characterized by a QT extension). The **GUT** command 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 types can be analyzed or designed, either on grade or in a sump condition. The **SDI** (stage-discharge), **SST** (stage-storage), and **RES** (reservoir) commands route in-system flow through a reservoir.

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.

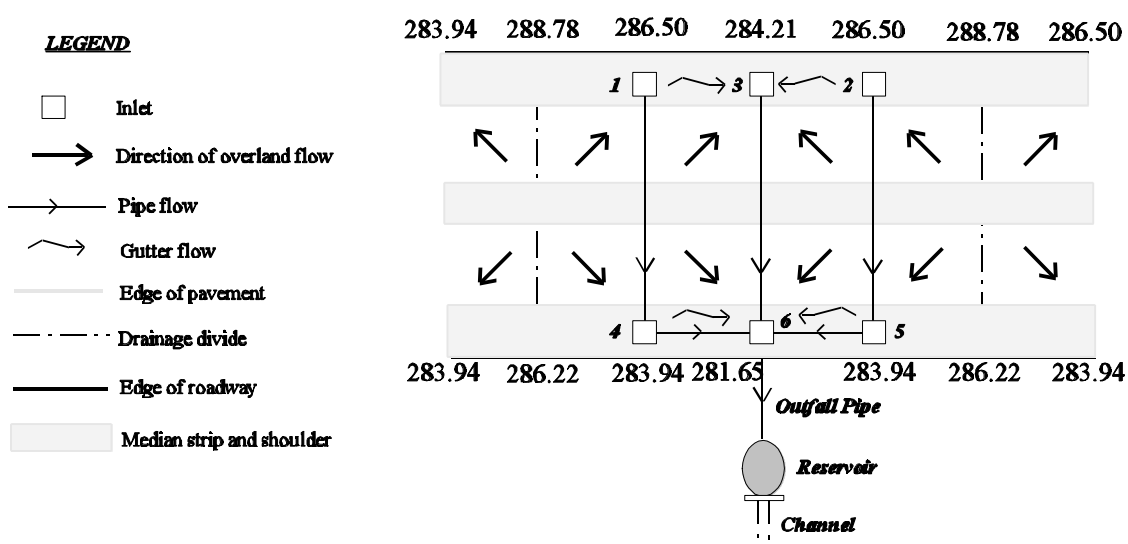

Figure 15. Hydrographic analysis.

Input File: HYDRA3.HDA

```
JOB Example Three:  Hydrographic Simulation and Design
SWI 3
CRI 1
PDA 0.013  300  1.52  1.22  0.762  0.001
PCO  300,150.9  375,167.3  450,187.0   525,206.7   600,226.4   675,242.8
     750,262.5  825,282.2  900,318.2  1050,357.6  1200,413.4  1350,469.2
    1500,525.0 1650,580.7 1800,675.9  2100,974.4
CST 1.5  0.457  0  0  0  0.152  8.12  1  0  1.99  1.05  0.78  2.04  1.99  0
EXC 1.52  0.94  7.62  1.48
TSL 0  0.25  3.05  0.25
STE 2
NEW PATH 1-4-6
UHY RUNOFF.QT
GUT 152.39  288.78  286.50  0.013  30  0.610  20
INL 1  1  1  101  0.610  1.22
PIP 26.82  286.50  283.94
UHY RUNOFF.QT
GUT 152.39  286.22  283.94  0.013  30  0.610  20
INL 4  1  1  104  0.610  1.22
PIP 152.39  283.94 281.65
HOL 4
NEW PATH 2-5-6
UHY RUNOFF.QT
GUT 152.39  288.78  286.50  0.013  30  0.610  20
INL 2  1  1  102  0.610  1.22
PIP 26.82  286.50  283.94
UHY RUNOFF.QT
GUT 152.39  286.22  283.94  0.013  30  0.610  20
INL 5  1  1  105  0.610  1.22
PIP 152.39  283.94  281.65
HOL 5
NEW PATH 3-6-OUTFALL
GET 101
UHY RUNOFF.QT
GUT 152.39  286.50  284.21  0.013  30  0.610  20
PUT 103
GET 102
UHY RUNOFF.QT
GUT 152.30  286.50  284.21  0.013  30  0.610  20
GET 103
INL 3  4  1  0  0.610  1.22
PIP 26.82  284.21  281.65
REC 4
REC 5
GET 104
UHY RUNOFF.QT
GUT 152.39  283.94  281.65  0.013  30  0.610  20
PUT 106
GET 105
UHY RUNOFF.QT
GUT 152.39  283.94  281.65  0.013  30  0.610  20
GET 106
INL 6  4  1  0  0.610  1.22
PIP 15.24  281.65  280.40  0  0  0  0  1  1
SDI 278.57,0  279.18,0.057  279.79,0.226  280.40,0.510  281.01,0.906
    281.62,1.42
SST 278.57,0  279.18,17.10  279.79,68.40  280.40,153.91  281.01,273.61
    281.62,427.52
RES 0  0
REM OUTFALL CHANNEL
CHA 304.78  278.57  277.96  0.034  1  1.22  1
END
```

Discussion of output:

The output illustrates that HYDRA provides warning and announcement messages as each command is processed. These messages can be helpful for debugging the system as well as providing design data. As exhibited in the output reservoir routing on in-system flow yields a maximum of 120 m^3 volume and maximum stage of 280.159 m.

Output file: HYDRA3.LST

```
        ******  HYDRA  ******* (Version 6.1) *****         Date 07-21-1998
                                                              Page No   1
  Example Three:  Hydrographic Simulation and Design

+++ Commands Read From File C:\HYDRA\HYDRA3.HDA
  JOB
  SWI 3
  CRI 1
  PDA 0.013  300  1.52  1.22  0.762  0.001
  PCO  300,150.9  375,167.3  450,187.0   525,206.7   600,226.4   675,242.8
    750,262.5  825,282.2  900,318.2  1050,357.6  1200,413.4  1350,469.2
   1500,525.0 1650,580.7 1800,675.9  2100,974.4
  CST 1.5  0.457  0  0  0  0.152  8.12  1  0  1.99  1.05  0.78  2.04  1.99  0
  EXC 1.52  0.94  7.62  1.48
  TSL 0  0.25  3.05  0.25
  STE 2
+++ Step reset from 15.0 minutes
  NEW PATH 1-4-6
  UHY RUNOFF.QT
+++ Notice:  Intermediate file has data in SI units
  GUT 152.39  288.78  286.50  0.013  30  0.610  20
+++ Depth =   .083 m, Vel =   1.276 m/s,  Width =   2.171 m
+++ Discharge =     .104 m^3/s, Slope =   .015 m/m
  INL 1  1  1  101  0.610  1.22
+++ Inlet capacity =      .076 m^3/s
  PIP 26.82  286.50  283.94
+++ Top width of trench ---> UP  1.1 m
                        ---> DN  1.1 m
+++ Link #  1,  Flow depth =    .105 m, Critical depth =    .215 m
  UHY RUNOFF.QT
+++ Notice:  Intermediate file has data in SI units
  GUT 152.39  286.22  283.94  0.013  30  0.610  20
+++ Depth =   .083 m, Vel =   1.276 m/s,  Width =   2.171 m
+++ Discharge =     .104 m^3/s, Slope =   .015 m/m
  INL 4  1  1  104  0.610  1.22
+++ Inlet capacity =      .076 m^3/s
  PIP 152.39  283.94 281.65
*** WARNING: Crowns not matched because cover and depth criteria override.
+++ Top width of trench ---> UP  1.2 m
                        ---> DN  1.2 m
+++ Link #  2,  Flow depth =    .236 m, Critical depth =    .287 m
  HOL 4
  NEW PATH 2-5-6
  UHY RUNOFF.QT
+++ Notice:  Intermediate file has data in SI units
  GUT 152.39  288.78  286.50  0.013  30  0.610  20
+++ Depth =   .083 m, Vel =   1.276 m/s,  Width =   2.171 m
+++ Discharge =     .104 m^3/s, Slope =   .015 m/m
```

```
  INL 2  1  1  102  0.610  1.22
+++ Inlet capacity =      .076 m^3/s
  PIP 26.82  286.50  283.94
+++ Top width of trench ---> UP  1.1 m
                        ---> DN  1.1 m
+++ Link #  3,  Flow depth =    .105 m, Critical depth =    .215 m
  UHY RUNOFF.QT
```

```
  Example Three:  Hydrographic Simulation and Design

 +++ Notice:  Intermediate file has data in SI units
   GUT 152.39  286.22  283.94  0.013  30  0.610  20
 +++ Depth =   .083 m, Vel =   1.276 m/s,  Width =   2.171 m
 +++ Discharge =     .104 m^3/s, Slope =   .015 m/m
   INL 5  1  1  105  0.610  1.22
 +++ Inlet capacity =      .076 m^3/s
   PIP 152.39  283.94  281.65
 *** WARNING: Crowns not matched because cover and depth criteria override.
 +++ Top width of trench ---> UP  1.2 m
                         ---> DN  1.2 m
 +++ Link #  4,  Flow depth =    .236 m, Critical depth =    .287 m
   HOL 5
   NEW PATH 3-6-OUTFALL
   GET 101
   UHY RUNOFF.QT
 +++ Notice:  Intermediate file has data in SI units
   GUT 152.39  286.50  284.21  0.013  30  0.610  20
 +++ Depth =   .082 m, Vel =   1.278 m/s,  Width =   2.169 m
 +++ Discharge =     .104 m^3/s, Slope =   .015 m/m
   PUT 103
   GET 102
   UHY RUNOFF.QT
 +++ Notice:  Intermediate file has data in SI units
   GUT 152.30  286.50  284.21  0.013  30  0.610  20
 +++ Depth =   .082 m, Vel =   1.278 m/s,  Width =   2.169 m
 +++ Discharge =     .104 m^3/s, Slope =   .015 m/m
   GET 103
   INL 3  4  1  0  0.610  1.22
Default orif area =    .670 m^2, Perimeter ( 3 sides) =   2.440 m
 +++ Maximum Storage =          69. m^3
 +++ Ponding Time =           16.0 min
   PIP 26.82  284.21  281.65
 +++ Top width of trench ---> UP  1.1 m
                         ---> DN  1.1 m
 +++ Link #  5,  Flow depth =    .108 m, Critical depth =    .218 m
   REC 4
   REC 5
   GET 104
   UHY RUNOFF.QT
 +++ Notice:  Intermediate file has data in SI units
   GUT 152.39  283.94  281.65  0.013  30  0.610  20
 +++ Depth =   .082 m, Vel =   1.278 m/s,  Width =   2.169 m
 +++ Discharge =     .104 m^3/s, Slope =   .015 m/m
   PUT 106
   GET 105
   UHY RUNOFF.QT
 +++ Notice:  Intermediate file has data in SI units
   GUT 152.39  283.94  281.65  0.013  30  0.610  20
 +++ Depth =   .082 m, Vel =   1.278 m/s,  Width =   2.169 m
 +++ Discharge =     .104 m^3/s, Slope =   .015 m/m
   GET 106
   INL 6  4  1  0  0.610  1.22
Default orif area =    .670 m^2, Perimeter ( 3 sides) =   2.440 m
 +++ Maximum Storage =          69. m^3
 +++ Ponding Time =           16.0 min
```

Example Three: Hydrographic Simulation and Design

```
  PIP 15.24  281.65  280.40  0  0  0  0  1  1
*** WARNING: Crowns not matched because cover and depth criteria override.
+++ Top width of trench ---> UP  1.3 m
                       ---> DN  1.2 m

                            SYSTEM HYDROGRAPH in m^3/s


.460+)))))3)))*))*))*)))))3)))))))))))))))3))))))))))))))3))))))))))))))),
 D       *     .            *  .              .              .
*
 i       *     *              .              .              .
*
 s   .4003     .              .              .              .
3
 c       *     .              *              .              .
*
 h       *     .              .              .              .
*
 a       *  *  .              .              .              .
*
 r   .3003     .              .  *           .              .
3
 g       *     .              .              .              .
*
 e       *     .              .              .              .
*
         *     .              .      *       .              .
*
 i   .2003     .              .              .              .
3
 n       *     .              .         *  *  *  *   *  *   .
*
         *     .              .              .              .
*
 m       *     .              .              .              .
*
 ^   .1003     .              .              .              .
3
 3       *     .              .              .              .
*
 /       *     .              .              .            *  .
*
 s       *     .              .              .              .
*

.000.)))))3)))))))))))))))3)))))))))))))))3)))))))))))))))3))*))*)))*))*))*
       6.    10.             20.             30.             40.
50.

                                   Time, t (min)
```

Example Three: Hydrographic Simulation and Design

PLOT-DATA (Time, t(min) vs. Discharge, (m^3/s))

t	Q	t	Q	t	Q	t	Q	t	Q
6.	.156	46.	.000	0.	.000	0.	.000	0.	.000
8.	.320	48.	.000	0.	.000	0.	.000	0.	.000
10.	.424	50.	.000	0.	.000	0.	.000	0.	.000
12.	.459	0.	.000	0.	.000	0.	.000	0.	.000
14.	.460	0.	.000	0.	.000	0.	.000	0.	.000
16.	.458	0.	.000	0.	.000	0.	.000	0.	.000
18.	.427	0.	.000	0.	.000	0.	.000	0.	.000
20.	.357	0.	.000	0.	.000	0.	.000	0.	.000
22.	.288	0.	.000	0.	.000	0.	.000	0.	.000
24.	.218	0.	.000	0.	.000	0.	.000	0.	.000
26.	.173	0.	.000	0.	.000	0.	.000	0.	.000
28.	.173	0.	.000	0.	.000	0.	.000	0.	.000
30.	.170	0.	.000	0.	.000	0.	.000	0.	.000
32.	.168	0.	.000	0.	.000	0.	.000	0.	.000
34.	.166	0.	.000	0.	.000	0.	.000	0.	.000
36.	.164	0.	.000	0.	.000	0.	.000	0.	.000
38.	.060	0.	.000	0.	.000	0.	.000	0.	.000
40.	.009	0.	.000	0.	.000	0.	.000	0.	.000
42.	.006	0.	.000	0.	.000	0.	.000	0.	.000
44.	.002	0.	.000	0.	.000	0.	.000	0.	.000

```
+++ System hydrograph registers full at time =    50. min
+++ Link #  6,  Flow depth =    .296 m, Critical depth =    .372 m
  SDI 278.57,0  279.18,0.057  279.79,0.226  280.40,0.510  281.01,0.906
   281.62,1.42
```

Example Three: Hydrographic Simulation and Design

STAGE - DISCHARGE CURVE

```
1.4+)))))))))3)))))))))))3)))))))))))3)))))))))))3)))))))))))3)))))))))))*
 D        *          .          .          .          .          .
*
 i        *          .          .          .          .          .
*
 s        *          .          .          .          .          .
*
 c        *          .          .          .          .          .
*
 h     1.03          .          .          .          .          .
3
 a        *          .          .          .          .          .
*
 r        *          .          .          .          .        * .
*
 g        *          .          .          .          .          .
*
 e        *          .          .          .          .          .
*
          *          .          .          .          .          .
*
 i        *          .          .          .          .          .
*
 n      .53          .          .          .       *  .          .
3
          *          .          .          .          .          .
*
 m        *          .          .          .          .          .
*
 ^        *          .          .          .          .          .
*
 3        *          .          .     *    .          .          .
*
 /        *          .          .          .          .          .
*
 s        *          .   *      .          .          .          .
*

.0*)))))))))3)))))))))))3)))))))))))3)))))))))))3)))))))))))3)))))))))))-
     278.6      279.0      279.5      280.0      280.5      281.0
281.6
```

Elevation, EL (m)

PLOT-DATA (Stage, EL(m) Vs. Discharge, Q(m^3/s))

EL	Q	EL	Q	EL	Q	EL	Q	EL	Q

278.570	.000	281.010	.906	.000	.000	.000	.000	.000	.000
279.180	.057	281.620	1.420	.000	.000	.000	.000	.000	.000
279.790	.226	.000	.000	.000	.000	.000	.000	.000	.000
280.400	.510	.000	.000	.000	.000	.000	.000	.000	.000

```
SST 278.57,0  279.18,17.10  279.79,68.40  280.40,153.91  281.01,273.61
 281.62,427.52
```

Example Three: Hydrographic Simulation and Design

STAGE - STORAGE CURVE

```
427.5+)))))))))3)))))))))))3)))))))))))3)))))))))))3)))))))))))3)))))))))))*
         *         .           .           .           .           .
*
         *         .           .           .           .           .
*
 V       *         .           .           .           .           .
*
 o  300.03         .           .           .           .           .
3
 l       *         .           .           .           .           .
*
 u       *         .           .           .           .           .
*
 m       *         .           .           .           .         * .
*
 e       *         .           .           .           .           .
*
    200.03         .           .           .           .           .
3
 i       *         .           .           .           .           .
*
 n       *         .           .           .           .           .
*
         *         .           .           .       *   .           .
*
 m       *         .           .           .           .           .
*
 ^  100.03         .           .           .           .           .
3
 3       *         .           .           .           .           .
*
         *         .           .     *     .           .           .
*
         *         .           .           .           .           .
*
         *         .   *       .           .           .           .
*

.0*)))))))))3)))))))))))3)))))))))))3)))))))))))3)))))))))))3)))))))))))-
     278.6      279.0       279.5       280.0       280.5       281.0
281.6
```

Elevation, EL (m)

PLOT-DATA (Stage, EL(m) vs. Storage, V(m^3))

EL	V	EL	V	EL	V	EL	V	EL	V

```
278.570    .000 281.010 273.610    .000    .000    .000    .000    .000    .000
279.180  17.100 281.620 427.520    .000    .000    .000    .000    .000    .000
279.790  68.400    .000    .000    .000    .000    .000    .000    .000    .000
280.400 153.910    .000    .000    .000    .000    .000    .000    .000    .000
```

```
  RES 0  0
+++ Max. volume =     120. m^3 at an elevation of  280.159 m
  REM OUTFALL CHANNEL
  CHA 304.78  278.57  277.96  0.034  1  1.22  1
+++ Link   7, Max. shear stress =      8.3 Pa
  END
 END OF INPUT DATA.
```

Example Three: Hydrographic Simulation and Design

*** PATH 1-4-6 Pipe Design

Link	Length (m)	Diam (mm)	Invert Up/Dn (m)	Slope (m/m)	Depth Up/Dn (m)	Min. Cover (m)	Velocity Act/Full (m/s)	--Flow-- Act/Full (m^3/s)	Estimated Cost ($)
1	27	300	284.955	.095	1.545	1.220	3.528	.076	4108.
			282.395		1.545		4.227	.299	
2	152	375	282.289	.015	1.651	1.220	2.099	.151	25933.
			280.024		1.626		1.935	.214	

Length = 179. m Total length = 179. m
Cost = 30041. Total Cost = 30041.

*** PATH 2-5-6 Pipe Design

Link	Length (m)	Diam (mm)	Invert Up/Dn (m)	Slope (m/m)	Depth Up/Dn (m)	Min. Cover (m)	Velocity Act/Full (m/s)	--Flow-- Act/Full (m^3/s)	Estimated Cost ($)
3	27	300	284.955	.095	1.545	1.220	3.528	.076	4108.
			282.395		1.545		4.227	.299	
4	152	375	282.289	.015	1.651	1.220	2.099	.151	25933.
			280.024		1.626		1.935	.214	

Length = 179. m Total length = 179. m
Cost = 30041. Total Cost = 30041.

Example Three: Hydrographic Simulation and Design

*** PATH 3-6-OUTFALL Pipe Design

Link	Length (m)	Diam (mm)	Invert Up/Dn (m)	Slope (m/m)	Depth Up/Dn (m)	Min. Cover (m)	Velocity Act/Full (m/s)	--Flow-- Act/Full (m^3/s)	Estimated Cost ($)
5	27	300	282.665	.095	1.545	1.220	3.561	.079	4108.
			280.105		1.545		4.227	.299	
6	15	375	279.918	.075	1.732	1.220	4.950	.460	2595.
			278.774		1.626		4.349	.480	

Length = 42. m Total length = 400. m
Cost = 6703. Total Cost = 66785.

*** PATH 3-6-OUTFALL Channel

Link	Length (m)	-Channel Shape-- Left (m)	Ctr (m)	Right (m)	Slope (m/m)	Invert Up/Dn (m)	Surface Up/Dn (m)	Depth (m)	Surf Width (m)	Flow (m^3/s)	Vel (m/s)
7	305	1.0	1.2	1.0	.002	278.570	278.994	.424	2.067	.398	.574
						277.960	278.384				

Length = 347. m Total length = 705. m

Example Three: Hydrographic Simulation and Design

NORMAL END OF HYDRA

Example Four: Hydrographic Analysis and Pressure Flow Simulation

Problem:

The example shown in figure 16 demonstrates the application of HYDRA to an existing storm sewer system by implementing hydrographic flow by way of the **UHY** command. The hydrographs appear in tabular form with a fixed format in a file with a **QT** extension. In addition, the time step on the **STE** command reflects the uniform time interval that occurs in the tabular user hydrographs. User-defined inlets are utilized and have sufficient efficiencies to capture the flow specified in the **QT** files. The tailwater elevation is given in the **TWE** command to be the invert of the outlet pipe. This elevation is necessary for the hydraulic gradeline and pressurized flow computations.

The pressure flow simulation command, **PFS**, establishes the control parameters for the pressurized flow computations. In this example, the simulation time is set for a duration in which the maximum surcharges within the system should occur (based on the times to peak of inflow hydrographs). The parameters, **ITMAX** and **SURTOL**, are given acceptable values of 30 and 0.05, respectively, to ensure adequate accuracy.

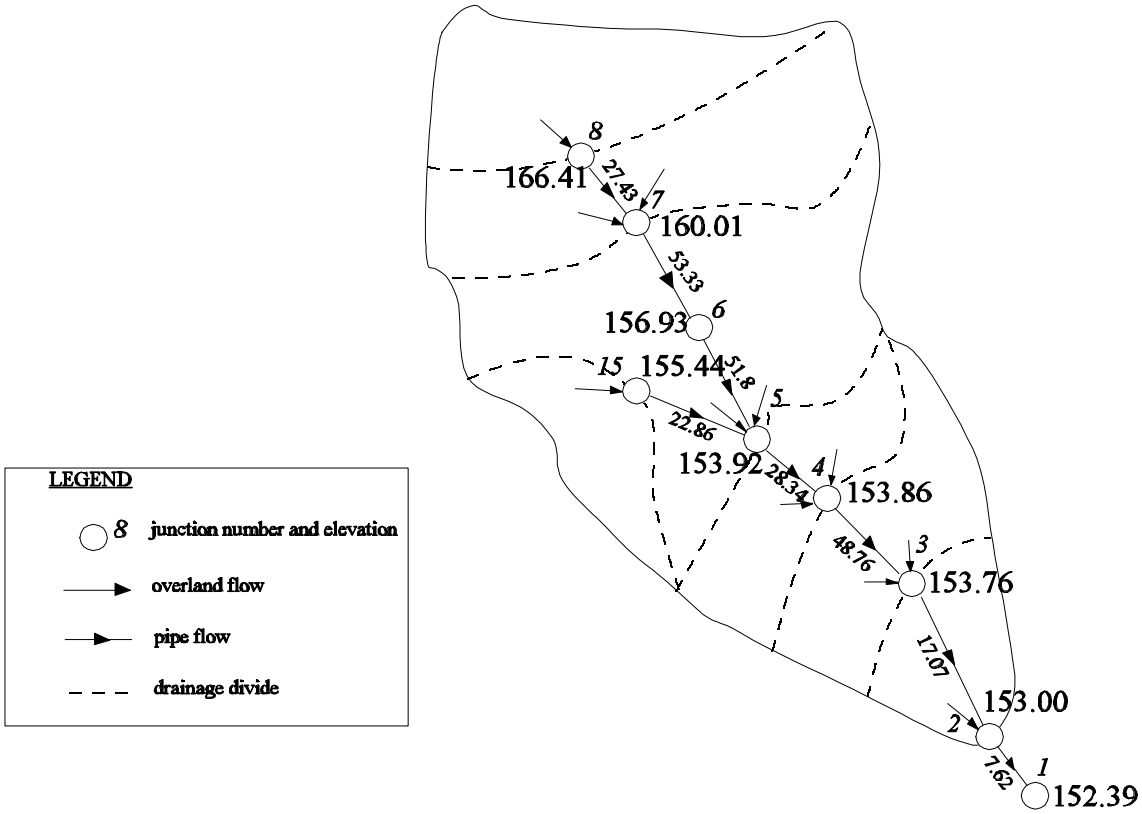

Figure 16. Hydrographic analysis with pressure flow.

Data file: HYDR15.QT

```
Example 4 - hydrograph for junctions 8 & 15
   27
         1       0.0    0.0000
         2      3.00    0.0011
         3      6.00    0.0059
         4      9.00    0.0127
         5     12.00    0.0224
         6     15.00    0.0345
         7     18.00    0.0481
         8     21.00    0.0617
         9     24.00    0.0682
        10     27.00    0.0753
        11     30.00    0.0793
        12     33.00    0.0801
        13     36.00    0.0790
        14     39.00    0.0750
        15     42.00    0.0702
        16     45.00    0.0643
        17     48.00    0.0566
        18     51.00    0.0490
        19     54.00    0.0422
        20     57.00    0.0374
        21     60.00    0.0326
        22     63.00    0.0283
        23     66.00    0.0246
        24     69.00    0.0218
        25     72.00    0.0193
        26     75.00    0.0170
        27     78.00    0.0144
```

Data file: HYDR4.QT

```
Example 4 - hydrograph for junctions 4 & 7
   26
         1       0.0    0.0000
         2      3.00    0.0017
         3      6.00    0.0079
         4      9.00    0.0170
         5     12.00    0.0294
         6     15.00    0.0453
         7     18.00    0.0631
         8     21.00    0.0813
         9     24.00    0.0937
        10     27.00    0.1022
        11     30.00    0.1053
        12     33.00    0.1033
        13     36.00    0.0968
        14     39.00    0.0886
        15     42.00    0.0790
        16     45.00    0.0696
        17     48.00    0.0589
        18     51.00    0.0515
        19     54.00    0.0442
```

```
        20     57.00    0.0391
        21     60.00    0.0337
        22     63.00    0.0294
        23     66.00    0.0252
        24     69.00    0.0221
        25     72.00    0.0190
        26     75.00    0.0164
```

Data file: HYDR05.QT

```
Example 4 - hydrograph for junction 5
   27
         1       0.0    0.0000
         2      3.00    0.0045
         3      6.00    0.0227
         4      9.00    0.0439
         5     12.00    0.0770
         6     15.00    0.1220
         7     18.00    0.1815
         8     21.00    0.2330
         9     24.00    0.2693
        10     27.00    0.2865
        11     30.00    0.2995
        12     33.00    0.3027
        13     36.00    0.2987
        14     39.00    0.2837
        15     42.00    0.2605
        16     45.00    0.2387
        17     48.00    0.2143
        18     51.00    0.1849
        19     54.00    0.1583
        20     57.00    0.1365
        21     60.00    0.1195
        22     63.00    0.1059
        23     66.00    0.0929
        24     69.00    0.0804
        25     72.00    0.0691
        26     75.00    0.0597
        27     78.00    0.0515
```

Data file: HYDR02.QT

```
Example 4 - hydrograph for junction 2
   26
         1       0.0    0.0000
         2      3.00    0.0003
         3      6.00    0.0008
         4      9.00    0.0020
         5     12.00    0.0031
         6     15.00    0.0048
         7     18.00    0.0068
         8     21.00    0.0091
         9     24.00    0.0102
        10     27.00    0.0113
        11     30.00    0.0116
        12     33.00    0.0113
```

```
13     36.00    0.0108
14     39.00    0.0096
15     42.00    0.0088
16     45.00    0.0079
17     48.00    0.0065
18     51.00    0.0057
19     54.00    0.0048
20     57.00    0.0042
21     60.00    0.0037
22     63.00    0.0034
23     66.00    0.0028
24     69.00    0.0023
25     72.00    0.0020
26     75.00    0.0017
```

Input file: HYDRA4.HDA

```
JOB Example Four: Hydrographic Analysis and Pressure Flow Simulation
SWI 3
CRI 0
STE 3.0
TWE 150.81
HGL 1
NEW LINK 8 TO 5
REM LINE 8 TO 6
PDA 0.022  300  1.22  0.914  0.610  0.001
UHY HYDR15.QT
GUT 30.48  167.14  166.41  0.013  50  0.914  40  0  1
INL 8  7  0  101 0 0 0 0 0 0 1
EFF 0  100  2.83  100
PIP 27.43  166.41  160.01  165.16  158.76  -300
PNC 8  7  0.914  22.0  0
REM LINK 7 TO 6
PDA 0.014  300  1.22  0.914  0.610  0.001
UHY HYDR04.QT
GUT 45.72  160.62  160.01  0.013  50  0.610  40  0  1
INL 7  7  0  102  0 0 0 0 0 0 1
EFF 0  100  2.83  100
PIP 53.33  160.01  156.93  158.58  155.50  -450
PNC 7  6  0.914  0.0  0
REM LINK 6 TO 5
PIP 51.81  156.93  153.92  155.50  152.51  -450
PNC 6  5  0.914  40.0  0
HOL 5
NEW MAINLINE 15 TO 1
REM LINK 15 TO 5
UHY HYDR15.QT
GUT 30.48  156.05  155.44  0.013  50  0.914  40  0  1
INL 15  7  0  103  0 0 0 0 0 0 1
EFF 0 100 2.83 100
PIP 22.86  155.44  153.92  154.19  152.67  -300
PNC 15  5  1.22  0  0
REM LINK 5 TO 4
UHY HYDR05.QT
GUT 15.24  154.07  153.92  0.013  50  1.52  30  0  1
INL 5  7  0  104  0 0 0 0 0 0 1
EFF 0  100  2.83  100
REC 5
PIP 28.34  153.92  153.61  152.48  152.21  -450
PNC 5  4  1.22  11.0  0
REM LINK 4 TO 3
UHY HYDR04.QT
GUT 36.57  154.53  153.86  0.013  30  1.52  30  0  1
INL 4  7  0  105  0 0 0 0 0 0 1
EFF 0  100  2.83  100
```

```
PIP 48.76  153.86  153.76  151.90  151.84  -750
PNC 4  3  1.22  0.0  0
REM LINK 3 TO 2
UHY HYDR04.QT
GUT 54.86  154.62  153.76  0.013  50  0.914  40  0  1
INL 6  7  0  106
EFF 0  100  2.83  100
PIP 28.95  153.76  153.00  151.84  151.26  -750
PNC 3  2  1.22  48  0
REM LINK 2 TO 1
UHY HYDR02.QT
GUT 22.86  153.46  153.00  0.013  50   0.914  40  0  1
INL 7  7  0  107  0 0 0 0 0 0 1
EFF 0  100  2.83  100
PIP 7.62  153.00  152.39  151.11  150.81  -600
PNC 2  1  0  0.0  2
PFS 0  60  3.0  5  0  9  8  30  0.05
PHJ 8  7  6  15  5  4  3  2  1
PFP 1  2   3  4  5  6   7  8
IQV 2.0  5.1  0  0  0  0  2.5  6.4
IDY IDY 0.0  0.0  0.0  0.0  0.6  0.0  0.0  0.0
END
```

Discussion of output:

The hydraulic gradeline (HGL) and pressure flow simulation (PFS) options present surcharge conditions of the storm sewer system. Generally, the HGL results are more conservative than the PFS results which the output depicts. If the detailed output had been requested, some computed depths and flows may have been followed by an asterisk. An asterisk following a depth indicates surcharging while an asterisk following a flow value indicates that the flow was set to normal flow. The PFS algorithm uses a convention in which the outfall is a pipe as opposed to a node. For this reason, it generates a synthetic outfall denoted as pipe 90009.

Only the first 1,000 lines of the output file will be displayed in the HYDRAIN editor. The entire file may be viewed in another text editor. See page 34 in Volume I: HYDRAIN for more information.

Output file: HYDRA4.LST

```
          ******  HYDRA  ******* (Version 6.1) *****         Date 07-21-1998
                                                                Page No   1

   Example Four: Hydrographic Analysis and Pressure Flow Simulation

 +++ Commands Read From File C:\HYDRA\HYDRA4.HDA
   JOB
   SWI 3
   CRI 0
   STE 3.0
 +++ Step reset from 15.0 minutes
   TWE 150.81
   HGL 1
   NEW LINK 8 TO 5
   REM LINE 8 TO 6
   PDA 0.022  300  1.22  0.914  0.610  0.001
   UHY HYDR15.QT
 +++ Notice:  Intermediate file has data in SI units
   GUT 30.48  167.14  166.41  0.013  50  0.914  40  0  1
 +++ Depth =   .054 m, Vel =   1.246 m/s,  Width =   2.493 m
 +++ Discharge =     .080 m^3/s, Slope =   .024 m/m

                              GUTTER HYDROGRAPH in m^3/s


.080+)))))**)))3)))))))))))3)))))))))))3)))))))))))3)))))))))))3)))))))))),
 D       *     *  *  .           .           .           .           .
*
 i       *         * .           .           .           .           .
*
 s       *    *      .           .           .           .           .
*
 c   .0603   *     * .           .           .           .           .
3
 h       *           .           .           .           .           .
*
 a       *          *.           .           .           .           .
*
 r       *           *           .           .           .           .
*
 g       *   *       .           .           .           .           .
*
 e   .0403           .*          .           .           .           .
3
         *           .*          .           .           .           .
*
 i       *  *        . *         .           .           .           .
*
 n       *           .  *        .           .           .           .
*
         *           .  *        .           .           .           .
*
 m   .0203 *          .   **     .           .           .           .
3
 ^       *           .     *     .           .           .           .
*
```

```
 3        **          .     *     .           .           .           .
*
 /        *           .           .           .           .           .
*
 s        **          .           .           .           .           .
*

.000*))))))))))3)))))*****3**********3**********3**********3*********
       3.          50.        100.        150.        200.        250.
288.
```

Time, t (min)

Example Four: Hydrographic Analysis and Pressure Flow Simulation

PLOT-DATA (Time, t(min) vs. Discharge, (m^3/s))

t	Q	t	Q	t	Q	t	Q	t	Q
3.	.001	63.	.028	123.	.000	183.	.000	243.	.000
6.	.006	66.	.025	126.	.000	186.	.000	246.	.000
9.	.013	69.	.022	129.	.000	189.	.000	249.	.000
12.	.022	72.	.019	132.	.000	192.	.000	252.	.000
15.	.034	75.	.017	135.	.000	195.	.000	255.	.000
18.	.048	78.	.014	138.	.000	198.	.000	258.	.000
21.	.062	81.	.000	141.	.000	201.	.000	261.	.000
24.	.068	84.	.000	144.	.000	204.	.000	264.	.000
27.	.075	87.	.000	147.	.000	207.	.000	267.	.000
30.	.079	90.	.000	150.	.000	210.	.000	270.	.000
33.	.080	93.	.000	153.	.000	213.	.000	273.	.000
36.	.079	96.	.000	156.	.000	216.	.000	276.	.000
39.	.075	99.	.000	159.	.000	219.	.000	279.	.000
42.	.070	102.	.000	162.	.000	222.	.000	282.	.000
45.	.064	105.	.000	165.	.000	225.	.000	285.	.000
48.	.057	108.	.000	168.	.000	228.	.000	288.	.000
51.	.049	111.	.000	171.	.000	231.	.000	0.	.000
54.	.042	114.	.000	174.	.000	234.	.000	0.	.000
57.	.037	117.	.000	177.	.000	237.	.000	0.	.000
60.	.033	120.	.000	180.	.000	240.	.000	0.	.000

```
+++ System hydrograph registers full at time =   288. min
  INL 8  7  0  101 0 0 0 0 0 0 1
  EFF 0  100  2.83  100
  PIP 27.43  166.41  160.01  165.16  158.76  -300
+++ Link #  1,  Flow depth =    .111 m, Critical depth =    .220 m
  PNC 8  7  0.914  22.0  0
  REM LINK 7 TO 6
  PDA 0.014  300  1.22  0.914  0.610  0.001
  UHY HYDR04.QT
+++ Notice:  Intermediate file has data in SI units
  GUT 45.72  160.62  160.01  0.013  50  0.610  40  0  1
+++ Depth =   .066 m, Vel =   1.059 m/s,  Width =   3.139 m
+++ Discharge =     .105 m^3/s, Slope =   .013 m/m
```

Example Four: Hydrographic Analysis and Pressure Flow Simulation

GUTTER HYDROGRAPH in m^3/s

```
.105+)))))*))))3)))))))))))3)))))))))))3)))))))))))3)))))))))))3)))))))))),
 D       *     *     .           .           .           .           .
*
 i       *    *  *   .           .           .           .           .
*
 s       *        *  .           .           .           .           .
*
 c   .0753   *       .           .           .           .           .
3
 h       *         * .           .           .           .           .
*
 a       *         * .           .           .           .           .
*
 r       *           .           .           .           .           .
*
 g       *   *      *.           .           .           .           .
*
 e   .0503           .           .           .           .           .
3
         *           *           .           .           .           .
*
 i       *  *        .*          .           .           .           .
*
 n       *           .*          .           .           .           .
*
         *           . *         .           .           .           .
*
 m   .0253 *         .  *        .           .           .           .
3
 ^       *           .   *       .           .           .           .
*
 3       **          .    **     .           .           .           .
*
 /       *           .           .           .           .           .
*
 s       **          .           .           .           .           .
*

.000*)))))))))))3)))))******3***********3***********3***********3**********
       4.          50.        100.        150.        200.        250.
289.
```

Time, t (min)

Example Four: Hydrographic Analysis and Pressure Flow Simulation

PLOT-DATA (Time, t(min) vs. Discharge, (m^3/s))

t	Q	t	Q	t	Q	t	Q	t	Q
4.	.002	64.	.029	124.	.000	184.	.000	244.	.000
7.	.008	67.	.025	127.	.000	187.	.000	247.	.000
10.	.017	70.	.022	130.	.000	190.	.000	250.	.000
13.	.029	73.	.019	133.	.000	193.	.000	253.	.000
16.	.045	76.	.016	136.	.000	196.	.000	256.	.000
19.	.063	79.	.000	139.	.000	199.	.000	259.	.000
22.	.081	82.	.000	142.	.000	202.	.000	262.	.000
25.	.094	85.	.000	145.	.000	205.	.000	265.	.000
28.	.102	88.	.000	148.	.000	208.	.000	268.	.000
31.	.105	91.	.000	151.	.000	211.	.000	271.	.000
34.	.103	94.	.000	154.	.000	214.	.000	274.	.000
37.	.097	97.	.000	157.	.000	217.	.000	277.	.000
40.	.089	100.	.000	160.	.000	220.	.000	280.	.000
43.	.079	103.	.000	163.	.000	223.	.000	283.	.000
46.	.070	106.	.000	166.	.000	226.	.000	286.	.000
49.	.059	109.	.000	169.	.000	229.	.000	289.	.000
52.	.052	112.	.000	172.	.000	232.	.000	0.	.000
55.	.044	115.	.000	175.	.000	235.	.000	0.	.000
58.	.039	118.	.000	178.	.000	238.	.000	0.	.000
61.	.034	121.	.000	181.	.000	241.	.000	0.	.000

```
+++ System hydrograph registers full at time =   289. min
  INL 7  7  0  102  0 0 0 0 0 0 1
  EFF 0  100  2.83  100
  PIP 53.33  160.01  156.93  158.58  155.50  -450
+++ Link #  2,  Flow depth =    .167 m, Critical depth =    .302 m
  PNC 7  6  0.914  0.0  0
  REM LINK 6 TO 5
  PIP 51.81  156.93  153.92  155.50  152.51  -450
+++ Link #  3,  Flow depth =    .167 m, Critical depth =    .302 m
  PNC 6  5  0.914  40.0  0
  HOL 5
  NEW MAINLINE 15 TO 1
  REM LINK 15 TO 5
  UHY HYDR15.QT
+++ Notice:  Intermediate file has data in SI units
  GUT 30.48  156.05  155.44  0.013  50  0.914  40  0  1
+++ Depth =   .056 m, Vel =   1.166 m/s,  Width =   2.581 m
+++ Discharge =     .080 m^3/s, Slope =   .020 m/m
```

Example Four: Hydrographic Analysis and Pressure Flow Simulation

GUTTER HYDROGRAPH in m^3/s

```
.080+)))))**)))3)))))))))))3)))))))))))3)))))))))))3)))))))))))3)))))))))),
 D       *     *  *  .           .           .           .           .
*
 i       *          * .           .           .           .           .
*
 s       *    *      .           .           .           .           .
*
 c   .0603   *     * .           .           .           .           .
3
 h       *            .           .           .           .           .
*
 a       *           *.           .           .           .           .
*
 r       *            *           .           .           .           .
*
 g       *   *        .           .           .           .           .
*
 e   .0403            .*          .           .           .           .
3
         *           .*           .           .           .           .
*
 i       *  *         . *         .           .           .           .
*
 n       *            .  *        .           .           .           .
*
         *            .  *        .           .           .           .
*
 m   .0203 *          .   **      .           .           .           .
3
 ^       *            .     *     .           .           .           .
*
 3       **           .     *     .           .           .           .
*
 /       *            .           .           .           .           .
*
 s       **           .           .           .           .           .
*

.000*)))))))))))3))))))*****3***********3***********3***********3**********
       3.          50.        100.        150.        200.        250.
288.
```

Time, t (min)

Example Four: Hydrographic Analysis and Pressure Flow Simulation

PLOT-DATA (Time, t(min) vs. Discharge, (m^3/s))

t	Q	t	Q	t	Q	t	Q	t	Q
3.	.001	63.	.028	123.	.000	183.	.000	243.	.000
6.	.006	66.	.025	126.	.000	186.	.000	246.	.000
9.	.013	69.	.022	129.	.000	189.	.000	249.	.000
12.	.022	72.	.019	132.	.000	192.	.000	252.	.000
15.	.034	75.	.017	135.	.000	195.	.000	255.	.000
18.	.048	78.	.014	138.	.000	198.	.000	258.	.000
21.	.062	81.	.000	141.	.000	201.	.000	261.	.000
24.	.068	84.	.000	144.	.000	204.	.000	264.	.000
27.	.075	87.	.000	147.	.000	207.	.000	267.	.000
30.	.079	90.	.000	150.	.000	210.	.000	270.	.000
33.	.080	93.	.000	153.	.000	213.	.000	273.	.000
36.	.079	96.	.000	156.	.000	216.	.000	276.	.000
39.	.075	99.	.000	159.	.000	219.	.000	279.	.000
42.	.070	102.	.000	162.	.000	222.	.000	282.	.000
45.	.064	105.	.000	165.	.000	225.	.000	285.	.000
48.	.057	108.	.000	168.	.000	228.	.000	288.	.000
51.	.049	111.	.000	171.	.000	231.	.000	0.	.000
54.	.042	114.	.000	174.	.000	234.	.000	0.	.000
57.	.037	117.	.000	177.	.000	237.	.000	0.	.000
60.	.033	120.	.000	180.	.000	240.	.000	0.	.000

```
+++ System hydrograph registers full at time =   288. min
  INL 15  7  0  103  0 0 0 0 0 0 1
  EFF 0 100 2.83 100
  PIP 22.86  155.44  153.92  154.19  152.67  -300
+++ Link #  4,  Flow depth =    .123 m, Critical depth =    .220 m
  PNC 15  5  1.22  0  0
  REM LINK 5 TO 4
  UHY HYDR05.QT
+++ Notice:  Intermediate file has data in SI units
  GUT 15.24  154.07  153.92  0.013  50  1.52  30  0  1
+++ Depth =   .115 m, Vel =   1.271 m/s,  Width =   4.719 m
+++ Discharge =     .303 m^3/s, Slope =   .010 m/m
```

Example Four: Hydrographic Analysis and Pressure Flow Simulation

GUTTER HYDROGRAPH in m^3/s

```
.303+)))))**)))3)))))))))))3)))))))))))3)))))))))))3)))))))))))3)))))))))),
 D       *     *  *  .           .           .           .           .
*
 i       *    *      .           .           .           .           .
*
 s       *         * .           .           .           .           .
*
 c       *   *     * .           .           .           .           .
*
 h   .2003           .           .           .           .           .
3
 a       *          *.           .           .           .           .
*
 r       *           *           .           .           .           .
*
 g       *   *       .           .           .           .           .
*
 e       *           .*          .           .           .           .
*
         *           .*          .           .           .           .
*
 i       *  *        . *         .           .           .           .
*
 n   .1003           .  *        .           .           .           .
3
         *           .  *        .           .           .           .
*
 m       * *         .   *       .           .           .           .
*
 ^       *           .    **     .           .           .           .
*
 3       **          .     *     .           .           .           .
*
 /       *           .           .           .           .           .
*
 s       **          .           .           .           .           .
*

.000*)))))))))))3))))))*****3***********3***********3***********3**********
       3.          50.        100.        150.        200.        250.
288.
```

Time, t (min)

Example Four: Hydrographic Analysis and Pressure Flow Simulation

PLOT-DATA (Time, t(min) vs. Discharge, (m^3/s))

t	Q	t	Q	t	Q	t	Q	t	Q
3.	.004	63.	.106	123.	.000	183.	.000	243.	.000
6.	.023	66.	.093	126.	.000	186.	.000	246.	.000
9.	.044	69.	.080	129.	.000	189.	.000	249.	.000
12.	.077	72.	.069	132.	.000	192.	.000	252.	.000
15.	.122	75.	.060	135.	.000	195.	.000	255.	.000
18.	.182	78.	.052	138.	.000	198.	.000	258.	.000
21.	.233	81.	.000	141.	.000	201.	.000	261.	.000
24.	.269	84.	.000	144.	.000	204.	.000	264.	.000
27.	.287	87.	.000	147.	.000	207.	.000	267.	.000
30.	.299	90.	.000	150.	.000	210.	.000	270.	.000
33.	.303	93.	.000	153.	.000	213.	.000	273.	.000
36.	.299	96.	.000	156.	.000	216.	.000	276.	.000
39.	.284	99.	.000	159.	.000	219.	.000	279.	.000
42.	.261	102.	.000	162.	.000	222.	.000	282.	.000
45.	.239	105.	.000	165.	.000	225.	.000	285.	.000
48.	.214	108.	.000	168.	.000	228.	.000	288.	.000
51.	.185	111.	.000	171.	.000	231.	.000	0.	.000
54.	.158	114.	.000	174.	.000	234.	.000	0.	.000
57.	.137	117.	.000	177.	.000	237.	.000	0.	.000
60.	.119	120.	.000	180.	.000	240.	.000	0.	.000

```
+++ System hydrograph registers full at time =   288. min
  INL 5  7  0  104  0 0 0 0 0 0 1
  EFF 0  100  2.83  100
  REC 5
  PIP 28.34  153.92  153.61  152.48  152.21  -450
+++ Link #  5,  Flow depth =    .450 m, Critical depth =    .450 m
  PNC 5  4  1.22  11.0  0
  REM LINK 4 TO 3
  UHY HYDR04.QT
+++ Notice:  Intermediate file has data in SI units
  GUT 36.57  154.53  153.86  0.013  30  1.52  30  0  1
+++ Depth =   .072 m, Vel =   1.357 m/s,  Width =   2.157 m
+++ Discharge =     .105 m^3/s, Slope =   .018 m/m
```

Example Four: Hydrographic Analysis and Pressure Flow Simulation

GUTTER HYDROGRAPH in m^3/s

```
.105+)))))*))))3)))))))))))3)))))))))))3)))))))))))3)))))))))))3)))))))),
 D       *     *     .           .           .           .           .
*
 i       *    *  *   .           .           .           .           .
*
 s       *        *  .           .           .           .           .
*
 c   .0753   *       .           .           .           .           .
3
 h       *         * .           .           .           .           .
*
 a       *         * .           .           .           .           .
*
 r       *           .           .           .           .           .
*
 g       *   *      *.           .           .           .           .
*
 e   .0503           .           .           .           .           .
3
         *           *           .           .           .           .
*
 i       *  *        .*          .           .           .           .
*
 n       *           .*          .           .           .           .
*
         *           . *         .           .           .           .
*
 m   .0253 *          .  *       .           .           .           .
3
 ^       *           .   *       .           .           .           .
*
 3       **          .    **     .           .           .           .
*
 /       *           .           .           .           .           .
*
 s       **          .           .           .           .           .
*

.000*)))))))))))3)))))******3**********3**********3**********3*********
       3.          50.        100.        150.        200.        250.
288.
```

Time, t (min)

Example Four: Hydrographic Analysis and Pressure Flow Simulation

PLOT-DATA (Time, t(min) vs. Discharge, (m^3/s))

t	Q	t	Q	t	Q	t	Q	t	Q
3.	.002	63.	.029	123.	.000	183.	.000	243.	.000
6.	.008	66.	.025	126.	.000	186.	.000	246.	.000
9.	.017	69.	.022	129.	.000	189.	.000	249.	.000
12.	.029	72.	.019	132.	.000	192.	.000	252.	.000
15.	.045	75.	.016	135.	.000	195.	.000	255.	.000
18.	.063	78.	.000	138.	.000	198.	.000	258.	.000
21.	.081	81.	.000	141.	.000	201.	.000	261.	.000
24.	.094	84.	.000	144.	.000	204.	.000	264.	.000
27.	.102	87.	.000	147.	.000	207.	.000	267.	.000
30.	.105	90.	.000	150.	.000	210.	.000	270.	.000
33.	.103	93.	.000	153.	.000	213.	.000	273.	.000
36.	.097	96.	.000	156.	.000	216.	.000	276.	.000
39.	.089	99.	.000	159.	.000	219.	.000	279.	.000
42.	.079	102.	.000	162.	.000	222.	.000	282.	.000
45.	.070	105.	.000	165.	.000	225.	.000	285.	.000
48.	.059	108.	.000	168.	.000	228.	.000	288.	.000
51.	.052	111.	.000	171.	.000	231.	.000	0.	.000
54.	.044	114.	.000	174.	.000	234.	.000	0.	.000
57.	.039	117.	.000	177.	.000	237.	.000	0.	.000
60.	.034	120.	.000	180.	.000	240.	.000	0.	.000

```
+++ System hydrograph registers full at time =   288. min
  INL 4  7  0  105  0 0 0 0 0 0 1
  EFF 0  100  2.83  100
  PIP 48.76  153.86  153.76  151.90  151.84  -750
+++ Link #  6,  Flow depth =    .750 m, Critical depth =    .750 m
  PNC 4  3  1.22  0.0  0
  REM LINK 3 TO 2
  UHY HYDR04.QT
+++ Notice:  Intermediate file has data in SI units
  GUT 54.86  154.62  153.76  0.013  50  0.914  40  0  1
+++ Depth =   .065 m, Vel =   1.133 m/s,  Width =   3.014 m
+++ Discharge =     .105 m^3/s, Slope =   .016 m/m
```

Example Four: Hydrographic Analysis and Pressure Flow Simulation

GUTTER HYDROGRAPH in m^3/s

```
.105+)))))*))))3)))))))))))3)))))))))))3)))))))))))3)))))))))))3)))))))))),
 D       *     *     .           .           .           .           .
*
 i       *    *  *   .           .           .           .           .
*
 s       *        *  .           .           .           .           .
*
 c   .0753   *       .           .           .           .           .
3
 h       *         * .           .           .           .           .
*
 a       *         * .           .           .           .           .
*
 r       *           .           .           .           .           .
*
 g       *   *      *.           .           .           .           .
*
 e   .0503           .           .           .           .           .
3
         *           *           .           .           .           .
*
 i       *  *        .*          .           .           .           .
*
 n       *           .*          .           .           .           .
*
         *           . *         .           .           .           .
*
 m   .0253 *         .  *        .           .           .           .
3
 ^       *           .   *       .           .           .           .
*
 3       **          .    **     .           .           .           .
*
 /       *           .           .           .           .           .
*
 s       **          .           .           .           .           .
*

.000*))))))))))3)))))******3**********3**********3**********3*********
       4.          50.        100.        150.        200.        250.
289.
```

Time, t (min)

Example Four: Hydrographic Analysis and Pressure Flow Simulation

PLOT-DATA (Time, t(min) vs. Discharge, (m^3/s))

t	Q	t	Q	t	Q	t	Q	t	Q
4.	.002	64.	.029	124.	.000	184.	.000	244.	.000
7.	.008	67.	.025	127.	.000	187.	.000	247.	.000
10.	.017	70.	.022	130.	.000	190.	.000	250.	.000
13.	.029	73.	.019	133.	.000	193.	.000	253.	.000
16.	.045	76.	.016	136.	.000	196.	.000	256.	.000
19.	.063	79.	.000	139.	.000	199.	.000	259.	.000
22.	.081	82.	.000	142.	.000	202.	.000	262.	.000
25.	.094	85.	.000	145.	.000	205.	.000	265.	.000
28.	.102	88.	.000	148.	.000	208.	.000	268.	.000
31.	.105	91.	.000	151.	.000	211.	.000	271.	.000
34.	.103	94.	.000	154.	.000	214.	.000	274.	.000
37.	.097	97.	.000	157.	.000	217.	.000	277.	.000
40.	.089	100.	.000	160.	.000	220.	.000	280.	.000
43.	.079	103.	.000	163.	.000	223.	.000	283.	.000
46.	.070	106.	.000	166.	.000	226.	.000	286.	.000
49.	.059	109.	.000	169.	.000	229.	.000	289.	.000
52.	.052	112.	.000	172.	.000	232.	.000	0.	.000
55.	.044	115.	.000	175.	.000	235.	.000	0.	.000
58.	.039	118.	.000	178.	.000	238.	.000	0.	.000
61.	.034	121.	.000	181.	.000	241.	.000	0.	.000

```
+++ System hydrograph registers full at time =   289. min
  INL 6  7  0  106
  EFF 0  100  2.83  100
  PIP 28.95  153.76  153.00  151.84  151.26  -750
+++ Link #  7,  Flow depth =    .390 m, Critical depth =    .546 m
  PNC 3  2  1.22  48  0
  REM LINK 2 TO 1
  UHY HYDR02.QT
+++ Notice:  Intermediate file has data in SI units
  GUT 22.86  153.46  153.00  0.013  50   0.914  40  0  1
+++ Depth =   .028 m, Vel =    .746 m/s,  Width =   1.160 m
+++ Discharge =     .012 m^3/s, Slope =   .020 m/m
```

Example Four: Hydrographic Analysis and Pressure Flow Simulation

GUTTER HYDROGRAPH in m^3/s

```
.012+)))))**))))3)))))))))))3)))))))))))3)))))))))))3)))))))))))3)))))))))),
 D       *       *   .           .           .           .           .
*
 i       *    *      .           .           .           .           .
*
 s   .0103        *  .           .           .           .           .
3
 c       *   *       .           .           .           .           .
*
 h       *         * .           .           .           .           .
*
 a       *         * .           .           .           .           .
*
 r   .0073           .           .           .           .           .
3
 g       *   *      *.           .           .           .           .
*
 e       *           .           .           .           .           .
*
         *           *           .           .           .           .
*
 i   .0053  *        .*          .           .           .           .
3
 n       *           .*          .           .           .           .
*
         *           . **        .           .           .           .
*
 m       * *         .  *        .           .           .           .
*
 ^   .0023           .   *       .           .           .           .
3
 3       **          .    **     .           .           .           .
*
 /       *           .           .           .           .           .
*
 s       **          .           .           .           .           .
*

.000*)))))))))))3)))))******3**********3**********3**********3**********
       4.          50.        100.        150.        200.        250.
289.
```

Time, t (min)

Example Four: Hydrographic Analysis and Pressure Flow Simulation

PLOT-DATA (Time, t(min) vs. Discharge, (m^3/s))

t	Q	t	Q	t	Q	t	Q	t	Q
4.	.000	64.	.003	124.	.000	184.	.000	244.	.000
7.	.001	67.	.003	127.	.000	187.	.000	247.	.000
10.	.002	70.	.002	130.	.000	190.	.000	250.	.000
13.	.003	73.	.002	133.	.000	193.	.000	253.	.000
16.	.005	76.	.002	136.	.000	196.	.000	256.	.000
19.	.007	79.	.000	139.	.000	199.	.000	259.	.000
22.	.009	82.	.000	142.	.000	202.	.000	262.	.000
25.	.010	85.	.000	145.	.000	205.	.000	265.	.000
28.	.011	88.	.000	148.	.000	208.	.000	268.	.000
31.	.012	91.	.000	151.	.000	211.	.000	271.	.000
34.	.011	94.	.000	154.	.000	214.	.000	274.	.000
37.	.011	97.	.000	157.	.000	217.	.000	277.	.000
40.	.010	100.	.000	160.	.000	220.	.000	280.	.000
43.	.009	103.	.000	163.	.000	223.	.000	283.	.000
46.	.008	106.	.000	166.	.000	226.	.000	286.	.000
49.	.007	109.	.000	169.	.000	229.	.000	289.	.000
52.	.006	112.	.000	172.	.000	232.	.000	0.	.000
55.	.005	115.	.000	175.	.000	235.	.000	0.	.000
58.	.004	118.	.000	178.	.000	238.	.000	0.	.000
61.	.004	121.	.000	181.	.000	241.	.000	0.	.000

```
+++ System hydrograph registers full at time =   289. min
  INL 7  7  0  107  0 0 0 0 0 0 1
  EFF 0  100  2.83  100
  PIP 7.62  153.00  152.39  151.11  150.81  -600
+++ Link #  8,  Flow depth =    .372 m, Critical depth =    .553 m
  PNC 2  1  0  0.0  2
  PFS 0  60  3.0  5  0  9  8  30  0.05
  PHJ 8  7  6  15  5  4  3  2  1
  PFP 1  2   3  4  5  6   7  8
  IQV 2.0  5.1  0  0  0  0  2.5  6.4
  IDY IDY 0.0  0.0  0.0  0.0  0.6  0.0  0.0  0.0
  END
 END OF INPUT DATA.
```

Example Four: Hydrographic Analysis and Pressure Flow Simulation

*** LINK 8 TO 5 Analysis of Existing Pipes

Link	Length (m)	Diam (mm)	Invert Up/Dn (m)	Slope (m/m)	Depth Up/Dn (m)	Cover Up/Dn (m)	Velocity Act/Full (m/s)	--Flow-- Act/Full (m^3/s)	Load (%)	-Solutions- Remove (m^3/s)	Diam (mm)
1	27	300	165.160	.233	1.250	.925	3.381	.080	29		
			158.760		1.250	.925	3.905	.276			
2	53	450	158.580	.058	1.430	.942	3.463	.184	29		
			155.500		1.430	.942	4.001	.636			
3	52	450	155.500	.058	1.430	.942	3.462	.184	29		
			152.510		1.410	.923	3.999	.636			

Length = 133. m Total length = 133. m

*** MAINLINE 15 TO 1 Analysis of Existing Pipes

Link	Length (m)	Diam (mm)	Invert Up/Dn (m)	Slope (m/m)	Depth Up/Dn (m)	Cover Up/Dn (m)	Velocity Act/Full (m/s)	--Flow-- Act/Full (m^3/s)	Load (%)	-Solutions- Remove (m^3/s)	Diam (mm)
4	23	300	154.190	.066	1.250	.925	2.972	.080	35		
			152.670		1.250	.925	3.276	.232			
5	28	450	152.480	.010	1.440	.953	3.561	.566	219	.308	508
			152.210		1.400	.913	1.625	.258			
6	49	750	151.900	.001	1.960	1.148	1.516	.670	185	.307	737
			151.840		1.920	1.107	.821	.363			
7	29	750	151.840	.020	1.920	1.107	3.360	.773	53		
			151.260		1.740	.928	3.312	1.463			
8	8	600	151.110	.039	1.890	1.240	4.320	.784	69		
			150.810		1.580	.930	4.001	1.131			

Length = 137. m Total length = 269. m

Example Four: Hydrographic Analysis and Pressure Flow Simulation

Hydraulic Gradeline Computations

Link #	Down-stream Node #	Hydraulic Gradeline Elevation	Crown Elev.	Possible Surcharge	Ground Elev.	Super-crit.?	Manhole Depth	Loss Coef
1	7	158.980	159.065	N	160.010	Y	.849	1.53
2	6	155.802	155.957	N	156.930	Y	.848	2.11
3	5	152.812	152.967	N	153.920	Y	2.882	2.65
4	5	152.890	152.975	N	153.920	Y	2.882	2.44
5	4	153.645	152.667	Y	153.860	N/A	1.198	5.74
6	3	152.940	152.602	Y	153.760	N/A	.999	1.23
7	2	151.806	152.022	N	153.000	Y	1.474	1.75
8	1	151.182	151.420	N	152.390	Y	.372	.00

Link #	Terminal Node #	Hydraulic Gradeline Elevation	Ground Elevation	Loss Coef.
1	8	166.145	166.410	1.50
4	15	154.989	155.440	1.50

Example Four: Hydrographic Analysis and Pressure Flow Simulation

Pressurized Flow Simulations

```
Total Simulation time:          60 min
Incremental time:                6 min
Length of integration step:      2 s
Initial time:                  .00 min
Surcharge variables: itMax      30 iterations
                     surTol   .050

Printed output at the following  9 junctions

      8      7      6     15      5      4      3      2      1

          and for the following  8 pipes

      1      2      3      4      5      6      7      8
```

Pipe Characteristics

Pipe Number	Length (m)	Area (m^2)	Manning "n"	Max. Width (m)	Depth (m)	Junctions at Ends		Invert Height above Junctions	
1	27.432	.073	.022	.305	.305	8	7	.000	.180
2	53.340	.164	.014	.457	.457	7	6	.000	.000
3	51.816	.164	.014	.457	.457	6	5	.000	.030
4	22.860	.073	.014	.305	.305	15	5	.000	.190
5	28.346	.164	.014	.457	.457	5	4	.000	.310
6	48.768	.456	.014	.762	.762	4	3	.000	.000
7	28.956	.456	.014	.762	.762	3	2	.000	.150
8	7.620	.292	.014	.610	.610	2	1	.000	.000

Junction Characteristics

Junction Number	Ground Elev.	Crown Elev.	Invert Elev.	Connecting Pipes	
8	166.410	165.465	165.160	1	
7	160.010	159.065	158.580	1	2
6	156.930	155.957	155.500	2	3
15	155.440	154.495	154.190	4	

Example Four: Hydrographic Analysis and Pressure Flow Simulation

Junction Characteristics

Junction Number	Ground Elev.	Crown Elev.	Invert Elev.	Connecting Pipes		
5	153.920	152.975	152.480	3	4	5
4	153.860	152.667	151.900	5	6	
3	153.760	152.602	151.840	6	7	
2	153.000	152.022	151.110	7	8	
1	152.390	151.420	150.810	8		

+++ Outfall control water-surface elev = 150.810 m

Summary of initial heads, flows and velocities

Pipe Number	Flow (m^3/s)	Velocity (m/s)	Pipe Number	Flow (m^3/s)	Velocity (m/s)	Pipe Number	Flow (m^3/s)	Velocity (m/s)
1	70.6	5.1	2	.0	.0	3	.0	.0
4	88.3	6.4	5	.0	.0	6	.0	.0
7	.0	.0	8	.0	.0	90009	.0	.0

Summary of initial depths

Junction Number	Depth (m)	Junction Number	Depth (m)	Junction Number	Depth (m)	Junction Number	Depth (m)
8	.000	7	.000	6	.000	15	.000
5	.000	4	.000	3	.000	2	.000
1	.000						

Example Four: Hydrographic Analysis and Pressure Flow Simulation

Summary of Junction Results

Junction Number	Ground /Invert Elev. (m)	Uppermost Pipe crown Elev. (m)	Maximum Computed Water Surface Elev	Time of Occurrence (h:min)	Surcharge at Max. Depth	Length of Surcharge (min)
8	166.410 165.160	165.465	165.270	0 : 33	.000	.000
7	160.010 158.580	159.065	158.745	0 : 30	.000	.000
6	156.930 155.500	155.957	155.665	0 : 30	.000	.000
15	155.440 154.190	154.495	154.311	0 : 33	.000	.000
5	153.920 152.480	152.975	153.920	0 : 22	.945	32.300
4	153.860 151.900	152.667	153.303	0 : 28	.636	27.767
3	153.760 151.840	152.602	153.366	0 : 25	.764	27.567
2	153.000 151.110	152.022	153.000	0 : 20	.978	31.633
1	152.390 150.810	151.420	150.810	0 : 0	.000	.000

Example Four: Hydrographic Analysis and Pressure Flow Simulation

Summary of Pipe Results

Pipe Number	Design Flo/Vel m^3/s|m/s	Pipe Vertical Depth (mm)	Maximum Computed Flo/Vel m^3/s|m/s	Time of Occurrence (h:min)	Ratio of Max. to Design Flow	Max. Depth above Invert Pipe Ends Up (m)	Dn (m)
1	.288 3.946	305.	.080 1.995	0 : 33	.3	.110	-.015
2	.664 4.043	458.	.185 3.461	0 : 30	.3	.165	.165
3	.664 4.041	458.	.185 1.352	0 : 30	.3	.165	1.410
4	.242 3.311	305.	.080 1.463	0 : 33	.3	.121	1.250
5	.270 1.642	458.	.503 3.062	0 : 24	1.9	1.440	1.093
6	.378 .829	763.	.612 1.642	0 : 26	1.6	1.403	1.526
7	1.527 3.347	763.	.824 2.282	0 : 21	.5	1.526	1.740
8	1.180 4.044	610.	1.315 7.105	0 : 20	1.1	1.890	.000

NORMAL END OF HYDRA

Example Five: Sanitary Sewer Design

Problem:

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 378 L/day to the sewer (GPC 100) and such that infiltration into the system occurs at a rate of 9 353 L/day/ha. The exception is the area serviced by the Kenyon Street lateral, where there is a rate of 18 705 L/day/ha. Figure 17 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 3 x 10^{-4} and 283 m^3/s.

Other commands shown in the example include the PDA command (pipe data), which gives pipe characteristics, such as Manning's "n" value, and the CST, 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.

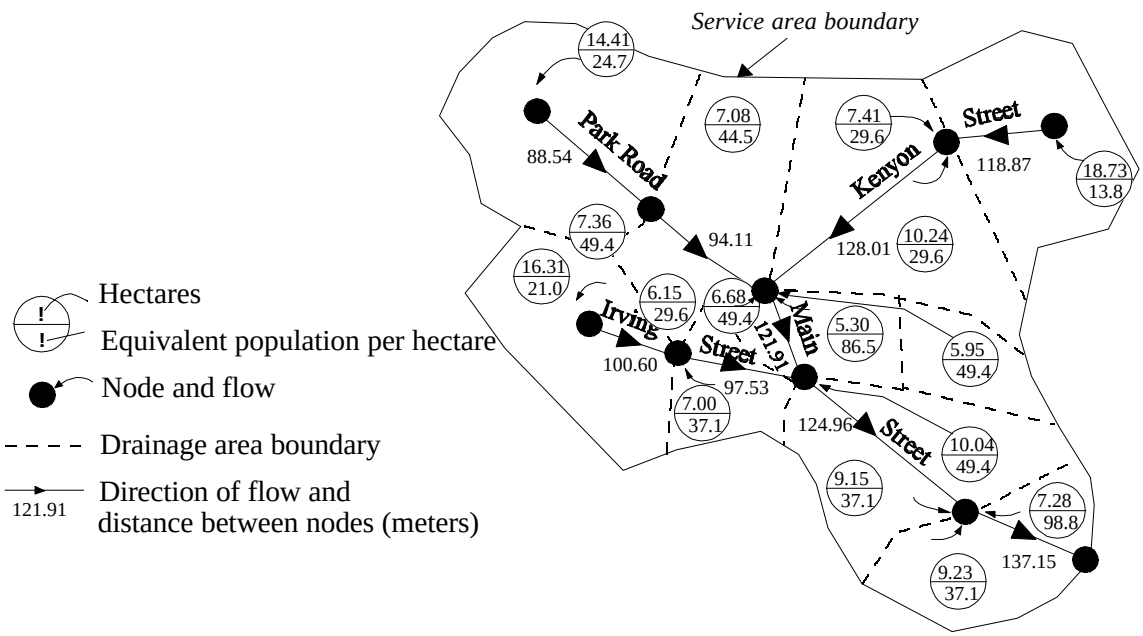

Figure 17. Sanitary sewer design.

Input file: HYDRA5.HDA

```
JOB Example Five: Sanitary Sewer Design
SWI 1
GPC 378.5
PEA 0.0003,4.46  0.0014,3.78  0.0028,3.3  0.0283,2.6  0.2831,2.1  2.831,1.7
    28.31,1.4  283.1,1.13
INF 0 9352.6
CST 1.5 0.457 0 0 0.152 0 0.65 0.5 0 5.23 1.15 0.52 3.27 4.58 2.69
EXC 0 0.98 3.05 0.98
PCO 8 8.20 10 11.48
PDA 0.013 150 2.13 1.22 0.762 0.001
TSL 0 0.2 3.05 0.2
NEW PARK ROAD
SAN 14.41 24.7
PIP 88.54 30.72 28.53
SAN 7.08 44.5
SAN 7.36 49.4
PIP 94.11 28.53 25.82
HOL 1
NEW IRVING STREET
SAN 16.31 21.0
PIP 100.60 28.95 24.75
SAN 6.15 29.6
SAN 7.00 37.1
PIP 97.53 24.75 22.65
HOL 2
NEW KENYON STREET
INF 0 18705.2
SAN 18.73 13.8
PIP 118.87 29.72 27.13
SAN 45.22 29.6
SAN 10.24 29.6
PIP 128.01 27.13 25.82
HOL 3
NEW MAIN STREET
INF 0 9352.6
REC 1
REC 3
SAN 6.68 49.4
SAN 5.30 86.5
SAN 5.95 49.4
PIP 121.91 25.82 22.65
REC 2
SAN 10.04 49.4
PIP 124.96 22.65 20.42
SAN 9.15 37.1
SAN 7.28 98.8
SAN 9.23 37.1
PIP 137.15 20.42 19.84
END
```

Discussion of output:

The results show that a 152-mm pipe has adequate capacity for the lateral links but larger diameter pipes are designated for the mainline links progressively.

Output file: HYDRA5.LST

```
         ******  HYDRA  ******* (Version 6.1) *****         Date 07-21-1998
                                                               Page No   1

  Example Five: Sanitary Sewer Design

+++ Commands Read From File C:\HYDRA\HYDRA5.HDA
  JOB
  SWI 1
  GPC 378.5
  PEA 0.0003,4.46  0.0014,3.78  0.0028,3.3  0.0283,2.6  0.2831,2.1  2.831,1.7
   28.31,1.4  283.1,1.13
  INF 0 9352.6
  CST 1.5 0.457 0 0 0.152 0 0.65 0.5 0 5.23 1.15 0.52 3.27 4.58 2.69
  EXC 0 0.98 3.05 0.98
  PCO 8 8.20 10 11.48
  PDA 0.013 150 2.13 1.22 0.762 0.001
  TSL 0 0.2 3.05 0.2
  NEW PARK ROAD
  SAN 14.41 24.7
  PIP 88.54 30.72 28.53
+++ Top width of trench ---> UP  1.1 m
                       ---> DN  1.1 m
+++ Link #  1,  Flow depth =    .049 m, Critical depth =    .068 m
  SAN 7.08 44.5
  SAN 7.36 49.4
  PIP 94.11 28.53 25.82
*** WARNING: Pipe invert at D/S end dropped to meet minimum depth
    to invert criterion at D/S end
+++ Top width of trench ---> UP  1.1 m
                       ---> DN  1.1 m
+++ Link #  2,  Flow depth =    .078 m, Critical depth =    .109 m
  HOL 1
  NEW IRVING STREET
  SAN 16.31 21.0
  PIP 100.60 28.95 24.75
+++ Top width of trench ---> UP  1.1 m
                       ---> DN  1.1 m
+++ Link #  3,  Flow depth =    .043 m, Critical depth =    .068 m
  SAN 6.15 29.6
  SAN 7.00 37.1
  PIP 97.53 24.75 22.65
*** WARNING: Pipe invert at D/S end dropped to meet minimum depth
    to invert criterion at D/S end
+++ Top width of trench ---> UP  1.1 m
                       ---> DN  1.1 m
+++ Link #  4,  Flow depth =    .076 m, Critical depth =    .099 m
  HOL 2
  NEW KENYON STREET
  INF 0 18705.2
  SAN 18.73 13.8
  PIP 118.87 29.72 27.13
+++ Top width of trench ---> UP  1.1 m
```

```
  Example Five: Sanitary Sewer Design

                         ---> DN  1.1 m
+++ Link #  5,  Flow depth =    .058 m, Critical depth =    .077 m
  SAN 45.22 29.6
  SAN 10.24 29.6
  PIP 128.01 27.13 25.82
*** WARNING: Pipe invert at D/S end dropped to meet minimum depth
    to invert criterion at D/S end
+++ Top width of trench ---> UP  1.2 m
                         ---> DN  1.2 m
+++ Link #  6,  Flow depth =    .123 m, Critical depth =    .141 m
  HOL 3
  NEW MAIN STREET
  INF 0 9352.6
  REC 1
  REC 3
  SAN 6.68 49.4
  SAN 5.30 86.5
  SAN 5.95 49.4
  PIP 121.91 25.82 22.65
*** WARNING: Pipe invert at D/S end dropped to meet minimum depth
    to invert criterion at D/S end
+++ Top width of trench ---> UP  1.2 m
                         ---> DN  1.2 m
+++ Link #  7,  Flow depth =    .126 m, Critical depth =    .186 m
  REC 2
  SAN 10.04 49.4
  PIP 124.96 22.65 20.42
*** WARNING: Pipe invert at D/S end dropped to meet minimum depth
    to invert criterion at D/S end
+++ Top width of trench ---> UP  1.2 m
                         ---> DN  1.2 m
+++ Link #  8,  Flow depth =    .162 m, Critical depth =    .210 m
  SAN 9.15 37.1
  SAN 7.28 98.8
  SAN 9.23 37.1
  PIP 137.15 20.42 19.84
*** WARNING: Pipe invert at D/S end dropped to meet minimum depth
    to invert criterion at D/S end
+++ Top width of trench ---> UP  1.3 m
                         ---> DN  1.3 m
+++ Link #  9,  Flow depth =    .247 m, Critical depth =    .215 m
  END
 END OF INPUT DATA.
```

Example Five: Sanitary Sewer Design

*** PARK ROAD Pipe Design

Link	Length (m)	Diam (mm)	Invert Up/Dn (m)	Slope (m/m)	Depth Up/Dn (m)	Min. Cover (m)	Velocity Act/Full (m/s)	--Flow-- Act/Full (m^3/s)	Estimated Cost ($)
1	89	150	28.590	.025	2.130	1.968	1.102	.006	23854.
			26.400		2.130		1.355	.024	
2	94	150	26.400	.029	2.130	1.968	1.484	.014	25355.
			23.690		2.130		1.463	.026	

Length = 183. m Total length = 183. m
Cost = 49209. Total Cost = 49209.

*** IRVING STREET Pipe Design

Link	Length (m)	Diam (mm)	Invert Up/Dn (m)	Slope (m/m)	Depth Up/Dn (m)	Min. Cover (m)	Velocity Act/Full (m/s)	--Flow-- Act/Full (m^3/s)	Estimated Cost ($)
3	101	150	26.820	.042	2.130	1.968	1.333	.006	27104.
			22.620		2.130		1.761	.031	
4	98	150	22.620	.022	2.130	1.968	1.274	.011	26276.
			20.520		2.130		1.265	.022	

Length = 198. m Total length = 198. m
Cost = 53380. Total Cost = 53380.

Example Five: Sanitary Sewer Design

*** KENYON STREET Pipe Design

Link	Length (m)	Diam (mm)	Invert Up/Dn (m)	Slope (m/m)	Depth Up/Dn (m)	Min. Cover (m)	Velocity Act/Full (m/s)	--Flow-- Act/Full (m^3/s)	Estimated Cost ($)
5	119	150	27.590	.022	2.130	1.968	1.124	.007	32026.
			25.000		2.130		1.272	.022	
6	128	300	25.000	.010	2.130	1.805	1.256	.034	66527.
			23.690		2.130		1.384	.098	

Length = 247. m Total length = 247. m
Cost = 98553. Total Cost = 98553.

*** MAIN STREET Pipe Design

Link	Length (m)	Diam (mm)	Invert Up/Dn (m)	Slope (m/m)	Depth Up/Dn (m)	Min. Cover (m)	Velocity Act/Full (m/s)	--Flow-- Act/Full (m^3/s)	Estimated Cost ($)
7	122	300	23.690	.026	2.130	1.805	2.032	.057	63357.
			20.520		2.130		2.206	.156	
8	125	300	20.520	.018	2.130	1.805	1.879	.072	64942.
			18.290		2.130		1.828	.129	
9	137	375	18.290	.004	2.130	1.724	1.133	.086	88429.
			17.710		2.130		1.032	.114	

Length = 384. m Total length = 1012. m
Cost = 216728. Total Cost = 417871.

Example Five: Sanitary Sewer Design

NORMAL END OF HYDRA

Example Six: Sanitary Sewer Analysis

Problem:

For this example, the system suggested by HYDRA in example five 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/ac numbers in the SAN commands and adding 0.099 m^3/s through a FLO command on Main Street. (The FLO command might represent the discharge of water from an industrial facility.)

Input file: HYDRA6.HDA

```
JOB Example Six: Sanitary Sewer Analysis
SWI 1
GPC 378.5
PEA 0.0003 4.46 0.0014 3.78 0.0028 3.3 0.0283 2.6 0.2831 2.1 100 2.831
    28.31 1.4 283.1 1.13
INF 0 1531.79
CST 1.5 4.92 0 0 1.64 0 3.27 0.5 0 5.23 1.15 0.52 3.27 4.58 2.69
EXC 0 0.98 3.05 0.98
PCO 8 8.20 10 11.48
PDA 0.013 150 2.13 1.22 0.76 0.001
TSL 0 0.2 3.05 0.2
NEW PARK ROAD
SAN 14.41 32.1
PIP 88.54 30.72 28.53 28.59 26.39 -150
SAN 7.08 69.2
SAN 7.37 74.13
PIP 94.12 28.53 25.82 26.39 23.68 -150
HOL 1
NEW IRVING STREET
SAN 16.31 28.4
PIP 100.5 28.95 24.75 26.82 22.62 -150
SAN 6.15 37.1
SAN 7.00 44.5
PIP 97.53 24.75 22.65 22.62 20.51 -150
HOL 2
NEW KENYON STREET
INF 0 9352.6
SAN 18.74 21.2
PIP 118.87 29.72 27.12 27.58 24.99 -150
SAN 7.41 37.1
SAN 10.24 37.1
PIP 128.01 27.13 25.82 24.99 23.68 -300
HOL 3
NEW MAIN STREET
INF 0 9352.6
FLO 0.0991
REC 1
REC 3
SAN 6.68 56.8
SAN 5.30 93.9
SAN 5.95 56.8
PIP 121.91 25.82 22.65 23.68 20.51 -300
REC 2
```

```
SAN 10.04 56.8
PIP 124.96 22.64 20.42 20.51 18.29 -300
SAN 9.15 44.5
SAN 7.28 106.3
SAN 9.23 44.5
PIP 137.15 20.42 19.84 18.29 17.71 -450
END
```

Discussion of output:

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 124.96-m link 8 under Main Street, HYDRA suggests somehow removing 0.027 m^3/s or constructing an additional 279-mm pipe to pass the flow.

Output file: HYDRA6.LST

```
          ******  HYDRA  ******* (Version 6.1) *****         Date 07-21-1998
                                                                Page No   1

   Example Six: Sanitary Sewer Analysis

 +++ Commands Read From File C:\HYDRA\HYDRA6.HDA
   JOB
   SWI 1
   GPC 378.5
   PEA 0.0003 4.46 0.0014 3.78 0.0028 3.3 0.0283 2.6 0.2831 2.1 100 2.831
    28.31 1.4 283.1 1.13
   INF 0 1531.79
   CST 1.5 4.92 0 0 1.64 0 3.27 0.5 0 5.23 1.15 0.52 3.27 4.58 2.69
   EXC 0 0.98 3.05 0.98
   PCO 8 8.20 10 11.48
   PDA 0.013 150 2.13 1.22 0.76 0.001
   TSL 0 0.2 3.05 0.2
   NEW PARK ROAD
   SAN 14.41 32.1
   PIP 88.54 30.72 28.53 28.59 26.39 -150
 +++ Link #  1,  Flow depth =    .049 m, Critical depth =    .066 m
   SAN 7.08 69.2
   SAN 7.37 74.13
   PIP 94.12 28.53 25.82 26.39 23.68 -150
 +++ Link #  2,  Flow depth =    .082 m, Critical depth =    .113 m
   HOL 1
   NEW IRVING STREET
   SAN 16.31 28.4
   PIP 100.5 28.95 24.75 26.82 22.62 -150
 +++ Link #  3,  Flow depth =    .043 m, Critical depth =    .067 m
   SAN 6.15 37.1
   SAN 7.00 44.5
   PIP 97.53 24.75 22.65 22.62 20.51 -150
 +++ Link #  4,  Flow depth =    .075 m, Critical depth =    .097 m
   HOL 2
   NEW KENYON STREET
   INF 0 9352.6
   SAN 18.74 21.2
```

```
  PIP 118.87 29.72 27.12 27.58 24.99 -150
+++ Link #  5,  Flow depth =    .055 m, Critical depth =    .073 m
  SAN 7.41 37.1
  SAN 10.24 37.1
  PIP 128.01 27.13 25.82 24.99 23.68 -300
+++ Link #  6,  Flow depth =    .081 m, Critical depth =    .091 m
  HOL 3
  NEW MAIN STREET
  INF 0 9352.6
  FLO 0.0991
  REC 1
  REC 3
  SAN 6.68 56.8
  SAN 5.30 93.9
```

```
  Example Six: Sanitary Sewer Analysis


  SAN 5.95 56.8
  PIP 121.91 25.82 22.65 23.68 20.51 -300
+++ Link #  7,  Flow depth =    .225 m, Critical depth =    .278 m
  REC 2
  SAN 10.04 56.8
  PIP 124.96 22.64 20.42 20.51 18.29 -300
+++ Link #  8,  Flow depth =    .300 m, Critical depth =    .300 m
  SAN 9.15 44.5
  SAN 7.28 106.3
  SAN 9.23 44.5
  PIP 137.15 20.42 19.84 18.29 17.71 -450
+++ Link #  9,  Flow depth =    .346 m, Critical depth =    .293 m
  END
 END OF INPUT DATA.
```

Example Six: Sanitary Sewer Analysis

*** PARK ROAD Analysis of Existing Pipes

Link	Length (m)	Diam (mm)	Invert Up/Dn (m)	Slope (m/m)	Depth Up/Dn (m)	Cover Up/Dn (m)	Velocity Act/Full (m/s)	--Flow-- Act/Full (m^3/s)	Load (%)	-Solutions- Remove (m^3/s)	Diam (mm)
1	89	150	28.590	.025	2.130	1.968	1.094	.005		22	
			26.390		2.140	1.978	1.359	.024			
2	94	150	26.390	.029	2.140	1.978	1.513	.015		58	
			23.680		2.140	1.977	1.462	.026			

Length = 183. m Total length = 183. m

*** IRVING STREET Analysis of Existing Pipes

Link	Length (m)	Diam (mm)	Invert Up/Dn (m)	Slope (m/m)	Depth Up/Dn (m)	Cover Up/Dn (m)	Velocity Act/Full (m/s)	--Flow-- Act/Full (m^3/s)	Load (%)	-Solutions- Remove (m^3/s)	Diam (mm)
3	101	150	26.820	.042	2.130	1.967	1.318	.005		17	
			22.620		2.130	1.968	1.762	.031			
4	98	150	22.620	.022	2.130	1.968	1.258	.011		48	
			20.510		2.140	1.977	1.268	.022			

Length = 198. m Total length = 198. m

Example Six: Sanitary Sewer Analysis

*** KENYON STREET Analysis of Existing Pipes

Link	Length (m)	Diam (mm)	Invert Up/Dn (m)	Slope (m/m)	Depth Up/Dn (m)	Cover Up/Dn (m)	Velocity Act/Full (m/s)	--Flow-- Act/Full (m^3/s)	Load (%)	-Solutions- Remove (m^3/s)	Diam (mm)
5	119	150	27.580	.022	2.140	1.978	1.098	.006	29		
			24.990		2.130	1.968	1.272	.022			
6	128	300	24.990	.010	2.140	1.815	.995	.015	15		
			23.680		2.140	1.815	1.384	.098			

Length = 247. m Total length = 247. m

*** MAIN STREET Analysis of Existing Pipes

Link	Length (m)	Diam (mm)	Invert Up/Dn (m)	Slope (m/m)	Depth Up/Dn (m)	Cover Up/Dn (m)	Velocity Act/Full (m/s)	--Flow-- Act/Full (m^3/s)	Load (%)	-Solutions- Remove (m^3/s)	Diam (mm)
7	122	300	23.680	.026	2.140	1.815	2.493	.140	90		
			20.510		2.140	1.815	2.206	.156			
8	125	300	20.510	.018	2.130	1.805	2.211	.156	121	.027	279
			18.290		2.130	1.805	1.824	.129			
9	137	450	18.290	.004	2.130	1.642	1.325	.174	94		
			17.710		2.130	1.642	1.166	.185			

Length = 384. m Total length = 1012. m

Example Six: Sanitary Sewer Analysis

NORMAL END OF HYDRA

Example Seven: Combined System Analysis

Problem:

HYDRA may be used to design or analyze a combined sanitary and storm sewer system. The example shown in figure 18 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.

Input file: HYDRA7.HDA

```
JOB Example Seven: Combined System Analysis
SWI 4
PEA 0.0004 3.71 0.0006 3.54 0.0008 3.45 0.0015 3.28  0.0028 3.1 0.0142 2.67
    0.0283 2.5 0.1416 2.15 0.2831 2.01 1.416 1.73 2.831 1.62
RAI 0 39.37 5 39.37 8 30.48 10 27.94 15 22.86 18 20.32 24 17.78 32 15.24
INF 0 4676.3
GPC 3785
PDA 0.013 200 1.22 0.914 0.610 0.001
EXC 1.52 0.95 7.62 1.50
TSL 0.914 0.5 3.05 0.5
PCO 200 8.83 900 81.50
CST 1.5 4.92 0 0 0 0.152 8.12 1 0 1.99 1.05 0.78 2.04 1.99 0
NEW HITDA ROAD
SAN 53.83 67.9
STO 53.83 0.25 30
PIP 152.39 30.48 30.48 29.08 28.89 -450
SAN 20.24 42.0
STO 20.24 0.2 25
SAN 8.50 30.9
STO 8.50 0.9 20
PIP 152.39 30.48 30.48 28.89 28.71 -450
SAN 16.19 21.0
STO 16.19 0.3 22
SAN 8.90 21.0
STO 8.90 0.3 18
PIP 30.48 30.48 30.02 28.71 28.65 -525
END
```

Discussion of output:

The results indicate that the entire system has the capacity to accommodate the respective flows as can be seen by the percentage of capacity noted in the output.

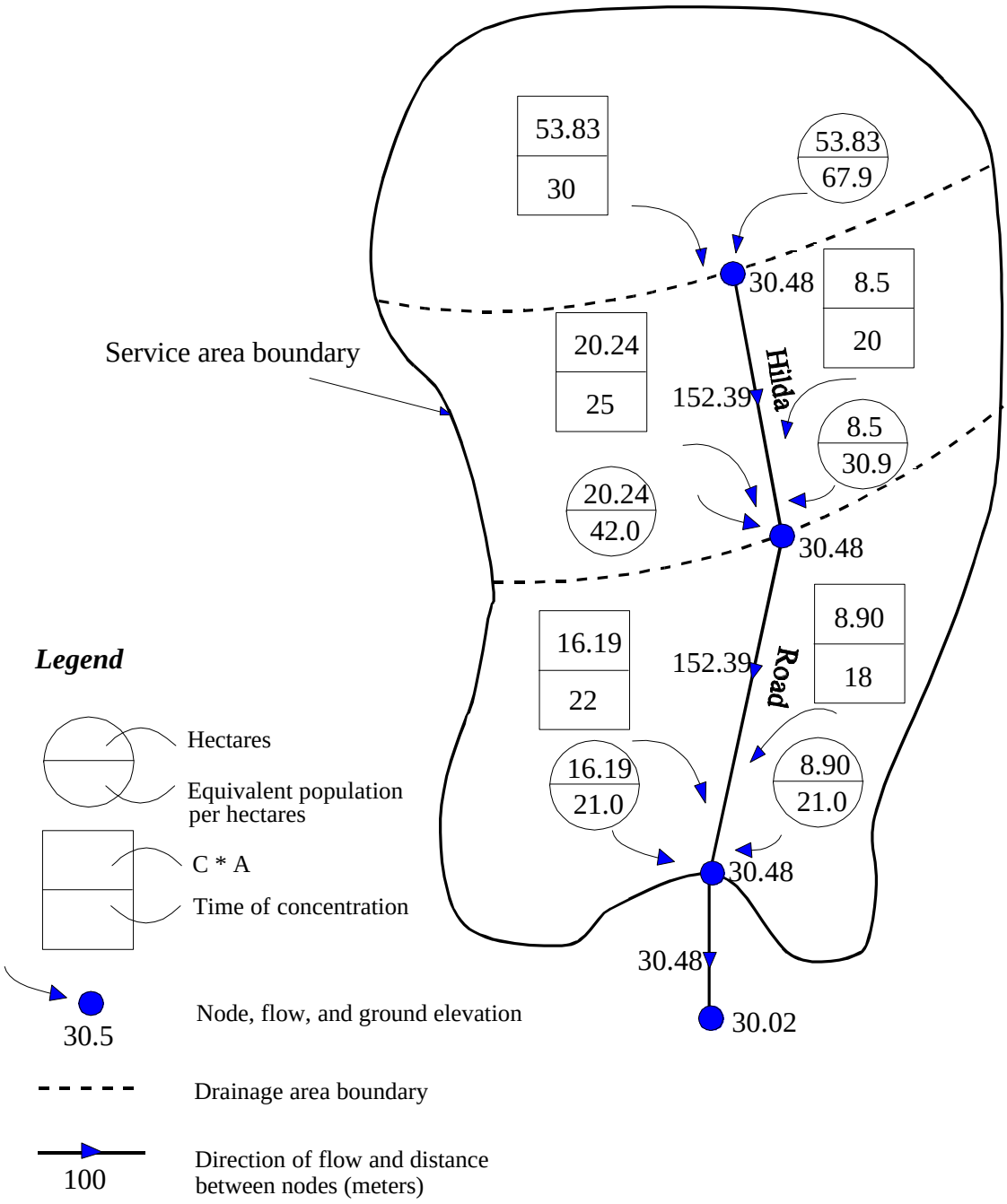

Figure 18. Combined system analysis.

Output file: HYDRA7.LST

```
          ******  HYDRA  ******* (Version 6.1) *****         Date 07-21-1998
                                                                Page No   1

   Example Seven: Combined System Analysis

 +++ Commands Read From File C:\HYDRA\HYDRA7.HDA
   JOB
   SWI 4
   PEA 0.0004 3.71 0.0006 3.54 0.0008 3.45 0.0015 3.28  0.0028 3.1 0.0142 2.67
    0.0283 2.5 0.1416 2.15 0.2831 2.01 1.416 1.73 2.831 1.62
   RAI 0 39.37 5 39.37 8 30.48 10 27.94 15 22.86 18 20.32 24 17.78 32 15.24

                                IDF CURVE


39.*)))))))))3)))))))))3)))))))))3)))))))))3)))))))))3)))))))))3)))),
         *          .          .          .          .          .          .
*
 R       *          .          .          .          .          .          .
*
 a       *          .          .          .          .          .          .
*
 i    30.3          .      *   .          .          .          .          .
3
 n       *          .          .          .          .          .          .
*
 f       *          .          *          .          .          .          .
*
 a       *          .          .          .          .          .          .
*
 l       *          .          .          *          .          .          .
*
 l    20.3          .          .          .     *    .          .          .
3
         *          .          .          .          .        * .          .
*
 i       *          .          .          .          .          .          .
*
 n       *          .          .          .          .          .          .
*
         *          .          .          .          .          .          .
*
 m    10.3          .          .          .          .          .          .
3
 m       *          .          .          .          .          .          .
*
 /       *          .          .          .          .          .          .
*
 h       *          .          .          .          .          .          .
*
         *          .          .          .          .          .          .
*
```

```
0.*)))))))))3)))))))))3)))))))))3)))))))))3)))))))))3)))))))))3)))-
       0.          5.         10.         15.         20.         25.         3
32.
```

Duration, t (min)

PLOT-DATA (Time, t(min) vs. Intensity, i(mm/h))

t	i	t	i	t	i	t	i	t	i
0.	39.	15.	23.	0.	0.	0.	0.	0.	0.
5.	39.	18.	20.	0.	0.	0.	0.	0.	0.
8.	30.	24.	18.	0.	0.	0.	0.	0.	0.
10.	28.	32.	15.	0.	0.	0.	0.	0.	0.

```
INF 0 4676.3
GPC 3785
PDA 0.013 200 1.22 0.914 0.610 0.001
EXC 1.52 0.95 7.62 1.50
```

```
  Example Seven: Combined System Analysis

  TSL 0.914 0.5 3.05 0.5
  PCO 200 8.83 900 81.50
  CST 1.5 4.92 0 0 0 0.152 8.12 1 0 1.99 1.05 0.78 2.04 1.99 0
  NEW HILDA ROAD
  SAN 53.83 67.9
  STO 53.83 0.25 30
  PIP 152.39 30.48 30.48 29.08 28.89 -450
+++ Tc =  30.0 min
+++ CA =  13.5
+++ Link #  1,  Flow depth =    .450 m, Critical depth =    .450 m
  SAN 20.24 42.0
  STO 20.24 0.2 25
  SAN 8.50 30.9
  STO 8.50 0.9 20
  PIP 152.39 30.48 30.48 28.89 28.71 -450
+++ Tc =  31.8 min
+++ CA =  25.2
+++ Link #  2,  Flow depth =    .450 m, Critical depth =    .450 m
  SAN 16.19 21.0
  STO 16.19 0.3 22
  SAN 8.90 21.0
  STO 8.90 0.3 18
  PIP 30.48 30.48 30.02 28.71 28.65 -525
+++ Tc =  33.3 min
+++ CA =  32.7
+++ Link #  3,  Flow depth =    .525 m, Critical depth =    .525 m
  END
 END OF INPUT DATA.
```

Example Seven: Combined System Analysis

*** HILDA ROAD Analysis of Existing Pipes

Link	Length (m)	Diam (mm)	Invert Up/Dn (m)	Slope (m/m)	Depth Up/Dn (m)	Cover Up/Dn (m)	Velocity Act/Full (m/s)	--Flow-- Act/Full (m^3/s)	Load (%)	-Solutions- Remove (m^3/s)	Diam (mm)
1	152	450	29.080	.001	1.400	.913	1.428	.227	226	.127	508
			28.890		1.590	1.103	.633	.101			
2	152	450	28.890	.001	1.590	1.103	1.692	.269	275	.171	584
			28.710		1.770	1.282	.616	.098			
3	30	525	28.710	.002	1.770	1.201	1.316	.285	149	.094	432
			28.650		1.370	.801	.881	.191			

Length = 335. m Total length = 335. m

Example Seven: Combined System Analysis

NORMAL END OF HYDRA

APPENDIX B. FOOTPRINTS FOR TYPICAL APPLICATIONS

This section presents basic HYDRA applications represented by arrangements of command strings. These arrangements of command strings, or footprints, are provided for the following typical applications:

1. Rational method.
2. Rational method with hydraulic gradeline and pressure flow simulations.
3. Hydrographic method.
4. Reservoir or impoundment routing.

These footprints are contained in files on the HYDRAIN package diskettes. These files contain command lines with empty data fields for which the user can supply the appropriate data (the footprint files should be copied and renamed before any editing is done. The simple pipe network which the first three footprints represent is depicted in figure 19.

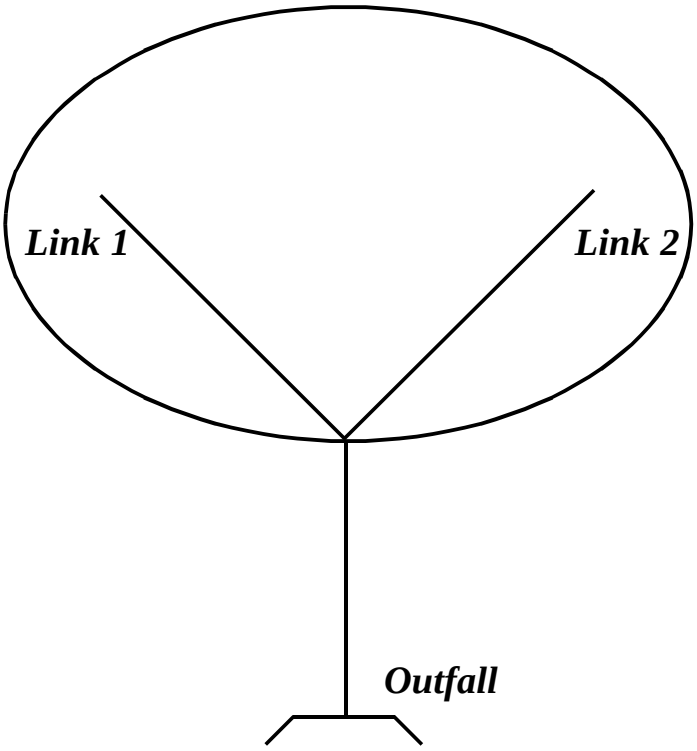

Figure 19. Schematic of footprint pipe network.

1. Rational Method Footprint

Filename: RTL˜FP.HDA

The following command string is typical for the Rational method design or analysis:

```
rem--->Rational Method Storm Drain Design/Analysis
rem--->REMOVE all unused command lines (Alt + D)
rem--->REQUIRED first command, JOB
JOB
SWI 2
RAI
PDA
rem--->OPTIONAL-Cost estimation---<CST>, <EXC>, <PCO>, <TSL> (design mode)
CST
EXC
PCO
TSL
rem--->OPTIONAL - additional cost commands---<ECF>, <LPC>, <PCF> (design mode)
ECF
LPC
PCF
rem--->Description of storm drain network: Link 1
NEW
STO
PIP
HOL
rem--->Description of storm drain network:  Link 2
NEW
STO
PIP
HOL
rem--->Description of storm drain network:  outfall
rem--->Recall system flows from Links 1 and 2 that were held:
NEW
REC
REC
PIP
END
```

2. Rational Method with Hydraulic Gradeline and Pressure Flow

Filename: HGLPF˜FP.HDA

The following command string is typical for rational analysis with hydraulic gradeline and pressure flow simulation:

```
rem--->Rational Method Storm Drain Analysis with HGL and Pressure Flow
Simulation
rem--->REMOVE all unused command lines (Alt + D)
rem--->REQUIRED first command, JOB
JOB
```

```
SWI 2
RAI
HGL
rem--->Description of storm drain network:  Link 1
NEW
STO
PIP
PNC
HOL
rem--->Description of storm drain network:  Link 2
NEW
STO
PIP
PNC
HOL
rem--->Description of storm drain network:  outfall
rem--->Recall flows in Links 1 and 2:
NEW
REC
REC
PIP
PNC
rem--->Pressure flow commands:  <TWE>, <PFS>, <PHJ>, <PFP>, <IQV>, <IDY>:
TWE
PFS
rem--->OPTIONAL-Print commands, <PFP>, <PHJ>:
PHJ
PFP
rem--->OPTIONAL-Initial condition commands, <IQV>, <IDY>:
IQV
IDY
END
```

3. Hydrographic Method

Filename: HYDˇFP.HDA

The following command string is typical for the hydrographic method (design or analysis):

```
rem--->Hydrographic Storm Drain Design/Analysis
rem--->REMOVE all unused command lines (Alt + D)
rem--->REQUIRED first command, JOB
JOB
SWI 3
STE
PDA
rem--->Description of storm drain network:  Link 1
rem--->GUT and INL commands must always precede the PIP command
NEW
UHY
GUT
INL
PIP
```

```
HOL
rem--->Description of storm drain network:  Link 2
NEW
UHY
GUT
INL
PIP
HOL
rem--->Description of storm drain network:  outfall
rem--->Recall flows from Links 1 and 2 that were held:
NEW
REC
REC
PIP
END
```

4. Reservoir or Impoundment Routing

Filename: DPON~FP.HDA

The following command string is typical for routing system flows through some sort of storage facility.

```
rem--->Reservoir Routing of a Detention Facility
rem--->First command, JOB
JOB
SWI 3
rem--->Use time step as dictated by hydrograph
STE
rem--->Use Pipe DAta command to establish design criteria:
PDA
rem--->Run HYDRO to obtain user-specified hydrograph on
rem--->UHY command.
UHY
rem--->Commands that introduce hydrograph to the system, GUT and INL
GUT
INL
EFF
PIP
rem--->Stage-storage and performance (stage-discharge) curve represented
rem--->by SST and SDI, respectively:
SST
SDI
rem--->REServoir command must follow routing commands
RES    0,0
PIP
rem--->The last command of the data set, END
END
```

APPENDIX C: 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 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, m.
2) Angle - Bend angle of the link described by the previous PNC statement, deg.

Note: The bend angle must be between 0 to 115 deg, otherwise, HYDRA produces an error message.

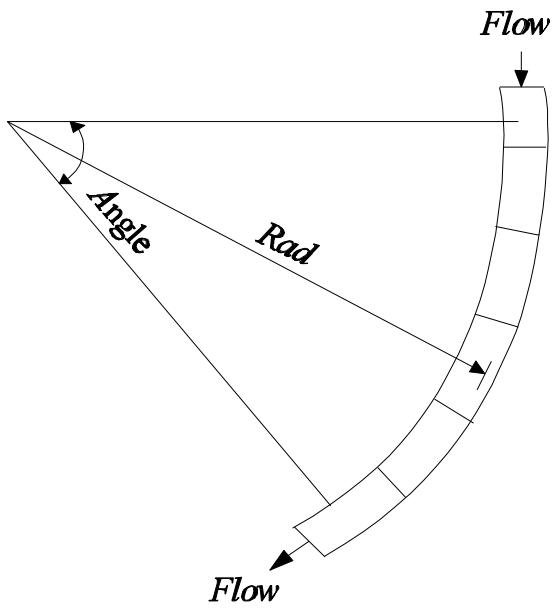

Figure 20. Description of BEN command.

COMMAND BOX - BOX Pipe

Purpose: This is one of the transport commands. It moves water from one point to another in a rectangular pipe. A PDA command is required somewhere in the command file ahead of the first BOX command.

Structure:

BOX length, grup, grdn, invup, invdn, minrise, span, lscost, trfac, plot

1) length - The length of the link or pipe, m. A negative number indicates a vertical box.
2) grup - Elevation of the ground at the upstream end of the link, m.
3) grdn - Elevation of the ground at the downstream end of the link, m.
4) invup - OPTIONAL - elevation of the invert of the pipe at the upstream end of the link, m.
5) invdn - OPTIONAL - elevation of the invert of the pipe at the downstream end of the link, m.
6) minrise - OPTIONAL - minimum depth of box, mm.
7) span - OPTIONAL - horizontal dimension of box, mm.
8) lscost - The lump sum to be added to the link cost calculated by HYDRA when cost parameters are used.
9) trfac - OPTIONAL - trench cost factor.
10) plot - OPTIONAL - enter 1 if plot is desired; enter 0 or leave blank if no plot is desired or if the Rational method is used.

Notes:

1) This command will accept 3, 5, 6, 7, 8, 9, or 10 parameters.
2) If “minrise” is given as a negative number, HYDRA will analyze the pipe assuming that the absolute value is its rise.

COMMAND CHA - CHAnnel

Purpose: CHAnnel is one of the HYDRA transport commands. It allows you to define an open channel or ditch.

Structure: (3 options)

CHA length, invup, invdn

---OR---

CHA length, invup, invdn, n

---OR---

CHA length, invup, invdn, n, lslope, bwidth, rslope (,eq, plot)

1) length - Length of link (distance between nodes), m.
2) invup - Invert elevation at the upstream end of the link, m.
3) invdn - Invert elevation at the downstream end of the link, m. If this value is less than 1.0 but greater than 0.0, HYDRA will take the value as a slope.

---OR---

4) n - Friction factor (Manning's "n").

---OR---

5) lslope - Slope of the channel's left side (horizontal : vertical).
6) bwidth - Width of the bottom (trapezoidal section), m.
7) rslope - Right side slope, (horizontal : vertical).
8) eq - (Optional) - enter 1 if gutter equation is to be used; enter 0 or leave blank if Manning's equation is to be used.
9) plot - (Optional) - enter 1 if plot is desired; enter 0 or leave blank if no plot is desired or if the Rational method is used..

Notes:

1) There is an automatic ditto feature in this command in that "n", left slope, bottom width, right slope, and eq will all be copied from the previous CHA command unless

overridden by subsequent entries in this command. The value of "n" may be changed without touching the geometry parameters, but all geometry parameters must be re-entered if one is. In other words, HYDRA will accept 3, 4, 7, 8, or 9 parameters for this command. Any other number of parameters is an error.

2) HYDRA does not check backwater problems on upstream channels or pipes so the designer should review the output carefully if such a condition is suspected.

3) The designer should consider the possibility for "scour" in channels where velocities are high.

4) The friction factor, "n", has a major influence in the CHA calculation. Its selection should consider the channel future as well as existing condition.

COMMAND CRI - CRIteria

Purpose: **CRI** is a switch that indicates if the inverts or the crowns are matched in a "free design".

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, the switch is 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: One of the required commands for a HYDRA cost estimate of pipe in place. 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 product of wmul & interior pipe diameter, m.
3) wmin - Minimum trench width, m.
4) bmul - Factor to establish depth of bedding.
5) badd - Added to above to get depth of bedding, m.
6) bmin - Minimum depth of bedding, m.
7) $bed - Cost/$m^3$ 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, m.
10) $pz - Cost/$m^3$ of pipe zone material in place.
11) shrink - Shrinkage of backfill material in place ($\geq$1.0).
12) $back - Cost/$m^3$ of replacing excavated backfill.
13) $waste - Cost/$m^3$ to remove excess native material.
14) $borrow - Cost/$m^3$ of borrow material in place.
15) $surf - Cost/$m^2$ for surface restoration.

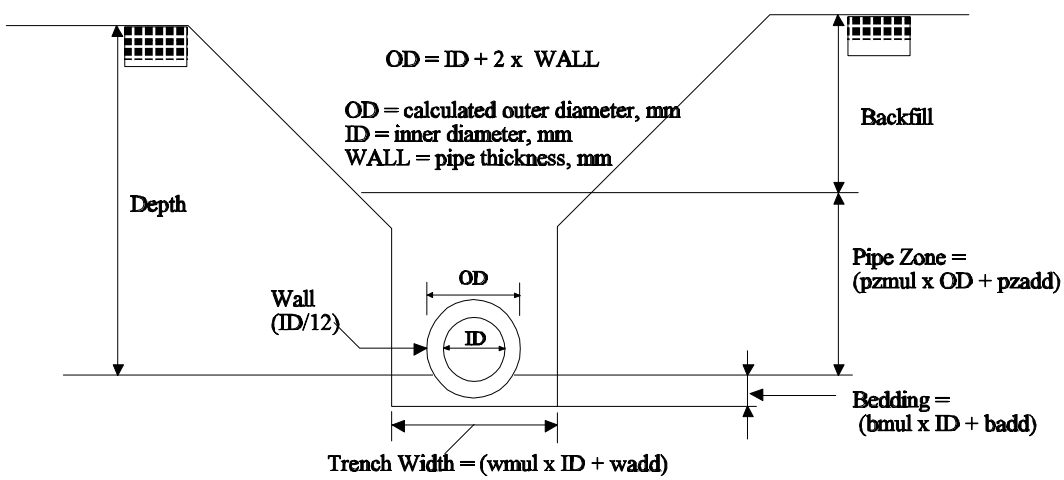

Figure 21. CST command trench and geometric factors.

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(1), Qdiv(1)...Qsys(n), Qdiv(n) (up to a maximum of 20 sets or a min of 2 sets - all values of Qsys must increase)

1)	hold	-	A HOLd number between 1 and 100 where DIVerted system flow is to be held. May be recalled with a REC command.
nx)	Qsys(i)	-	System flow, m^3/s.
ny)	Qdiv(i)	-	Flow, m^3/s, 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 0.0 then no flow is diverted.

Notes:

1) A maximum of 20 points (20 sets of Qsys and Qdiv) can be defined on the sys/div curve. All values of sys must increase div can be any value (so long as it is positive and not greater than sys).

2) This is a very flexible command and can be used for any type of weir or regulator in a system. It could be used to model a manhole that “blows its lid,” by loosing the diverted flow or by taking it back into the system at another point by using the REC or GET commands depending upon the situation. (The GET command is applicable only for hydrological analysis).

3) If this command is used without the SWI command or with the SWI command set to 1 or 2 HYDRA calculates the “peak” flow, looks at the DIV curve to find the amount to divert and then splits the population (in the event of sanitary flow) or Sum of C*A (in the case of normal storm flow) into two units. As a result the sum of the 2 downstream flows may be slightly greater than the upstream flow in some cases.

4) For hydrological analysis, both sanitary and misc. flow are dumped into the storm hydrograph so a rational split can be made. This will cause the sanitary flow to start over again and because of the peaking factor, result in the downstream flows being slightly greater than the upstream flow.

COMMAND ECF - Extra Cost per length

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(1), cost(1)...depth(n), cost(n) (up to a maximum of 20 sets or a minimum of 2 sets - all values of depth must increase)

nx)	depth(i)	-	Depth from the surface to the pipe invert, m.
ny)	cost(i)	-	Added cost/m of depth at the above depth.

Notes:

1) HYDRA interpolates between the points supplied for any values needed. For this reason, at least 2 sets of data must be supplied. The depth must always increase, the $/m can be any value.

2) More than one line may be used if needed.

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(1), eff(1), flow(2), eff(2),... flow(n), eff(n) (up to a maximum of 20 pairs and a minimum of 2 pairs - all values of flow must increase)

nx)	flow(i)	-	Flow arriving at the inlet, m^3/s.
ny)	eff(i)	-	Capture efficiency corresponding to previous flow, expressed as a percentage.

COMMAND ELP - ELiptical Pipe

Purpose: This is one of the transport commands. It moves water from one point to another in a horizontal or vertical elliptical pipe. A PDA command is required somewhere in the command file ahead of the first ELP command.

Structure:

ELP length, grup, grdn, invup, invdn, minrise, span, lscost, trfac, plot

1) length - The length of the link or pipe, m. A negative number indicates a vertical ellipse.
2) grup - Elevation of the ground at the upstream end of the link, m.
3) grdn - Elevation of the ground at the downstream end of the link, m.
4) invup - OPTIONAL - elevation of the invert of the pipe at the upstream end of the link, m.
5) invdn - OPTIONAL - elevation of the invert of the pipe at the downstream end of the link, m.
6) minrise - OPTIONAL - minimum depth of ellipse, mm.
7) span - OPTIONAL - horizontal dimension of ellipse, mm.
8) lscost - The lump sum to be added to the link cost calculated by HYDRA when cost parameters are used.
9) trfac - OPTIONAL - trench cost factor.
10) plot - OPTIONAL - enter 1 if plot is desired; enter 0 or leave blank if no plot is desired or if the Rational method is used.

Notes:

1) This command will accept 3, 5, 6, 7, 8, 9, or 10 parameters.

2) If “minrise” is given as a negative number, HYDRA will analyze the pipe assuming that the absolute value is its rise.

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(1), cost(1)...depth(n), cost(n) (up to a maximum of 20 sets or a minimum of 2 sets - all values of depth must increase)

nx)	depth(i)	-	Depth from surface to excavation depth, m.
ny)	cost(i)	-	The cost in dollars/m^3 at excavation depth.

Notes:

1) HYDRA interpolates between the points supplied for any values needed. For this reason at least 2 sets of data must be supplied. The cost can be any value.

2) More than one line may be used if needed.

3) HYDRA calculates the excavation costs for every 1-m strip. The cubic meters of every strip is calculated and then the excavation cost of that strip is determined from the data supplied.

COMMAND FLO - miscellaneous FLOw

Purpose: FLO command adds a constant flow to the system. (A negative value indicates removal from the system.)

Structure:

FLO qpk

qpk - The volume of water to be entered into or removed from the system, m^3/s. In the case of removing flow, the value would be negative.

Notes:

1) This command must be followed by a PIP command before a HOL command is used or the flow will not be taken into the system.

2) Some of the uses of this command:

   a) Known major sources of infiltration.

   b) Cooling water.

   c) Subdrain flow.

   d) Stream flow.

   e) A given design flow.

   f) Irrigation tap (negative).

COMMAND GET - GET gutter hydrograph or peak flow

Purpose: GET is very similar to the REC command in function except it retrieves a gutter hydrograph or peak flow from data storage that was put there by the PUT or INL command. It has no use in nonhydrographic analysis.

Structure:

GET number

number - A number between 101 and 200 representing the gutter hydrograph or peak flow that was put in data storage by the PUT or INL command.

Note: For a rational analysis with inlets, GET must follow the STO command for bypass flow to be added to local runoff.

COMMAND GPC - unit flow of wastewater

Purpose: This command allows you to set the liters per capita per day that HYDRA is to use in its flow calculation in the SAN and SUN commands.

Structure:

GPC uflow

uflow - Unit flow of wastewater, in liters per capita per day, generated. 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 provides spread, velocity and depth for the inlet command.

Structure:

```
                -- Uniform Gutter --
GUT  length, invup, invdn, n, Sx, bwidth (, 0, 0, plot)
                        or
                -- Composite Gutter --
GUT  length, invup, invdn, n, Sx, bwidth, Sw, 0 (, plot)
                         or
                -- Roadside Channel --
GUT  length, invup, invdn, n, lslope, bwidth, rslope, 1 (, plot)
```

1) length - Total length of the gutter, m.
2) invup - Invert elevation at the upstream end, m.
3) invdn - Invert elevation at the downstream end, m.
4) n - Manning's roughness coefficient for the gutter.
5) Sx or lslope - Roadway cross slope (uniform or composite gutter) or left side slope (roadside channel) horizontal distance per unit vertical (__:1).
6) bwidth - Width of the bottom of the trapezoidal channel bottom OR width corresponding to Sw for a composite gutter, OR width corresponding to Sx for a uniform gutter, m.
7) Sw or rslope- Composite gutter cross slope or right side slope (roadside channel) horizontal distance per unit vertical (__:1).
8) eq - OPTIONAL - enter 1 if using a roadside channel, enter 0 or leave blank if using a composite or uniform gutter.
9) 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) There is an automatic "ditto" feature in this command. Values for Manning's n, Sx or left slope, bottom width, Sw or right slope, and the eighth parameter will all be copied from the previous GUT command unless overridden by entries in this command. While the value of Manning's n may be changed without entering the remaining parameters; all of the gutter geometry parameters must be entered if there is a change in one of them.

2) The roughness coefficient "n" has a major influence in the gutter calculations so it should be selected with care.

3) All slopes, "lslope," "rslope," "Sx," and "Sw," are in units of distance horizontal per unit distance 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 100 in which lateral data is to be stored. The REC command can then be used to bring this data back into the system. A register can be re-used any number of times but previously stored data will be lost. This should be of no concern if a REC command has already retrieved the data.

Note: It is good practice to immediately follow a HOL command by a NEW command. It is possible to lose data if not done.

COMMAND IDY - Initial Depth

Purpose: Establishes the initial depth in a junction for pressure flow evaluation.

Structure:

IDY y(1), y(2), y(3),...., y(n) (up to a maximum of 20 values)

y(j) - Initial depth in junction, m.

Notes:

1) IQV must precede IDY

2) This command is ignored in the rational formula analysis.

3) The junction depth is defined as the water level in the junction above the lowest pipe invert connected to the junction, usually the outflow pipe. The flow depth in the outflow pipe can often be estimated as the initial junction depth.

4) The order of initial depth entries should correspond to respective pipes as they appear on the PIP commands preceding the PFS command. The order of pipe entries, in turn, corresponds to the identification of new junctions. That is, each new pipe described adds a new junction to the system at its upstream end.

5) If any depth value, y(j), is zero or unknown, the zero must be entered.

6) The number of junctions is always 1 greater than the number of pipes. Therefore, the last initial depth corresponds to the outfall depth relative to the outfall pipe invert.

COMMAND INF - INFiltration

Purpose: Provide infiltration flows based on population or area.

Structure:

INF lcd, lhd (Use either)

1) lcd - Liters per capita per day of ground water finding its way into the system.

2) lhd - Liters per hectare per day of ground water finding its way into the system.

Notes:

1) Normally one would use gcd <u>or</u> gad, but not both at the same time. The one not used would be set to 0.0. Some feel the gcd better reflects the number of side sewer connections (where much of the problem exists), while others prefer the gad. Remember this can be changed during a run to reflect changing ground water conditions.

2) Infiltration is only calculated on sanitary (SAN or SUN) data, not the storm (HYD or STO) data.

3) This is an important parameter in all “real” sanitary sewer systems. In numerous cases, infiltration into a sanitary sewer system exceeds the waste water flows. The value selected should be based on the assumption that the system has been in the ground for 50 years or more--not on new construction standards.

COMMAND INL - storm drain INLet

Purpose: Allows specification of inlet characteristics and/or performance. Adds a runoff hydrograph generated by a UHY command and transported by a GUT command to the system (as specified in the subsequent CHA or PIP command) modified by inlet performance.

Structure: (four options)

INL id, itype, subtype, store, w (, length, 0, 0, perim, area, plot) << Grate Inlet

- OR -

INL id, itype, 0, store, w (, length, a, wdepr, 0, 0, plot) << Curb Inlet

- OR -

INL id, itype, 0, store, h (, length, a, wdepr, 0, 0, plot) << Slotted Drain Inlet

- OR -

INL id, itype, 0, store << User-defined Inlet

1) id - Inlet identification number (a suggestion is to use the node number at the inlet location).

2) itype - One digit code, between 1 and 7, that defines the inlet type to be analyzed or designed.

(1) Grate on grade.
(2) Curb opening on grade.
(3) Slotted drain on grade.
(4) Grate in sump condition.
(5) Curb opening in sump condition.
(6) Slotted drain in sump condition.
(7) User-defined (command EFF must follow immediately after INL command in this case). ON GRADE ONLY. May be used to simulate combination inlets.

3) subtype - One digit code, between 0 and 7, used for grate inlets (i.e., for inlet types one and four). This parameter must be set to zero if considering the other five inlet types.

(0) Subtype not applicable.
(1) Parallel bar P-1-7/8 in (50 mm).
(2) Narrow parallel bar P-1-1/8 in (30 mm).
(3) Curved vane.
(4) Tilt bar - 45 degrees.
(5) Safety parallel bar P-1-7/8-4 in (50-4 mm).
(6) Tilt bar - 30 degrees.
(7) Reticuline.

4) store - Storage register for excess flow for hydrograph ANALYSIS of inlets on grade. When used, it must be a number from 101 to 200. When using the Rational method or hydrograph DESIGN mode, set this parameter equal to zero.

5) w or h - Width (w) of grate or slot opening OR height (h) of curb inlet, m.

6) length - OPTIONAL - length of inlet, m. Must be 150 mm or greater.

7) a - OPTIONAL - inlet depression for curb or slot inlet, m. Enter zero if inlet not depressed or if depression should be calculated from previous GUT command.

8) wdepr - OPTIONAL - width of inlet depression for curb or slotted inlets, m. Enter zero if inlet not depressed or if depression width should be calculated from previous GUT command.

9) perim - OPTIONAL - inlet perimeter, m. Used only for grate inlet in sump condition.

10) area - OPTIONAL - area of orifice opening of the inlet, m^2. Used only for grate inlet in sump condition.

11) plot - OPTIONAL - enter 1 if a plot is desired; enter 0 or leave blank if no plot is desired or if the Rational method is used.

Notes:

1) Grate length can be greater than 6 000 mm, although if this occurs, a message will be displayed.

2) Zeros should be used as place holders to skip past unneeded parameters.

3) To properly analyze or design an inlet, **all** flows reaching an inlet must first travel through a gutter (GUT command). When appropriate, a nominal gutter length at the correct slope can be used.

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 IQV - Initial flow (Q) and Velocity

Purpose: Specifies the initial discharge and velocity in a pipe for a pressure flow simulation.

Structure:

IQV q(1), v(1), q(2), v(2),...., q(n), v(n) (up to a maximum of 20 pair)

nx) q(i) - Initial discharge in pipe, m^3/s.

ny) v(i) - Initial velocity in pipe, m/s.

Notes:

1) Initial flows and velocities correspond to the respective pipes in the order they appear in the data set.

2) In the detailed output (ndetail = 2 in the PFS command), HYDRA will report flows for a conceptual pipe which is used to record flow volume leaving the system through the outlet and to permit flow continuity computations at the outlet.

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 output.

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, m, 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 pipe on the previous PIP command and should model minor losses due to structures other than junctions and manholes.

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, m.
2) start depth - Invert depth, m, at which cost estimate table is to start.
3) end depth - Invert depth, m, of last cost estimate.
4) increment - The number of m between each cost estimate. If left blank or set to 0, HYDRA will set to 0.3.

Note: All data used in this command must be in 0.3 m increments, for example 6.0 or 6.3 is acceptable.

COMMAND MAP - MAP scale

Purpose: The SAN, SUN, and STO commands all require entry of land segment areas in ha. The user may choose to enter a raw ratio instead with a negative sign preceding each value. HYDRA converts to ha using the value set by this command. Even if the MAP command is in the command file, the user may still choose to enter ha directly.

Structure:

MAP scale

scale - The map ratio (scale) of the map being used, (_ : 1).

Notes:

1) As with nearly all HYDRA commands, this command can be used any number of times in the command string. This allows the user to use any number of different maps on a single system.

2) The formula used to calculate ha is illustrated below. This formula is used anytime "areas" are negative. The negative value is first changed to a positive value and then:

$$\text{Area, ha} = (\text{area, mm}^2) \bullet (\text{scale})^2 / 10{,}000\ \text{m}^2/\text{ha})$$

COMMAND NEW - start NEW lateral

Purpose: This command is used to initiate calculation for a new lateral.

Structure:

NEW lateral name

lateral name- Up to 20 alphanumeric characters.

Notes:

1) This command starts off a new lateral. Any flow entering this lateral must follow this command in the command string.

2) After the first lateral, be sure to use a HOL command before a NEW command if you intend to recall the flow from a lateral back into the system. The NEW command clears any flows calculated, but not explicitly saved.

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(1), factor(1)...depth(n), factor(n) (up to a maximum of 20 sets, or a minimum of 2 sets - all values of depth must increase).

nx)	depth(i)	-	Depth from the surface to the pipe invert, m.
ny)	factor(i)	-	Some factor which when multiplied by pipe cost from the PCO command will result in a reasonable adjustment for a class of pipe.

Notes:

1) HYDRA interpolates between the points supplied for any values needed. For this reason at least two sets of data must be supplied. The factor can be any value.

2) More than one line may be used if needed.

COMMAND PCO - Pipe Costs

Purpose: One of the required commands for cost estimates. It establishes the cost per m of pipe in place.

Structure:

PCO dia(1), cost(1)...dia(n), cost(n) (up to a maximum of 20 sets or a minimum of 2 sets - all values of dia must increase).

nx)	dia(i)	-	Inside diameter of pipe, m.
ny)	cost(i)	-	Cost, dollars/m, of pipe laid in place but not backfilled.

Notes:

1) HYDRA interpolates between the points supplied for any values needed. For this reason at least two sets of data must be supplied. The cost can be any value.

2) More than one line may be used if needed.

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," mm.
3)	mindepth	-	In a free design, HYDRA will not place the invert shallower than this depth, m.
4)	mincover	-	In a free design, HYDRA will not allow cover over the pipe to be less than this value, m.
5)	minvel	-	In a free design, HYDRA will not allow the full flow velocity to drop below this value, m/s.
6)	minslope	-	In a free design, HYDRA will not select a slope less than this value, m/m. This value MUST be greater than zero (0.0).
7)	maxdia	-	OPTIONAL - If it is used, HYDRA will not select a pipe larger than this diameter, mm. This parameter should probably not be used for the first run on any design.

Note: PDA is usually placed near the beginning of a input data set. 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 adf(1), pf(1), adf(2), pf(2)...adf(n), pf(n) (up to a maximum of 20 sets, or a minimum of 2 sets - all values of m^3/s must increase).

nx)	adf(i)	-	Accumulated average daily flow from SAN and SUN commands.
ny)	pf(i)	-	The peaking factor. Normally ranges between 1.0 and 4.0.

Note: The last average daily flow value should be greater than the maximum expected adf in the system, otherwise the interpolating features of the command may yield unexpected results. Also, experience indicates that the curve should start at zero, as initial flows in a system are often very small.

COMMAND PFP - Printed Flow Pipe

Purpose: Contains list of pipes for which flows and velocities are to be printed for a pressure flow simulation.

Structure:

PFP pipe(1), pipe(2), pipe(3),...., pipe(npprt) (up to a maximum fo 20 values)

pipe(i) - Pipe number for detailed printout.

Note: The number of pipes entered should correspond to npprt on the PFS command.

COMMAND PFS - Pressure Flow Simulation

Purpose: Specifies control parameters for the pressure flow simulation option and initiates the pressure flow simulation.

Structure:

PFS tzero, nstime, delt, nsdelt, ndetail, njprt, npprt, itmax, surtol

1) tzero - Start time of simulation, min.
2) nstime - Total simulation time, min.
3) delt - Incremental time to be used to calculate flows, s.
4) nsdelt - Printing interval between points in history table (whole number).
5) ndetail - Printout type: select
   - 0 - summary table
   - 1 - summary and time history tables
   - 2 - summary, time history tables, and detailed printout including each result.
6) njprt - Number of junctions for detailed printing of head output when print option is 1 or 2 (20 maximum). Used by PHJ command.
7) npprt - Number of pipes for detailed discharge printing when print option is 1 or 2 (20 maximum). Used with PFP command.
8) itmax - Maximum number of iterations to readjust head and flow of surcharged junctions.
9) surtol - Fraction of flow in surcharged area to be used as the tolerance for ending surcharge iterations.

Notes:

1) "nstime" should be equal to or greater than the longest base time of hydrographs in the system plus the travel time for the longest path.

2) "delt" is critical in terms of computing time and stability of the program. If a time step provided by the user violates the preset stability limit, the program will select an appropriate time step.

3) "itmax" and "surtol" control the accuracy of the solution in surcharged areas. Flows and heads in these areas are recalculated until the difference between inflow and outflow is less than the tolerance limit selected, or until the maximum number of iterations specified has been reached. Effective values for "itmax" and "surtol" have been found to be 30 and 0.05 (5 percent difference between inflows and outflows), respectively.

COMMAND PHJ - Print Heads at Junctions

Purpose: Contains list of individual junctions for which water depth and water surface elevations are to be printed for a pressure flow simulation.

Structure:

PHJ junction(1), junction(2),...., junction(njprt) (up to a maximum of 20 values)

junction(j) - Junction number for detailed printout.

Note: The number of junctions entered should correspond to “njprt” on the PFS command.

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, plot

1) length - The length of the link or pipe, m.
2) grup - Elevation of the ground at the upstream end of the link, m.
3) grdn - Elevation of the ground at the downstream end of the link, m.
4) invup - OPTIONAL - elevation of the invert of the pipe at the upstream end of the link, m.
5) invdn - OPTIONAL - elevation of the invert of the pipe at the downstream of the link, m.
6) mindia - OPTIONAL - minimum diameter of pipe, mm.
7) lscost - The lump sum to be added to the link cost calculated by HYDRA when cost parameters are used.
8) trfac - OPTIONAL - trench cost factor.
9) plot - OPTIONAL - enter 1 if plot is desired; enter 0 or leave blank if no plot is desired or if the Rational method is used.

Notes:

1) This command will accept 3, 5, 6, 7, 8, or 9 parameters.

2) If “mindia” is given as a negative number, HYDRA will analyze the pipe assuming that the absolute value is its diameter.

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, Nodtyp, 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, m, of the manhole at the downstream end of the link (or the width of Dnode). If junction is not a manhole or drop inlet, enter 0 as a place holder.
4) Angle - The angle, deg, between the link specified by Unode and Dnode above and the outflow pipe leaving Dnode (0 to 360 degrees).
5) Nodtyp - Code signifying type of node at the downstream end.
   0 - manhole
   1 - pipe junction
   2 - outfall
6) Bench - OPTIONAL - Used only with manhole junctions. Enter a value of 0, 1, 2, or 3 to signify the type of benching present at Dnode:
   0 - flat bench (Default).
   1 - 1/2 bench
   2 - full bench
   3 - improved bench

Notes:

1) Five or six parameters will be accepted.

2) Selection of Nodtyp and Bench determines how energy loss calculations are performed in a hydraulic gradeline analysis.

COMMAND PON - surface PONding

Purpose: This command allows surface ponding of flows UHY, GUT, and GET commands. Pond size can be designed or reviewed.

Structure:

PON cap, return

1) cap - Desired pond capacity, m^3. (Enter zero to design pond size.)
2) return - Maximum return discharge, m^3/s. (Enter zero to design maximum return discharge.)

Note: If inflow hydrograph has multiple peaks, Option 1 may compute a larger return flow than necessary. In this case use Option 2 in a trial and error solution until desired pond capacity is obtained.

COMMAND PSZ - Pipe SiZe

Purpose: To allow the user to define available pipe sizes to which the pipe design process will be limited.

Structure:

PSZ pipsiz(1), pipsiz(2), pipsiz(3),....,pipsiz(n) (up to a maximum of 40 values - all values of pipsiz must be in increasing order)

pipsiz(i) - Size of pipe diameter that is available for Design Mode, mm.

COMMAND PUM - PUMp

Purpose: Lifts hydraulic gradient the specified amount and sizes discharge pipe.

Structure:

PUM length, elevout, maxvel, dia, cost

1) length - The length of the discharge pipe, m.
2) elevout - Discharge invert elevation, m.
3) maxvel - Maximum velocity in the discharge pipe, m/s.
4) dia - Diameter, mm, either zero or a positive number. If zero, HYDRA will select a diameter. If a diameter is given, HYDRA will ignore maxvel.
5) cost - Lump sum cost of the pump station and the discharge pipe. If not used, will be set to zero.

Note: Many sanitary and combined collection systems require pumps to life the waste water to a higher elevation. This command is used to model this requirement.

COMMAND PUT - PUT gutter flow into storage

Purpose: This is one of the commands that can be used for by pass simulation. It is very similar to the HOL command in function except it stores away the gutter hydrograph and peak flows . This gutter hydrograph or peak flow is recalled by GET.

Structure:

PUT number

number - A number from 101 to 200 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.

Note: Recalling information from a PUT register can only be done with a GET command. Although the GET command recalls the information stored in a PUT register, it does not destroy the data in the register. Therefore, if the user wishes to “see” the gutter hydrograph or peak flow at any point, he may use the PUT command to store it away, then the GET command to bring it back leaving an “image” of the hydrograph or peak flow in the PUT register.

COMMAND RAI - RAInfall data

Purpose: The rational formula requires an intensity-versus-duration curve. This command allows you to set the values on the curve. There are two formats for this command.

Structure:

RAI time(1), int(1)...time(n), int(n)...(up to a maximum of 20 sets or a minimum of 2 sets - all values of time must increase)

- OR -

RAI filename

nx)	time(i)	-	The duration of a specific rainfall intensity, min, which is experienced in a storm of a certain return period (such as a 5-year storm).
ny)	int(i)	-	Rainfall intensity, mm/h.
	filename	-	The filename of the externally produced IDF data set located in the intermediate directory and typically having the file extension "IDF."

Notes:

1) More than one line can be used if needed.

2) HYDRA interpolates between the points supplied for any values needed. For this reason, at least two sets of data must be supplied. The time must always increase; the intensity can be any value.

3) It is always wise to have the last two points have the same intensity, so the extension of the curve will never go negative.

4) Data in the file for the second command form must exist in the "ITM" subdirectory and must be in the following format (HYDRO uses this format):

Line 1:	Comment line 1	
Line 2:	NPTS	<< number of points
Line 3+:	DUR(n), INT(n)	<< duration, in min; intensity, mm/h

The data in lines three through the end must be in adjacent 10 space fields beginning in column 1. Make sure that no tabs exist in any of the fields in the file.

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 100 representing the storage location of data previously stored by a HOL or DIV command.

Notes:

1) CAUTION - HOL and DIV commands use the same 100 registers to store flow, so do not inadvertently overwrite them - however, HYDRA will warn of this problem.

2) There is a limit of five recalls at one node. If more than five laterals contribute to a downstream link, insert a short PIPe (say, 1.0 m) and then recall the rest.

COMMAND REM - REMarks

Purpose: Allows a line for remarks or comments.

Structure:

REM Any alphanumeric information.

Note: REM commands can be entered anywhere in the data set after the JOB command.

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: (2 options)

-- OPTION 1 --

RES Cap, Return

1) Cap - The capacity of the reservoir, m^3. 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 give a message stating that the capacity was exceeded.
2) Return - The maximum rate of return to the system from the reservoir, m^3/s. 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 --

RES 0, 0

Analysis using user-supplied stage-storage and stage-discharge curves as specified in the SST and SDI, respectively. Routing by the storage-indication method is performed.

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 SUN 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 preceded by a transport command.

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 the STO or UHY commands.
4)	flo	-	Safety factor for flow generated by the FLO command.

Notes:

1) None of the parameters can be less than 1.00.

2) The above values should all be set to 1.00 when calibrating a system against recorded flows so HYDRA will not indicate an overloaded condition, when none exists.

3) This command may be used any number of times in the command string, so if you are analyzing a system in which some laterals are existing and some are being designed, altering the safety factors from 1.0 to design values should be considered.

4) If this command is not used, all values will be set to 1.0.

COMMAND SAN - SANitary flow

Purpose: Enters sanitary flow into the system. It uses data supplied in the PEA and GPC commands.

Structure:

SAN area, density

1) area - Area, ha, served by the following link. The user can input map measurements, in^2, (as a negative value) using the MAP command to make the conversion to ha.
2) density - The equivalent population per ha. This value normally ranges from 6 to 50.

Notes:

1) This command must be followed by a transport command (PIP, CHA, PUM, etc.) before a HOL command is used.

2) This command generates flow as follows:

   a) If area is negative (mm^2), the MAP command is used to convert the mm^2 to ha.

   b) Area is multiplied by parameter 2 to yield population; this is then added to upstream population.

   c) This total population is converted to m^3/s using criteria set in the GPC command.

   d) The Peaking (PEA) factor curve is used to adjust this flow for peak loads on the system.

   e) The area or population in this command is used in conjunction with the data supplied by the INF command to calculate the infiltration into the system.

COMMAND SDI - Stage-Discharge curve

Purpose: This command allows the user to input a stage-discharge 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 SST commands.

Structure:

SDI stage(1), dschrge(1), stage(2), dschrge(2),...,stage(n), dschrge(n) (up to a maximum of 20 pairs)

nx)	stage(i)	-	The stage of the reservoir, m.
ny)	dschrge(i)	-	The discharge of the reservoir corresponding to the stage specified above, m^3/s.

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) If stage exceeds the last “stage” value, HYDRA calculates discharge based on a linear interpolation of the last two ordered pairs. The user should verify that this is appropriate when it occurs.

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(1), Strge(1), Stage(2), Strge(2),...Stage(n), Strge(n) (up to a maximum of 20 pairs

1)	Stage(i)	-	The stage of the reservoir, m.
2)	Strge(i)	-	The storage of the reservoir corresponding to the stage specified above, m^3.

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) If stage exceeds the last “Stage” value, HYDRA calculates storage based on a linear interpolation of the last two ordered pairs. The user should verify that this is appropriate when it occurs.

COMMAND STE - STEp

Purpose: Sets the length of the step in hydrographic simulation.

Structure:

STE min/step

min/step - min/step. If this command is not used, the min/step defaults to 15 min. In this case, there will be 15 times 96 or 24 h total simulation.

Note: HYDRA works with 96 internal registers in hydrographic simulation. For this reason, when the step length is set to 5 min, the period of calculation is 8 h. When the step is set to 15 min, the period of calculation is 24 h, etc.

COMMAND STO - STOrm flow

Purpose: Enters subbasin 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: (3 options)

STO area, C, time

-- OR --

STO area, C, oup, odn, odis, gtime

-- OR --

STO area, C, oup, odn, odis, gup, gdn, gdis

1) area - Service area, ha (or mm^2 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 the watershed.

3)	time	-	Minimum time, min, runoff takes to get from the most hydraulically remote point of the subbasin to the inlet.

- or -

3)	oup	-	Upper overland flow elevation, m.
4)	odn	-	Lower overland flow elevation, m.
5)	odis	-	Overland flow distance, m (measured from oup to odn).
6)	gtime	-	Gutter time, min, (measured from odn to the inlet).

- or -

6)	gup	-	Upper gutter elevation, m.
7)	gdn	-	Lower gutter elevation, m.
8)	gdis	-	Length of the gutter, m (measured from odn to the inlet).

Notes: This command must contain 3, 6, or 8 parameters.

COMMAND SUN - Sanitary Units

Purpose: Enters the number of “sanitary units” contributing to the sanitary flow at a node.

Structure:

SUN units, area

1) units - The number of “units” (as in dwelling units) contributing to the system at this node.
2) area - OPTIONAL - The area containing the units, ha. If the MAP command has been used, mm^2 can be entered (as a negative value) and HYDRA will calculate the area.

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 two contributing areas.

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, where:
- 1 - Sanitary only.
- 2 - Storm (Rational) only.
- 3 - Storm (Hydrographic) only.
- 4 - Sanitary and Rational.
- 5 - Sanitary and hydrographic.

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)

Note: A HOL command cannot be used after TRA.

COMMAND TSL - Trench side SLope

Purpose: One of the required commands for HYDRA to make a cost estimate of pipe in place. It sets the slope of the trench side walls above the top of the pipe.

Structure:

TSL depth(1), slope(1)...depth(n), slope(n) (up to a maximum of 20 sets or a minimum of 2 sets - all values of depth must increase)

nx)	depth(i)	-	Depth from ground surface to the invert, m.
ny)	slope(i)	-	Slope of the portion of the trench above the top of the pipe when the invert is at the above depth, m/m.

Notes:

1) HYDRA interpolates between the points supplied for any values needed. For this reason, at least 2 sets of data must be supplied. The slope can be any value.

2) More than one line may be used if needed.

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, m.

COMMAND UHY - User Hydrograph

Purpose: Enables the user to use externally produced hydrographs in an analysis.

Structure: (2 options)

UHY time(1), flow(1), ... , time(n), flow(n) (up to a maximum of 96 sets or a minimum of 2 sets–all values of time must increase)

---OR---

UHY filename

(nx)time(i) - Time, min, of hydrograph.
(ny)flow(i) - Discharge, m^3/s, of hydrograph at time(i).
filename - The filename of the hydrograph data set located in the intermediate directory. The HYDRO produced hydrographs have the file extension "QT."

Notes:

1) Data in the file must exist in the "ITM" subdirectory and must be in the following format (HYDRO uses this format):

Line 1 : Comment Line 1
Line 2 : NPTS
Line 3+: time (n), flow (n)

where:

NPTS = number of points

N = point number

2) The data in lines three through the end must be in adjacent 10 space fields beginning in column 1. Make sure that no tabs are entered in any of the fields in the hydrograph file.

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HYDRAIN - INTEGRATED DRAINAGE DESIGN COMPUTER SYSTEM

VOLUME IV. WSPRO - STEP BACKWATER AND BRIDGE HYDRAULICS

for:

Office of Technology Applications
Federal Highway Administration
Washington, DC

March 1999

(insert metric conversion page here)

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INTRODUCTION

The Water-Surface Profile (WSPRO) computer program 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 guide banks, (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 some of the necessary steps toward the determination of water-surface profiles. Detailed technical and application information can be found in other documents.[1,2]

WSPRO was originally developed by the United States Geological 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. This release of HYDRAIN also incorporates a new graphical interface for developing input files and reviewing program output.

WSPRO requires the creation of an input file, consisting of commands to describe the physical characteristics of a waterway. The program shell or WSPRO Input/Output program 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, regardless of how the input file is created.

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.

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 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 situations 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 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 can 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 guide banks on the water-surface profile are estimated when guide banks data are entered.

- The model can analyze multiple waterway openings for a cross-section, including culverts when used as one of the multiple openings.

- The model can now utilize multiple cross-section templates with second and subsequent templates replacing previous template data. See the notes following the XT command in Appendix C of this volume.

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 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

The WSPRO Input/Output program greatly eases the task of creating input data sets by automating the process; however, effective use of WSPRO requires an understanding of how to prepare a program data file “manually.” It is, therefore, 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 **W**ater-**S**urface 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 C.

- **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.

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:

$$h_1 + h_{v_1} = h_0 + h_{v_0} + h_f + h_e \qquad (1)$$

Where:

$h_{1,0}$ = Water-surface elevation; 0=downstream, 1=upstream.

$h_{v1,v0}$ = Velocity head.

h_f = Friction loss.

h_e = Expansion/contraction loss.

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, arithmetic average of conveyance, arithmetic 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 that is within an acceptable tolerance. Generally the user-specified tolerance (given in the **J1** - Job Parameter command) is on the order of 0.01 m. The default value is 0.006. 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 <u>either</u> 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 supercritical flow 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. Trial water-surface elevations are constrained to be greater than minimum ground elevation and less than or equal to the critical water-surface elevation computing downstream. Computing upstream trials are constrained to be greater than the critical 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 bound of the subcritical flow regime. Any trial elevation at or higher than the critical will be acceptable for upstream computations 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 guide banks are present. An additional cross-section describing the guide banks 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.

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.

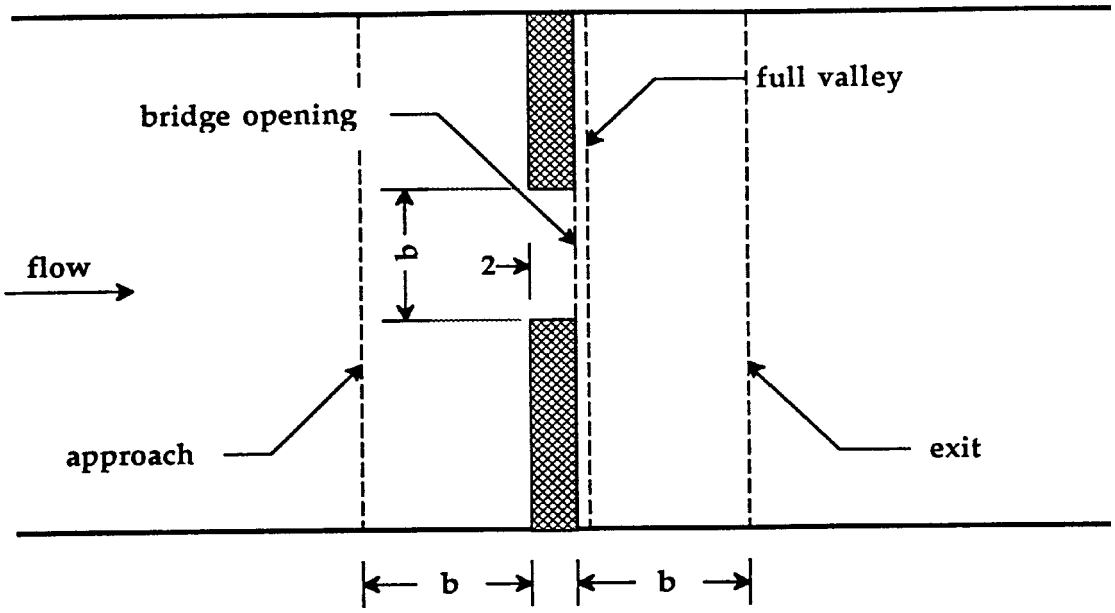


Figure 1. Schematic of single bridge opening.[2]

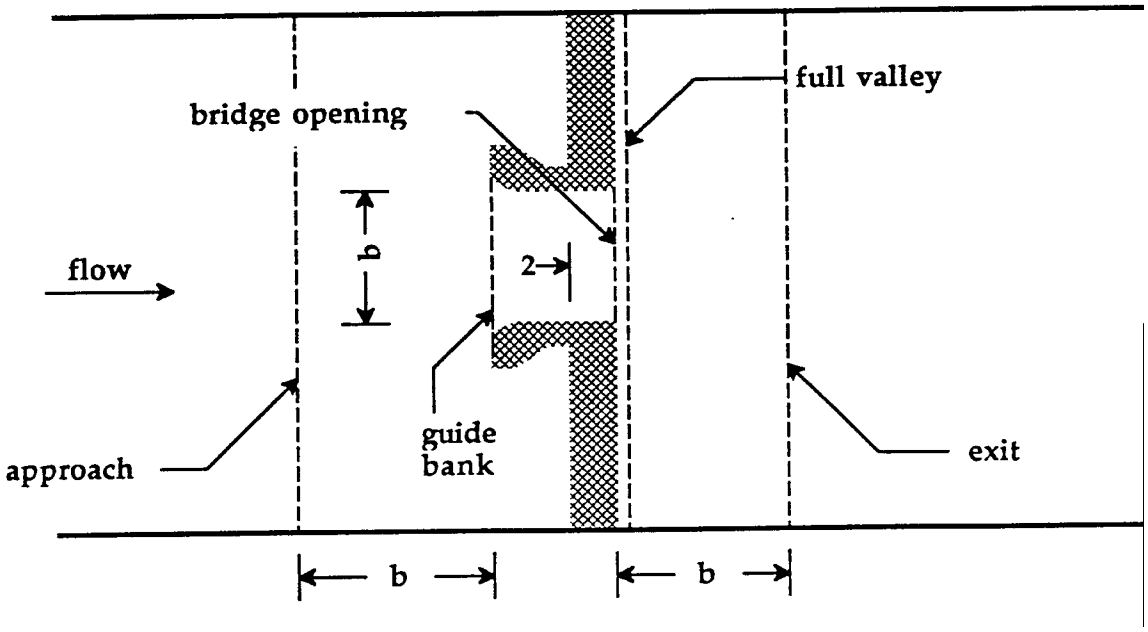


Figure 2. Schematic of single bridge opening with guide banks.[2]

Table 1. Summary of flow classes for a single bridge opening.

Class #	Flow Class	Relative Elevations						
		Road Overflow	$h_{ds} < y_{ls}$	$h_{ds} > y_{ls}$	$h_{us} < y_{ls}$	$h_{us} > y_{ls}$	$h_{us} < y_{min}$	$h_{us} > y_{min}$
1	free-surface		✓		✓		✓	
2	orifice		✓			✓	✓	
3	submerged			✓		✓	✓	
4	free-surface	✓	✓		✓			✓
5	orifice	✓	✓			✓		✓
6	submerged	✓		✓		✓		✓

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.

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.[2]

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 guide bank 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 valleystrips for each of the openings. Discharge apportionment uses a channel resistance ratio to define the flow capacities of each valley strip.[2]

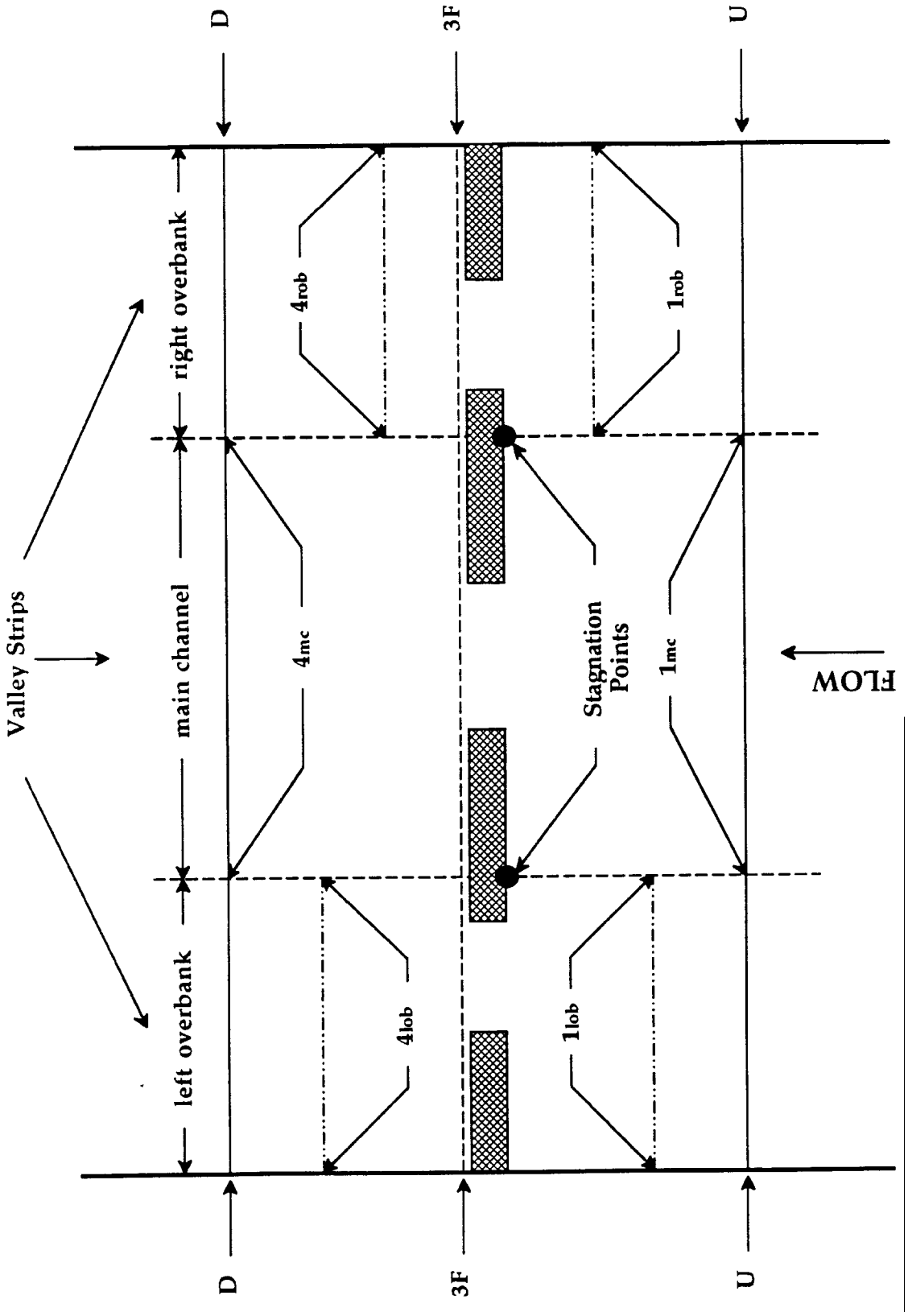


Figure 3. Multiple bridge opening showing valley strips and cross-section locations.[2]

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.

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 for 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.

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. More information pertaining to WSPRO can be found in the WSPRO Users Manual.[1]

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 each must follow a specific format. A list, to date, of these commands along with their definitions and format specifications is included in appendix C.

A glossary of all the commands is shown in table 2. Detailed descriptions 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. Commands operate in "free format" fashion; that is, a space [ ] or a comma [,] are parameter subfield separators that may be used in any amount between each parameter value (spacing between subfields is not critical). Because the HYDRAIN editor is best suited for editing free format data files, WSPRO has a utility that allows the user to input data in free format (the ***F** command).

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's 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 output 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.
UT	-	User defined 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, computation direction(s), and floodways.
ER	-	Indicates end of input (End of Run).

CROSS-SECTION DEFINITION - Header Records
(required for each cross-section)

XS	-	Unconstricted valley section.
BR	-	Bridge-opening section.
GB	-	Guidebank section (SD record still recognized).
XR	-	Road-grade section.
XS	-	Approach section (AS record no longer required).
CV	-	Culvert section.
XT	-	Template section.

CROSS-SECTION DEFINITION - Cross-Sectional Geometry Data

GR	-	x,y-coordinates of ground points in a cross-section with exceptions at bridges, guidebanks, and culverts; and for data propagation.

CROSS-SECTION DEFINITION - Roughness Data

N	-	Roughness coefficients ('n'-values).
SA	-	x-coordinates of subarea breakpoints in cross-section.
ND	-	Hydraulic-depth breakpoints for vertical variation of roughness.

CROSS-SECTION DEFINITION - Flow Length Data

FL	-	Flow lengths and (or) friction slope averaging technique.

Table 2. Input record types (continued).

CROSS-SECTION DEFINITION - Special Data

Bridge Section Data (COMPONENT MODE - no GR data)

BL	-	Bridge length and location.
BC	-	Bridge low-chord parameters.
AB	-	Abutment slopes.
CD	-	Opening type and configuration.
PD	-	Pier or pile data (PW record is still recognized).
KQ	-	Conveyance breakpoints (KD record is still recognized).

Bridge Section Data (COORDINATE MODE - requires GR data)

CD	-	Opening type and configuration.
AB	-	Abutment toe elevations.
PD	-	Pier or pile data (PW record is still recognized).
KQ	-	Conveyance breakpoints (KD record is still recognized).

Approach Section Data

BP	-	Horizontal datum correction between bridge and approach sections.

Road-grade Section Data

BP	-	Horizontal datum correction between bridge and road-grade sections.

Culvert Section Data

CG	-	Culvert geometry.
CC	-	Culvert coefficients.

Scour Computation Record

DA	-	Abutment scour data.
DC	-	Contraction scour data.
DP	-	Local pier scour data.

Effective Flow Record

EF	-	Effective flow input.

Floodway Computation Record

FW	-	Mandatory record for floodway analysis to specify parameters.
FS	-	Optional record for floodway analysis to specify global surcharges.

Metric/English Record

SI	-	Metric/english input/output

Template Geometry Propagation

GT	-	Replaces GR data when propagating template section geometry.

Table 3. Output key words.

WSEL	-	Water-surface elevation
VHD	-	Velocity head
Q	-	Discharge
SRD	-	Section reference distance
EGL	-	Energy grade line
ERR	-	Error in energy/discharge balance
FLEN	-	Flow distance
SLEN	-	Straight-line (SRD) distance
HF	-	Friction loss
HO	-	Other losses
VEL	-	Velocity
FR#	-	Froude number
CRWS	-	Critical water-surface elevation
K	-	Cross-section conveyance
AREA	-	Cross-section area
ALPHA	-	Velocity head correction factor
BETA	-	Momentum correction factor
XMAX	-	Maximum station in cross-section
YMAX	-	Maximum elevation in cross-section
XMIN	-	Minimum station in cross-section
YMIN	-	Minimum elevation in cross-section
SPLT	-	Stagnation point, left
SPRT	-	Stagnation point, right
SKEW	-	Skew of cross-section
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

BLEN	-	Bridge opening length
XLAB	-	Abutment station, left toe
XRAB	-	Abutment station, right toe
LSEL	-	Low steel elevation
FLOW	-	Flow classification code
TYPE	-	Bridge opening type
C	-	Coefficient of discharge
PPCD	-	Pier or pile code
P/A	-	Pier area ratio
Q	-	Flow over road
WLEN	-	Weir length
LEW	-	Left edge of weir
REW	-	Right edge of weir
DMAX	-	Maximum depth of flow
CAVG	-	Average weir coefficient
HAVG	-	Average total head
DAVG	-	Average depth of flow
VMAX	-	Maximum velocity
VAVG	-	Average velocity
M(K)	-	Flow contraction ratio
KQ	-	Conveyance of Kq-section
XLKQ	-	Left edge of Kq-section
XRKQ	-	Right edge of Kq-section
M(G)	-	Geometric contraction ratio
OTEL	-	Road overtopping elevation

THE HYDRAIN ENVIRONMENT

For those users who have obtained WSPRO as part of the Federal Highway Administration's HYDRAIN package, consult the HYDRAIN Volume I documentation for information on how to use the software system.

There are three methods by which WSPRO can be run within the HYDRAIN environment. One method is to run WSPRO from the HYDRAIN editor. This allows the user the option of immediate review and editing capabilities. The second method is to run WSPRO from the HYDRAIN shell using the **Execute** option. Finally, WSPRO can be executed from the DOS prompt. Discussion of all three options is in the HYDRAIN documentation.

Upon completion of the run, the output file is automatically assigned an **.LST** filename extension. The output file contains an echo of the input data and the results. The output file may contain messages describing warnings or errors encountered during execution. These messages are useful in debugging a data set.

THE WSPRO INPUT/OUTPUT PROGRAM

The WSPRO Input/Output Program is a Graphical User Interface (GUI) program and set of supporting files which allow a user to interface with the WSPRO model in a Windows-like environment. This facilitates viewing and editing input data, output data, cross-sections and other aspects of interaction with WSPRO. The Input/Output Program is not intended to replace familiarity with the WSPRO mode. Its objective is to facilitate interaction with the model. Use of the WSPRO Input/Output Program requires a VGA monitor or better.

Much of the user's interaction with the program is done with the mouse. Actions which can be taken with the mouse are pointing, clicking, left-clicking, right-clicking, double-clicking, dragging and "dragging and dropping." The user gets visual feedback of actions taken by movements of the arrow-shaped cursor on the screen.

- Pointing is done by moving the mouse so the cursor points at a desired location on the screen. As the mouse is moved, the cursor tracks its movements.

- Left- and right-clicking are done by pointing to a desired location on the screen and then operating the mouse's left or right button, respectively, by pressing and then releasing the appropriate mouse button. Right-clicking on an icon button displays a short help message about that object at the bottom of the screen.

- Double-clicking is done by pointing at the desired screen object and then pressing and releasing the left mouse button quickly in succession. Pointing and left-clicking is the standard action to take to select and object for use. Double-clicking both selects the object for use and causes a logical action to be taken on it.

- Dragging is done by pointing to a desired location on the screen, pressing (and holding) the left mouse button, moving the mouse to another desired location on the screen, and the releasing the mouse button.

- Dragging and dropping is a special capability offered by some screen objects. Physically, it is done exactly like dragging; however, there are additional visual and functional effects. When the mouse button is pressed on an object offering drag-and-drop functionality, the cursor will change to indicate it has be "loaded" and is prepared for the drop. When the mouse is moved to the target area of the screen and the mouse button released, the cursor returns to its normal appearance and the action represented by the dragged icon takes effect.

The Screen

The WSPRO Input/Output Program divides the screen into four areas: the Command Bar, the Tool Bar, the Schematic Layout Window, and the Browser Window. These areas are used in conjunction with each other to carry out WSPRO-related tasks. Only one of these areas is "active" at a time. The active area is indicated by an orange box which highlights the

perimeter of the active area. In addition to the orange box to indicate the active window, the title bars of the Schematic Layout and Browser windows are green when active and white when not.

Some screen control features are common to more than one area. These are discussed below.

Up, down, left and right, respectively. These icon buttons are the up, down, left, and right button icons, respectively. There are left and right buttons at the left end of the Command Bar and one of each on appropriate ends of the scroll bars in the Schematic Layout and Browser windows. Clicking on one of these buttons causes the affected bar or window to scroll in the indicated direction revealing additional information or icon buttons.

Maximize and *minimize window*, respectively. One of these buttons can always be found in the upper right-hand corner of the Schematic Layout and Browser windows. When the button is present and left clicked, the affected window will expand to full-screen size. When the is present and left-clicked, the window contracts to its normal size and place on the screen.

Clear. This button is found in the upper left-hand corner of the Schematic Layout and Browser Windows and in dialog boxes. In the Schematic Layout and Browser windows, left-clicking it causes whatever information is displayed there to be cleared. In dialog boxes, it has the same effect as the Cancel button.

Scroll Bar. A vertical or horizontal scroll bar appear at the bottom or right edge, respectively, of the Schematic Layout and Browser windows. (Only a horizontal scroll bar is shown here.) Clicking on the arrow button at either end of the scroll bar causes the affected display to scroll in increments of one line or character. Dragging the "thumb" (the button icon on the scroll bar between the arrow buttons) causes the display to scroll an amount proportional to the distance the thumb is dragged. Clicking in the gray area between the thumb and the arrow causes the display to scroll an amount equal the one window's width.

<u>The Command Bar</u>

The command bar contains 21 button icons which, when clicked with the mouse, carry out specific actions. Not all 21 buttons are visible simultaneously. At the left end of the command bar are left and right scroll buttons. Clicking these buttons causes the command bar to "scroll" making the "hidden" buttons "scroll" into view for access. The actions associated with each button is described below.

Open/Create. Summons a dialog from which the user selects and loads a particular existing input data set or creates a new one.

Save. Saves the currently open data set to disk.

Run. Executes (analyzes) the currently open data set and presents the output in the Browser window.

Quit. Quits and exits the WSPRO Input/Output Program.

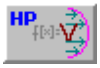
Flow Characteristics. Summons a scrollable dialog box where the user enters flow characteristics and inserts an appropriate Q command in the data set.

Title. Summons a dialog for entry of up to three lines of textual information inserted into the ASCII data set as T1, T2, and T3 commands.

DA Command. Summons a scrollable dialog box which allows entry of abutment scour information and inserts a DA command into the ASCII data set.

DC Command. Summons a scrollable dialog box for entry of live-bed and clear-water scour information and inserts an appropriate DC command into the ASCII data set.

DP Command. Summons a scrollable dialog box for entry of parameters with which to perform local pier scour computations and inserts a DP command into the ASCII data set.



HP command. Summons a scrollable dialog box where the user provides hydraulic property information and inserts an HP command in the data set.

J1 Command. Summons a dialog for entry of computational control parameters and inserts a J1 command into the data set.

UT command. Summons a scrollable dialog box for entry of parameters specifying user-defined output tables by inserting a UT command in the data set.

Input. Summons the currently established input data set to the Browser window. Whatever was previously displayed in the Browser window is cleared before the input file is displayed. (No input data are lost when the Browser window is cleared.)

Output. Summons the current output data file to the Browser window. Whatever was previously displayed in the Browser window is cleared before the output file is shown. (No output data are lost when the Browser window is cleared.)

Section. Summons a scrollable dialog in which the names of available output cross-sections are displayed. Left-clicking on a cross-section name and the OK button (or double-clicking on the cross-section name) displays the cross-section with water-surface elevation in the Browser window. (Note: Since no output cross-sections are available until after the input data set has been analyzed, the dialog will be empty until the input data are analyzed.)

Profile. Summons a scrollable dialog in which the names of available output profiles are displayed. Left-clicking on a profile name and the OK button (or double-clicking on the profile name) displays the cross-section and water-surface elevation in the Browser window. (Note: Since no output profile are available until after the input data set has been analyzed, the dialog will be empty until the input data are analyzed.)

.

Paths. Allows the user to change the default path and file name information. (Not implemented in the current program.)

Units. Summons a dialog where the user sets the unit system for the input data set and inserts and appropriate SI command in the data set.

Device. Allows the user to set the default output device. (Not implemented in the current program.)

Globals. Summons a dialog in which the user specifies global defaults. (Not implemented in the current program.)

Graphic Defaults. Summons a dialog in which the user specified graphic defaults. (Not implemented in the current program.)

<u>The Tool Bar</u>

The Tool Bar becomes active when clicked. This is indicated by the orange box surrounding its three icon buttons. The tools in the Tool Bar are used to select and view elements of the WSPRO data set and its output. Icon buttons are used by dragging and dropping them onto the icons attached to the River in the Schematic Layout window. The reverse,

dragging and dropping the attached icons from the Schematic Layout window onto these buttons, has the same effect. The three buttons are:

Edit. Summons the dialog associated with that header. This allows the user to edit an existing header. (Using this icon button has the same effect as double-clicking an attached icon.) Whatever was previously displayed in the Browser window is first cleared. (No data are lost by clearing the Browser window.)

Graph. Summons a graph of that element to the Browser window. Whatever was previously displayed in the Browser window is first cleared. (No data are lost by clearing the Browser window.)

Print. Sends the current data to the output device.

<u>The Schematic Layout Window</u>

The Schematic Layout window normally occupies the left side of the screen. It becomes "active" when left-clicked. This is indicated when its title bar turns green and the orange box surrounds it. When no header information is available in the data set, most of the window is blank containing only a representation of a channel labeled "RIVER".

To the far left of the Schematic Layout is an area labeled "Header" containing eight icon buttons. The top six of these buttons represent header records. To use one of these icons, drag and drop it on the "RIVER" in the Schematic Layout window. This will summon a dialog box in which the user can specify parameters associated with that header and attach an icon to the River to indicate the header is present in the data set. Initially, the icon will attach to the River at the top, but its location along the River will change when its location is edited in the corresponding dialog box.

Once attached to the River, information associated with these icons can be viewed and modified. Dragging and dropping an attached icon on the Edit, Graph, or Print icons causes and edit, graph, or print action, respectively, to be carried out on the information associated with the dragged icon. (The reverse action, dragging and dropping the Edit, Graph, or Print icons on an attached header icon, has the identical effect.) Left-clicking on an attached icon selects it as indicated by highlighting around its perimeter. Double-clicking on an attached icon summons its dialog box so data associated with that element can be edited.

The six header icons are:

XS Header. When dragged to the River in the Schematic Layout window, this icon summons a dialog box where the user sets cross-section information.

BR Header. When dragged to the River in the Schematic Layout window, this icon summons a dialog box where the user sets bridge cross-section information.

CV Header. When dragged to the River in the Schematic Layout window, this icon summons a dialog box where the user sets culvert cross-section information.

GB Header. When dragged to the River in the Schematic Layout window, this icon summons a dialog box where the user sets guidebank cross-section information.

XR Header. When dragged to the River in the Schematic Layout window, this icon summons a dialog box where the user sets road-grade cross-section information.

XT Header. When dragged to the River in the Schematic Layout window, this icon summons a dialog box where the user sets template cross-section information. See notes following the XT command in Appendix C of this volume.

Two of the icons under the Header title allow the user to edit header records. These icons are also "drag and drop" icons.

Clipboard. Dragging and dropping an icon attached to the River onto the Clipboard icon (or vice versa) creates a copy of the dragged header information and summons its dialog box for the user to edit. The two icon button images shown represent and empty and loaded clipboard, respectively.

Trash can. Dragging an attached header from the River to the trash can icon (or vice versa) deletes the header from the data set.

<u>The Browser Window</u>

The Browser window allows the user to view both textual and graphical input and output information. It is a "read only" viewer and does not allow files shown to be edited as text. When occupying only half the screen, the Browser window can be enlarged to full screen by left-clicking on the button at its upper-right corner. Left-clicking the button in the same corner again causes the Browser window to reduce to its normal size. When the information being Browsed contains more data than can be displayed in the window, the scroll bars can be used to access the additional data. Graphical data are always displayed in a format which fits within the boundaries of the Browser window, regardless of its size.

Dialog Boxes

Not all interaction is done through the mouse and screen. Text input to the Program is made by the user with the keyboard and accepted by the Input/Output Program in dialog boxes. Dialog boxes may contain buttons, text fields, and scroll bars. When a dialog box is presented, the user can left-click in a text field to begin data entry in that field. Clicking on a radio button (circular) sets the associated property. Sometimes, further data is associated with the property set by a particular radio button, so the Program presents a further dialog box to accept the additional data. When too many fields are needed to display all the available fields within the space of the dialog box, a vertical scroll bar is available on the right side of the dialog box allowing the user to scroll up and down to reach all the available data fields. Once all the data is entered and the choices made, the user dismisses the dialog box by left-clicking on the OK button. If the user left-clicks on the Cancel button, conditions are reset to the state which existed before the dialog was summoned.

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.

4. Demonstrate what to expect for output.

In particular, the examples are used to illustrate two flow situations: unconstricted flow and a single-opening bridge. Example two "builds" on example one so that the user may get a "feel" for the necessary data required to create a more complicated waterway. The two examples presented in this appendix illustrate the following options:

1. Water-surface profile computation without considering bridges.

2. Simple single-opening bridges.

Example One: Unconstricted Water-surface Profile Computations

Problem:

Given the following site conditions, for a proposed bridge site, determine the water-surface profile for the unconstricted valley. The stream reach is about 1 km 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 750 m. A gauging station is located at SRD 300 m, providing a stage-discharge relation at that location. Figures 4 and 5 illustrate the cross-sectional and channel profiles.

Input data are 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.

Identifiers **T1, T2, T3** (Title information) provide the user with an area in which output identification information is entered. This information can be site location data, comments, report names, etc.

Two job parameter data records (with identifiers **J1, UT**) are available to define parameters pertaining to the profile computations in their entirety. A **J1** record is used to specify the computational control parameters.

If the default values are acceptable, then ignore **J1.** Likewise, the **UT** record is not used if using default values. The **UT** record can specify parameters for special output tables. Default values for **UT** indicate that no special output tables are desired. In this case, default values are used.

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.

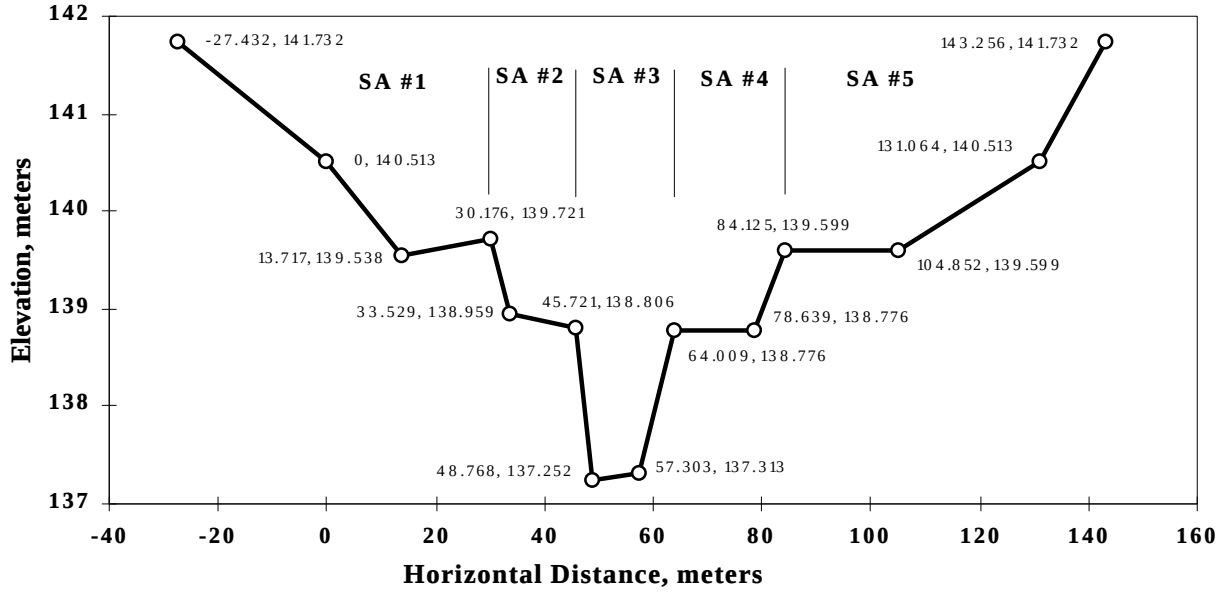


Figure 4. Example cross-section.[1]

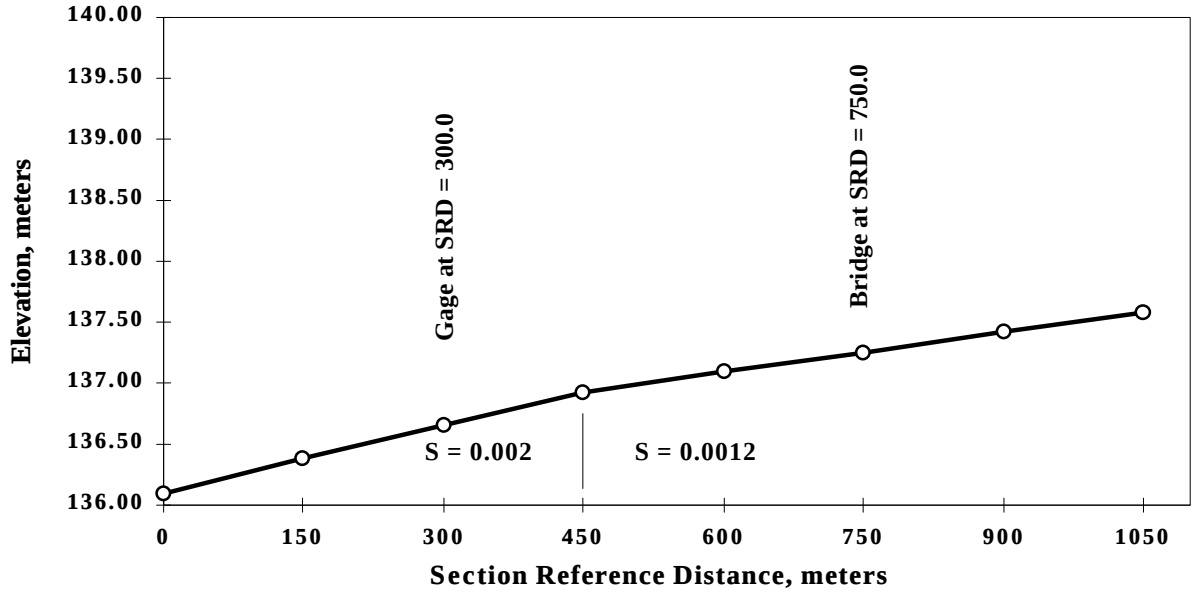


Figure 5. Example channel profile.[1]

In this example, three 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 are shown below:

Q (m^3/s)	**WS** (m)
84.90	139.056
127.35	139.385
169.92	139.629

The cross-section definition will be separated into three subgroups: cross-section coordinates, roughness coefficients, and cross-section information.

1. Cross-Section Coordinates

   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. WSPRO provides the ability to specify expansion and contraction energy loss coefficients. In this case, 0.5 and 0.1 are used, respectively, in the **XS** record at SRD 300.

2. Roughness Data

   Figure 4 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. Manning's n values are summarized as follows:

Subarea	Low Depth Range (m)	n	High Depth Range (m)	n
1	≤ 0.305	0.07	≥ 0.914	0.06
2	≤ 0.61	0.06	≥ 1.524	0.05
3	≤ 0	0.045	≥ 0.305	0.035
4	≤ 0.3305	0.06	≥ 1.219	0.05
5	≤ 0.305	0.07	≥ 0.914	0.06

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 this example, this means entering information for a cross-section at SRD 450.0 and every 150 m to upstream of the bridge site at SRD 1050.0.

Finally, the **EX** (Execution) 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** or **END** record indicates the end of the run.

Input File: WSPRO1.WSP

```
*F
SI 1
T1        Example One: Simple Unconstricted Flow - Metric
T2        FHWA Model for Water Surface Profile Computations
*
Q         84.90     127.35    169.92
WS        139.056   139.385   139.629
*
XT  SURVY 300.0
GR        -27.432, 140.982    0.000, 139.763   13.717, 138.788
           30.176, 138.971   33.529, 138.209   45.721, 138.056
           48.768, 136.502   57.303, 136.563   64.009, 138.026
           78.639, 138.026   84.125, 138.849  104.852, 138.849
          131.064, 139.763  143.256, 140.982
*
XS  GAGE  300.0  *  0.5  0.1
N         0.070, 0.060     0.060, 0.050       0.045, 0.035
N         0.060, 0.050     0.070, 0.060
ND        0.305, 0.914     0.610, 1.524       0.000, 0.305
ND        0.305, 1.219     0.305, 0.9144
SA        30.176    45.721    64.009    84.125
*
XS  XS2   450.0   *  *  *  0.002
XS  XS3   600.0   *  *  *  0.0015
XS  XS4   750.0
XS  XS5   900.0
XS  XS6   1050.0
*
EX
ER
```

Discussion of output:

Initially, data in the input data file are echoed, processed and saved. The data for the cross-section "SURVY" are used to compute the X, Y coordinate pairs for the remaining cross-sections. The parameter in the **GT** record identifies the shift from SRD = 750 to SRD = 300. The "max - min" points are calculated and all data are summarized.

Upon completion of the input echo and data summary, the model calculates a water-surface profile for each of the coded discharges.

Output File: WSPRO1.LST

```
    *************************  W S P R O  ***************************
       Federal Highway Administration  -  U. S. Geological Survey
              Model for Water-Surface Profile Computations.
         Run Date & Time: 10/15/97 06:10 am    Version V070197
          Input File: WSPRO1.WSP     Output File: WSPRO1.LST
    *-------------------------------------------------------------*
 *F
  ***                    Input Data In Free Format                    ***

 SI  1
                     Metric (SI) Units Used in WSPRO

                Quantity    SI Unit              Precision
               ------------ -------------------- -----------
               Length       meters                 0.001
               Depth        meters                 0.001
               Elevation    meters                 0.001
               Widths       meters                 0.001

               Velocity     meters/second          0.001
               Discharge    cubic meters/second    0.001
               Slope        meter/meter            0.001

               Angles       degrees                0.01
               ------------ -------------------- -----------

 T1         EXAMPLE ONE: SIMPLE UNCONSTRICTED FLOW - METRIC
 T2         FHWA MODEL FOR WATER SURFACE PROFILE COMPUTATIONS
 Q          84.90     127.35    169.92

  ***   Processing Flow Data; Placing Information into Sequence  1   ***

 WS         139.056   139.385   139.629
```

```
*************************  W S P R O  **************************
   Federal Highway Administration  -  U. S. Geological Survey
          Model for Water-Surface Profile Computations.
          Input Units: Metric  /  Output Units: Metric
*-------------------------------------------------------------*
          EXAMPLE ONE: SIMPLE UNCONSTRICTED FLOW - METRIC
         FHWA MODEL FOR WATER SURFACE PROFILE COMPUTATIONS

       *----------------------------------------------------*
       *      Starting To Process Header Record SURVY       *
       *----------------------------------------------------*

XT  SURVY 300.0
GR         -27.432, 140.982    0.000, 139.763   13.717, 138.788
GR          30.176, 138.971   33.529, 138.209   45.721, 138.056
GR          48.768, 136.502   57.303, 136.563   64.009, 138.026
GR          78.639, 138.026   84.125, 138.849  104.852, 138.849
GR         131.064, 139.763  143.256, 140.982

 ***   Completed Reading Data Associated With Header Record SURVY   ***
 ***         Storing Template Header Record Data In Memory          ***


 ***              Data Summary For Header Record SURVY              ***
 SRD Location:      300.    Valley Slope:  *******     Error Code   0

                     X,Y-coordinates (14 pairs)
     X          Y             X          Y             X          Y
----------  ----------   ----------  ----------   ----------  ----------
   -27.432     140.982         .000     139.763       13.717     138.788
    30.176     138.971       33.529     138.209       45.721     138.056
    48.768     136.502       57.303     136.563       64.009     138.026
    78.639     138.026       84.125     138.849      104.852     138.849
   131.064     139.763      143.256     140.982
----------  ----------   ----------  ----------   ----------  ----------

                 Minimum and Maximum X,Y-coordinates
  Minimum X-Station:     -27.432  ( associated Y-Elevation:  140.982 )
  Maximum X-Station:     143.256  ( associated Y-Elevation:  140.982 )
  Minimum Y-Elevation:   136.502  ( associated X-Station:     48.768 )
  Maximum Y-Elevation:   140.982  ( associated X-Station:    -27.432 )

       *----------------------------------------------------*
       *      Finished Processing Header Record SURVY       *
       *----------------------------------------------------*
```

```
*************************  W S P R O  ***************************
   Federal Highway Administration  -  U. S. Geological Survey
          Model for Water-Surface Profile Computations.
          Input Units: Metric  /  Output Units: Metric
*-------------------------------------------------------------*
          EXAMPLE ONE: SIMPLE UNCONSTRICTED FLOW - METRIC
         FHWA MODEL FOR WATER SURFACE PROFILE COMPUTATIONS

       *-----------------------------------------------------*
       *      Starting To Process Header Record GAGE         *
       *-----------------------------------------------------*

XS  GAGE  300.0  *  0.5  0.1
N          0.070, 0.060     0.060, 0.050       0.045, 0.035
N          0.060, 0.050     0.070, 0.060
ND         0.305, 0.914     0.610, 1.524       0.000, 0.305
ND         0.305, 1.219     0.305, 0.9144
SA         30.176    45.721    64.009    84.125

 ***   Completed Reading Data Associated With Header Record GAGE    ***
 ***  Storing X-Section Data In Temporary File As Record Number  1  ***

 ***              Data Summary For Header Record GAGE               ***
 SRD Location:      300.   Cross-Section Skew:    .0   Error Code   0
 Valley Slope:   .00000    Averaging Conveyance By Geometric Mean.
 Energy Loss Coefficients ->   Expansion:   .50   Contraction:   .10

                     X,Y-coordinates (14 pairs)
     X          Y             X          Y             X          Y
----------  ----------   ----------  ----------   ----------  ----------
   -27.432     140.982         .000     139.763       13.717     138.788
    30.176     138.971       33.529     138.209       45.721     138.056
    48.768     136.502       57.303     136.563       64.009     138.026
    78.639     138.026       84.125     138.849      104.852     138.849
   131.064     139.763      143.256     140.982
----------  ----------   ----------  ----------   ----------  ----------

                 Minimum and Maximum X,Y-coordinates
  Minimum X-Station:     -27.432  ( associated Y-Elevation:  140.982 )
  Maximum X-Station:     143.256  ( associated Y-Elevation:  140.982 )
  Minimum Y-Elevation:   136.502  ( associated X-Station:     48.768 )
  Maximum Y-Elevation:   140.982  ( associated X-Station:    -27.432 )

                    Roughness Data (  5 SubAreas )
                 Transition   Roughness   Hydraulic  Horizontal
       SubArea     Point    Coefficient    Depth    Breakpoint
       -------  ----------  -----------  ---------  ----------
          1       Bottom        .070         .305      ---
                   Top          .060         .914      ---
                    --          ---         ---        30.176
          2       Bottom        .060         .610      ---
                   Top          .050        1.524      ---
                    --          ---         ---        45.721
          3       Bottom        .045         .000      ---
                   Top          .035         .305      ---
                    --          ---         ---        64.009
          4       Bottom        .060         .305      ---
                   Top          .050        1.219      ---
                    --          ---         ---        84.125
          5       Bottom        .070         .305      ---
```

```
          Top          .060         .914      ---

*-----------------------------------------------------*
*      Finished Processing Header Record GAGE         *
*-----------------------------------------------------*
```

```
*************************  W S P R O  **************************
   Federal Highway Administration  -  U. S. Geological Survey
          Model for Water-Surface Profile Computations.
          Input Units: Metric  /  Output Units: Metric
*-------------------------------------------------------------*
          EXAMPLE ONE: SIMPLE UNCONSTRICTED FLOW - METRIC
         FHWA MODEL FOR WATER SURFACE PROFILE COMPUTATIONS

       *---------------------------------------------------*
       *      Starting To Process Header Record XS2        *
       *---------------------------------------------------*

XS  XS2   450.0   *  *  *  0.002

 ***   Completed Reading Data Associated With Header Record XS2     ***
 ***   No Roughness Data Input, Propagating From Previous Section   ***
 ***  Storing X-Section Data In Temporary File As Record Number  2  ***

 ***              Data Summary For Header Record XS2                ***
 SRD Location:      450.   Cross-Section Skew:    .0   Error Code   0
 Valley Slope:   .00200    Averaging Conveyance By Geometric Mean.
 Energy Loss Coefficients ->   Expansion:   .50   Contraction:   .00

                    X,Y-coordinates (14 pairs)
     X          Y             X          Y             X          Y
----------  ----------   ----------  ----------   ----------  ----------
   -27.432     141.282         .000     140.063       13.717     139.088
    30.176     139.271       33.529     138.509       45.721     138.356
    48.768     136.802       57.303     136.863       64.009     138.326
    78.639     138.326       84.125     139.149      104.852     139.149
   131.064     140.063      143.256     141.282
----------  ----------   ----------  ----------   ----------  ----------

                 Minimum and Maximum X,Y-coordinates
  Minimum X-Station:     -27.432  ( associated Y-Elevation:  141.282 )
  Maximum X-Station:     143.256  ( associated Y-Elevation:  141.282 )
  Minimum Y-Elevation:   136.802  ( associated X-Station:     48.768 )
  Maximum Y-Elevation:   141.282  ( associated X-Station:    -27.432 )

                   Roughness Data (  5 SubAreas )
                Transition   Roughness   Hydraulic  Horizontal
       SubArea    Point    Coefficient    Depth    Breakpoint
       -------  ----------  -----------  ---------  ----------
          1       Bottom        .070         .305      ---
                   Top          .060         .914      ---
                    --          ---         ---       30.176
          2       Bottom        .060         .610      ---
                   Top          .050        1.524      ---
                    --          ---         ---       45.721
          3       Bottom        .045         .000      ---
                   Top          .035         .305      ---
                    --          ---         ---       64.009
          4       Bottom        .060         .305      ---
                   Top          .050        1.219      ---
                    --          ---         ---       84.125
          5       Bottom        .070         .305      ---
                   Top          .060         .914      ---

       *---------------------------------------------------*
       *      Finished Processing Header Record XS2        *
```

```
        *----------------------------------------------------*
   ************************  W S P R O  **************************
      Federal Highway Administration  -  U. S. Geological Survey
             Model for Water-Surface Profile Computations.
             Input Units: Metric  /  Output Units: Metric
   *-------------------------------------------------------------*
             EXAMPLE ONE: SIMPLE UNCONSTRICTED FLOW - METRIC
            FHWA MODEL FOR WATER SURFACE PROFILE COMPUTATIONS

        *----------------------------------------------------*
        *      Starting To Process Header Record XS3         *
        *----------------------------------------------------*

XS  XS3   600.0   *  *  *  0.0015

 ***   Completed Reading Data Associated With Header Record XS3     ***
 ***   No Roughness Data Input, Propagating From Previous Section   ***
 ***  Storing X-Section Data In Temporary File As Record Number  3  ***

 ***              Data Summary For Header Record XS3                ***
 SRD Location:      600.   Cross-Section Skew:    .0   Error Code   0
 Valley Slope:   .00150    Averaging Conveyance By Geometric Mean.
 Energy Loss Coefficients ->   Expansion:   .50   Contraction:   .00

                    X,Y-coordinates (14 pairs)
     X          Y             X          Y             X          Y
----------  ----------   ----------  ----------   ----------  ----------
   -27.432     141.507         .000     140.288       13.717     139.313
    30.176     139.496       33.529     138.734       45.721     138.581
    48.768     137.027       57.303     137.088       64.009     138.551
    78.639     138.551       84.125     139.374      104.852     139.374
   131.064     140.288      143.256     141.507
----------  ----------   ----------  ----------   ----------  ----------

                 Minimum and Maximum X,Y-coordinates
  Minimum X-Station:     -27.432  ( associated Y-Elevation:  141.507 )
  Maximum X-Station:     143.256  ( associated Y-Elevation:  141.507 )
  Minimum Y-Elevation:   137.027  ( associated X-Station:     48.768 )
  Maximum Y-Elevation:   141.507  ( associated X-Station:    -27.432 )

                   Roughness Data (  5 SubAreas )
                Transition   Roughness   Hydraulic  Horizontal
       SubArea     Point    Coefficient    Depth    Breakpoint
       -------  ----------  -----------  ---------  ----------
          1       Bottom        .070         .305      ---
                   Top          .060         .914      ---
                    --          ---         ---        30.176
          2       Bottom        .060         .610      ---
                   Top          .050        1.524      ---
                    --          ---         ---        45.721
          3       Bottom        .045         .000      ---
                   Top          .035         .305      ---
                    --          ---         ---        64.009
          4       Bottom        .060         .305      ---
                   Top          .050        1.219      ---
                    --          ---         ---        84.125
          5       Bottom        .070         .305      ---
                   Top          .060         .914      ---

        *----------------------------------------------------*
```

```
         *      Finished Processing Header Record XS3        *
         *-----------------------------------------------------*
   *************************  W S P R O  ***************************
      Federal Highway Administration  -  U. S. Geological Survey
             Model for Water-Surface Profile Computations.
             Input Units: Metric  /  Output Units: Metric
   *-----------------------------------------------------------------*
             EXAMPLE ONE: SIMPLE UNCONSTRICTED FLOW - METRIC
            FHWA MODEL FOR WATER SURFACE PROFILE COMPUTATIONS

         *-----------------------------------------------------*
         *      Starting To Process Header Record XS4        *
         *-----------------------------------------------------*

XS  XS4   750.0

 ***   Completed Reading Data Associated With Header Record XS4     ***
 ***   No Roughness Data Input, Propagating From Previous Section   ***
 ***  Storing X-Section Data In Temporary File As Record Number  4  ***

 ***              Data Summary For Header Record XS4                ***
 SRD Location:      750.   Cross-Section Skew:    .0   Error Code   0
 Valley Slope:   .00150    Averaging Conveyance By Geometric Mean.
 Energy Loss Coefficients ->   Expansion:   .50   Contraction:   .00

                     X,Y-coordinates (14 pairs)
     X          Y             X          Y             X          Y
----------  ----------   ----------  ----------   ----------  ----------
   -27.432     141.732         .000     140.513       13.717     139.538
    30.176     139.721       33.529     138.959       45.721     138.806
    48.768     137.252       57.303     137.313       64.009     138.776
    78.639     138.776       84.125     139.599      104.852     139.599
   131.064     140.513      143.256     141.732
----------  ----------   ----------  ----------   ----------  ----------

                 Minimum and Maximum X,Y-coordinates
  Minimum X-Station:     -27.432  ( associated Y-Elevation:  141.732 )
  Maximum X-Station:     143.256  ( associated Y-Elevation:  141.732 )
  Minimum Y-Elevation:   137.252  ( associated X-Station:     48.768 )
  Maximum Y-Elevation:   141.732  ( associated X-Station:    -27.432 )

                    Roughness Data (  5 SubAreas )
                 Transition   Roughness   Hydraulic  Horizontal
       SubArea     Point    Coefficient    Depth    Breakpoint
       -------  ----------  -----------  ---------  ----------
          1       Bottom        .070         .305      ---
                   Top          .060         .914      ---
                    --          ---         ---        30.176
          2       Bottom        .060         .610      ---
                   Top          .050        1.524      ---
                    --          ---         ---        45.721
          3       Bottom        .045         .000      ---
                   Top          .035         .305      ---
                    --          ---         ---        64.009
          4       Bottom        .060         .305      ---
                   Top          .050        1.219      ---
                    --          ---         ---        84.125
          5       Bottom        .070         .305      ---
                   Top          .060         .914      ---
```

```
         *-----------------------------------------------------*
         *      Finished Processing Header Record XS4          *
         *-----------------------------------------------------*
   *************************  W S P R O  ***************************
      Federal Highway Administration  -  U. S. Geological Survey
             Model for Water-Surface Profile Computations.
             Input Units: Metric  /  Output Units: Metric
   *-----------------------------------------------------------------*
             EXAMPLE ONE: SIMPLE UNCONSTRICTED FLOW - METRIC
            FHWA MODEL FOR WATER SURFACE PROFILE COMPUTATIONS

         *-----------------------------------------------------*
         *      Starting To Process Header Record XS5          *
         *-----------------------------------------------------*

XS  XS5   900.0

 ***   Completed Reading Data Associated With Header Record XS5     ***
 ***   No Roughness Data Input, Propagating From Previous Section   ***
 ***  Storing X-Section Data In Temporary File As Record Number  5  ***

 ***              Data Summary For Header Record XS5                ***
 SRD Location:      900.   Cross-Section Skew:    .0   Error Code   0
 Valley Slope:   .00150    Averaging Conveyance By Geometric Mean.
 Energy Loss Coefficients ->   Expansion:   .50   Contraction:   .00

                     X,Y-coordinates (14 pairs)
     X          Y             X          Y             X          Y
----------  ----------   ----------  ----------   ----------  ----------
   -27.432     141.957         .000     140.738       13.717     139.763
    30.176     139.946       33.529     139.184       45.721     139.031
    48.768     137.477       57.303     137.538       64.009     139.001
    78.639     139.001       84.125     139.824      104.852     139.824
   131.064     140.738      143.256     141.957
----------  ----------   ----------  ----------   ----------  ----------

                 Minimum and Maximum X,Y-coordinates
  Minimum X-Station:     -27.432  ( associated Y-Elevation:  141.957 )
  Maximum X-Station:     143.256  ( associated Y-Elevation:  141.957 )
  Minimum Y-Elevation:   137.477  ( associated X-Station:     48.768 )
  Maximum Y-Elevation:   141.957  ( associated X-Station:    -27.432 )

                    Roughness Data (  5 SubAreas )
                 Transition   Roughness   Hydraulic  Horizontal
       SubArea     Point    Coefficient    Depth    Breakpoint
       -------  ----------  -----------  ---------  ----------
          1       Bottom        .070         .305      ---
                   Top          .060         .914      ---
                    --          ---         ---        30.176
          2       Bottom        .060         .610      ---
                   Top          .050        1.524      ---
                    --          ---         ---        45.721
          3       Bottom        .045         .000      ---
                   Top          .035         .305      ---
                    --          ---         ---        64.009
          4       Bottom        .060         .305      ---
                   Top          .050        1.219      ---
                    --          ---         ---        84.125
          5       Bottom        .070         .305      ---
                   Top          .060         .914      ---
```

```
         *-----------------------------------------------------*
         *      Finished Processing Header Record XS5          *
         *-----------------------------------------------------*
   *************************  W S P R O  ***************************
      Federal Highway Administration  -  U. S. Geological Survey
             Model for Water-Surface Profile Computations.
             Input Units: Metric  /  Output Units: Metric
   *-----------------------------------------------------------------*
             EXAMPLE ONE: SIMPLE UNCONSTRICTED FLOW - METRIC
            FHWA MODEL FOR WATER SURFACE PROFILE COMPUTATIONS

         *-----------------------------------------------------*
         *      Starting To Process Header Record XS6          *
         *-----------------------------------------------------*

XS  XS6   1050.0

 ***   Completed Reading Data Associated With Header Record XS6     ***
 ***   No Roughness Data Input, Propagating From Previous Section   ***
 ***  Storing X-Section Data In Temporary File As Record Number  6  ***

 ***              Data Summary For Header Record XS6                ***
 SRD Location:     1050.   Cross-Section Skew:    .0   Error Code   0
 Valley Slope:   .00150    Averaging Conveyance By Geometric Mean.
 Energy Loss Coefficients ->   Expansion:   .50   Contraction:   .00

                     X,Y-coordinates (14 pairs)
     X          Y             X          Y             X          Y
----------  ----------   ----------  ----------   ----------  ----------
   -27.432     142.182         .000     140.963       13.717     139.988
    30.176     140.171       33.529     139.409       45.721     139.256
    48.768     137.702       57.303     137.763       64.009     139.226
    78.639     139.226       84.125     140.049      104.852     140.049
   131.064     140.963      143.256     142.182
----------  ----------   ----------  ----------   ----------  ----------

                 Minimum and Maximum X,Y-coordinates
  Minimum X-Station:     -27.432  ( associated Y-Elevation:  142.182 )
  Maximum X-Station:     143.256  ( associated Y-Elevation:  142.182 )
  Minimum Y-Elevation:   137.702  ( associated X-Station:     48.768 )
  Maximum Y-Elevation:   142.182  ( associated X-Station:    -27.432 )

                    Roughness Data (  5 SubAreas )
                 Transition   Roughness   Hydraulic  Horizontal
       SubArea     Point    Coefficient    Depth    Breakpoint
       -------  ----------  -----------  ---------  ----------
          1       Bottom        .070         .305      ---
                   Top          .060         .914      ---
                    --          ---         ---        30.176
          2       Bottom        .060         .610      ---
                   Top          .050        1.524      ---
                    --          ---         ---        45.721
          3       Bottom        .045         .000      ---
                   Top          .035         .305      ---
                    --          ---         ---        64.009
          4       Bottom        .060         .305      ---
                   Top          .050        1.219      ---
                    --          ---         ---        84.125
          5       Bottom        .070         .305      ---
                   Top          .060         .914      ---
```

```
        *-----------------------------------------------------*
        *      Finished Processing Header Record XS6          *
        *-----------------------------------------------------*
   *************************  W S P R O  **************************
      Federal Highway Administration  -  U. S. Geological Survey
             Model for Water-Surface Profile Computations.
             Input Units: Metric  /  Output Units: Metric
   *-----------------------------------------------------------------*
             EXAMPLE ONE: SIMPLE UNCONSTRICTED FLOW - METRIC
            FHWA MODEL FOR WATER SURFACE PROFILE COMPUTATIONS
EX

        *=====================================================*
        *     Summary of Boundary Condition Information       *
        *=====================================================*

          Reach      Water Surface   Friction
    #   Discharge      Elevation      Slope         Flow Regime
   --   ---------    -------------   --------   --------------------
    1       84.90       139.056       ******        Sub-Critical
    2      127.35       139.385       ******        Sub-Critical
    3      169.92       139.629       ******        Sub-Critical
   --   ---------    -------------   --------   --------------------

        *=====================================================*
        *        Beginning  3 Profile Calculation(s)          *
        *=====================================================*
```

```
*************************  W S P R O  ***************************
   Federal Highway Administration  -  U. S. Geological Survey
          Model for Water-Surface Profile Computations.
          Input Units: Metric  /  Output Units: Metric
*-------------------------------------------------------------*
          EXAMPLE ONE: SIMPLE UNCONSTRICTED FLOW - METRIC
         FHWA MODEL FOR WATER SURFACE PROFILE COMPUTATIONS

              << Beginning Computations for Profile  1 >>

                  WSEL    VHD       Q         AREA      SRDL      LEW
                  EGEL     HF       V          K        FLEN      REW
                  CRWS     HO      FR #        SF       ALPHA     ERR
                --------- ------ ---------- ---------- --------- ---------
Section: GAGE     139.056   .112     84.899     78.375 *********     9.945
Header Type: XS   139.168 ******      1.083    2352.43 *********   110.790
SRD:    299.999   138.361 ******       .538     ******     1.881    ******

Section: XS2      139.262   .136     84.899     69.157   149.999    11.257
Header Type: XS   139.399   .218      1.227    2101.53   149.999   108.116
SRD:    449.999   138.659   .012       .616      .0015     1.779      .000

Section: XS3      139.508   .130     84.899     71.218   149.999    10.958
Header Type: XS   139.639   .238      1.192    2156.04   149.999   108.726
SRD:    599.999   138.884   .000       .599      .0016     1.806      .006

Section: XS4      139.743   .128     84.899     72.121   149.999    10.827
Header Type: XS   139.871   .230      1.177    2180.33   149.999   108.986
SRD:    749.999   139.111   .000       .591      .0015     1.817      .006

Section: XS5      139.972   .127     84.899     72.506   149.999    10.773
Header Type: XS   140.099   .226      1.170    2190.66   149.999   109.102
SRD:    899.999   139.336   .000       .588      .0015     1.821      .005

Section: XS6      140.198   .126     84.899     72.682   149.999    10.749
Header Type: XS   140.325   .224      1.168    2195.43   149.999   109.152
SRD:   1049.999   139.561   .000       .586      .0015     1.823      .005

              << Completed Computations of Profile  1 >>
```

```
*************************  W S P R O  ***************************
   Federal Highway Administration  -  U. S. Geological Survey
          Model for Water-Surface Profile Computations.
          Input Units: Metric  /  Output Units: Metric
*-------------------------------------------------------------*
          EXAMPLE ONE: SIMPLE UNCONSTRICTED FLOW - METRIC
         FHWA MODEL FOR WATER SURFACE PROFILE COMPUTATIONS

              << Beginning Computations for Profile  2 >>

                  WSEL    VHD       Q         AREA      SRDL      LEW
                  EGEL     HF       V          K        FLEN      REW
                  CRWS     HO      FR #        SF       ALPHA     ERR
                --------- ------ ---------- ---------- --------- ---------
Section: GAGE     139.385   .129    127.350    113.867 *********     5.317
Header Type: XS   139.514 ******      1.118    3442.19 *********   120.224
SRD:    299.999   138.682 ******       .511     ******     2.032    ******

Section: XS2      139.599   .153    127.350    104.154   149.999     6.525
Header Type: XS   139.752   .225      1.222    3127.55   149.999   117.761
SRD:    449.999   138.982   .011       .573      .0015     2.013      .000

Section: XS3      139.849   .145    127.350    106.969   149.999     6.170
Header Type: XS   139.995   .241      1.190    3218.41   149.999   118.486
SRD:    599.999   139.209   .000       .554      .0016     2.019      .003

Section: XS4      140.082   .143    127.350    107.936   149.999     6.048
Header Type: XS   140.226   .232      1.179    3249.93   149.999   118.731
SRD:    749.999   139.432   .000       .547      .0016     2.020     -.005

Section: XS5      140.313   .141    127.350    108.542   149.999     5.972
Header Type: XS   140.455   .228      1.173    3269.58   149.999   118.888
SRD:    899.999   139.659   .000       .543      .0015     2.021      .000

Section: XS6      140.541   .141    127.350    108.887   149.999     5.931
Header Type: XS   140.682   .226      1.169    3280.93   149.999   118.972
SRD:   1049.999   139.884   .000       .541      .0015     2.022      .001

              << Completed Computations of Profile  2 >>
```

```
*************************  W S P R O  ***************************
   Federal Highway Administration  -  U. S. Geological Survey
          Model for Water-Surface Profile Computations.
          Input Units: Metric  /  Output Units: Metric
*-------------------------------------------------------------*
          EXAMPLE ONE: SIMPLE UNCONSTRICTED FLOW - METRIC
         FHWA MODEL FOR WATER SURFACE PROFILE COMPUTATIONS

              << Beginning Computations for Profile  3 >>

                  WSEL    VHD       Q         AREA      SRDL      LEW
                  EGEL     HF       V          K        FLEN      REW
                  CRWS     HO      FR #        SF       ALPHA     ERR
               --------- ------ ---------- ---------- --------- ---------
Section: GAGE      139.629   .147    169.920    143.177 *********     1.884
Header Type: XS    139.776 ******      1.186    4435.71 *********   127.221
SRD:    299.999    139.027 ******       .509     ******     2.058    ******

Section: XS2       139.855   .168    169.920    134.123   149.999     2.913
Header Type: XS    140.024   .237      1.266    4118.97   149.999   125.124
SRD:    449.999    139.331   .010       .554      .0016     2.056      .000

Section: XS3       140.111   .159    169.920    137.900   149.999     2.480
Header Type: XS    140.270   .247      1.232    4250.00   149.999   126.007
SRD:    599.999    139.554   .000       .534      .0016     2.058     -.002

Section: XS4       140.351   .155    169.920    139.780   149.999     2.265
Header Type: XS    140.506   .236      1.215    4315.87   149.999   126.444
SRD:    749.999    139.780   .000       .525      .0016     2.058      .000

Section: XS5       140.585   .152    169.920    140.923   149.999     2.135
Header Type: XS    140.738   .230      1.205    4355.91   149.999   126.710
SRD:    899.999    140.004   .000       .519      .0015     2.058      .004

Section: XS6       140.814   .151    169.920    141.375   149.999     2.087
Header Type: XS    140.966   .227      1.201    4372.00   149.999   126.808
SRD:   1049.999    140.229   .000       .517      .0015     2.058      .001

              << Completed Computations of Profile  3 >>

 ER

 ******************  Normal end of WSPRO execution.  *****************
 ***************  Elapsed Time:   0 Minutes  4 Seconds  **************
```

Example Two: Single-Opening Bridge

Problem:

At the same site described in the first example, we wish to analyze the backwater effects of a bridge with a roadway centerline at SRD 750.0. The bridge length between the tops of the abutments will be 30 m; bridge width is 10 m. Abutments, in this case, are vertical (without wingwalls).

Initially, the input for this example closely follows the input for example 1. The template section for SRD 750 and sections XS2, XS3, XS5, and XS6 are unchanged. SRD 750.0 (FULLV), SRD 800.0 (APPR), and SRD 720.0 (EXIT) must be added to the example one data.

The user is familiar with all input coding up to the description of the bridge site; explanation of this section of input follows using the design mode:

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.

A **BC** record specifies the bridge chord parameters. The first entry in this record is the elevation of the low chord 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 top of the abutments. 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** 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. Entries three through seven are not coded since defaults are used. 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 0 degrees is used. Wingwall width is the sixth entry; we will use the default value 0 ft 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 0 ft is used.

Finally, the Manning's roughness values for the bridge surface are given. The parameters are the same as discussed earlier.

Execution Commands:

Finally, the user codes the **EX** and **ER** records, indicating the start of calculation and end of run, respectively.

Input File: WSPRO2.WSP

```
*F
SI 1
T1        Example Two:  Metric Single Bridge Opening - Component Mode
T2        FHWA Model for Water Surface Profile Computations
*
Q         84.90     127.35    169.92
WS        139.056   139.385   139.629
*
XT  SURVY 300.0
GR        -27.432, 140.982    0.000, 139.763   13.717, 138.788
           30.176, 138.971   33.529, 138.209   45.721, 138.056
           48.768, 136.502   57.303, 136.563   64.009, 138.026
           78.639, 138.026   84.125, 138.849  104.852, 138.849
          131.064, 139.763  143.256, 140.982
*
XS  GAGE  300.0  *  0.5  0.1
N         0.070, 0.060     0.060, 0.050       0.045, 0.035
N         0.060, 0.050     0.070, 0.060
ND        0.305, 0.914     0.610, 1.524       0.000, 0.305
ND        0.305, 1.219     0.305, 0.9144
SA        30.176    45.721    64.009    84.125
*
XS  XS2   450.0   *  *  *  0.002
XS  XS3   600.0   *  *  *  0.0012
XS  EXIT  720.0
XS  FULV  750.0
*
BR  BRDG  750.0
BL 0      30   45   65
BC        141.0
CD        1  10.0
*
XS  APPR  800.0
*
XS  XS5   900.0
XS  XS6   1050.0
*
EX
ER
```

Discussion of output:

The input echo section of the output is very similar to that described in example 1 until the bridge section is echoed. A detailed explanation of the bridge and approach sections follow.

Bridge Section:

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, valley slope, expansion and contraction coefficient values were initially input at cross-section "exit" SRD 720.0 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**, **BC**, **BL** and **CD**) are echoed.

Approach Section:

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. The input echo for the approach section is displayed.

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 139.056 m^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.

Comparison of the results for unconstricted flow and constricted flow at SRD 750.0 point out the effects of constricting the channel: area is lessened; cross-section total conveyance is lessened; velocity head increased (the alpha velocity head correction factor decreased); friction loss increased; a critical water-surface elevation is indicated; and velocity increased.

Comparing the elevations at the approach section illustrates the effect of backwater occurrence resulting from the constriction of flow.

Output File: WSPRO2.LST

```
   *************************  W S P R O  **************************
      Federal Highway Administration  -  U. S. Geological Survey
             Model for Water-Surface Profile Computations.
        Run Date & Time: 10/15/97 06:10 am    Version V070197
         Input File: WSPRO2.WSP     Output File: WSPRO2.LST
   *-----------------------------------------------------------------*
*F
 ***                    Input Data In Free Format                    ***

SI  1
                    Metric (SI) Units Used in WSPRO

               Quantity    SI Unit              Precision
             ------------ -------------------- -----------
              Length       meters                 0.001
              Depth        meters                 0.001
              Elevation    meters                 0.001
              Widths       meters                 0.001

              Velocity     meters/second          0.001
              Discharge    cubic meters/second    0.001
              Slope        meter/meter            0.001

              Angles       degrees                0.01
             ------------ -------------------- -----------

T1         EXAMPLE TWO:  METRIC SINGLE BRIDGE OPENING - COMPONENT MODE
T2         FHWA MODEL FOR WATER SURFACE PROFILE COMPUTATIONS
Q          84.90     127.35    169.92

 ***   Processing Flow Data; Placing Information into Sequence  1   ***

WS         139.056   139.385   139.629
```

```
*************************  W S P R O  **************************
   Federal Highway Administration  -  U. S. Geological Survey
          Model for Water-Surface Profile Computations.
          Input Units: Metric  /  Output Units: Metric
*-----------------------------------------------------------------*
    EXAMPLE TWO:  METRIC SINGLE BRIDGE OPENING - COMPONENT MODE

          FHWA MODEL FOR WATER SURFACE PROFILE COMPUTATIONS


        *-----------------------------------------------------*
        *      Starting To Process Header Record SURVY        *
        *-----------------------------------------------------*

XT  SURVY 300.0
GR         -27.432, 140.982    0.000, 139.763   13.717, 138.788
GR          30.176, 138.971   33.529, 138.209   45.721, 138.056
GR          48.768, 136.502   57.303, 136.563   64.009, 138.026
GR          78.639, 138.026   84.125, 138.849  104.852, 138.849
GR         131.064, 139.763  143.256, 140.982

 ***   Completed Reading Data Associated With Header Record SURVY   ***
 ***         Storing Template Header Record Data In Memory          ***


 ***              Data Summary For Header Record SURVY              ***
 SRD Location:      300.    Valley Slope:  *******     Error Code   0

                     X,Y-coordinates (14 pairs)
     X          Y             X          Y             X          Y
----------  ----------   ----------  ----------   ----------  ----------
   -27.432     140.982         .000     139.763       13.717     138.788
    30.176     138.971       33.529     138.209       45.721     138.056
    48.768     136.502       57.303     136.563       64.009     138.026
    78.639     138.026       84.125     138.849      104.852     138.849
   131.064     139.763      143.256     140.982
----------  ----------   ----------  ----------   ----------  ----------

                 Minimum and Maximum X,Y-coordinates
  Minimum X-Station:     -27.432  ( associated Y-Elevation:  140.982 )
  Maximum X-Station:     143.256  ( associated Y-Elevation:  140.982 )
  Minimum Y-Elevation:   136.502  ( associated X-Station:     48.768 )
  Maximum Y-Elevation:   140.982  ( associated X-Station:    -27.432 )

        *-----------------------------------------------------*
        *      Finished Processing Header Record SURVY        *
        *-----------------------------------------------------*
```

```
*************************  W S P R O  ***************************
   Federal Highway Administration  -  U. S. Geological Survey
          Model for Water-Surface Profile Computations.
          Input Units: Metric  /  Output Units: Metric
*-----------------------------------------------------------------*
    EXAMPLE TWO:  METRIC SINGLE BRIDGE OPENING - COMPONENT MODE

          FHWA MODEL FOR WATER SURFACE PROFILE COMPUTATIONS


        *-----------------------------------------------------*
        *      Starting To Process Header Record GAGE         *
        *-----------------------------------------------------*

XS  GAGE  300.0  *  0.5  0.1
N          0.070, 0.060     0.060, 0.050       0.045, 0.035
N          0.060, 0.050     0.070, 0.060
ND         0.305, 0.914     0.610, 1.524       0.000, 0.305
ND         0.305, 1.219     0.305, 0.9144
SA         30.176    45.721    64.009    84.125

 ***   Completed Reading Data Associated With Header Record GAGE    ***
 ***  Storing X-Section Data In Temporary File As Record Number  1  ***

 ***              Data Summary For Header Record GAGE               ***
 SRD Location:      300.   Cross-Section Skew:    .0   Error Code   0
 Valley Slope:   .00000    Averaging Conveyance By Geometric Mean.
 Energy Loss Coefficients ->   Expansion:   .50   Contraction:   .10

                     X,Y-coordinates (14 pairs)
     X          Y             X          Y             X          Y
----------  ----------   ----------  ----------   ----------  ----------
   -27.432     140.982         .000     139.763       13.717     138.788
    30.176     138.971       33.529     138.209       45.721     138.056
    48.768     136.502       57.303     136.563       64.009     138.026
    78.639     138.026       84.125     138.849      104.852     138.849
   131.064     139.763      143.256     140.982
----------  ----------   ----------  ----------   ----------  ----------

                 Minimum and Maximum X,Y-coordinates
  Minimum X-Station:     -27.432  ( associated Y-Elevation:  140.982 )
  Maximum X-Station:     143.256  ( associated Y-Elevation:  140.982 )
  Minimum Y-Elevation:   136.502  ( associated X-Station:     48.768 )
  Maximum Y-Elevation:   140.982  ( associated X-Station:    -27.432 )

                    Roughness Data (  5 SubAreas )
                Transition   Roughness   Hydraulic  Horizontal
       SubArea    Point    Coefficient    Depth    Breakpoint
       -------  ----------  -----------  ---------  ----------
          1       Bottom        .070         .305      ---
                   Top          .060         .914      ---
                   --           ---         ---        30.176
          2       Bottom        .060         .610      ---
                   Top          .050        1.524      ---
                   --           ---         ---        45.721
          3       Bottom        .045         .000      ---
                   Top          .035         .305      ---
                   --           ---         ---        64.009
          4       Bottom        .060         .305      ---
                   Top          .050        1.219      ---
```

```
          --          ---         ---        84.125
 5       Bottom       .070         .305      ---
          Top         .060         .914      ---


*----------------------------------------------------*
*      Finished Processing Header Record GAGE        *
*----------------------------------------------------*
```

```
*************************  W S P R O  ***************************
   Federal Highway Administration  -  U. S. Geological Survey
          Model for Water-Surface Profile Computations.
          Input Units: Metric  /  Output Units: Metric
*-----------------------------------------------------------------*
    EXAMPLE TWO:  METRIC SINGLE BRIDGE OPENING - COMPONENT MODE

          FHWA MODEL FOR WATER SURFACE PROFILE COMPUTATIONS


        *-----------------------------------------------------*
        *      Starting To Process Header Record XS2          *
        *-----------------------------------------------------*

XS  XS2   450.0   *  *  *  0.002

 ***   Completed Reading Data Associated With Header Record XS2     ***
 ***   No Roughness Data Input, Propagating From Previous Section   ***
 ***  Storing X-Section Data In Temporary File As Record Number  2  ***

 ***              Data Summary For Header Record XS2                ***
 SRD Location:      450.   Cross-Section Skew:    .0   Error Code   0
 Valley Slope:   .00200    Averaging Conveyance By Geometric Mean.
 Energy Loss Coefficients ->   Expansion:   .50   Contraction:   .00

                    X,Y-coordinates (14 pairs)
     X          Y             X          Y             X          Y
----------  ----------   ----------  ----------   ----------  ----------
   -27.432     141.282         .000     140.063       13.717     139.088
    30.176     139.271       33.529     138.509       45.721     138.356
    48.768     136.802       57.303     136.863       64.009     138.326
    78.639     138.326       84.125     139.149      104.852     139.149
   131.064     140.063      143.256     141.282
----------  ----------   ----------  ----------   ----------  ----------

                 Minimum and Maximum X,Y-coordinates
  Minimum X-Station:     -27.432  ( associated Y-Elevation:  141.282 )
  Maximum X-Station:     143.256  ( associated Y-Elevation:  141.282 )
  Minimum Y-Elevation:   136.802  ( associated X-Station:     48.768 )
  Maximum Y-Elevation:   141.282  ( associated X-Station:    -27.432 )

                   Roughness Data (  5 SubAreas )
                Transition   Roughness   Hydraulic  Horizontal
       SubArea    Point    Coefficient    Depth    Breakpoint
       -------  ----------  -----------  ---------  ----------
          1       Bottom        .070         .305      ---
                   Top          .060         .914      ---
                    --          ---         ---        30.176
          2       Bottom        .060         .610      ---
                   Top          .050        1.524      ---
                    --          ---         ---        45.721
          3       Bottom        .045         .000      ---
                   Top          .035         .305      ---
                    --          ---         ---        64.009
          4       Bottom        .060         .305      ---
                   Top          .050        1.219      ---
                    --          ---         ---        84.125
          5       Bottom        .070         .305      ---
                   Top          .060         .914      ---
```

```
*----------------------------------------------------*
*      Finished Processing Header Record XS2         *
*----------------------------------------------------*
```

```
*************************  W S P R O  ***************************
   Federal Highway Administration  -  U. S. Geological Survey
          Model for Water-Surface Profile Computations.
          Input Units: Metric  /  Output Units: Metric
*-----------------------------------------------------------------*
    EXAMPLE TWO:  METRIC SINGLE BRIDGE OPENING - COMPONENT MODE

          FHWA MODEL FOR WATER SURFACE PROFILE COMPUTATIONS


        *-----------------------------------------------------*
        *      Starting To Process Header Record XS3          *
        *-----------------------------------------------------*

XS  XS3   600.0   *  *  *  0.0012

 ***   Completed Reading Data Associated With Header Record XS3     ***
 ***   No Roughness Data Input, Propagating From Previous Section   ***
 ***  Storing X-Section Data In Temporary File As Record Number  3  ***

 ***              Data Summary For Header Record XS3                ***
 SRD Location:      600.   Cross-Section Skew:    .0   Error Code   0
 Valley Slope:   .00120    Averaging Conveyance By Geometric Mean.
 Energy Loss Coefficients ->   Expansion:   .50   Contraction:   .00

                    X,Y-coordinates (14 pairs)
     X          Y             X          Y             X          Y
----------  ----------   ----------  ----------   ----------  ----------
   -27.432     141.462         .000     140.243       13.717     139.268
    30.176     139.451       33.529     138.689       45.721     138.536
    48.768     136.982       57.303     137.043       64.009     138.506
    78.639     138.506       84.125     139.329      104.852     139.329
   131.064     140.243      143.256     141.462
----------  ----------   ----------  ----------   ----------  ----------

                 Minimum and Maximum X,Y-coordinates
  Minimum X-Station:     -27.432  ( associated Y-Elevation:  141.462 )
  Maximum X-Station:     143.256  ( associated Y-Elevation:  141.462 )
  Minimum Y-Elevation:   136.982  ( associated X-Station:     48.768 )
  Maximum Y-Elevation:   141.462  ( associated X-Station:    -27.432 )

                   Roughness Data (  5 SubAreas )
                Transition   Roughness   Hydraulic  Horizontal
       SubArea    Point    Coefficient    Depth    Breakpoint
       -------  ----------  -----------  ---------  ----------
          1       Bottom        .070         .305      ---
                   Top          .060         .914      ---
                    --          ---         ---        30.176
          2       Bottom        .060         .610      ---
                   Top          .050        1.524      ---
                    --          ---         ---        45.721
          3       Bottom        .045         .000      ---
                   Top          .035         .305      ---
                    --          ---         ---        64.009
          4       Bottom        .060         .305      ---
                   Top          .050        1.219      ---
                    --          ---         ---        84.125
          5       Bottom        .070         .305      ---
                   Top          .060         .914      ---
```

```
*-----------------------------------------------------*
*      Finished Processing Header Record XS3          *
*-----------------------------------------------------*
```

```
*************************  W S P R O  ***************************
   Federal Highway Administration  -  U. S. Geological Survey
          Model for Water-Surface Profile Computations.
          Input Units: Metric  /  Output Units: Metric
*-----------------------------------------------------------------*
    EXAMPLE TWO:  METRIC SINGLE BRIDGE OPENING - COMPONENT MODE

         FHWA MODEL FOR WATER SURFACE PROFILE COMPUTATIONS


       *-----------------------------------------------------*
       *      Starting To Process Header Record EXIT         *
       *-----------------------------------------------------*

XS  EXIT  720.0

 ***   Completed Reading Data Associated With Header Record EXIT    ***
 ***   No Roughness Data Input, Propagating From Previous Section   ***
 ***  Storing X-Section Data In Temporary File As Record Number  4  ***

 ***              Data Summary For Header Record EXIT               ***
 SRD Location:      720.   Cross-Section Skew:    .0   Error Code   0
 Valley Slope:   .00120    Averaging Conveyance By Geometric Mean.
 Energy Loss Coefficients ->   Expansion:   .50   Contraction:   .00

                    X,Y-coordinates (14 pairs)
     X          Y             X          Y             X          Y
----------  ----------   ----------  ----------   ----------  ----------
   -27.432     141.606         .000     140.387       13.717     139.412
    30.176     139.595       33.529     138.833       45.721     138.680
    48.768     137.126       57.303     137.187       64.009     138.650
    78.639     138.650       84.125     139.473      104.852     139.473
   131.064     140.387      143.256     141.606
----------  ----------   ----------  ----------   ----------  ----------

                 Minimum and Maximum X,Y-coordinates
  Minimum X-Station:     -27.432  ( associated Y-Elevation:  141.606 )
  Maximum X-Station:     143.256  ( associated Y-Elevation:  141.606 )
  Minimum Y-Elevation:   137.126  ( associated X-Station:     48.768 )
  Maximum Y-Elevation:   141.606  ( associated X-Station:    -27.432 )

                    Roughness Data (  5 SubAreas )
                Transition   Roughness   Hydraulic  Horizontal
       SubArea    Point    Coefficient    Depth    Breakpoint
       -------  ----------  -----------  ---------  ----------
          1       Bottom        .070         .305      ---
                   Top          .060         .914      ---
                   --           ---         ---        30.176
          2       Bottom        .060         .610      ---
                   Top          .050        1.524      ---
                   --           ---         ---        45.721
          3       Bottom        .045         .000      ---
                   Top          .035         .305      ---
                   --           ---         ---        64.009
          4       Bottom        .060         .305      ---
                   Top          .050        1.219      ---
                   --           ---         ---        84.125
          5       Bottom        .070         .305      ---
                   Top          .060         .914      ---
```

```
*-----------------------------------------------------*
*      Finished Processing Header Record EXIT         *
*-----------------------------------------------------*
```

```
*************************  W S P R O  ***************************
   Federal Highway Administration  -  U. S. Geological Survey
          Model for Water-Surface Profile Computations.
          Input Units: Metric  /  Output Units: Metric
*-----------------------------------------------------------------*
    EXAMPLE TWO:  METRIC SINGLE BRIDGE OPENING - COMPONENT MODE

         FHWA MODEL FOR WATER SURFACE PROFILE COMPUTATIONS


        *-----------------------------------------------------*
        *      Starting To Process Header Record FULV         *
        *-----------------------------------------------------*

XS  FULV  750.0

 ***   Completed Reading Data Associated With Header Record FULV    ***
 ***   No Roughness Data Input, Propagating From Previous Section   ***
 ***  Storing X-Section Data In Temporary File As Record Number  5  ***

 ***              Data Summary For Header Record FULV               ***
 SRD Location:      750.   Cross-Section Skew:    .0   Error Code   0
 Valley Slope:   .00120    Averaging Conveyance By Geometric Mean.
 Energy Loss Coefficients ->   Expansion:   .50   Contraction:   .00

                    X,Y-coordinates (14 pairs)
     X          Y             X          Y             X          Y
----------  ----------   ----------  ----------   ----------  ----------
   -27.432     141.642         .000     140.423       13.717     139.448
    30.176     139.631       33.529     138.869       45.721     138.716
    48.768     137.162       57.303     137.223       64.009     138.686
    78.639     138.686       84.125     139.509      104.852     139.509
   131.064     140.423      143.256     141.642
----------  ----------   ----------  ----------   ----------  ----------

                 Minimum and Maximum X,Y-coordinates
  Minimum X-Station:     -27.432  ( associated Y-Elevation:  141.642 )
  Maximum X-Station:     143.256  ( associated Y-Elevation:  141.642 )
  Minimum Y-Elevation:   137.162  ( associated X-Station:     48.768 )
  Maximum Y-Elevation:   141.642  ( associated X-Station:    -27.432 )

                    Roughness Data (  5 SubAreas )
                Transition   Roughness   Hydraulic  Horizontal
       SubArea    Point    Coefficient    Depth    Breakpoint
       -------  ----------  -----------  ---------  ----------
          1       Bottom        .070         .305      ---
                   Top          .060         .914      ---
                   --           ---         ---        30.176
          2       Bottom        .060         .610      ---
                   Top          .050        1.524      ---
                   --           ---         ---        45.721
          3       Bottom        .045         .000      ---
                   Top          .035         .305      ---
                   --           ---         ---        64.009
          4       Bottom        .060         .305      ---
                   Top          .050        1.219      ---
                   --           ---         ---        84.125
          5       Bottom        .070         .305      ---
                   Top          .060         .914      ---
```

```
*----------------------------------------------------*
*      Finished Processing Header Record FULV        *
*----------------------------------------------------*
```

```
*************************  W S P R O  ***************************
   Federal Highway Administration  -  U. S. Geological Survey
          Model for Water-Surface Profile Computations.
          Input Units: Metric  /  Output Units: Metric
*-----------------------------------------------------------------*
    EXAMPLE TWO:  METRIC SINGLE BRIDGE OPENING - COMPONENT MODE

          FHWA MODEL FOR WATER SURFACE PROFILE COMPUTATIONS


        *-----------------------------------------------------*
        *      Starting To Process Header Record BRDG         *
        *-----------------------------------------------------*

  BR  BRDG  750.0
  BL  0      30   45   65
  BC         141.0
  CD         1  10.0

   ***   Completed Reading Data Associated With Header Record BRDG    ***
   ***   No Roughness Data Input, Propagating From Previous Section   ***
+++072 NOTICE:  X-coordinate # 2 increased to eliminate vertical segment.
+++072 NOTICE:  X-coordinate # 8 increased to eliminate vertical segment.
   ***   Storing Bridge Data In Temporary File As Record Number  6    ***

   ***              Data Summary For Bridge Record BRDG               ***
   SRD Location:      750.   Cross-Section Skew:    .0   Error Code   0
   Valley Slope:  *******    Averaging Conveyance By Geometric Mean.
   Energy Loss Coefficients ->   Expansion:   .50   Contraction:   .00

                      X,Y-coordinates ( 9 pairs)
      X          Y             X          Y             X          Y
  ----------  ----------   ----------  ----------   ----------  ----------
      40.000     141.000       40.100     138.788       45.721     138.716
      48.768     137.162       57.303     137.223       64.009     138.686
      70.000     138.686       70.100     141.000       40.000     141.000
  ----------  ----------   ----------  ----------   ----------  ----------

                  Minimum and Maximum X,Y-coordinates
    Minimum X-Station:      40.000  ( associated Y-Elevation:  141.000 )
    Maximum X-Station:      70.100  ( associated Y-Elevation:  141.000 )
    Minimum Y-Elevation:   137.162  ( associated X-Station:     48.768 )
    Maximum Y-Elevation:   141.000  ( associated X-Station:     40.000 )

                     Roughness Data (  5 SubAreas )
                 Transition   Roughness   Hydraulic  Horizontal
        SubArea    Point    Coefficient    Depth    Breakpoint
        -------  ----------  -----------  ---------  ----------
           1       Bottom        .070         .305      ---
                    Top          .060         .914      ---
                     --          ---         ---        30.176
           2       Bottom        .060         .610      ---
                    Top          .050        1.524      ---
                     --          ---         ---        45.721
           3       Bottom        .045         .000      ---
                    Top          .035         .305      ---
                     --          ---         ---        64.009
           4       Bottom        .060         .305      ---
                    Top          .050        1.219      ---
                     --          ---         ---        84.125
```

```
     5       Bottom        .070         .305      ---
              Top          .060         .914      ---
  -------  ----------  -----------  ---------  ----------

            Discharge coefficient parameters
   BRType   BRWdth   WWAngl   WWWdth   EntRnd    UserCD
     1       10.000  ******  ******** ******** **********

                Pressure flow elevations
                   AVBCEL     PFElev
                  141.000    141.000

                  Abutment Parameters
   ABSLPL  ABSLPR   XTOELT    YTOELT    XTOERT    YTOERT
  ******* *******    40.000   138.788    70.000   138.686

     Bridge Length and Bottom Chord component input data
BRLEN   LOCOPT   XCONLT    XCONRT    BCELEV   BCSLP   BCXSTA
30.000    0       45.000    65.000   141.000   .0000    55.000

            ** No Pier/Pile Data Encountered **


    *-----------------------------------------------------*
    *      Finished Processing Header Record BRDG         *
    *-----------------------------------------------------*
```

```
*************************  W S P R O  ***************************
   Federal Highway Administration  -  U. S. Geological Survey
          Model for Water-Surface Profile Computations.
          Input Units: Metric  /  Output Units: Metric
*-----------------------------------------------------------------*
    EXAMPLE TWO:  METRIC SINGLE BRIDGE OPENING - COMPONENT MODE

         FHWA MODEL FOR WATER SURFACE PROFILE COMPUTATIONS


        *-----------------------------------------------------*
        *      Starting To Process Header Record APPR         *
        *-----------------------------------------------------*

XS  APPR  800.0

 ***   Completed Reading Data Associated With Header Record APPR    ***
 ***   No Roughness Data Input, Propagating From Previous Section   ***
 ***  Storing X-Section Data In Temporary File As Record Number  7  ***

 ***              Data Summary For Header Record APPR               ***
 SRD Location:      800.   Cross-Section Skew:    .0   Error Code   0
 Valley Slope:   .00120    Averaging Conveyance By Geometric Mean.
 Energy Loss Coefficients ->   Expansion:   .50   Contraction:   .00

                    X,Y-coordinates (14 pairs)
     X          Y             X          Y             X          Y
----------  ----------   ----------  ----------   ----------  ----------
   -27.432     141.702         .000     140.483       13.717     139.508
    30.176     139.691       33.529     138.929       45.721     138.776
    48.768     137.222       57.303     137.283       64.009     138.746
    78.639     138.746       84.125     139.569      104.852     139.569
   131.064     140.483      143.256     141.702
----------  ----------   ----------  ----------   ----------  ----------

                 Minimum and Maximum X,Y-coordinates
  Minimum X-Station:     -27.432  ( associated Y-Elevation:  141.702 )
  Maximum X-Station:     143.256  ( associated Y-Elevation:  141.702 )
  Minimum Y-Elevation:   137.222  ( associated X-Station:     48.768 )
  Maximum Y-Elevation:   141.702  ( associated X-Station:    -27.432 )

                   Roughness Data (  5 SubAreas )
                Transition   Roughness   Hydraulic  Horizontal
       SubArea    Point    Coefficient    Depth    Breakpoint
       -------  ----------  -----------  ---------  ----------
          1       Bottom        .070         .305      ---
                   Top          .060         .914      ---
                    --          ---         ---        30.176
          2       Bottom        .060         .610      ---
                   Top          .050        1.524      ---
                    --          ---         ---        45.721
          3       Bottom        .045         .000      ---
                   Top          .035         .305      ---
                    --          ---         ---        64.009
          4       Bottom        .060         .305      ---
                   Top          .050        1.219      ---
                    --          ---         ---        84.125
          5       Bottom        .070         .305      ---
                   Top          .060         .914      ---
```

```
Bridge datum projection(s):  XREFLT  XREFRT  FDSTLT  FDSTRT
                            ******* ******* ******* *******

           *-----------------------------------------------------*
           *      Finished Processing Header Record APPR         *
           *-----------------------------------------------------*
```

```
*************************  W S P R O  ***************************
   Federal Highway Administration  -  U. S. Geological Survey
          Model for Water-Surface Profile Computations.
          Input Units: Metric  /  Output Units: Metric
*-----------------------------------------------------------------*
    EXAMPLE TWO:  METRIC SINGLE BRIDGE OPENING - COMPONENT MODE

         FHWA MODEL FOR WATER SURFACE PROFILE COMPUTATIONS


       *---------------------------------------------------*
       *      Starting To Process Header Record XS5        *
       *---------------------------------------------------*

XS  XS5   900.0

 ***   Completed Reading Data Associated With Header Record XS5     ***
 ***   No Roughness Data Input, Propagating From Previous Section   ***
 ***  Storing X-Section Data In Temporary File As Record Number  8  ***

 ***              Data Summary For Header Record XS5                ***
 SRD Location:      900.   Cross-Section Skew:    .0   Error Code   0
 Valley Slope:   .00120    Averaging Conveyance By Geometric Mean.
 Energy Loss Coefficients ->   Expansion:   .50   Contraction:   .00

                    X,Y-coordinates (14 pairs)
     X          Y             X          Y             X          Y
----------  ----------   ----------  ----------   ----------  ----------
   -27.432     141.822         .000     140.603       13.717     139.628
    30.176     139.811       33.529     139.049       45.721     138.896
    48.768     137.342       57.303     137.403       64.009     138.866
    78.639     138.866       84.125     139.689      104.852     139.689
   131.064     140.603      143.256     141.822
----------  ----------   ----------  ----------   ----------  ----------

                 Minimum and Maximum X,Y-coordinates
  Minimum X-Station:     -27.432  ( associated Y-Elevation:  141.822 )
  Maximum X-Station:     143.256  ( associated Y-Elevation:  141.822 )
  Minimum Y-Elevation:   137.342  ( associated X-Station:     48.768 )
  Maximum Y-Elevation:   141.822  ( associated X-Station:    -27.432 )

                    Roughness Data (  5 SubAreas )
                Transition   Roughness   Hydraulic  Horizontal
       SubArea    Point    Coefficient    Depth    Breakpoint
       -------  ----------  -----------  ---------  ----------
          1       Bottom        .070         .305      ---
                   Top          .060         .914      ---
                    --          ---         ---        30.176
          2       Bottom        .060         .610      ---
                   Top          .050        1.524      ---
                    --          ---         ---        45.721
          3       Bottom        .045         .000      ---
                   Top          .035         .305      ---
                    --          ---         ---        64.009
          4       Bottom        .060         .305      ---
                   Top          .050        1.219      ---
                    --          ---         ---        84.125
          5       Bottom        .070         .305      ---
                   Top          .060         .914      ---
```

```
*-----------------------------------------------------*
*      Finished Processing Header Record XS5          *
*-----------------------------------------------------*
```

```
*************************  W S P R O  ***************************
   Federal Highway Administration  -  U. S. Geological Survey
          Model for Water-Surface Profile Computations.
          Input Units: Metric  /  Output Units: Metric
*-----------------------------------------------------------------*
    EXAMPLE TWO:  METRIC SINGLE BRIDGE OPENING - COMPONENT MODE

          FHWA MODEL FOR WATER SURFACE PROFILE COMPUTATIONS


        *-----------------------------------------------------*
        *      Starting To Process Header Record XS6          *
        *-----------------------------------------------------*

XS  XS6   1050.0

 ***   Completed Reading Data Associated With Header Record XS6     ***
 ***   No Roughness Data Input, Propagating From Previous Section   ***
 ***  Storing X-Section Data In Temporary File As Record Number  9  ***

 ***              Data Summary For Header Record XS6                ***
 SRD Location:     1050.   Cross-Section Skew:    .0   Error Code   0
 Valley Slope:   .00120    Averaging Conveyance By Geometric Mean.
 Energy Loss Coefficients ->   Expansion:   .50   Contraction:   .00

                     X,Y-coordinates (14 pairs)
     X          Y             X          Y             X          Y
----------  ----------   ----------  ----------   ----------  ----------
   -27.432     142.002         .000     140.783       13.717     139.808
    30.176     139.991       33.529     139.229       45.721     139.076
    48.768     137.522       57.303     137.583       64.009     139.046
    78.639     139.046       84.125     139.869      104.852     139.869
   131.064     140.783      143.256     142.002
----------  ----------   ----------  ----------   ----------  ----------

                 Minimum and Maximum X,Y-coordinates
  Minimum X-Station:     -27.432  ( associated Y-Elevation:  142.002 )
  Maximum X-Station:     143.256  ( associated Y-Elevation:  142.002 )
  Minimum Y-Elevation:   137.522  ( associated X-Station:     48.768 )
  Maximum Y-Elevation:   142.002  ( associated X-Station:    -27.432 )

                    Roughness Data (  5 SubAreas )
                Transition   Roughness   Hydraulic  Horizontal
       SubArea    Point    Coefficient    Depth    Breakpoint
       -------  ----------  -----------  ---------  ----------
          1       Bottom        .070         .305      ---
                   Top          .060         .914      ---
                    --          ---         ---        30.176
          2       Bottom        .060         .610      ---
                   Top          .050        1.524      ---
                    --          ---         ---        45.721
          3       Bottom        .045         .000      ---
                   Top          .035         .305      ---
                    --          ---         ---        64.009
          4       Bottom        .060         .305      ---
                   Top          .050        1.219      ---
                    --          ---         ---        84.125
          5       Bottom        .070         .305      ---
                   Top          .060         .914      ---
```

```
*-----------------------------------------------------*
*      Finished Processing Header Record XS6          *
*-----------------------------------------------------*
```

```
************************  W S P R O  **************************
   Federal Highway Administration  -  U. S. Geological Survey
          Model for Water-Surface Profile Computations.
          Input Units: Metric  /  Output Units: Metric
*-------------------------------------------------------------*
    EXAMPLE TWO:  METRIC SINGLE BRIDGE OPENING - COMPONENT MODE

         FHWA MODEL FOR WATER SURFACE PROFILE COMPUTATIONS

EX

      *===================================================*
      *     Summary of Boundary Condition Information     *
      *===================================================*

        Reach      Water Surface   Friction
  #   Discharge      Elevation      Slope         Flow Regime
--   ---------    -------------   --------   --------------------
 1       84.90       139.056       ******        Sub-Critical
 2      127.35       139.385       ******        Sub-Critical
 3      169.92       139.629       ******        Sub-Critical
--   ---------    -------------   --------   --------------------

      *===================================================*
      *        Beginning  3 Profile Calculation(s)        *
      *===================================================*
```

```
************************  W S P R O  **************************
   Federal Highway Administration  -  U. S. Geological Survey
          Model for Water-Surface Profile Computations.
          Input Units: Metric  /  Output Units: Metric
*-------------------------------------------------------------*
    EXAMPLE TWO:  METRIC SINGLE BRIDGE OPENING - COMPONENT MODE

         FHWA MODEL FOR WATER SURFACE PROFILE COMPUTATIONS


                << Beginning Computations for Profile  1 >>

                    WSEL    VHD       Q         AREA      SRDL      LEW
                    EGEL     HF       V          K        FLEN      REW
                    CRWS     HO      FR #        SF       ALPHA     ERR
                 --------- ------ ---------- ---------- --------- ---------
  Section: GAGE      139.056   .112     84.899     78.375 *********     9.945
  Header Type: XS    139.168 ******      1.083    2352.43 *********   110.790
  SRD:    299.999    138.361 ******       .538     ******     1.881    ******

  Section: XS2       139.262   .136     84.899     69.157   149.999    11.257
  Header Type: XS    139.399   .218      1.227    2101.53   149.999   108.116
  SRD:    449.999    138.659   .012       .616      .0015     1.779      .000

  Section: XS3       139.506   .119     84.899     75.391   149.999    10.361
  Header Type: XS    139.626   .226      1.126    2269.44   149.999   109.937
  SRD:    599.999    138.841   .000       .563      .0015     1.852      .000

  Section: EXIT      139.676   .113     84.899     78.003   120.000     9.997
  Header Type: XS    139.789   .162      1.088    2342.00   120.000   110.684
  SRD:    720.000    138.983   .000       .541      .0014     1.877      .003

  Section: FULV      139.716   .112     84.899     78.459    29.999     9.933
  Header Type: FV    139.829   .039      1.082    2354.79    29.999   110.814
  SRD:    749.999    139.021   .000       .537      .0013     1.881      .001

        <<< The Preceding Data Reflect The "Unconstricted" Profile >>>

  Section: APPR      139.782   .110     84.899     79.075    49.999     9.848
  Header Type: AS    139.893   .064      1.073    2372.12    49.999   110.989
  SRD:    799.999    139.079   .000       .533      .0013     1.887      .001

        <<< The Preceding Data Reflect The "Unconstricted" Profile >>>

         <<< The Following Data Reflect The "Constricted" Profile >>>
           <<< Beginning Bridge/Culvert Hydraulic Computations >>>


                    WSEL    VHD       Q         AREA      SRDL      LEW
                    EGEL     HF       V          K        FLEN      REW
                    CRWS     HO      FR #        SF       ALPHA     ERR
                 --------- ------ ---------- ---------- --------- ---------
  Section: BRDG      139.667   .190     84.899     48.948    29.999    40.060
  Header Type: BR    139.857   .048      1.734    1904.08    29.999    70.042
  SRD:    749.999    138.958   .019       .433     ******     1.239     -.001

Specific Bridge Information   C     P/A   PFELEV    BLEN      XLAB      XRAB
Bridge Type 1   Flow Type 1 ------ ----- -------- -------- --------- ---------
Pier/Pile Code **            .8984  .000  140.999   29.999    39.999    69.999
--------------------------- ------ ----- -------- -------- --------- ---------
```

```
    Unconstricted Full Valley Section Water Surface Elevation:    139.716
    Downstream Bridge Section Water Surface Elevation:            139.667
    Bridge DrawDown Distance:                                        .049
-------------------------------------------------------------------------

                     WSEL    VHD       Q         AREA      SRDL      LEW
                     EGEL     HF       V          K        FLEN      REW
                     CRWS     HO      FR #        SF       ALPHA     ERR
                  --------- ------ ---------- ---------- --------- ---------
Section: APPR      139.840   .098     84.899     84.952    40.000     9.040
Header Type: AS    139.938   .061       .999    2540.47    41.135   112.635
SRD:    799.999    139.079   .019       .490      .0013     1.932      .002

        ** Change in Approach Section Water Surface Elevation:  .058 **

              Approach Section APPR  Flow Contraction Information
            M( G )   M( K )     KQ       XLKQ      XRKQ     OTEL
           -------- -------- --------- --------- --------- --------
               .704     .161    2129.5    40.508    70.490  139.840
           -------- -------- --------- --------- --------- --------

               <<< End of Bridge Hydraulics Computations >>>

Section: XS5       139.952   .099     84.899     84.185    99.999     9.143
Header Type: XS    140.052   .112      1.008    2518.18    99.999   112.425
SRD:    899.999    139.199   .000       .495      .0011     1.926      .003

Section: XS6       140.124   .101     84.899     83.311   149.999     9.263
Header Type: XS    140.226   .172      1.019    2492.92   149.999   112.181
SRD:   1049.999    139.381   .000       .501      .0011     1.920      .000

                 << Completed Computations of Profile  1 >>
```

```
************************  W S P R O  **************************
   Federal Highway Administration  -  U. S. Geological Survey
          Model for Water-Surface Profile Computations.
          Input Units: Metric  /  Output Units: Metric
*-------------------------------------------------------------*
    EXAMPLE TWO:  METRIC SINGLE BRIDGE OPENING - COMPONENT MODE

          FHWA MODEL FOR WATER SURFACE PROFILE COMPUTATIONS


                << Beginning Computations for Profile  2 >>

                    WSEL    VHD       Q         AREA      SRDL      LEW
                    EGEL     HF       V          K        FLEN      REW
                    CRWS     HO      FR #        SF       ALPHA     ERR
                 --------- ------ ---------- ---------- --------- ---------
  Section: GAGE      139.385   .129    127.350    113.867 *********     5.317
  Header Type: XS    139.514 ******      1.118    3442.19 *********   120.224
  SRD:    299.999    138.682 ******       .511     ******     2.032    ******

  Section: XS2       139.599   .153    127.350    104.154   149.999     6.525
  Header Type: XS    139.752   .225      1.222    3127.55   149.999   117.761
  SRD:    449.999    138.982   .011       .573      .0015     2.013      .000

  Section: XS3       139.848   .133    127.350    111.986   149.999     5.544
  Header Type: XS    139.982   .230      1.137    3381.63   149.999   119.757
  SRD:    599.999    139.162   .000       .522      .0015     2.027     -.001

  Section: EXIT      140.021   .126    127.350    115.357   120.000     5.135
  Header Type: XS    140.148   .164      1.103    3490.45   120.000   120.596
  SRD:    720.000    139.308   .000       .503      .0014     2.035      .004

  Section: FULV      140.064   .124    127.350    116.155    29.999     5.038
  Header Type: FV    140.189   .039      1.096    3516.36    29.999   120.794
  SRD:    749.999    139.344   .000       .499      .0013     2.036      .005

         <<< The Preceding Data Reflect The "Unconstricted" Profile >>>

  Section: APPR      140.132   .123    127.350    117.083    49.999     4.925
  Header Type: AS    140.255   .065      1.087    3546.62    49.999   121.023
  SRD:    799.999    139.404   .000       .494      .0013     2.038      .004

         <<< The Preceding Data Reflect The "Unconstricted" Profile >>>

          <<< The Following Data Reflect The "Constricted" Profile >>>
            <<< Beginning Bridge/Culvert Hydraulic Computations >>>


                    WSEL    VHD       Q         AREA      SRDL      LEW
                    EGEL     HF       V          K        FLEN      REW
                    CRWS     HO      FR #        SF       ALPHA     ERR
                 --------- ------ ---------- ---------- --------- ---------
  Section: BRDG      139.955   .337    127.350     57.583    29.999    40.047
  Header Type: BR    140.293   .057      2.211    2428.58    29.999    70.054
  SRD:    749.999    139.328   .087       .510     ******     1.353     -.001

Specific Bridge Information   C     P/A   PFELEV    BLEN      XLAB      XRAB
Bridge Type 1   Flow Type 1 ------ ----- -------- -------- --------- ---------
Pier/Pile Code **            .8596  .000  140.999   29.999    39.999    69.999
--------------------------- ------ ----- -------- -------- --------- ---------
```

```
    Unconstricted Full Valley Section Water Surface Elevation:    140.064
    Downstream Bridge Section Water Surface Elevation:            139.955
    Bridge DrawDown Distance:                                        .109
-------------------------------------------------------------------------

                     WSEL    VHD       Q         AREA      SRDL      LEW
                     EGEL     HF       V          K        FLEN      REW
                     CRWS     HO      FR #        SF       ALPHA     ERR
                  --------- ------ ---------- ---------- --------- ---------
Section: APPR       140.295   .091    127.350    136.495    40.000     2.641
Header Type: AS     140.386   .066       .932    4201.10    41.621   125.678
SRD:    799.999     139.404   .027       .406      .0013     2.057      .004

        ** Change in Approach Section Water Surface Elevation:  .163 **

              Approach Section APPR  Flow Contraction Information
            M( G )   M( K )     KQ       XLKQ      XRKQ     OTEL
           -------- -------- --------- --------- --------- --------
               .741     .273    3052.2    40.741    70.749  140.295
           -------- -------- --------- --------- --------- --------

               <<< End of Bridge Hydraulics Computations >>>

Section: XS5        140.388   .095    127.350    133.186    99.999     3.018
Header Type: XS     140.484   .094       .956    4086.57    99.999   124.909
SRD:    899.999     139.524   .002       .419      .0009     2.056      .003

Section: XS6        140.535   .101    127.350    129.283   149.999     3.474
Header Type: XS     140.637   .150       .985    3953.16   149.999   123.981
SRD:   1049.999     139.704   .002       .435      .0010     2.054      .000

                 << Completed Computations of Profile  2 >>
```

```
************************  W S P R O  **************************
   Federal Highway Administration  -  U. S. Geological Survey
          Model for Water-Surface Profile Computations.
          Input Units: Metric  /  Output Units: Metric
*-------------------------------------------------------------*
    EXAMPLE TWO:  METRIC SINGLE BRIDGE OPENING - COMPONENT MODE

          FHWA MODEL FOR WATER SURFACE PROFILE COMPUTATIONS


                << Beginning Computations for Profile  3 >>

                    WSEL    VHD       Q         AREA      SRDL      LEW
                    EGEL     HF       V          K        FLEN      REW
                    CRWS     HO      FR #        SF       ALPHA     ERR
                 --------- ------ ---------- ---------- --------- ---------
  Section: GAGE      139.629   .147    169.920    143.177 *********     1.884
  Header Type: XS    139.776 ******      1.186    4435.71 *********   127.221
  SRD:    299.999    139.027 ******       .509     ******     2.058    ******

  Section: XS2       139.855   .168    169.920    134.123   149.999     2.913
  Header Type: XS    140.024   .237      1.266    4118.97   149.999   125.124
  SRD:    449.999    139.331   .010       .554      .0016     2.056      .000

  Section: XS3       140.113   .146    169.920    143.709   149.999     1.822
  Header Type: XS    140.259   .236      1.182    4454.46   149.999   127.348
  SRD:    599.999    139.509   .000       .506      .0016     2.058     -.001

  Section: EXIT      140.291   .138    169.920    148.010   120.000     1.345
  Header Type: XS    140.429   .168      1.148    4608.31   120.000   128.320
  SRD:    720.000    139.655   .000       .487      .0014     2.056      .002

  Section: FULV      140.333   .136    169.920    148.857    29.999     1.252
  Header Type: FV    140.470   .040      1.141    4638.80    29.999   128.511
  SRD:    749.999    139.689   .000       .483      .0014     2.056      .002

        <<< The Preceding Data Reflect The "Unconstricted" Profile >>>

  Section: APPR      140.402   .134    169.920    149.929    49.999     1.133
  Header Type: AS    140.537   .066      1.133    4677.53    49.999   128.752
  SRD:    799.999    139.749   .000       .479      .0013     2.056      .000

        <<< The Preceding Data Reflect The "Unconstricted" Profile >>>

         <<< The Following Data Reflect The "Constricted" Profile >>>
           <<< Beginning Bridge/Culvert Hydraulic Computations >>>


                    WSEL    VHD       Q         AREA      SRDL      LEW
                    EGEL     HF       V          K        FLEN      REW
                    CRWS     HO      FR #        SF       ALPHA     ERR
                 --------- ------ ---------- ---------- --------- ---------
  Section: BRDG      140.168   .503    169.920     63.973    29.999    40.037
  Header Type: BR    140.671   .066      2.656    2847.24    29.999    70.063
  SRD:    749.999    139.641   .175       .581     ******     1.399     -.001

Specific Bridge Information   C     P/A   PFELEV    BLEN      XLAB      XRAB
Bridge Type 1   Flow Type 1 ------ ----- -------- -------- --------- ---------
Pier/Pile Code **            .8456  .000  140.999   29.999    39.999    69.999
--------------------------- ------ ----- -------- -------- --------- ---------
```

```
    Unconstricted Full Valley Section Water Surface Elevation:    140.333
    Downstream Bridge Section Water Surface Elevation:            140.168
    Bridge DrawDown Distance:                                        .165
-------------------------------------------------------------------------

                     WSEL    VHD       Q         AREA      SRDL      LEW
                     EGEL     HF       V          K        FLEN      REW
                     CRWS     HO      FR #        SF       ALPHA     ERR
                  --------- ------ ---------- ---------- --------- ---------
Section: APPR       140.693   .083    169.920    188.608    40.000    -4.728
Header Type: AS     140.776   .069       .900    6136.91    42.169   133.165
SRD:    799.999     139.749   .035       .350      .0013     2.020      .004

        ** Change in Approach Section Water Surface Elevation:  .291 **

              Approach Section APPR  Flow Contraction Information
            M( G )   M( K )     KQ       XLKQ      XRKQ     OTEL
           -------- -------- --------- --------- --------- --------
               .765     .354    3959.7    40.862    70.889  140.693
           -------- -------- --------- --------- --------- --------

               <<< End of Bridge Hydraulics Computations >>>

Section: XS5        140.769   .089    169.920    182.664    99.999    -3.758
Header Type: XS     140.859   .079       .930    5902.75    99.999   132.733
SRD:    899.999     139.869   .002       .366      .0008     2.028      .000

Section: XS6        140.896   .097    169.920    175.445   149.999    -2.556
Header Type: XS     140.993   .130       .968    5623.83   149.999   132.199
SRD:   1049.999     140.050   .003       .387      .0009     2.037      .001

                 << Completed Computations of Profile  3 >>

 ER

  ******************  Normal end of WSPRO execution.  *****************
  ***************  Elapsed Time:   0 Minutes  9 Seconds  **************
```

APPENDIX B: FOOTPRINTS FOR TYPICAL APPLICATIONS

This section presents two basic WSPRO applications represented by an arrangement of command strings. These arrangements of command strings, or footprints, are provided for the following typical applications:

1. Unconstricted water-surface profile.

2. Single-opening bridge (design mode).

These two footprints are contained in files on the HYDRAIN package diskettes. These files are comprised of command lines with empty data fields for which the user can supply the appropriate data (the footprint files should be copied and renamed before any editing is done.)

1. Unconstricted Water-Surface Profile

Filename: UNC˜FP.WSP

The following command string is a typical footprint of an unconstricted water-surface profile model:

```
*  --->Unconstricted Channel Water-Surface Profile
*  --->REMOVE all unused command lines
*  ---> OPTIONAL---First command, *F switches to free data format
*F
*  ---> OPTIONAL---<T1, T2, and T3> commands
T1
T2
T3
*
*  ---> OPTIONAL---J1 AND UT commands
J1
UT
*
*  ---> Initial Flow Conditions:  CHOOSE <Q and WS> or <Q and SK>
Q
WS
SK
*
*  ---> Channel (most downstream) Cross-section
XS
GR
*  ---> ONLY N command is REQUIRED for Roughness Data
N
*  ---> Use SA and ND as appropriate
SA
ND
*
```

```
*  ---> Next upstream channel cross-section
XS
*  ---> UPDATE GR, N, SA, and ND commands ONLY if their parameters have changed
*       from the previous channel cross-section
GR
N
SA
ND
*  ---> OPTIONAL---FL command
FL
*
*  ---> FOR ADDITIONAL Cross-sections:  Repeat the sequence of commands
*       (XS, GR, N, SA, ND, FL) as shown in preceding cross-section
*
EX
*  ---> Either the ER or END command can be used to indicate end of run
ER
```

2. Single-Opening Bridge--Design Mode

Filename: BRDES˜FP.WSP

The following command string is a typical footprint of a single-opening bridge model for the design mode:

```
*  --->Single Opening Bridge (DESIGN)
*  --->REMOVE all unused command lines
*  ---> OPTIONAL---First command, *F switches to free data format
*F
*  ---> OPTIONAL---T1, T2, and T3 commands
T1
T2
T3
*
*  ---> OPTIONAL---J1 AND UT commands
J1
UT
*
*  ---> Initial Flow Conditions:  CHOOSE <Q and WS> or <Q and SK>
Q
WS
SK
*
*  ---> EXIT Channel Cross-section
XS
GR
*  ---> ONLY N command is REQUIRED for Roughness Data
N
*  ---> Use SA and ND as appropriate
SA
ND
*
*  ---> FULL VALLEY Channel Cross-section
XS
```

```
*  ---> UPDATE GR, N, SA, and ND commands ONLY if parameters have changed
*  ---> from the previous (EXIT) cross-section.
GR
N
SA
ND
*  ---> OPTIONAL---FL command
FL
*
*  ---> BRIDGE Cross-section (design mode)
BR
BC
BL
CD
*  ---> AB command REQUIRED for a Type 3 Opening ONLY
AB
*  ---> OPTIONAL---KD command---REQUIRED ONLY to override the default
*                               position of the KQ-section
KD
*  ---> OPTIONAL---PIER or PILE Data---PD command
PD
*  ---> UPDATE N, SA, and ND commands ONLY if parameters have changed
*       from the previous (FULL VALLEY) cross-section
N
SA
ND
*
*  ---> OPTIONAL---GUIDE BANK Data---GB and GR commands
GB
*  ---> OPTIONAL---GR command
GR
*  ---> UPDATE N, SA, and ND commands ONLY if parameters have changed
*       from the previous (BRIDGE) cross-section
N
SA
ND
*
*  ---> OPTIONAL---ROAD GRADE Data---XR, GR or RG, and BP commands
XR
*  ---> CHOOSE <GR> or <RG>
GR
RG
*  ---> OPTIONAL---BP command
BP
*  ---> UPDATE N, SA, and ND commands ONLY if their parameters have changed
*       from the previous (FULL VALLEY) cross-section
N
SA
ND
*
*  ---> APPROACH Channel Cross-section
AS
*  ---> UPDATE GR command ONLY if its parameters have changed from the
*       previous (FULL VALLEY) cross-section
```

```
GR
*  ---> UPDATE N, SA, and ND commands ONLY if parameters have changed from
*       the previous (ROAD GRADE or FULL VALLEY) cross-section
N
SA
ND
*  ---> OPTIONAL---FL command
FL
*
EX
*  ---> The ER command is used to indicate end of run
ER
```

APPENDIX C: WSPRO COMMANDS

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 of left abutment. Required only for Type 3 opening COMPONENT MODE.

2) abslpr - slope of right abutment. Required only for Type 3 opening COMPONENT MODE. (Note: this parameter not required if same as abslpl.)

-- OR --

1) yablt - toe elevation at left abutment. Required only for Type 2 opening in COORDINATE MODE.

2) yabrt - toe elevation at right abutment. Required only for Type 2 opening in COORDINATE MODE. (Note: this parameter not required if same as yablt). See CD command for explanation of these parameters.

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 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. 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 BC - Bridge deck parameters

Purpose: To specify bridge deck parameters (DESIGN MODE ONLY).

Structure:

BC bcelev [bcslp, bcsta]

1) bcelev - low-chord elevation. If bridge deck is not horizontal, bcslp and bcsta are also required.
2) bcslp - slope of the bridge deck (negative for left-to-right fall).
3) bcsta - x-coordinate corresponding to bcelev.

Note: The above data provides 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.

   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).
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.

Note: If only three parameters are used in this command, locopt defaults to zero.

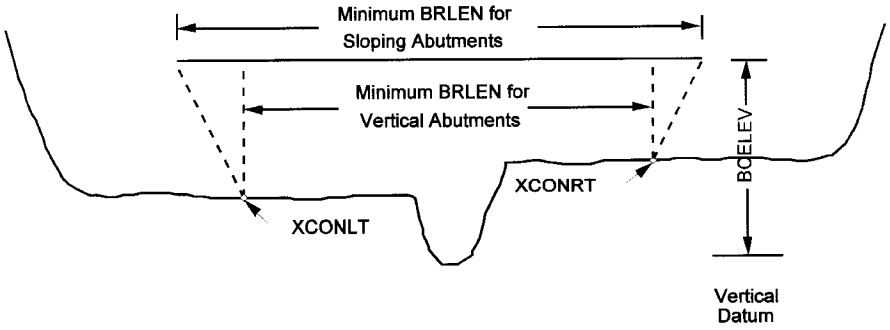
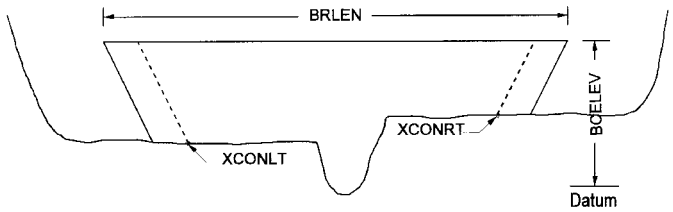
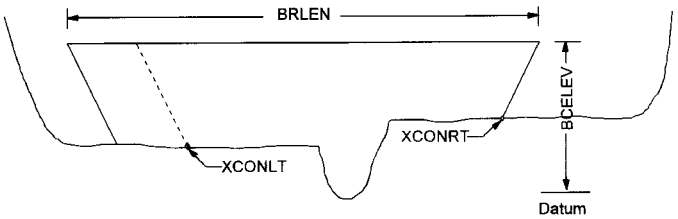


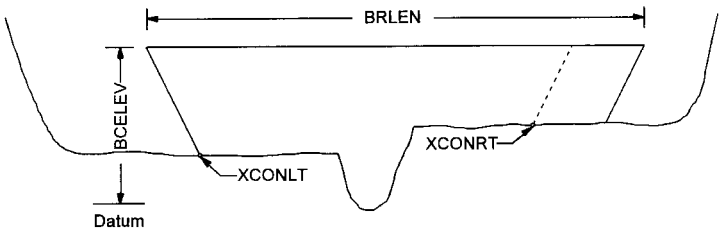
Figure 6. BL command parameters



a) LOCOPT = 0, bridge opening centered at midpoint of tops of abutments



b) LOCOPT= 1, right abutment toe fixed at XCONRT



c) LOCOPT = 2, left abutment toe fixed at XCONLT

Figure 7. Effect of locopt on bridge opening section command (BL command).

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 left projection lines.
4) fdstrt - flow distance measured along the right projection lines.

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.

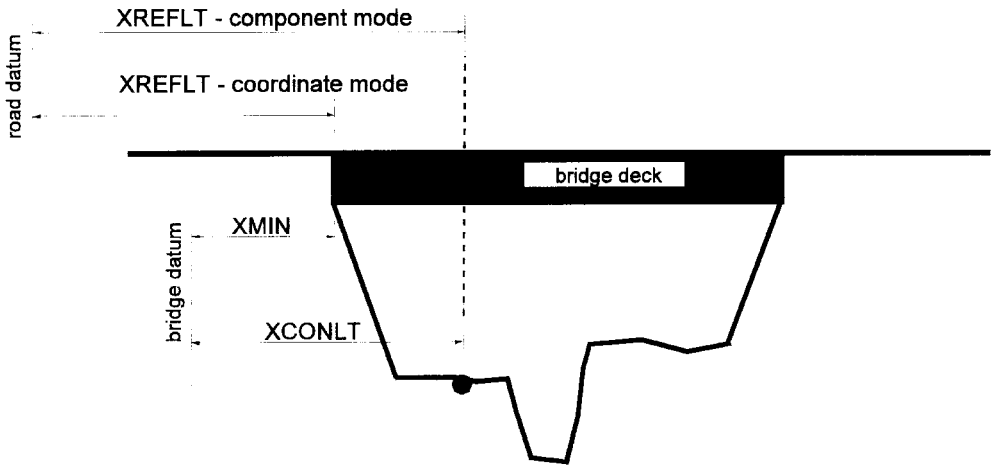


Figure 8. Datum correction between bridge opening and road grade sections.

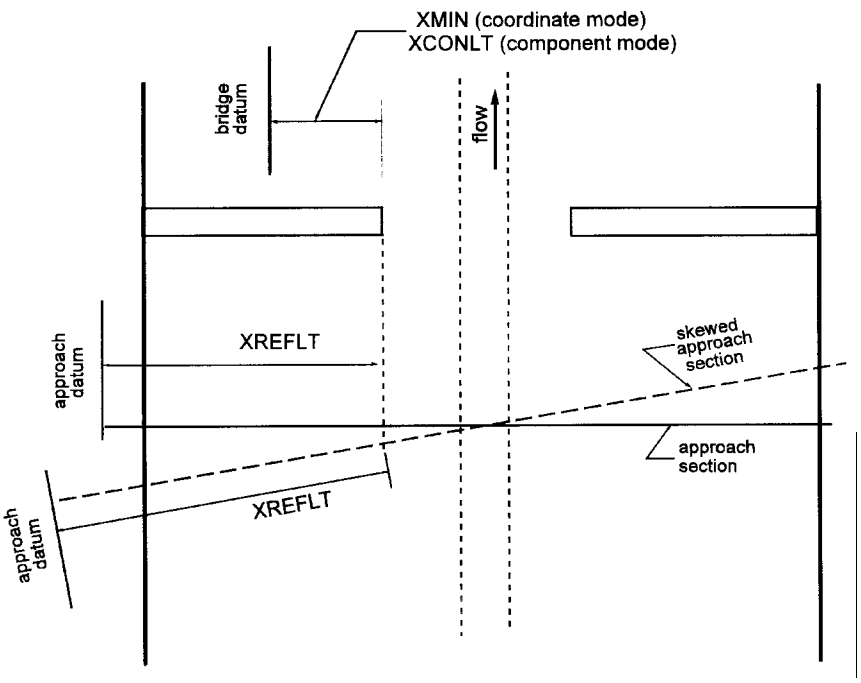


Figure 9. Datum correction between bridge opening and approach sections.

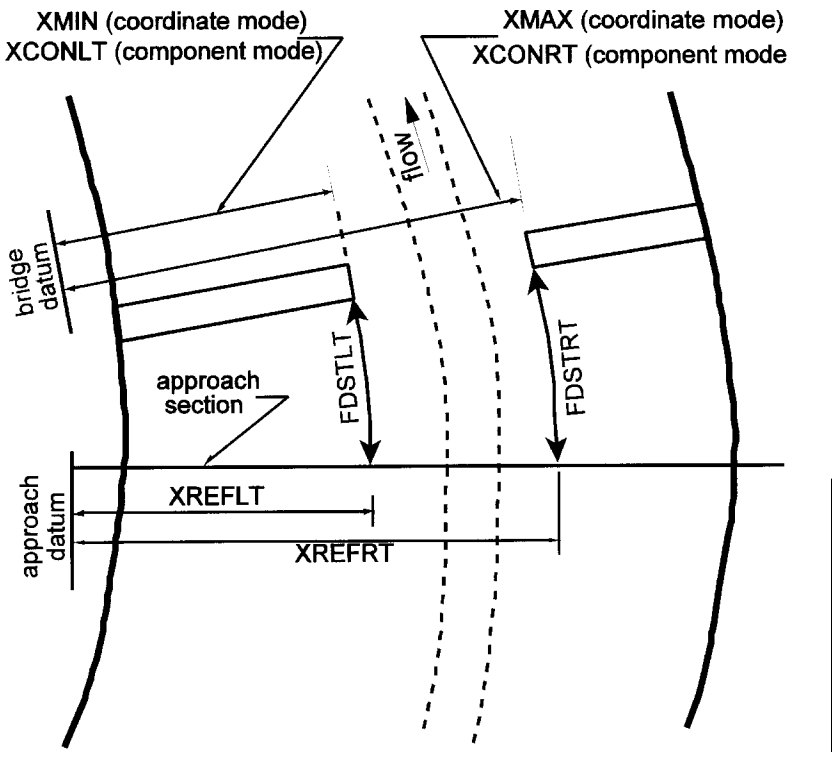


Figure 10. Curvilinear flow between approach and bridge.

COMMAND BR - BRidge section

Purpose: To establish bridge cross-section.

Structure:

BR secid, srd, pfelev, 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)	pfelev	-	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, α, 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.

Table 4. Manning's roughness coefficient, n, and velocity head correction coefficient, α, for culverts.

	Shape	Box	Circle	Arch
Material	n	Velocity Head Correction Coefficient, α		
Concrete	0.012	1.00	1.04	1.05
Corrugated metal	0.035	-	1.12	1.16

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 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. Required only for type 1 openings with wingwalls. (Default is 0.0.)
7) entrnd - radius of entrance rounding. 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).
   (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.

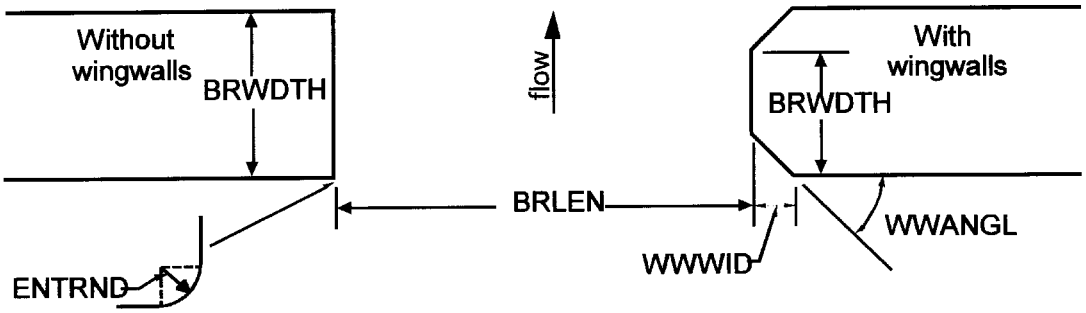


Figure 11. Type 1 bridge opening (br = 1, CD command).

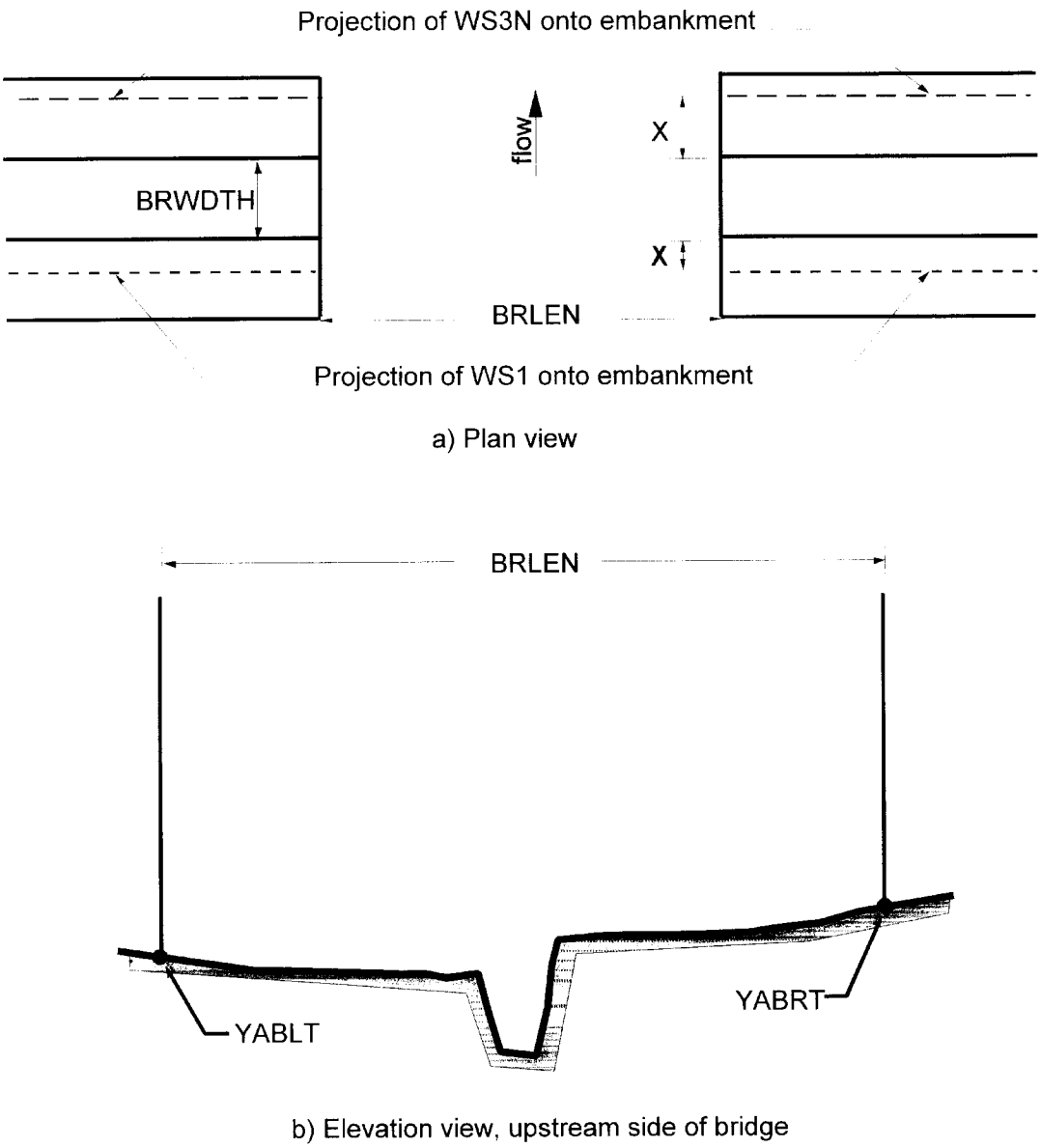


Figure 12. Type 2 bridge opening (brtype = 2, CD command).

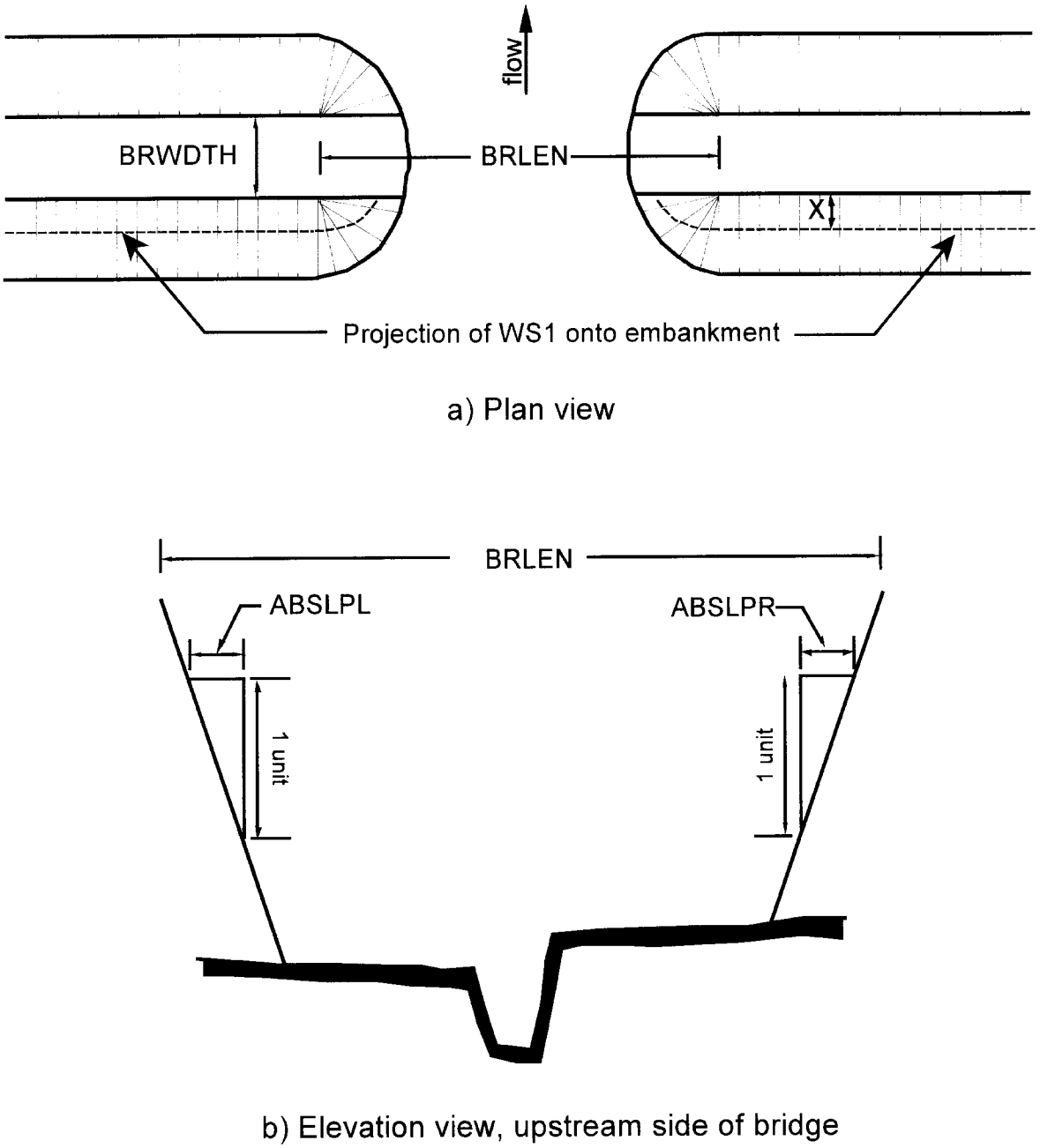


Figure 13. Type 3 bridge opening (brtype = 3, CD command).

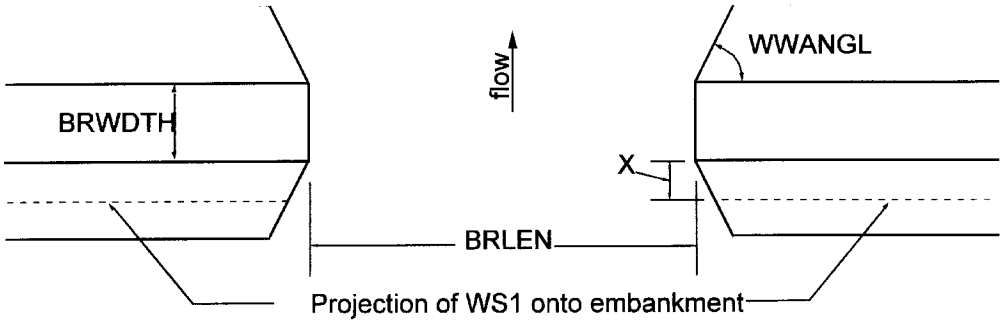


Figure 14. Type 4 bridge opening (brtype = 4, CD command).

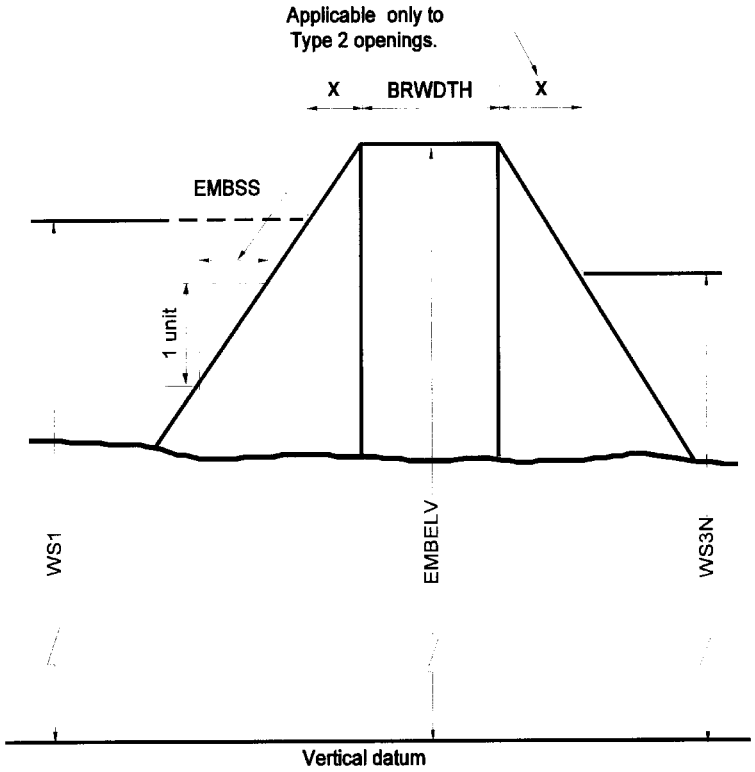


Figure 15. Embankment parameters (brtype 2, 3, and 4, CD command).

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.
3) span - the maximum horizontal dimension of the culvert barrel. 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.
5) toprad - top radius of pipe-arch culvert barrel.
6) corrad - corner radius of pipe-arch culvert barrel.

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.

Table 5. Coefficients used in the analysis of culverts (CG command).

I	J	K	Type of inlet[1]	K_e[2]
1	1	1	WINGWALLS: 30°-75° flare; square top edge	0.4
1	1	2	HEADWALL: (a) normal or (b) 45° skew; square edge	0.5
1	1	3	WINGWALLS: 15° flare with square edges	0.5
1	1	4	WINGWALLS: extended with 0° flare; square top edge	0.7
1	1	5	HEADWALL: (a) normal of (b) 45° skew; 1:1 bevels	0.2
1	1	6	WINGWALLS: (a) 18° - 33.7° flare with 1½:1 top bevels; or (b) 45° flare with 1:1 top bevel	0.2
1	1	7	HEADWALL: normal with 1½:1 bevel on three sides	0.2
2	1	1	PROJECTING: socket end	0.2
2	1	2	HEADWALL: socket end	0.2
2	1	3	PROJECTING: square edge	0.5
2	1	4	HEADWALL: square edge	0.5
2	1	5	END SECTION	0.5
2	2	5	END SECTION	0.5
2	2	6	BEVEL: 1:1	0.2
2	2	6	BEVEL: 1:1	0.2
2	1	7	BEVEL: 1½:1	0.2
2	2	7	BEVEL: 1½:1	0.2
2	2	1	PROJECTING:	0.9
2	2	2	MITERED:	0.7
2	2	3	HEADWALL:	0.5
3	1	1	HEADWALL: square edge	0.5
3	1	2	HEADWALL: grooved end	0.2
3	1	3	PROJECTING: grooved end	0.2
3	2	1	PROJECTING: CR[3] ≤ 457 mm (18")	0.9
3	2	2	PROJECTING: CR = 787 mm (31")	0.9
3	2	3	PROJECTING: CR = 1194 mm (47")	0.9
3	2	4	MITERED: CR ≤ 457 mm (18")	0.7
3	2	5	MITERED: CR = 787 mm (31")	0.7
3	2	6	MITERED: CR = 1194 mm (47")	0.7
3	3	2	MITERED: CR = 808 mm (31.8")	0.7
3	2	7	HEADWALL: CR ≤ 457 mm (18")	0.5
3	2	8	HEADWALL: CR = 787 mm (31")	0.5
3	2	8	HEADWALL: CR = 787 mm (31")	0.5
3	2	9	HEADWALL: CR = 1194 mm (47")	0.5
3	3	3	HEADWALL: CR = 808 mm (31.8")	0.5

[1] I, J, and K are codes representing shape, material, and inlet type, respectively. The shape code (I) indicates either box (1), circular (2), or arch (3). The material code (J) indicates either concrete (1), corrugated metal (steel) pipe (2), or aluminum (3). The inlet code (K) indicates the inlet conditions described under the Type of inlet column.

[2] K_e is the culvert entrance-loss coefficient.

[3] CR is the corner radius of arch culverts.

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. 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.
5)	dsinv	-	elevation of downstream invert (above the common elevation datum).
6)	usinv	-	elevation of upstream invert (above the common elevation datum).
7)	nbbl	-	number of culvert barrels.

COMMAND DA - Depth of Abutment scour

Purpose: Specifying parameters for the computation of abutment scour.

Structure:

DA secid, [k1, k2, yal, yar, q, fs]

1) secid - Unique cross-section identification code. secid is optional (depending on placement in the data stream as with the Q and HP Records.

2) k1,k2 - k1 and k2 are the two correction/adjustment factors for abutment shape and embankment skew (default value is 1.0 for both factors).

3) yal,yar - A user-specified override for left and right abutment depth in meters, y_a, for cases when an average overbank depth may not be realistic for scour computations (e.g., if the abutment location is within the main channel, some weighted average value of y_a may yield more meaningful estimates of scour depths).

4) q - Discharge through the bridge opening (cubic meters per second).

5) fs - Factor of safety (default = 1.0).

COMMAND DC - Depth of Contraction scour

Purpose: Specifying parameters to perform live-bed and clear-water contraction scour depth computations.

Structure:

DC	0, secid [bxl, bxr, axl, axr, kl, pw, yb, ya]	*(live-bed)*
	---or---	
dc	1, secid [bxl, bsr, axl, axr, d50, pw, yb, ya]	*(clear-water)*

1)	secid	-	unique cross-section identification code. secid is optional (depending on placement in the data stream as with the q and hp records.
2)	bxl, bxr, axl axr	-	bxl, bxr, axl, axr are the left and right horizontal limits of the bx and ax channel segments, respectively. Defaults for these limits are the main channel top-of-bank stations (input parameters to be added to cross-section header records). ax and bx will be limited, of course, to the difference between left- and right-edges of water. W_2 will be reduced by gross pier width based on pd record input data.
3)	k1	-	the k_1 exponent in the contraction scour estimation equation (default 0.59).
4)	pw	-	pier width.
5)	yb	-	depth of flow in bridge opening.
6)	ya	-	depth of flow in channel or floodplain.
7)	d50	-	median diameter of bed material in bridge opening or in the floodplain.

Notes:

(1) Multiple DC records can be used to evaluate different combinations of left and right horizontal limits and/or different values of k_1.

(2) It is also possible to add variables yb (water-surface elevation in contracted section), qb (flow through bridge opening), ws1 (water-surface elevation at approach section), qt (total flow at the approach section) to permit contraction scour computations 'divorced' from profile computations.

COMMAND DP - Depth of Pier scour

Purpose: Specifying parameters to perform local pier scour computations.

Structure:

DP secid [bxl, bxr, pw, yb, qb, k1, k2, k3, v1m, y1m]

1)	secid	-	unique cross-section identification code.
2)	bxl	-	left horizontal limit of channel segment to be examined for pier scour computations.
3)	bxr	-	right horizontal limit of channel segment to be examined for pier scour computations.
4)	pw	-	pier width.
5)	yb	-	user-specified override for the water-surface elevation in the bridge opening.
6)	qb	-	discharge through the bridge opening.
7)	k1,k2, k3	-	correction/adjustment factors applied to the scour estimation equation (default values are 1.1, 1.0, and 1.0).
8)	v1m	-	velocity multiplier.
9)	y1m	-	depth multiplier.

Notes:

(1) The v1m and y1m parameters are multipliers to increase or decrease the maximum velocity and depth values. These parameters could be used as safety factors and/or to perform fundamental sensitivity analyses to show variation in scour depth for different combinations of velocity and depth. Multiple DP records can be used to specify different v1m and y1m values for sensitivity analyses.

(2) Pier scour computations can be divorced from the profile computations by coding the yb and qb parameters. This feature is useful when it is deemed necessary to adjust computed elevations and/or in complex flow situations where water-surface elevations are not determined by WSPRO computations. Velocity and depth values are determined as per the above discussion. These computations could be accomplished by inputting only the bridge section.

COMMAND EF - Effective Flow

Purpose: Allows user to set effective flow limits and user-defined stagnation points.

Structure:

EF xlef, ylef, xref, yref

1) ylef - left station.
2) ylef - left depth.
3) xref - right station.
4) yref - right depth.

COMMAND ER - End of Run

Purpose: To signify end of run.

Structure:

ER (no parameters)

Note: Command indicates end of data input; if omitted, harmless error message is generated.

COMMAND EX - EXecutive profile computations

Purpose: To instruct model to begin execution of profile computations and to specify computation direction. **No profiles are computed if EX record is not coded.**

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 (typically supercrtitical) 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) [,xfl(1), flen(2)] [,xfl(2), flen(3)]

1) ihfno - code to select the friction slope (or conveyance) averaging technique in the friction loss computations. Valid entries are:
   - 0 - uses geometric mean of conveyance.
   - 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. Up to three values may be specified, and these lengths override srd values except in bridge backwater computations. (See figure 16.)
3) xfl - x-coordinate of breakpoints between the segments of the cross-section for which multiple flen values are to be applied. One value is necessary if 2 flen values are specified and two values are necessary if 3 flen values are specified. (See figure 16.)

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.

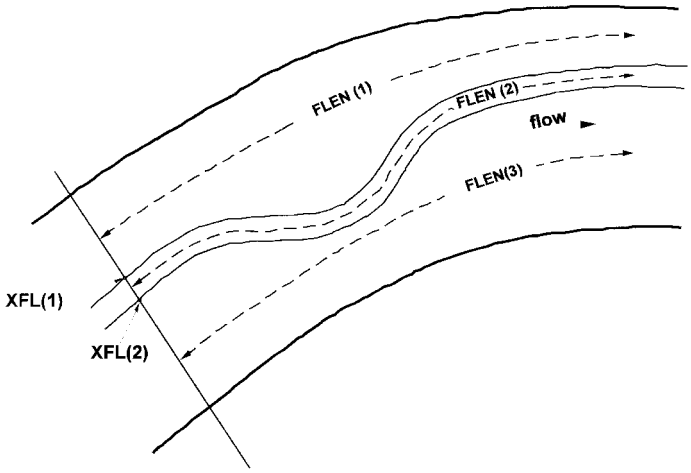


Figure 16. FL command parameters.

COMMAND FS - Floodways global Surcharges

Purpose: Optional record for floodway analysis to specify global surcharges that vary based on some corresponding flow on the Q record.

Structure:

fs fs(1), fs(2), . . ., fs(nprof)

nx) fs(i) - Floodway surcharges, in meters, representing the allowable surcharge to be calculated at each section with a corresponding FW record. If FS record is used, a surcharge **must be provided** for FS for each discharge specified in the Q record. Values on the FW record can override these surcharges for a specif ic cross-section (nprof must be $\leq$ 20).

COMMAND FW - FloodWays

Purpose: Mandatory record for floodway analysis to specify the encroachment method, desired surcharge, left and right encroachment limits for distance, and subareas of each cross section.

Structure:

FW mthd, target, xenclt, xencrt

1) mthd - Encroachment method option code. Valid values are:

0 (or blank)	equal encroachment.
1	left encroachment.
2	right encroachment.
3	set encroachment (need xenclt, xencrt).

2) target - the desired surcharge.
3) xenclt - the x-station of the encroachment constraint on left bank.
4) xencrt - the x-station of the encroachment constraint on right bank.

COMMAND GB - GuideBanks

Purpose: Header record for guidebanks cross-section.

Structure:

GB secid, srd, gbtype, bsubdr, gboff, skew, ek, ck, vslope

1) secid - unique cross-section identification code.
2) srd - section reference distance.
3) gbtype - code to indicate the type of guidebanks. Valid entries are:

   1 Elliptical guidebanks, no skew.
   2 Elliptical guidebanks, skewed.
   3 Straight guidebanks, no offset.
   4 Straight guidebanks, with offset.

4) bsubd - distance that straight banks are offset from the bridge abutments (not to be confused with gboff below). This parameter is only relevant to gbtype = 4.
5) bgoff - measured normal to the flow at the mouth of the banks, the horizontal offset between the banks and the bridge abutments. Use an average value if the left and right offsets are not equal. The model places the base of the banks at this distance from the abutment stations. Side slope of the banks are equal to the bridge abutment slopes. Remaining ground points are obtained from the full-valley cross-section.
6) skew - the acute angle that the section must be rotated to orient the section normal to the flow direction. The model applies the cosine of skew to the horizontal dimension of the section to compute cross-sectional properties. Default is zero degrees.
7) ek, ck - coefficients used for computing the expansion and contraction losses, respectively, for the energy equation balance. These coefficients would apply only to downstream computations from the guidebank to the bridge opening. Default values are either **ex** = 0.5 and **ck** = 0.0 or the current values being propagated from downstream data.

8) vslope - valley slope. Used to adjust elevations of x,y-coordinates for the guidebank when geometric data are propagated. Default value is zero or the current value being propagated from downstream data.

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. (See figure 17.)
2) y(i) - y-coordinate, distance above common elevation datum, of the ith ground point. (See figure 17.)

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 facing downstream. (ngp is the total number of coordinates.)

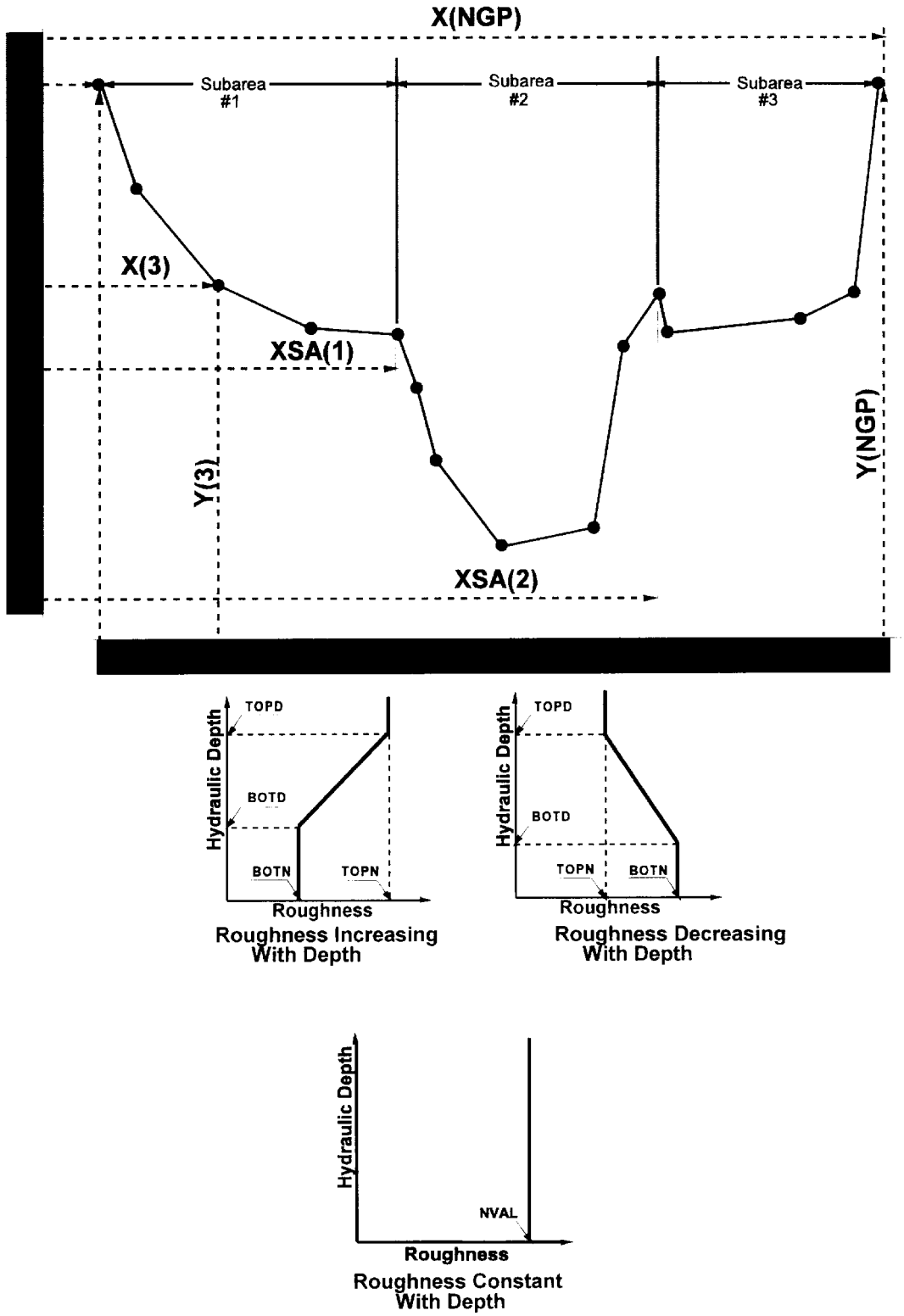


Figure 17. GR, N, ND, and SA command parameters.

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 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 ihp, secid, elmin, yinc, elmax, q

1) ihp - option code indicating the following device:

ihp = 0	for table of cross-sectional properties for entire cross-section.
ihp = 1	for table of cross-sectional properties for each subarea as well as the entire cross-section.
ihp = 2	for table(s) of velocity and conveyance distribution.

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.)

4) yinc - the elevation increment between successive elevations for which properties are to be computed. (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.)

6) q - discharge (coded for ihp = 2 only) is required to compute velocity and conveyance distribution.

COMMAND J1 - Job computational parameters

Purpose: To set computational control parameters.

Structure:

J1 deltay, ytol, qtol, fntest, ihfnoj

1) deltay - elevation stepping increment between successive assumptions of trail water-surface elevations when balancing the energy equation.
2) ytol - allowable tolerance (error) between successive computed elevations for acceptable energy equation balance. (Default value is 0.02.)
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) fntest - 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 KQ - conveyance, K, Distribution

Purpose: To designate user-defined breakpoints of the kq segment of the approach sections.

Structure:

KQ xlkq, xrkq

1) xlkq - x-coordinate of the left limit of the conveyance (flow) distribution for the kq-section.
2) xrkq - x-coordinate of the right limit of conveyance (flow) distribution for the kq-section.

Note: The model, unless overridden by some combination of xlkq and xrkq, will place the kq-section based on the location of the computed centroid of conveyance.

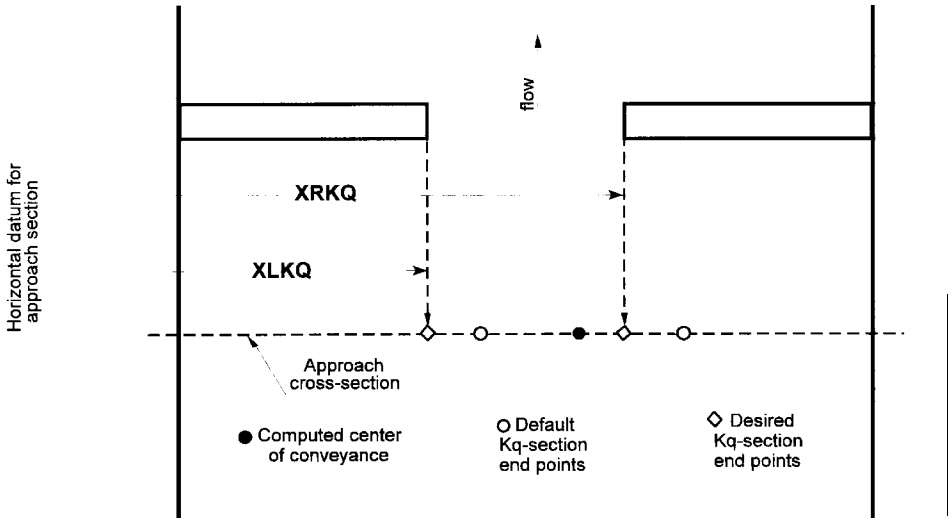


Figure 18. KQ command parameters.

COMMAND N - Manning's coefficient, N

Purpose: To specify values of Manning's "n" roughness coefficient.

Structure: (2 options)

N botn(1), botn(2), ..., botn(nsa)

-- OR --

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 ND 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.
2) topd(i) - hydraulic depth of the ith subarea at and above which the n-value of topn(i) is applicable.

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 PD - Pier (or Pile) elevation-wiDth data

Purpose: To establish pier or pile data.

Structure:

PD ppcd, pelv(1), pddth(1), pnum(1), pelv(2), pnum(2), pddth(2), ..., pelv(npd), pddth (npd), pnum(npd)

1) ppcd - code to indicate whether the obstruction is in the form of piers (ppcd = 0) 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 (above datum).
3) pddth(i) - the gross width of all piers (or pile bents) for the ith pair of elevation-width data.
4) pnum(i) the number of piers/piles at the specific elevation pelv(i).

Notes:

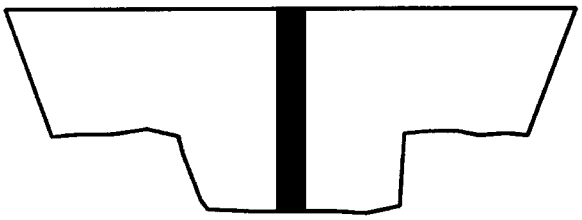
1) The model creates an elevation-area relationship from the elevation-width data. Straight-line interpolation is used to obtain pier (pile) area between specified elevations. A constant pier (pile) area is assumed between the highest elevation coded and the maximum bridge opening elevation.

2) The minimum pier (pile) data requirement is one elevation-width pair. The elevation is taken as the minimum elevation at which the pier (pile) 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.

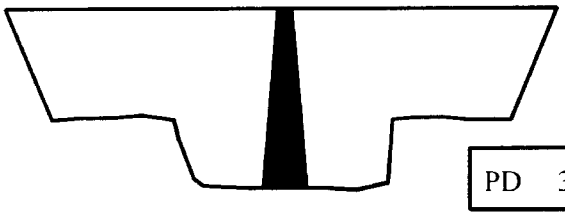
5) An abrupt change can be: (1) additional piers coming into effect with increasing elevation; (2) changes in pier dimensions; and (3) loss of piers with increasing elevation (sloping low chord). The maximum number of elevation-width pairs is 50.



Constant pier width (1.52 m) from channel bottom (elevation 30.48 m) to horizontal low chord

PD 30.48, 1.52, 0.30

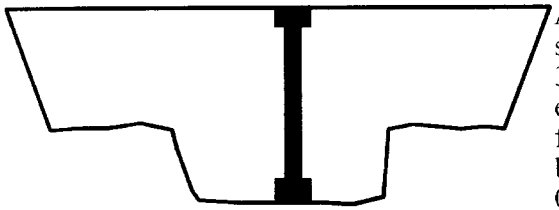
a) constant pier width



Uniformly varying pier width: 1.83 m at channel bottom (elevation 30.48) to 1.22 m at horizontal low chord (elevation 38.10)

PD 30.48, 1.83, 0.30 38.10, 1.22, 0.30

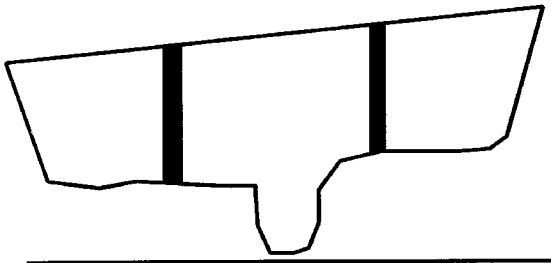
b) uniformly varying pier width



Abrupt variation in pier width due to shape: channel bottom elevation is 30.48 m; horizontal low chord elevation is 38.10 m; 0.91 m wide footer extends 0.61m above channel bottom; 0.91m wide pier cap extends 0.61 m below low chord; 0.46 m pier

PD 30.48,0.91,0.30 31.09,0.91,0.30 31.09,0.46,0.30 37.49,0.46,0.30 37.49,0.91,0.30

c) abruptly varying pier width with shape



Abrupt variation in pier width due to elevation: each pier is 0.61 m wide. Elevations: left pier -at ground 30.78, at low chord 36.58 m; right pier - at ground 31.55 m, at low chord 36.88 m

PD 30.78,0.61,0.30 31.55,0.61,0.30 31.55,1.22,0.61 36.58,1.22,0.61
PD 36.58,0.61,0.31 36.88,0.61,0.30 36.88,0,0

d) abrupt changes in pier width with elevation

Figure 19. PD command parameters.

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 SA - SubArea 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)

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)

COMMAND SI - SI and english units

Purpose: Allows user the option of specifying the unit system for both input and output.

Structure:

SI (code number, 0, 1, 2, or 3)

		Input	Output
code number	0	ENGLISH	ENGLISH
	1	METRIC	METRIC
	2	ENGLISH	METRIC
	3	METRIC	ENGLISH

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 (m/m).

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 - Title and header line 1

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 conjunction 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 - Title and header line 2

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 conjunction 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 - Title and header line 3

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 conjunction 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.

COMMAND UT - User output Tables

Purpose: To specify input data control parameters (up to 3 tables can be obtained).

Structure:

UT varnos (list 1), varnos (list 2), varnos (list 3)

1) 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 (80 columns maximum). The model automatically uses 12 columns, thus leaving a maximum of 68 columns for the user.

Table 6. Variables available for user-defined tables (UT record).

	Variable code number	Heading
Cross-section conveyance	1	K
Cross-section area	2	AREA
Velocity head correction factor, α	3	ALPH
Momentum correction factor, β	4	BETA
Water-surface elevation	5	WSEL
Velocity head	6	VHD
Discharge	7	Q
Section reference distance	8	SRD
Maximum station in cross section	9	XMAX
Maximum elevation in cross section	10	YMAX
Minimum station in cross section	11	XMIN
Minimum elevation in cross section	12	YMIN
Boundary cross-section conveyance	13	K
Boundary cross-section area	14	AREA
Boundary velocity head correction factor, α	15	ALPH
Boundary momentum correction factor, β	16	BETA
Boundary water-surface elevation	17	WSEL
Boundary velocity head	18	VHD
Boundary discharge	19	Q
Boundary section reference distance	20	SRD
Boundary maximum station in cross section	21	XMAX
Boundary maximum elevation in cross section	22	YMAX
Boundary minimum station in cross section	23	XMIN
Boundary minimum elevation in cross section	24	YMIN
Energy grade line	25	EGL
Velocity	26	VEL
Froude number	27	FR#
Critical water-surface elevation	28	CRWS
Minimum flow depth	29	DMIN
Friction loss	30	HF
Other losses (expansion/contraction)	31	HO

Table 6. Variables available for user-defined tables (UT record) (continued).

	Variable code number	Heading
Expansion loss coefficient	32	EK
Contraction loss coefficient	33	CK
Friction slope	34	SF
Error in energy/discharge balance	35	ERR
Flow distance	36	FLEN
Straight-line (SRD) distance	37	SRDL
Stagnation point, left	38	SPLT
Stagnation point, right	39	SPRT
Skew of cross section	40	SKEW
Cross-section wetted perimeter	41	XSWP
Cross-section top width	42	XSTW
Left edge of water	43	LEW
Right edge of water	44	REW
Low steel (submergence) elevation	45	LSEL
Bridge opening length	46	BLEN
Bridge opening type	47	TYPE
Flow classification code	48	FLOW
Abutment station, left toe	49	XLAB
Abutment station, right toe	50	XRAB
Coefficient of discharge	51	C
Pier or pile code	52	PPCD
Pier area ratio	53	P/A
Road overtopping elevation	54	OTEL
Left Road Section		
Flow over road	55	Q
Weir length	56	WLEN
Left edge of water	57	LEW
Right edge of water	58	REW
Maximum depth of flow	59	DMAX
Average depth of flow	60	DAVG
Average total head	61	HAVG
Average weir coefficient	62	CAVG
Maximum velocity	63	VMAX
Average velocity	64	VAVG
Right Road Section		
Flow over road	65	Q
Weir length	66	WLEN
Left edge of water	67	LEW
Right edge of water	68	REW
Maximum depth of flow	69	DMAX
Average depth of flow	70	DAVG
Average total head	71	HAVG
Average weir coefficient	72	CAVG
Maximum velocity	73	VMAX
Average velocity	74	VAVG
Flow contraction ratio (conveyance)	75	M(K)
Geometric contraction ratio (width)	76	M(G)
Conveyance of Kq-section	77	KQ
Left edge of Kq-section	78	XLKQ
Right edge of Kq-section	79	XRKQ

COMMAND WS - Water-Surface elevations

Purpose: To initialize water-surface elevations for profile computations.

Structure:

WS wsi(1), wsi(2), ..., wsi(nprof)

nx) wsi(i) - elevation representing the water-surface elevation to be used at the first cross-section of the ith profile computation (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

1) secid - unique cross-section identification code.
2) srd - section reference distance. Should represent the location of the centerline of the road near the center of the bridge.
3) embwid - the top width 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.)

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. Cumulative distance along the stream measured 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 (m/m). 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. This provides the reference point for elevation adjustments by valley slope.
3) vslope - valley slope, m/m. 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.)

Note: This version of WSPRO now supports use of multiple cross-section templates. Second and subsequent template data overwrite previous cross-section data as they appear in the data set. Template data no longer propagates for cross-sections that precede the XT command. Users must, therefore, ensure that older data sets satisfy this convention. In other words, templates propagate to upstream SRDs for subcritical flow and to downstream SRDs for supercritical flow.

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.

COMMAND *F - Free Format

Purpose: To allow data to be entered in free format.

Structure:

*F (no parameters)

Note: This command should be the first command in the data file if the data following are in free format.

REFERENCES

1) J. Shearman, "WSPRO Users Manual," Federal Highway Administration, Washington, D. C., Draft.

2) "Bridge Waterways Analysis Model: Research Report," Report Number FHWA/RD-86/108, Federal Highway Administration, Washington, DC, July 1986.

3) V. T. Chow, Open-channel Hydraulics, New York, NY, McGraw-Hill, Inc., 1959.

4) V. R. Schneider, J. W. Board, B. E. Colson, F. N. Lee, and L. A. Druffel, "Computation of Backwater and Discharge at Width Constrictions of Heavily Vegetated Flood Plains," U. S. Geological Survey Water-Resources Investigation 76-129, 1977.

HYDRAIN - INTEGRATED DRAINAGE DESIGN COMPUTER SYSTEM

VOLUME V. HY8 - CULVERTS

for:

Office of Technology Applications
Federal Highway Administration
Washington, DC

March 1999

(metric)

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INTRODUCTION

HY8 is a collection of BASIC programs that allows the user to investigate the hydraulic performance of a culvert *system*. A 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 automates the methods presented in HDS-5, "Hydraulic Design of Highway Culverts," HEC-14, "Hydraulic Design of Energy Dissipators for Culverts and Channels," HEC-19, "Hydrology," and information published by pipe manufacturers pertaining to the culvert sizes and materials.[1,2,3,4] This volume of documentation describes the concepts and theories used within HY8. The user may refer to the listed references for detailed explanations.

The documentation is divided into three additional sections: System overview, technical information, and user documentation. System overview provides insight into the capabilities and hydrological aspects covered in the program. The technical information section provides the user with equations and methodologies used by HY8 when performing a culvert analysis. The last section discusses how to apply the program, particularly as it pertains to the HYDRAIN microcomputer package.

The HY8 program runs on IBM PC/XT and compatible microcomputers. It is designed to run on MS-DOS version 2.1 (and higher). HY8 Versions 3.1 and higher have been developed and provided to the Federal Highway Administration (FHWA) for distribution. HY8 Versions 1.1, 2.1, and 3.0 were produced by the Pennsylvania State University in cooperation with FHWA. The HY8 Versions 3.0 and earlier versions were sponsored by the Rural Technical Assistance Program (RTAP) of the National Highway Institute under Project 18B administered by the Pennsylvania Department of Transportation.

Users can apply HY8 both as an interactive program and as a batch program. The program operates both as a stand-alone product and through HYDRAIN.

SYSTEM OVERVIEW

The FHWA 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 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.

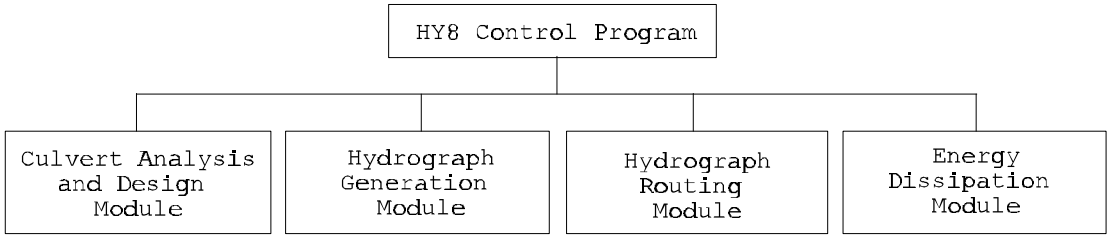

Figure 1. HY8 program modules.

CULVERT ANALYSIS AND DESIGN

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, lengths, and cross-sectional shape characteristics (e.g., diameter), can be analyzed. Each culvert system may consist of several barrels.

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.

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 displayed 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. The program recomputes associated hydraulic parameters for the design discharge when the minimization routine is activated.

HYDROGRAPH GENERATION AND ROUTING

The hydrologic module generates a storm hydrograph that can be used singly or as input into culvert routing analyses. The hydrograph is generated using methods found in the FHWA HEC-19 document.[3] 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 option allows a user-defined storm hyetograph to be entered from which a hydrograph is produced. As a final alternative, the user can enter a hydrograph.

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. 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: employing the prism method, entering a surface area-versus-elevation curve, entering a volume-versus-elevation curve, and providing 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 rela-

tionship. The final option uses actual upstream cross section profiles to calculate the stage-storage relationship. Given some ingenuity, this option could be used to design a stormwater detention basin.

Note: Regardless of storage volume calculation method used, HY8 converts the data entered into storage volumes at even 1-ft (or 0.3048-m intervals if data are in SI units). If this procedure results in a storage depth shallower than 1-ft (0.3048 m), the user is notified and instructed to re-enter storage volume data with greater depth.

Users should also be aware how HY8 uses input hydrograph to be routed. The initial input hydrograph flow value is assumed to be the base flow. If the storage reservoir has not been depleted by the final time step in the input hydrograph, HY8 assumes an input flow equal to the initial value of the input hydrograph (base flow) for as many time steps as are required to deplete the storage reservoir.

ENERGY DISSIPATION

The final module permits the design and analysis of an energy dissipator at the culvert outlet. It follows the design procedures used in FHWA publication HEC-14.[2] Similar to the routing module, this module needs the performance curve generated from 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, the user has to specify which system is used 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.

TECHNICAL INFORMATION

This section describes the technical methods used by HY8 to analyze culvert *systems*. Analysis of culverts using a peak flow is discussed along with hydrograph generation and routing and energy dissipator design. Culvert analysis involves calculating the inlet 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 used in the case of multiple systems.

HY8 performs calculations using equations derived in English units. HY8 allows the user to input SI data and gives reports using SI data, if the user desires. The Benchmark Examples in appendix A of this volume illustrate the use of HY8 in SI units.

INLET CONTROL

Using regression analysis, FHWA 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 three times the culvert rise. 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 applied at headwaters between 0.5 and 3.0 culvert depths, and are of the form:

$$H_{wi} = \left[a + (bzF) + c(zF)^2 + d(zF)^3 + e(zF)^4 + f(zF)^5 - 0.5S\right] \times D \qquad (1)$$

Where:

H_{wi}	=	The inlet control headwater, m.
D	=	The rise of the culvert barrel, m.
a to f	=	Regression coefficients for each type of culvert.
F	=	$Q/D^{5/2}$ for circular culverts, or $Q/(BD^{3/2})$ for box arch pipe culverts,
		Where: Q = flow, m^3/s.
		D = culvert rise, m.
		B = culvert span, m.
S	=	Barrel slope, m/m.
z	=	1.81130889 (metric conversion constant).

The regression coefficients are tabulated in table 1 along with the corresponding chart and scale numbers from HDS-5. These coefficients have been compiled, and in some cases corrected, from a variety of sources for use in HY8.[7, 8, 9, 10, 11]

For discharges that create inlet control heads above the regression equation limits, headwater to culvert rise ratios greater than 3.0, an orifice equation is used to estimate headwater. 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 noncircular 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:

$$H_{wi} = \left[\frac{Q}{k}\right]^2 + 0.5 \ x \ D \qquad (2)$$

Where:

H_{wi}	=	Inlet control headwater, m.
Q	=	Design discharge, m^3/s.
k	=	Coefficient based on the discharge and culvert rise.
D	=	Rise of culvert, m.

The coefficient, **k**, is determined by setting the orifice equation equal to the regression equation at the upper limit of the regression equation. The coefficient is calculated as:

$$k = \frac{Q_{3.0}}{\sqrt{2.5 \ x \ D}} \qquad (3)$$

Where:

$Q_{3.0}$	=	Discharge from regression equation (1) at H_{wi} / D = 3.0, m^3/s.

For discharges corresponding to inlet control heads less than half the rise 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:

$$F_r^2 = \frac{Q^2 \times T}{g \times A^3} = 1 \qquad (4)$$

Table 1. Polynomial coefficients.

HDS-5 Chart No.	HDS-5 Scale	a	b	c	d	e	f
1	1	0.087483	0.706578	-0.2533	0.0667	-0.00662	0.000251
	2	0.114099	0.653562	-0.2336	0.059772	-0.00616	0.000243
	3	0.108786	0.662381	-0.2338	0.057959	-0.00558	0.000205
2	1	0.167433	0.538595	-0.14937	0.039154	-0.00344	0.000116
	2	0.107137	0.757789	-0.3615	0.123393	-0.01606	0.000767
	3	0.187321	0.567719	-0.15654	0.044505	-0.00344	0.00009
3	A	0.063343	0.766512	-0.316097	0.08767	-0.00984	0.000417
	B	0.081730	0.698353	-0.25368	0.065125	-0.0072	0.000312
8	1	0.072493	0.507087	-0.11747	0.02217	-0.00149	0.000038
	2	0.122117	0.505435	-0.10856	0.020781	-0.00137	0.0000346
	3	0.144138	0.461363	-0.09215	0.020003	-0.00136	0.000036
9	1	0.156609	0.398935	-0.06404	0.011201	-0.00064	0.000015
10	2	0.156609	0.398935	-0.06404	0.011201	-0.00064	0.000015
11	2	0.122117	0.505435	-0.10856	0.020781	-0.00137	0.000034
	4	0.089563	0.441247	-0.07435	0.012732	-0.00076	0.000018
12	2	0.156698	0.398935	-0.06404	0.011201	-0.00064	0.000015
29	1	0.13432	0.55951	-0.1578	0.03967	-0.0034	0.00011
	2	0.15067	0.50311	-0.12068	0.02566	-0.00189	0.00005
	3	0.03817	0.84684	-0.32139	0.0755	-0.00729	0.00027
30	1	0.13432	0.55951	-0.1578	0.03967	-0.0034	0.00011
	2	0.15067	0.50311	-0.12068	0.02566	-0.00189	0.00005
	3	0.03817	0.84684	-0.32139	0.0755	-0.00729	0.00027
34	1	0.111281	0.610579	-0.194937	0.051289	-0.00481	0.000169
	2	0.083301	0.795145	-0.43408	0.163774	-0.02491	0.001411
	3	0.089053	0.712545	-0.27092	0.792502	-0.00798	0.000293
35	1	0.089053	0.712545	-0.27092	0.792502	-0.00798	0.000293
36	1	0.089053	0.712545	-0.27092	0.792502	-0.00798	0.000293
41,42, 43	1	0.111281	0.610579	-0.104937	0.051289	-0.00481	0.000169
	2	0.083301	0.795145	-0.43408	0.163774	-0.02491	0.001411
	3	0.089053	0.712545	-0.27092	0.792502	-0.00798	0.000293
55	1	0.2115	0.3927	-0.0414	0.0042	0.0003	-0.00003
	2	0.2252	0.3471	-0.0252	0.0011	0.0005	-0.00003

Note: ***Values for English system of units. Equation (1) is valid with these coefficients when the metric conversion constant (z) is used.***

Where:

F_r	=	The Froude number (equal to one in this case).
Q	=	The culvert flow rate, m^3/s.
A	=	The culvert's cross sectional flow area, m^2.
T	=	The culvert's cross section top width, m.
g	=	The gravitational acceleration (9.81 m/s^2).

Based on the critical values of depth and velocity described in equation (4), the following minimum energy equation is used to estimate headwater:

$$H_{wi} = d_c + (1 + K_e) \frac{V_c^2}{2 \times g} \tag{5}$$

Where:

d_c	=	The critical depth at culvert entrance for given discharge, m.
K_e	=	The entrance loss coefficient.
V_c	=	The velocity at critical depth, m/s.

The entrance loss 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 coefficient is calculated using the following equation:

$$K_e = \left[\frac{(0.5 \times D - d_c) \times 2 \times g}{\left[\frac{Q_{0.5}^2}{A_c^2} \right]} - 1 \right] \tag{6}$$

Where:

$Q_{0.5}$	=	Discharge computed using regression equation at a H_{wi} /D value of 0.5 m^3/s.
A_c	=	Cross-section area at critical flow, m^2.

The minimum energy equation, with the velocity head loss adjusted by K_e, generally describes the low flow portion of the inlet control headwater curve; however, numerical errors in the calculation of flow for very small depths tends to increase the velocity head as the flow approaches zero. This presents little or no problem in most single system 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 depth 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.

$$E = 1.5 \times d_c \tag{7}$$

Where:

E	=	The approximation of the minimum energy, m.
d_c	=	The critical depth, m.

The critical depth is continuously decreasing and approaches zero as the flow approaches zero. The headwater calculation between flow at zero and half the rise 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 weighting 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 rise to zero flow, the velocity head is gradually converted to one half the critical depth. First, the fractional contribution of a given flow, Q, in relation with the 15-percent flow is calculated;

$$Q_{frac} = \frac{0.15 \times Q_{0.5} - Q}{0.15 \times Q_{0.5}} \tag{8}$$

Where:

Q_{frac}	=	The fractional contribution of a given flow.
$Q_{0.5}$	=	The discharge that creates inlet control head of one half the rise of the culvert, m^3/s.
Q	=	A given discharge, between 0 and 15 percent of $Q_{0.5}$, m^3/s.

Next, a velocity head coefficient, based on the fractional contribution and the velocity head is computed;

$$C_{vh} = \frac{1 - Q_{frac}}{1 + \left[\frac{V^2}{2 \times g} \; x \; Q_{frac}\right]} \tag{9}$$

Where:

C_{vh}	=	The velocity head coefficient.
Q_{frac}	=	The fractional contribution of a given flow.
V	=	The average velocity, m/s.

Finally, the corrected velocity head can be calculated;

$$\frac{V_{corr}^2}{2 \times g} = \left[Q_{frac} \times 0.5 \times d_c\right] + \left[\frac{V^2}{2 \times g} \times C_{vh}\right] \tag{10}$$

Where:

V_{corr}	=	The corrected velocity, m.
Q_{frac}	=	The fractional contribution of a given flow.
d_c	=	The critical depth for given flow, m.

As the discharge, Q, approaches zero, Q_{frac} approaches unity and C_{vh} vanishes. Inversely, as Q approaches $Q_{0.5}$, Q_{frac} vanishes and C_{vh} approaches unity. From equation (10), it can be said that for low flows (i.e., less than 15 percent of $Q_{0.5}$), the inlet control equation becomes:

$$H_{wi} = d_c + (1 + C_{vh}) \times \frac{V_{corr}^2}{2 \times g} \tag{11}$$

Where:

H_{wi}	=	The inlet control headwater, m.
d_c	=	The critical depth, m.
C_{vh}	=	The velocity head coefficient.
V_{corr}	=	The corrected velocity, m/s.

DETERMINING INLET OR OUTLET CONTROL

On mild slopes, the direct step method is used to calculate water-surface profiles when open channel flow occurs in the culverts. That is, when a portion or all of the culvert is flowing less than full, water-surface profile computations are used to compute friction losses. The water-surface profile computations begin at the culvert barrel exit and proceed upstream for culverts under outlet control. For inlet control, computations commence at the inlet and proceed downstream. If the water surface 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 outlet is submerged. 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.

OUTLET CONTROL

Headwater elevation under outlet control is determined by adding the friction losses in the pipe barrel, the entrance loss, and exit loss 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 hydraulically mild or steep and whether the culvert outlet crown is submerged or unsubmerged (i.e., whether the downstream water surface is above or below the outlet crown).

The procedure for determining outlet depth is based on the submerged or unsubmerged condition of the culvert outlet and is summarized in figure 2. Critical depth and normal depth are computed and compared to determine if the culvert assumes a mild or steep slope. Next, the program determines whether the inlet and outlet are submerged or unsubmerged. Outlet depth is determined based on the combination of possible tailwater conditions.

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.

In steep culverts, a hydraulic jump may form 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.

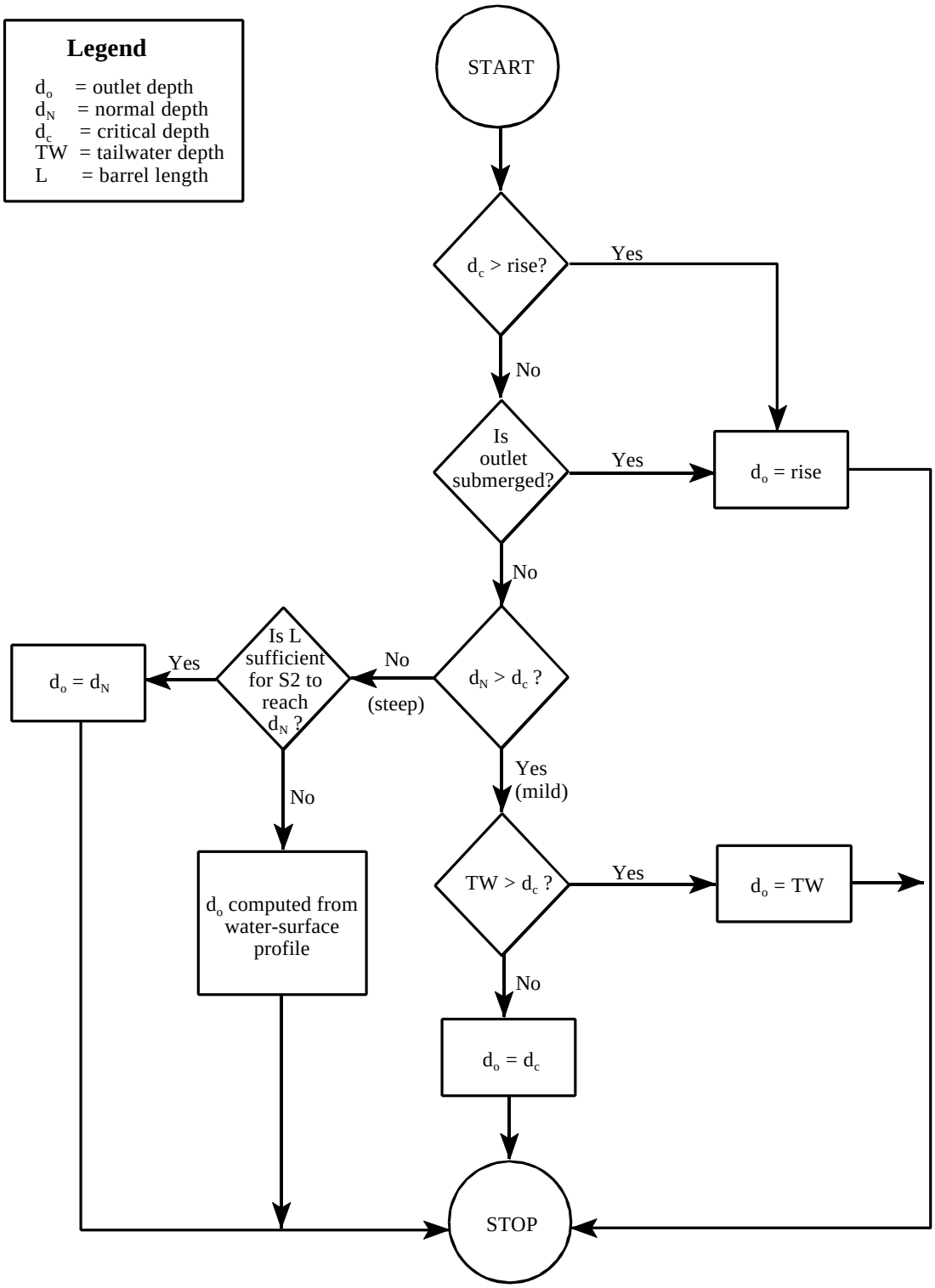

Figure 2. Determination of outlet depth.

Friction losses in the barrel are determined by manipulating Manning's formula to solve for friction slope:

$$S_f = \left[\frac{Q \times n}{A \times R_h^{0.67}} \right]^2 \tag{12}$$

Where:

S_f	=	The friction slope, m/m.
Q	=	The culvert barrel discharge, m^3/s.
n	=	Manning's roughness coefficient.
A	=	The cross section flow area, m^2.
R_h	=	The hydraulic radius of the culvert, m.

If the barrel is flowing full, the friction slope is constant over the length of the full-flowing barrel and frictional head loss can be computed by the following:

$$H_f = S_f \times L \tag{13}$$

Where:

H_f	=	The head loss due to friction in the culvert barrel, m.
S_f	=	The friction slope, m/m.
L	=	The length, m, 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:

$$\delta H_f = S_f \times \delta L \tag{14}$$

Where:

δH_f	=	The incremental head loss, m.
S_f	=	The friction slope, m/m, at δL.
δL	=	The incremental change in length, m.

The open channel barrel loss calculations for outlet control proceed as follows:

1. An increment of head loss is determined.

2. The friction slope is calculated at the outlet.

3. The incremental 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 incremental 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).

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:

$$H_e = K_e \times \frac{V^2}{2 \times g} \tag{15}$$

Where:

H_e	=	The entrance head loss, m.
K_e	=	The entrance loss coefficient.
V	=	The flow velocity just inside culvert barrel, m/s.
g	=	The gravitational acceleration (9.81 m/s^2).

Values of K_e are selected by HY8 from the values in HDS-5 based on culvert shape and entrance condition.

Similarly, the exit loss equation is:

$$H_o = 1.0 \times \frac{V^2}{2 \times g} \tag{16}$$

Where:

H_o = The exit head loss, m.
V = The flow velocity inside the culvert barrel upstream of the outlet, m/s.

Outlet control water surface elevation is computed as the sum of all losses and the outlet depth:

$$H_{wo} = H_f + H_e + H_o + h_o \tag{17}$$

Where:

h_o = Tailwater depth or (d_c + rise)/2, m.

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 (normal depth) 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. 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.

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 algorithm 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:

$$\tau = \gamma \times S_f \times TW \tag{18}$$

Where:

τ	=	The maximum shear, in Pa (N/m^2).
γ	=	The specific weight of water, (9800 N/m^3).
S_f	=	The friction slope (equal to channel slope for uniform flow), m/m.
TW	=	The tailwater depth, or the maximum depth of flow occurring in the natural channel just beyond the culvert outlet, m.

Froude number is determined from the following equation:

$$F_r^2 = \left[\frac{Q^2 \times T}{g \times A^3}\right] \tag{19}$$

Where:

F_r	=	The Froude number.
Q	=	The discharge in the channel, m^3/s.
T	=	The channel cross section's top width, m.
A	=	The channel's waterway cross sectional area, m^2.

ROADWAY OVERTOPPING

The flow that overtops an embankment is analogous to that of a broad crested weir. The following weir equation is used to determine flow over embankments:

$$Q_o = \frac{C_d \times L \times H_{wr}^{\frac{3}{2}}}{z} \tag{20}$$

Where:

Q_o	=	The discharge over embankment, m^3/s.
C_d	=	The discharge coefficient (weir coefficient).
L	=	The length of weir crest, m.
H_{wr}	=	The upstream head above embankment crest, m.
z	=	0.81130889 (metric conversion constant).

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.[1] 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 analysis of flow through two or more barrels and/or over the roadway may be necessary. If 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 considerably erroneous. 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 and tailwater elevations) and the total flow conveyed must be equal to the sum of the flows through each of the culverts and over the roadway.

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 experienced in 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.[5] 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:

$$Q_i = \frac{Q_{ic}}{\Sigma Q_{ic}} \tag{21}$$

Where:

Q_i	=	The adjusted flow through barrel i, m^3/s.
Q_{ic}	=	The calculated flow through barrel i, m^3/s.
ΣQ_{ic}	=	The sum of the calculated flows, m^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.

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. A limit of 50 iterations is set after which the process is aborted and the program proceeds with 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. The criterion 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 one percent times the number of barrels.

After the tabulation of the performance curve for multiple culverts, a table of errors for the iterative technique is given. This table includes error of percent total flow and headwater elevation error.

MINIMIZATION OF CULVERT SIZE

A culvert minimization routine permits a steady-state culvert design calculation to be made. The minimization routine uses an allowable headwater elevation and design discharge as the controlling hydraulic factors 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 result. 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.

HYDROGRAPH GENERATION AND ROUTING

The hydrograph generation and routing modules permit a dynamic evaluation of culvert system performance. Hydrographs may be developed within HY8 based on drainage area characteristics and rainfall patterns or they may be incorporated from other sources such as the HYDRO program (also part of HYDRAIN). For technical documentation of the internal generation of hydrographs, the user is referred to Masch.[3]

Hydrograph routing is accomplished using hydrographs developed in the hydrograph generation module and the site and culvert characteristics of interest. The hydrograph is routed through the system using the storage indication method. Results include variations in headwater and outflow as a function of time. **(Caution: In HY8, hand-inputted hydrographs force this computational time increment. Make sure there are sufficient points or routing will be inaccurate.)**

ENERGY DISSIPATOR DESIGN

HY8 follows the design procedures presented in HEC-14.[2] Restrictions and limitations on these dissipators are presented in a table format for each dissipator category within the HY8 software. Hydraulic parameters computed in the culvert design program are imported into this module. The following categories of energy dissipators are available:

(1) Internal Energy Dissipators (Box or Circular shapes):
- Increased Resistance
- Tumbling Flow

(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

Hydrologic data and soil type characteristics are used to estimate the scour hole geometry at the culvert outlet. HY8 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.

USER DOCUMENTATION

For those users who have obtained HY8 as part of the FHWA's **HYDRAIN** package, the following section discusses the procedures for accessing HY8 through the HYDRAIN System Shell. The user is referred to the HYDRAIN documentation if additional information is required on the working of the HYDRAIN System Shell.

The interactive capabilities of HY8 provide much of ease (self contained within the menu screens and helps) in performing an analysis . This interactive capability 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 can be edited and summary tables of input data and output results are generated periodically throughout the data entry process. HY8 also can be operated in a batch mode. In this mode, the user creates an input file and uses HY8 to process the data into an output screen or file.

THE HYDRAIN ENVIRONMENT

HY8, as well as the other HYDRAIN software packages, are activated through the use of what is known as the HYDRAIN "shell." This shell is a separate program that ties the system components together and allows them to be accessed. Before work on a specific HY8 example can begin, the HYDRAIN shell must first be entered. This process is begun, from DOS by entering the C:\HYDRAIN directory, typing the command **HYDRAIN**. A screen will appear showing the member sponsors of the Pooled Fund Project. Another <Enter> reveals a message (a "disclaimer"). A third <Enter> will place the user in the Main Menu.

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

- File - File operations, DOS shell, Exit.
- Editor - input or edit data for HYDRA, WSPRO, **HY8**, HYDRO, or HYCHL batch programs.
- Analyze - run HYDRA, WSPRO, **HY8**, HYDRO, HYCHL, NFF, or HYEQT.

- Utilities - System maintenance, HYDRAIN setup.

- Help - long help files for selected topics in HYDRAIN.

Selection of an option within the Main Menu is accomplished by using the ARROW keys 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.

As mentioned earlier, although HY8 has an interactive program, it can also be run in batch mode. To access the HY8 interactive mode, move the cursor to the Analyze option and strike <Enter>. Once within the Analyze pulldown menu, move to the HY8 option with the "down" ARROW cursor key. Once the menu bar is over the **HY8** field, striking <Enter> will initiate the HY8 program.

At times, there may be insufficient RAM to run HY8 within the HYDRAIN shell. If this problem is encountered, HY8 can be executed without the shell.

EXECUTING HY8 WITHOUT THE HYDRAIN SYSTEM SHELL

HY8 can be executed apart from the HYDRAIN System Shell by moving to the default HY8 directory, typing the command **HY8** and striking <Enter>. A good idea is to place the HY8 directory name into the PATH statement, usually found in the AUTOEXEC.BAT file.

HY8 PROGRAM MENU

The program begins in the HY8 option menu. It is at this juncture that the user has access to the 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.

Culvert Analysis (and Design) Module

The culvert analysis section of the program allows for data entry, editing, and analysis. The user is sequentially led through the analysis process and is provided with an understanding of the necessary procedures used in the analysis of a culvert.

The option menu consists of six sections; Culvert File, Available Files, Design Options, Single Culvert, Multiple Culverts, and Default Options. The user may end HY8 by pressing <Q> or may view documentation by pressing <ENTER>.

The Culvert File section contains choices which enable users to <C>reate a new input file, <E>dit the available input file, load an input file by <N>ame, or choose an input file from a <D>irectory list.

The Available Files section indicates the names of the currently loaded Input (INP), output (PC), and Report (PRN or LST) files. If no input file is specified, one must either be loaded using the <N>ame or <D>irectory options or created using the <C>reate option. Once loaded, the available input file may be edited using the <E>dit option.

The Design Options section gives user access to the other three modules of HY8. <H>ydrograph allows generation of hydrograph files for use with HY8 and other programs. <R>outing allows the user to generate a routed hydrograph specifying upstream storage characteristics. <J> allows the user to design energy dissipators for culvert outfalls.

When creating a new culvert file (<C>reate under the Culvert File section), 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 are entered. There are two possible options for entering these 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 are used by the program to generate invert data for the inlet and outlet. One barrel is the default. This number can be edited to fit the user's desired number of barrels.

```
   CULVERT FILE: NHIRR       FHWA CULVERT ANALYSIS          DATE: 10-15-97
 TAILWATER FILE: REGULAR       HY8, VERSION 6.1             CULVERT NO. 1 OF 1



                    CULVERT INVERT DATA


              NO.     ITEM                           VALUE

              <1> INLET STATION (m)                   0.00
              <2> INLET ELEVATION (m)                30.00
              <3> OUTLET STATION (m)                 60.00
              <4> OUTLET ELEVATION (m)               29.50
              <5> ENTER NUMBER OF BARRELS             1


                  <NUMBER> TO EDIT ITEM
                  <ENTER>  TO CONTINUE DATA INPUT
                  <ESC>    FOR SITE DATA OPTION MENU
```

Figure 3. Culvert invert data screen.

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 are 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 x, y coordinates. There are also options to enter the user's 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. From this data, a tailwater rating curve is developed in tabular 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. A weir coefficient and the embankment width are also needed for the overtopping analysis. The analysis is similar to that of a broad crested weir and similar data are needed. For 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 **P** for plot. This, and other graphics, may be printed using the print screen keys if the GRAPHICS.COM (CGA, EGA, VGA drivers) or MSHERC.COM (Hercules monochrome driver) was invoked prior to initiating the HY8 session.

A minimization routine allows the designer to enter an allowable headwater elevation which will 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 Options Menu screen. Only culvert number one can be minimized.

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. Output file may be directed to the screen, printer, or a file (having the standard HYDRAIN **.LST** extension).

FHWA CULVERT ANALYSIS
HY8, VERSION 6.1
SUMMARY TABLE

DATE: 10-15-97
TIME: 15:50:10

CULV NO.	<S> SITE DATA			<C> CULVERT SHAPE, MATERIAL, INLET				
	INLET ELEV. (m)	OUTLET ELEV. (m)	CULVERT LENGTH (m)	BARRELS SHAPE MATERIAL	SPAN (m)	RISE (m)	MANNING n	INLET TYPE
1	30.00	29.50	60.00	1 - RCB	652	652	.012	CONVENTIONAL

HEADWATER ELEVATIONS (m)			FLOW VELOCITY (m/s)			FLOW DEPTHS (m)		
ENTER ALLOWABLE	=	31.00	CULVERT	=	2.63	CULVERT	=	0.36
CONTROLLING	=	30.68	CHANNEL	=	1.05	CHANNEL	=	0.26
INLET CONTROL	=	30.68	DISCHARGE	=	0.50	NORMAL	=	0.39
OUTLET CONTROL	=	30.41	SLOPE	=	0.0083	CRITICAL	=	0.45

MAXIMUM HEADWATER <ENTER > TO RETURN <S> TO SAVE FILE
<H> TO CHANGE HEADWATER

Figure 4. Data summary table screen.

The output includes a performance table for individual culverts in the roadway so that culverts can be compared using plots. 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 on diskette.

Help screens are operational throughout HY8 by pressing <F1>. Pressing <F2> displays a list of the various authors that have contributed to the HY8 program. HY8 can be exited by pressing <F5>. HY8 can be temporarily exited to DOS by striking <F9>. The CSU editor can be accessed by striking <F7>. These function keys are operational whenever they are displayed at the bottom of any HY8 screen.

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 ensure that data are placed on a file for later reuse or editing.

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. 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 HY8 was initially accessed.

APPENDIX A. BENCHMARK EXAMPLES

The following examples are hypothetical systems modeled by HY8 which illustrate some of the program's capabilities. It should be recognized that these examples are not meant to give a comprehensive guide of every program. These examples demonstrates how culvert hydraulic analysis and design can be accomplished using HY8. At the HY8 options menu, the user selects the option, "<C> Create", to enter the culvert analysis and design module. Additional examples may be found in Ginsberg.[6] The intent is that these examples will achieve at least these two objectives:

1. Provide information on how to set up a problem.

2. Demonstrate what to expect for output.

The examples include a figure to schematically represent the problems. Each example provides the output data set developed by the run. Each of the examples provides a different type of HY8 application. The applications are:

1. Designing a box culvert curve.

2. Multiple culvert analyses.

Example One: Peak Flow Box Culvert Design

Problem: A box culvert located at the site shown in figure 5 is to be designed to pass a flow of 6.2 m^3/s without reaching within 0.3 m of the roadway elevation (i.e., 0.3 m of freeboard). Also the culvert crown must be at least 1 m below the road surface. The freeboard and cover requirements provide the design criteria of a 1.220-m maximum culvert rise and a 2.0-m allowable headwater, respectively. The inlet is a square headwall with 1 to 1.5 bevels (used to reduce entrance losses). The example uses an irregular channel shape to generate the tailwater rating curve. The Manning's n value in the channel is 0.03 and 0.1 in the overbank areas. The site data also provides roadway information so the example can consider roadway overtopping. A maximum flow of 14.2 m^3/s sets the upper bound of the performance curve. The interactive program prompts for the needed data. Call the input file HY81.

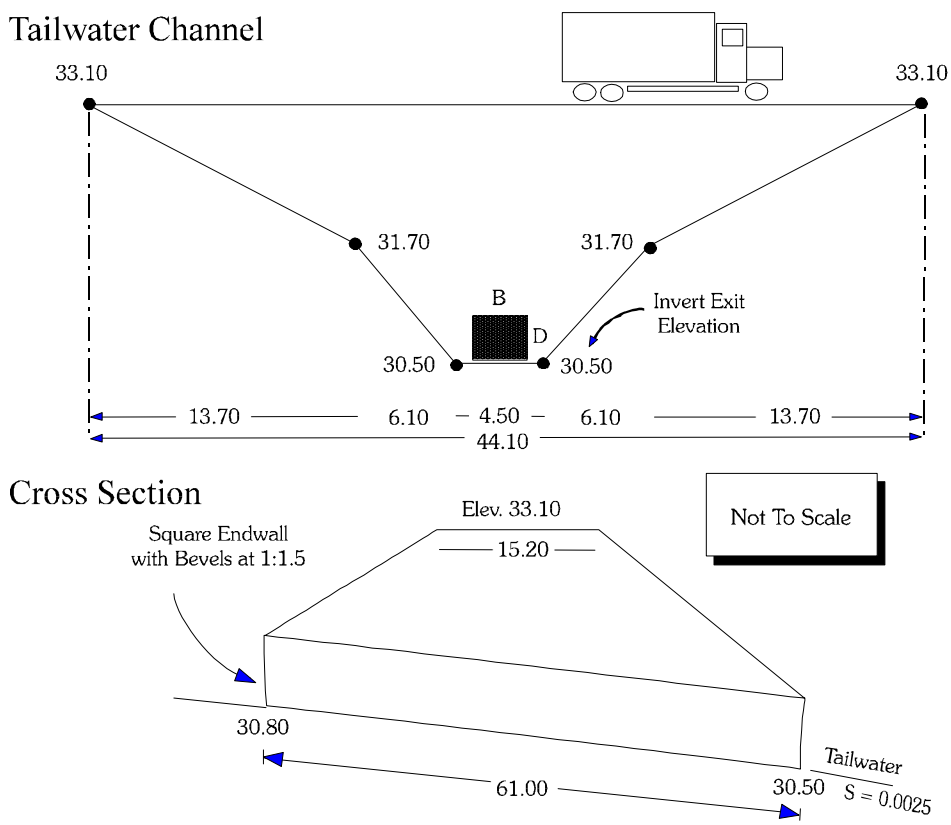

Figure 5. Site data for example one.

Input:

After creating a file called HY81, the user will be prompted for discharge range, site data, and culvert characteristics (shape, size, material and inlet type). The discharge range for this example will be from 0 to 14.2 m^3/s. The design flow will equal 6.2 m^3/s, based on the use of USGS regression equations at the site.

As an initial estimate, select a 1.220-m by 1.220-m concrete box culvert. As each group of culvert data is entered the user is allowed to edit any incorrect entries.

After all culvert data is entered, the program will prompt for data pertaining to the channel so that tailwater rating curve can be determined. After entering the irregular channel information, 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.

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. Selecting option (I) will permit the user to interpolate data between calculated points.

The Tailwater Rating Curve table consists of tailwater elevation at normal depth, natural channel velocity, and the shear stress at the bottom of the channel for various flow rates. Entering <P> will cause the computer to display the rating curve for the channel.

The next prompts are for the roadway profile, so that an overtopping analysis can be performed. Assume the roadway profile is a constant, level surface 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 15.20 m. Once all data is entered, HY8 takes the user to the Data Summary screen.

Minimize Culvert Span

Use the Minimize Culvert Span option to see if the 1.220-m by 1.220-m box culvert can meet the allowable headwater constraints. Minimize is option M in the Data Summary screen. After selecting this option, HY8 prompts for the allowable headwater elevation. Once the value is entered (32.50 m), the program designs a culvert size that passes the allowable headwater at the design flow. The resulting culvert size is a 1.83-m by 1.220-m box culvert. Leave the Minimize option and press <Enter> to perform additional analysis on the culvert.

Output:

The culvert performance curve table can be obtained by selecting option (O). When option (O) is selected, the program will compute the performance curve table, considering overtopping in the analysis. Once the overtopping calculations have finished, the program will provide and opportunity to create output reports. The report for example one follows.

Output File: HY81.LST

1

CURRENT DATE: 05-01-1997 FILE DATE: 05/01/97
CURRENT TIME: 06:01:00 FILE NAME: HY81

))
)))))))))))))))))))))))))) FHWA CULVERT ANALYSIS))))))))))))))))))))))))))
)))))))))))))))))))))))))) HY-8, VERSION 6.1))))))))))))))))))))))))))

C	SITE DATA			CULVERT SHAPE, MATERIAL, INLET				
U L V NO.	INLET ELEV. (m)	OUTLET ELEV. (m)	CULVERT LENGTH (m)	BARRELS SHAPE MATERIAL	SPAN (mm)	RISE (mm)	MANNING n	INLET TYPE
1	30.80	30.50	61.00	1 - RCB	1830	1220	.012	CONVENTIONAL
2								
3								
4								
5								
6								

))
SUMMARY OF CULVERT FLOWS (m3/s) FILE: HY81 DATE: 05-01-1997

ELEV (m)	TOTAL	1	2	3	4	5	6	ROADWAY	ITR
30.80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	1
31.40	1.4	1.4	0.0	0.0	0.0	0.0	0.0	0.00	1
31.76	2.8	2.8	0.0	0.0	0.0	0.0	0.0	0.00	1
32.06	4.3	4.3	0.0	0.0	0.0	0.0	0.0	0.00	1
32.36	5.7	5.7	0.0	0.0	0.0	0.0	0.0	0.00	1
32.47	6.2	6.2	0.0	0.0	0.0	0.0	0.0	0.00	1
33.10	8.5	8.5	0.0	0.0	0.0	0.0	0.0	0.00	1
33.16	9.9	8.7	0.0	0.0	0.0	0.0	0.0	1.15	5
33.20	11.4	8.8	0.0	0.0	0.0	0.0	0.0	2.46	4
33.24	12.8	8.9	0.0	0.0	0.0	0.0	0.0	3.71	3
33.27	14.2	9.0	0.0	0.0	0.0	0.0	0.0	5.05	3
33.10	8.5	8.5	0.0	0.0	0.0	0.0	0.0	OVERTOPPING	

))

))
SUMMARY OF ITERATIVE SOLUTION ERRORS FILE: HY81 DATE: 05-01-1997

HEAD ELEV (m)	HEAD ERROR (m)	TOTAL FLOW (m3/s)	FLOW ERROR (m3/s)	% FLOW ERROR
30.80	0.000	0.00	0.00	0.00
31.40	0.000	1.42	0.00	0.00
31.76	0.000	2.84	0.00	0.00
32.06	0.000	4.26	0.00	0.00
32.36	0.000	5.68	0.00	0.00
32.47	0.000	6.20	0.00	0.00
33.10	0.000	8.52	0.00	0.00
33.16	-0.002	9.94	0.07	0.70
33.20	-0.001	11.36	0.06	0.52
33.24	-0.002	12.78	0.12	0.98
33.27	-0.002	14.20	0.12	0.82

))
<1> TOLERANCE (m) = 0.003 <2> TOLERANCE (%) = 1.000

))

CURRENT DATE: 05-01-1997 FILE DATE: 05-01-1997
CURRENT TIME: 13:12:44 FILE NAME: HY81

))

PERFORMANCE CURVE FOR CULVERT 1 - 1(1830 mm BY 1220 mm) RCB

))

DIS- CHARGE FLOW (m3/s)	HEAD- WATER ELEV. (m)	INLET CONTROL DEPTH (m)	OUTLET CONTROL DEPTH (m)	FLOW TYPE <F4>	NORMAL DEPTH (m)	CRIT. DEPTH (m)	OUTLET DEPTH (m)	TW DEPTH (m)	OUTLET VEL. (m/s)	TW VEL. (m/s)
0.00	30.80	0.00	-0.30	0-NF	0.00	0.00	0.00	0.00	0.00	0.00
1.42	31.40	0.60	0.55	1-S2n	0.34	0.40	0.30	0.34	2.55	0.69
2.84	31.76	0.96	0.78	1-S2n	0.54	0.63	0.55	0.49	2.84	0.84
4.26	32.06	1.26	1.07	1-S2n	0.73	0.82	0.70	0.60	3.33	0.94
5.68	32.35	1.55	1.42	5-S2n	0.90	1.00	0.87	0.70	3.55	1.02
6.20	32.47	1.67	1.57	5-S2n	0.96	1.05	0.93	0.73	3.63	1.05
8.52	33.10	2.25	2.30	6-FFc	1.22	1.22	1.22	0.85	3.82	1.14
8.72	33.16	2.30	2.36	6-FFc	1.22	1.22	1.22	0.92	3.91	1.19
8.85	33.20	2.34	2.40	6-FFc	1.22	1.22	1.22	0.98	3.96	1.23
8.94	33.24	2.37	2.44	6-FFc	1.22	1.22	1.22	1.03	4.01	1.27
9.03	33.27	2.40	2.47	6-FFc	1.22	1.22	1.22	1.09	4.05	1.30

))

El. inlet face invert 30.80 m El. outlet invert 30.50 m
El. inlet throat invert 0.00 m El. inlet crest 0.00 m

))

***** SITE DATA ***** CULVERT INVERT **************

INLET STATION 0.00 m
INLET ELEVATION 30.80 m
OUTLET STATION 61.00 m
OUTLET ELEVATION 30.50 m
NUMBER OF BARRELS 1
SLOPE (V/H) 0.0049
CULVERT LENGTH ALONG SLOPE 61.00 m

***** CULVERT DATA SUMMARY ************************

BARREL SHAPE BOX
BARREL SPAN 1830 mm
BARREL RISE 1220 mm
BARREL MATERIAL CONCRETE
BARREL MANNING'S n 0.012
INLET TYPE CONVENTIONAL
INLET EDGE AND WALL 1.5:1 BEVEL (90 DEG.)
INLET DEPRESSION NONE

))

```
CURRENT DATE: 05-01-1997                                FILE DATE: 05-01-1997
CURRENT TIME: 13:12:44                                  FILE NAME: HY81

))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))
))))))))))))))))))))))))))         TAILWATER         ))))))))))))))))))))))))))
))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))

***** USER DEFINED CHANNEL CROSS-SECTION                FILE NAME: HY81
      MAIN CHANNEL AND LT & RT OVER BANKS               FILE DATE: 01/01/96
      LEFT CHANNEL BOUNDARY           2
      RIGHT CHANNEL BOUNDARY          5
      MANNING n LEFT OVER BANK        0.100
      MANNING n MAIN CHANNEL          0.030
      MANNING n RIGHT OVER BANK        0.100
      SLOPE OF CHANNEL                0.0025 m/m

      CROSS-SECTION    X          Y
        COORD. NO.     (m)        (m)
            1           0.00      33.10
            2          13.70      31.70
            3          19.80      30.50
            4          24.30      30.50
            5          30.40      31.70
            6          44.10      33.10

******* UNIFORM FLOW RATING CURVE FOR DOWNSTREAM CHANNEL

        FLOW     W.S.E.  FROUDE   DEPTH    VEL.   SHEAR
        (m3/s)     (m)   NUMBER     (m)   (m/s)    (Pa)
         0.00     30.50   0.000    0.00    0.00    0.00
         1.42     30.84   0.424    0.34    0.69    6.46
         2.84     30.99   0.446    0.49    0.84    8.71
         4.26     31.10   0.459    0.60    0.94   10.39
         5.68     31.20   0.468    0.70    1.02   11.73
         6.20     31.23   0.471    0.73    1.05   12.16
         8.52     31.35   0.481    0.85    1.14   13.84
         9.94     31.42   0.486    0.92    1.19   14.70
        11.36     31.48   0.490    0.98    1.23   15.51
        12.78     31.53   0.494    1.03    1.27   16.28
        14.20     31.59   0.497    1.09    1.30   17.00
Note: Shear stress was calculated using R.

))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))
))))))))))))))))))))))))))  ROADWAY OVERTOPPING DATA  ))))))))))))))))))))))))))
))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))

      ROADWAY SURFACE                             PAVED
      EMBANKMENT TOP WIDTH                        15.24 m
      CREST LENGTH                                44.10 m
      OVERTOPPING CREST ELEVATION                 33.10 m

))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))
```

Example Two: Multiple Culvert Analysis

Problem: This example demonstrates that HY8 can analyze up to six culvert systems, with different barrel shapes, roughness, inverts, and/or slopes during the same run. For this example, use HY8 to concurrently analyze a single barrel, 1.220-m by 1.220-m reinforced concrete box (RCB) and a single barrel, 1.220-m diameter, corrugated steel pipe (CSP). Assume that while the RCB is at the same invert elevation as example one, the CSP inverts are 0.150 m higher in elevation (i.e., upstream invert at 30.80 m, downstream invert at 30.50-m elevation). Otherwise, assume the culvert data is the same as example one. The design flow for this example is 11.3 m^3/s with flows up to 28.3 m^3/s being analyzed. Once again, the roadway profile is a constant level surface. The tailwater rating curve derived for example one can be used again in this example. Call the input file HY82 so the original file does not get overwritten.

Do not use the minimize option (it only works on one culvert system), but after entering all the data, proceed to the overtopping analysis option. Selecting the print option enables an output file HY82.LST to be written to the disk.

Output File: HY82.LST

```
                                                                           1

CURRENT DATE: 05-01-1997                                FILE DATE: 05/01/97
CURRENT TIME: 13:24:14                                  FILE NAME: HY82

))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))
))))))))))))))))))))))))))   FHWA CULVERT ANALYSIS    ))))))))))))))))))))))))))
))))))))))))))))))))))))))     HY-8, VERSION 6.1      ))))))))))))))))))))))))))
```

C	SITE DATA			CULVERT SHAPE, MATERIAL, INLET				
U L V NO.	INLET ELEV. (m)	OUTLET ELEV. (m)	CULVERT LENGTH (m)	BARRELS SHAPE MATERIAL	SPAN (mm)	RISE (mm)	MANNING n	INLET TYPE
1	30.80	30.50	61.00	1 - RCB	1220	1220	.012	CONVENTIONAL
2	30.95	30.65	61.00	1 - CSP	1220	1220	.024	CONVENTIONAL
3								
4								
5								
6								

))

SUMMARY OF CULVERT FLOWS (m3/s)   FILE: HY82   DATE: 05-01-1997

ELEV (m)	TOTAL	1	2	3	4	5	6	ROADWAY	ITR
30.80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0
31.44	1.4	1.0	0.4	0.0	0.0	0.0	0.0	0.00	4
31.78	2.8	1.8	1.0	0.0	0.0	0.0	0.0	0.00	3
32.14	4.3	2.5	1.8	0.0	0.0	0.0	0.0	0.00	4
32.53	5.7	3.3	2.4	0.0	0.0	0.0	0.0	0.00	6
32.86	6.2	3.5	2.7	0.0	0.0	0.0	0.0	0.00	5
33.18	8.5	3.8	3.0	0.0	0.0	0.0	0.0	1.66	5
33.22	9.9	3.9	3.0	0.0	0.0	0.0	0.0	3.01	4
33.25	11.4	3.9	3.0	0.0	0.0	0.0	0.0	4.40	4
33.28	12.8	4.0	3.0	0.0	0.0	0.0	0.0	5.69	3
33.31	14.2	4.2	3.1	0.0	0.0	0.0	0.0	6.93	3
33.10	6.7	3.8	2.9	0.0	0.0	0.0	0.0	OVERTOPPING	

))

))

SUMMARY OF ITERATIVE SOLUTION ERRORS   FILE: HY82   DATE: 05-01-1997

HEAD ELEV (m)	HEAD ERROR (m)	TOTAL FLOW (m3/s)	FLOW ERROR (m3/s)	% FLOW ERROR
30.80	0.000	0.00	0.00	0.00
31.44	-0.002	1.42	0.01	0.58
31.78	0.001	2.84	-0.00	-0.16
32.14	0.002	4.26	-0.01	-0.17
32.53	0.002	5.68	-0.01	-0.15
32.86	-0.003	6.20	0.01	0.20
33.18	-0.002	8.52	0.05	0.53
33.22	-0.003	9.94	0.05	0.51
33.25	-0.002	11.36	0.03	0.25
33.28	-0.001	12.78	0.08	0.66
33.31	-0.001	14.20	0.05	0.35

))

<1> TOLERANCE (m) = 0.003   <2> TOLERANCE (%) = 1.000

))

```
CURRENT DATE: 05-01-1997                                FILE DATE: 05-01-1997
CURRENT TIME: 14:13:37                                  FILE NAME: HY82
))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))
      PERFORMANCE CURVE FOR CULVERT 1 - 1(1220 mm BY 1220 mm) RCB
))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))
   DIS-    HEAD-  INLET  OUTLET
  CHARGE   WATER CONTROL CONTROL FLOW NORMAL  CRIT. OUTLET   TW   OUTLET   TW
   FLOW    ELEV.  DEPTH   DEPTH  TYPE  DEPTH  DEPTH  DEPTH  DEPTH   VEL.   VEL.
  (m3/s)    (m)    (m)     (m)   <F4>    (m)    (m)    (m)    (m)  (m/s)  (m/s)
))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))
    0.00    30.80   0.00  -0.30 0-NF     0.00   0.00   0.00   0.00   0.00   0.00
    1.03    31.44   0.64   0.63 1-S2n    0.38   0.42   0.39   0.34   2.18   0.69
    1.85    31.78   0.95   0.98 1-S2n    0.58   0.62   0.58   0.49   2.61   0.84
    2.50    32.14   1.16   1.34 5-S2n    0.73   0.76   0.73   0.60   2.80   0.94
    3.27    32.67   1.39   1.87 5-S2n    0.90   0.90   0.90   0.70   2.98   1.02
    3.50    32.83   1.47   2.03 2-M2c    0.95   0.94   0.94   0.73   3.04   1.05
    3.85    33.17   1.57   2.37 2-M2c    1.02   1.01   1.01   0.85   3.13   1.14
    3.88    33.22   1.58   2.42 2-M2c    1.03   1.01   1.01   0.92   3.14   1.19
    3.92    33.25   1.60   2.45 2-M2c    1.04   1.02   1.02   0.98   3.15   1.23
    3.96    33.28   1.61   2.48 3-M2t    1.05   1.03   1.04   1.03   3.14   1.27
    4.16    33.48   1.68   2.68 3-M2t    1.09   1.06   1.09   1.09   3.13   1.30
))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))
        El. inlet face invert      30.80 m    El. outlet invert    30.50 m
        El. inlet throat invert     0.00 m    El. inlet crest       0.00 m
))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))

***** SITE DATA ***** CULVERT INVERT **************
      INLET STATION                             0.00 m
      INLET ELEVATION                          30.80 m
      OUTLET STATION                           61.00 m
      OUTLET ELEVATION                         30.50 m
      NUMBER OF BARRELS                         1
      SLOPE (V/H)                               0.0049
      CULVERT LENGTH ALONG SLOPE               61.00 m

***** CULVERT DATA SUMMARY ************************
      BARREL SHAPE          BOX
      BARREL SPAN             1220 mm
      BARREL RISE             1220 mm
      BARREL MATERIAL       CONCRETE
      BARREL MANNING'S n    0.012
      INLET TYPE            CONVENTIONAL
      INLET EDGE AND WALL   1.5:1 BEVEL (90 DEG.)
      INLET DEPRESSION      NONE

))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))
```

CURRENT DATE: 05-01-1997 FILE DATE: 05-01-1997
CURRENT TIME: 14:13:37 FILE NAME: HY82

PERFORMANCE CURVE FOR CULVERT 2 - 1(1220 mm BY 1220 mm) CSP

DIS- CHARGE FLOW (m3/s)	HEAD- WATER ELEV. (m)	INLET CONTROL DEPTH (m)	OUTLET CONTROL DEPTH (m)	FLOW TYPE <F4>	NORMAL DEPTH (m)	CRIT. DEPTH (m)	OUTLET DEPTH (m)	TW DEPTH (m)	OUTLET VEL. (m/s)	TW VEL. (m/s)
0.00	30.95	0.00	-0.30	0-NF	0.00	0.00	0.00	-0.15	0.00	0.00
0.38	31.44	0.41	0.49	2-M2c	0.41	0.32	0.32	0.19	1.54	0.69
0.99	31.78	0.75	0.83	2-M2c	0.71	0.53	0.53	0.34	2.02	0.84
1.77	32.13	1.05	1.18	2-M2c	1.22	0.73	0.73	0.45	2.44	0.94
2.42	32.52	1.28	1.57	2-M2c	1.22	0.85	0.85	0.55	2.77	1.02
2.68	32.86	1.38	1.91	2-M2c	1.22	0.90	0.90	0.58	2.92	1.05
2.97	33.18	1.49	2.23	2-M2c	1.22	0.94	0.94	0.70	3.07	1.14
2.99	33.20	1.50	2.25	2-M2c	1.22	0.94	0.94	0.77	3.08	1.19
3.01	33.25	1.51	2.30	2-M2c	1.22	0.95	0.95	0.83	3.09	1.23
3.04	33.28	1.52	2.33	2-M2c	1.22	0.95	0.95	0.88	3.11	1.27
3.06	33.31	1.53	2.36	2-M2c	1.22	0.96	0.96	0.94	3.12	1.30

El. inlet face invert 30.95 m El. outlet invert 30.65 m
El. inlet throat invert 0.00 m El. inlet crest 0.00 m

***** SITE DATA ***** CULVERT INVERT **************

INLET STATION	0.00 m
INLET ELEVATION	30.95 m
OUTLET STATION	61.00 m
OUTLET ELEVATION	30.65 m
NUMBER OF BARRELS	1
SLOPE (V/H)	0.0049
CULVERT LENGTH ALONG SLOPE	61.00 m

***** CULVERT DATA SUMMARY ************************

BARREL SHAPE	CIRCULAR
BARREL DIAMETER	1220 mm
BARREL MATERIAL	CORRUGATED STEEL
BARREL MANNING'S n	0.024
INLET TYPE	CONVENTIONAL
INLET EDGE AND WALL	BEVELED EDGE (1.5:1)
INLET DEPRESSION	NONE

CURRENT DATE: 05-01-1997 FILE DATE: 05-01-1997
CURRENT TIME: 14:13:37 FILE NAME: HY82

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)))))))))))))))))))))))))) TAILWATER))))))))))))))))))))))))))
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***** USER DEFINED CHANNEL CROSS-SECTION FILE NAME: HY82
MAIN CHANNEL AND LT & RT OVER BANKS FILE DATE: 01/01/96

LEFT CHANNEL BOUNDARY	2
RIGHT CHANNEL BOUNDARY	5
MANNING n LEFT OVER BANK	0.100
MANNING n MAIN CHANNEL	0.030
MANNING n RIGHT OVER BANK	0.100
SLOPE OF CHANNEL	0.0025 m/m

CROSS-SECTION COORD. NO.	X (m)	Y (m)
1	0.00	33.10
2	13.70	31.70
3	19.80	30.50
4	24.30	30.50
5	30.40	31.70
6	44.10	33.10

******* UNIFORM FLOW RATING CURVE FOR DOWNSTREAM CHANNEL

FLOW (m3/s)	W.S.E. (m)	FROUDE NUMBER	DEPTH (m)	VEL. (m/s)	SHEAR (Pa)
0.00	30.50	0.000	0.00	0.00	0.00
1.42	30.84	0.424	0.34	0.69	6.46
2.84	30.99	0.446	0.49	0.84	8.71
4.26	31.10	0.459	0.60	0.94	10.39
5.68	31.20	0.468	0.70	1.02	11.73
6.20	31.23	0.471	0.73	1.05	12.16
8.52	31.35	0.481	0.85	1.14	13.84
9.94	31.42	0.486	0.92	1.19	14.70
11.36	31.48	0.490	0.98	1.23	15.51
12.78	31.53	0.494	1.03	1.27	16.28
14.20	31.59	0.497	1.09	1.30	17.00

Note: Shear stress was calculated using R.

))
)))))))))))))))))))))))))) ROADWAY OVERTOPPING DATA))))))))))))))))))))))))))
))

ROADWAY SURFACE	PAVED
EMBANKMENT TOP WIDTH	15.24 m
CREST LENGTH	44.10 m
OVERTOPPING CREST ELEVATION	33.10 m

))

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HYDRAIN - INTEGRATED DRAINAGE DESIGN COMPUTER SYSTEM

VOLUME VI. HYCHL - ROADSIDE CHANNELS

for:

Office of Technology Applications
Federal Highway Administration
Washington, DC

March 1999

(Metric Conversion Table)

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INTRODUCTION

This document discusses the HYCHL computer program. HYCHL assists in designing stable roadside channel and irregular channel riprap linings. The channel lining stability analysis uses permissible shear stress. The bases for program algorithms are the Federal Highway Administration (FHWA) publications Hydraulic Engineering Circular 15 (HEC-15) and HEC-11.[1, 2]

When provided design flow and channel conditions (i.e., slope, shape, and lining type), HYCHL can analyze drainage channels for stability. The HYCHL program determines stability through application of tractive force theory. The tractive force theory compares shear exerted on the lining, as a result of flow, with the permissible shear stress of the lining. HYCHL also calculates the maximum discharge a particular channel can convey given permissible shear stress and the corresponding allowable depth. HYCHL can analyze all linings with a known permissible shear for both stability and maximum discharge. The output generated by HYCHL includes flow depth, velocity, calculated shear stress, permissible shear stress, and maximum discharge.

HYCHL capabilities allow analysis of lining having both rigid and flexible composition. Flexible lining installation can be on a temporary or permanent basis. The lining can consist of a single material or a composite set of materials (i.e., a paved low flow channel section with a vegetative upper channel section). HYCHL allows analysis of both straight and curved channel segments. The channel shape can consist of regular and irregular profiles. The channel flow can be either a constant or variable throughout the channel length. (Variable channel flow recognizes that runoff enters the channel, increasing flow.)

The remaining document provides a more detailed explanation of HYCHL capabilities. The next section provides an overview of the components that form the HYCHL program. The third section describes the technical information incorporated into HYCHL. The information includes all relevant equations from HEC-15, HEC-11, and other sources in the literature. The fourth section provides instruction and commentary on the HYCHL program, input data, commands, and support programs. Three appendixes provide examples of HYCHL applications, general descriptions of typical applications, and explanations of the HYCHL commands.

SYSTEM OVERVIEW

HYCHL represents a consolidation of analysis and design techniques presented in HEC-15 and HEC-11.[1, 2] Although both documents are directed towards the analysis of lining stability, each document addresses different classes of problems. HEC-15 focuses on linings in roadside channels which are characterized by relatively uniform cross sections on a constant slope. Alternatively, HEC-11 addresses natural channels with irregular cross sections, varying bottom slopes, and generally carrying larger flows. HEC-11 focuses on the design of riprap lining in such cases. Together, HEC-15 and HEC-11 provide a series of analysis and design tools that are present in HYCHL.

RIGID, VEGETATIVE, GABION, AND TEMPORARY LININGS

HEC-15 outlines procedures for analyzing channel linings based on tractive force theory. The procedure involves comparing an estimated shear stress resulting from flow in a channel to the maximum permissible shear stress determined for a given lining type. If the shear from flowing water increases to the point where it is greater than the permissible shear of the lining, failure may occur. This concept allows for calculation of the maximum discharge a channel can convey, when the calculated shear is assumed to equal permissible shear.

The analysis of rigid, vegetative, gabion, and temporary linings in HYCHL is applicable to channels of uniform cross section and constant bottom slope. Roadside channels typically exhibit such characteristics. HYCHL offers a variety of design and analysis options including:

- Rigid or flexible linings.
- Temporary or permanent linings.
- Single or composite linings.
- Straight or bend channel sections.
- Alternative regular channel shapes.
- Constant or variable channel flow.

Depending on channel function, material availability, costs, aesthetics, and desired service life, a designer may choose from a variety of lining types. Rigid linings in HYCHL include concrete, grouted riprap, stone masonry, soil cement, and asphalt. Flexible linings in HYCHL include those which may be considered permanent and those considered temporary. Permanent flexible linings include vegetation, riprap, and gabions. Temporary linings include woven paper, jute mesh, fiberglass roving, straw with net, curled wood mat, synthetic mat, and bare soil (unlined).

HYCHL provides for the analysis of all of these lining types individually and when two linings are specified together as a composite lining. Composite linings are typically designed with

a low flow lining protecting the bottom of a channel where higher shear stresses are anticipated and a side slope lining protecting the channel sides. Composite linings are used when lining side slopes with the same material applied to the bottom is undesirable for reasons of economics, aesthetics, or safety.

The designer of rigid, vegetative, and temporary linings may apply HYCHL to a variety of geometric configurations. HYCHL calculates the shear stresses on linings in straight channel sections as well as the higher stresses found in bend sections. Channel cross sections available in HYCHL for these lining types are trapezoidal, parabolic, triangular, and triangular with rounded bottom.

Finally, the performance of rigid, vegetative, gabion, and temporary linings can be evaluated using a design flow which is assumed to be constant for the entire channel length or a variable inflow. The variable inflow is characterized as a uniform lineal flow that results in an increasing discharge with channel length. Under such conditions, HYCHL provides the designer with an estimate of the length of channel for which a given lining may be suitable.

HEC-15 includes limited guidance, for the analysis of gabion linings on steep slopes (10 to 25 percent), but provides no guidance on any other conditions. Therefore, calculating shear stress for gabion linings follows the same methodologies as described for riprap in HEC-15, using the D_{50} for the gabion fill material. This assumes that the wire enclosure does not significantly affect the roughness of the lining. This assumption is supported by prior research.[3]

RIPRAP LININGS

HEC-15 and HEC-11 both outline procedures for analyzing riprap-lined channels. These procedures are based on the same logic (i.e., the tractive force theory), but include additional considerations not necessary for analyzing rigid, vegetative, gabion, and temporary lining types. Although HEC-15 is recommended for design flows less than 1.4 m^3/s, and HEC-11 for flows in excess of 1.4 m^3/s, the same basic principles are used in deriving the analysis/design equations in these documents. The tractive force procedure is applied to develop the riprap analysis and design procedures used in HYCHL.

A channel lined with riprap can be analyzed for stability given the riprap size, or the riprap size can be determined based on a user-supplied stability factor. Composite channels which have riprap for the low flow lining and another lining type for the high-flow channel can be analyzed. HYCHL can also analyze irregular channel shapes which are lined with riprap only.

Riprap-lined channels base most hydraulic calculations on Manning's equation. An exception occurs in cases where the flow depth is small compared to a characteristic riprap size such that the effects of the rock protruding into the flow field cannot be ignored. Such conditions may occur, for example, on steep slopes. The Bathurst hydraulic procedure given in HEC-15 is applied in this case to determine the flow depth and velocity in a given channel.

TECHNICAL INFORMATION

This section provides technical descriptions of the key methodologies implemented in HYCHL. The theory and practice of analyzing and designing rigid, vegetative, temporary linings, and gabion linings as applied in HYCHL is provided. This is followed by additional considerations necessary for the analysis and design of riprap linings.

RIGID, VEGETATIVE, GABION, AND TEMPORARY LININGS

The analysis and design of rigid, vegetative, gabion, and temporary linings in channels of constant cross section and slope, typical of roadside channels, is accomplished in HYCHL by the application of tractive force theory. The procedure used to analyze temporary linings is identical to that applied for permanent linings. However, since temporary linings are intended to have a shorter service life, the design flow may be lower. The hydraulic characterization of the channel flow and the calculation of the shear stresses is presented for a variety of lining types and channel configurations.

Calculated Shear Stress

Most roadside channels carry uniform flow that can be represented by Manning's formula. For analysis and design purposes, uniform flow conditions are assumed with the energy slope approximately equal to average bed slope. By making this assumption, flow conditions can be defined by a uniform flow equation such as Manning's equation. This section discusses how to estimate Manning's friction factor, for both single and composite channels, and how to solve for depth from the Manning's equation.

The first set of linings to address is temporary linings. These include: woven paper, jute mesh, fiberglass roving, straw with net, curled wood mat, and synthetic mat. The Manning's n value for these linings is defined by the following equation:

$$n = \frac{R_h^{\frac{1}{6}}}{\left[3.13 \times \left[a + b \times \log\left(\frac{R_h}{K_s}\right)\right]\right]} \tag{1}$$

Where:

n	=	Manning's n.
R_h	=	Channel hydraulic radius, m.
K_s	=	Roughness element height, m, summarized in table 1.
a, b	=	Dimensionless empirical coefficients associated with each lining summarized in table 1.

Table 1. Empirical coefficients for temporary linings.

Lining Material	K_s		
	(mm)	a	b
Woven Paper	1.2	0.73	8.00
Jute Mesh	11.6	0.74	8.04
Fiberglass Roving	10.7	0.73	8.00
Straw with Net	36.6	0.72	7.83
Curled Wood Mat	33.5	0.65	1.20
Synthetic Mat	19.8	0.96	8.13

For values of R_h/K_s less than one, n becomes negative when using equation (1). To avoid this situation, an upper limit is placed on n. For a given lining type, the maximum n is computed when the hydraulic radius is 10 percent greater than the hydraulic radius which would result in the denominator of equation (1) equaling zero. This quantity is denoted as R_o. Therefore, for all values of hydraulic radius less than $1.1 \times R_o$, Manning's n remains the same.

For vegetative linings, n is dependent upon the physical characteristics of the vegetation as well as the shear stress exerted on the grass. It is a function of physical channel parameters, average grass height, and stiffness. The following equation is used to estimate n for vegetative linings:

$$n = \frac{R_h^{\frac{1}{6}}}{19.91 \times \log\left[44.8 \times R_h^{1.4} \times S^{0.4} \times h^{0.6} \times MEI^{-0.4}\right]} \qquad (2)$$

Where:

R_h	=	Hydraulic radius, m.
S	=	Slope, m/m.
h	=	Average grass height, m.
MEI	=	Stiffness, $N \times m^2$.

Values of h and MEI for the five different classifications of retardance (A - E) are empirical coefficients associated with each lining and are shown in table 2. The classification is a user input which determines the channel roughness for the particular vegetative lining.

Table 2. Relative roughness parameters for vegetation.

Retardance Class	Average Height, h	Stiffness, MEI
	(mm)	($N \times m^2$)
A	920	300
B	610	20
C	200	0.5
D	100	0.05
E	40	0.005

Bare soil (considered to be a temporary lining) and rigid linings exhibit Manning's n values that are a function of flow depth. Table 3 shows the n values that HYCHL uses for these linings. Linear interpolation is used to smooth transition between various depth ranges.

Table 3. Manning's roughness coefficients for rigid and bare soil linings.

Lining Type	Depth Ranges					
	meter	$d \leq 0.15$	$0.15 < d \leq 0.20$	$0.20 < d \leq 0.60$	$0.60 < d < 0.65$	$d \geq 0.65$
Rigid Concrete		0.015	Linear Interpolation	0.013	Linear Interpolation	0.013
Grouted Riprap		0.040		0.030		0.028
Stone Masonry		0.042		0.032		0.030
Soil Cement		0.025		0.022		0.020
Asphalt		0.018		0.016		0.016
Unlined Bare Soil		0.023		0.020		0.020

If the channel lining is composite, roughness values for each lining are determined and an effective **n**-value is calculated. The effective **n**-value for a composite lining is defined by the following relationship:

$$n_E = \left[\frac{P_L}{P} + \left(1 - \frac{P_L}{P}\right) \times \left(\frac{n_S}{n_L}\right)^{\frac{3}{2}} \right]^{\frac{2}{3}} \times n_L \tag{3}$$

Where:

n_E	=	Effective Manning's **n**-value.
P_L	=	Low-flow perimeter, m.
P	=	Total perimeter, m.
n_S	=	Manning's roughness value for side slope lining.
n_L	=	Manning's roughness value for low flow lining.

This equation reduces to $\mathbf{n_E} = \mathbf{n_L}$ for channels that have a flow depth less than the lining transition depth. In this case, $\mathbf{P_L} = \mathbf{P}$ and the effective Manning's **n**-value equals the low flow lining **n**-value. The lining is effectively treated as a single lining. The user has the option of supplying **n**-values for one or both linings, otherwise, the program computes roughness.

Normal depth is calculated using an iterative process beginning with an initial estimate for depth. HYCHL calculates the geometric parameters (area, wetted perimeter, and top width) and Manning's **n**-value based on the initial depth. The equation for calculating flow values combines Manning's equation and the continuity equation:

$$Q_i = \frac{1}{n_E} \times A_i \times R_{h_i}^{\frac{2}{3}} \times S_f^{\frac{1}{2}} \tag{4}$$

Where:

Q_i	=	Flow in channel for depth estimate, m^3/s.
A_i	=	Flow area of channel for depth estimate, m^2.
R_{hi}	=	Hydraulic radius for depth estimate, m.
S_f	=	Friction slope of channel, m/m.

The iteration process continues until the estimated flow, $\mathbf{Q_i}$ calculated from an assumed depth is within 0.1 percent of the given design flow, $\mathbf{Q_D}$. Until this is achieved, successive estimates of depth are calculated from the following equation:

$$d_{i+1} = \left[\frac{d_i + \frac{Q_D}{Q_i} \times d_i}{2} \right] \tag{5}$$

Where:

d_i	=	Estimated depth at iteration **i**, m.
d_{i+1}	=	Estimated depth at iteration i+1.

Once the flow depth is established, the analytical relationships summarized in figure 1 are applied to calculate area, wetted perimeter, and top width for the regular channel shapes. These parameters are calculated numerically for irregular channel shapes. Once the depth has been calculated, shear stress for the channel bottom is obtained from the following equation:

$$\tau_c = \gamma \times d_{MAX} \times S_F \tag{6}$$

Where:

τ_c	=	Calculated shear stress on the channel bottom, N/m^2.
γ	=	Specific weight of water, N/m^3.
d_{MAX}	=	Normal depth, m.
S_F	=	Friction slope, m/m.

Permissible Shear Stress

Shear stress is the force exerted on the lining by flowing water per unit area of the lining. Each lining has associated with it a permissible shear stress, τ_p. Most of the permissible shear values come from tables or charts in HEC-15 and are considered conservative, that is, they are appropriate for design purposes. Table 4 summarizes the permissible shear stress values.

For rigid linings, table 4 shows that the permissible shear stress approaches infinity. For purposes of evaluating failure resulting from tractive forces this is a reasonable assumption for rigid linings in good condition.

If the channel is lined with a **gabion mattress**, the permissible shear stress is the larger value obtained from the following two equations:

$$\tau_p = 359.1 \times D_{50} \tag{7}$$

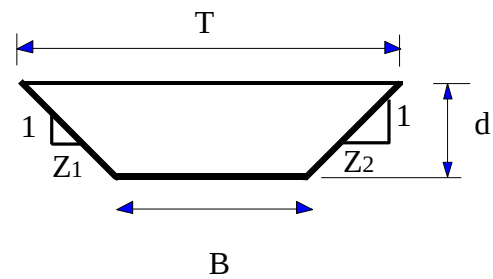
$$\tau_p = 51.2 \times MT + 177.2 \tag{8}$$

Trapezoidal or V-Shaped

$$A = Bd + \tfrac{1}{2}d^2\,(Z_1 + Z_2)$$

$$P = B + d\sqrt{Z_1^2 + 1} + d\sqrt{Z_2^2 + 1}$$

$$T = B + d\,Z_1 + d\,Z_2$$



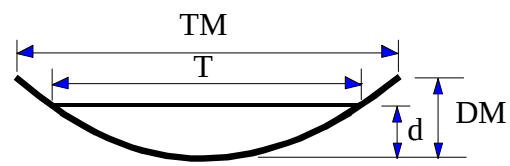
Parabolic

$$K = 4\frac{(DM)}{(TM^2)}$$

$$A = 2/3\ Td$$

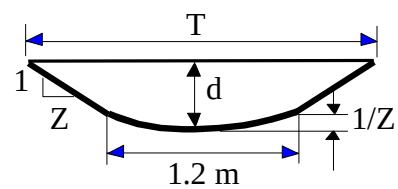
$$T = \sqrt{\frac{4d}{K}}$$

$$P = 1/2\sqrt{16d^2 + T^2} + \left(\frac{T^2}{8d}\right)\ln_e\left(\frac{4d + \sqrt{16d^2 + T^2}}{T}\right)$$



V-Shaped with Rounded Bottom

(Two Cases)



1) $d \le \dfrac{1}{Z}$

$$A = 1.472\,d\sqrt{dZ}$$

$$T = 2.208\sqrt{dZ}$$

$$P = 0.610\,Z\ln_e\left(\frac{d}{0.305\,Z} + \sqrt{1 + \frac{d}{0.305Z}}\right) + 0.610\sqrt{\left(\frac{d}{0.305}\right)^Z + \frac{dZ}{0.305}}$$

2) $d > \dfrac{1}{Z}$

$$A = 0.248Z + 0.372\left(\frac{d}{0.305} - \frac{1}{Z}\right) + 0.093Z\left(1 - \frac{1}{Z}\right)^2$$

$$T = 0.610Z\left(\frac{d}{0.305} + \frac{1}{Z}\right)$$

$$P = 0.610Z\ln_e\left(\frac{1}{Z} + \frac{\sqrt{Z^2 + 1}}{Z}\right) + 0.610\frac{(1 + Z^2)}{Z} + 0.610\left(\frac{d}{0.305} - \frac{1}{Z}\right)\sqrt{1 + Z^2}$$

Figure 1. Equations for regular channel shapes.

Table 4. Permissible shear stresses for lining materials.

Lining Category	Lining Type	Permissible Shear Stress (N/m^2)
Temporary	Woven Paper Net	7.2
	Jute Net	21.5
	Fiberglass Roving:	
	Single	28.7
	Double	40.7
	Straw with Net	69.4
	Curled Wood Mat	74.2
	Synthetic Mat	95.8
	Soils	variable
Vegetative	Class A	177.2
	Class B	100.6
	Class C	47.9
	Class D	28.7
	Class E	16.8
Rigid	Concrete	approaches ∞
	Grouted Riprap	approaches ∞
	Stone Masonry	approaches ∞
	Soil Cement	approaches ∞
	Asphalt	approaches ∞

Where:

D_{50} = Median rock diameter, m.
MT = Mattress thickness, m.

Equations (7) and (8) are obtained from HEC-15 Charts 23 and 24, respectively. Notice that equation (7) is dependent on D_{50} and equation (8) is dependent on mattress thickness.

For a **noncohesive soil** lining, equation (9) defines the permissible shear stress value:

$$\tau_p = 801.1 \times D_{50} \tag{9}$$

Where:

τ_p = Permissible shear stress of soil, N/m^2.
D_{50} = Mean soil particle diameter, m.

Permissible shear stress of **cohesive soils** is dependent on soil type and a plasticity index and is determined from one of the following three equations:

Loose, $\tau_p = 0.1628 \times PI^{0.84}$ (10)

Medium Compact, $\tau_p = 0.2011 \times PI^{1.071}$ (11)

Compact, $\tau_p = 0.2729 \times PI^{1.26}$ (12)

Where:

PI = Plasticity index of soil.

The user may override computation of permissible shear stress as discussed above by supplying a user input value for the permissible shear stress of a lining. The permissible shear stress can be input for both the low flow lining as well as the side slope lining of composite channels.

The ratio of permissible shear stress to calculated shear stress can be called the stability factor. For roadside channels, or other uniform channels, where hydraulic conditions are consistent, a channel design can be considered stable when the stability factor is greater than one.

Side Shear

Channel side slopes are also subject to shear and in some cases may limit selection of linings. Side shear is analyzed by use of the parameter, $\mathbf{K_{SIDE}}$. $\mathbf{K_{SIDE}}$ is the ratio of maximum channel side shear to channel bottom shear. It is a function solely of channel shape. It is dependent on channel geometry and channel side slopes. Figure 2 displays a schematic of shear stress distribution for a trapezoidal channel. The maximum shear stress on the side slope will always be less than or equal to that on the bottom.

Taken from Anderson, figures 3 and 4 are used to obtain $\mathbf{K_{SIDE}}$ for trapezoidal and V-shaped channels, respectively.[4] The other two shapes, parabolic and V-shaped with rounded bottom, are assumed to require a $\mathbf{K_{SIDE}}$ value equal to 1.0 because these shapes have no clear distinction between side slopes and base of channel. This conservative assumption implies that the maximum side shear occurs at a point directly adjacent to the deepest point and must resist the same shear as the deepest point in the channel. Setting side shear equal to bottom shear yields $\mathbf{K_{SIDE}}$ value equal to 1.0.

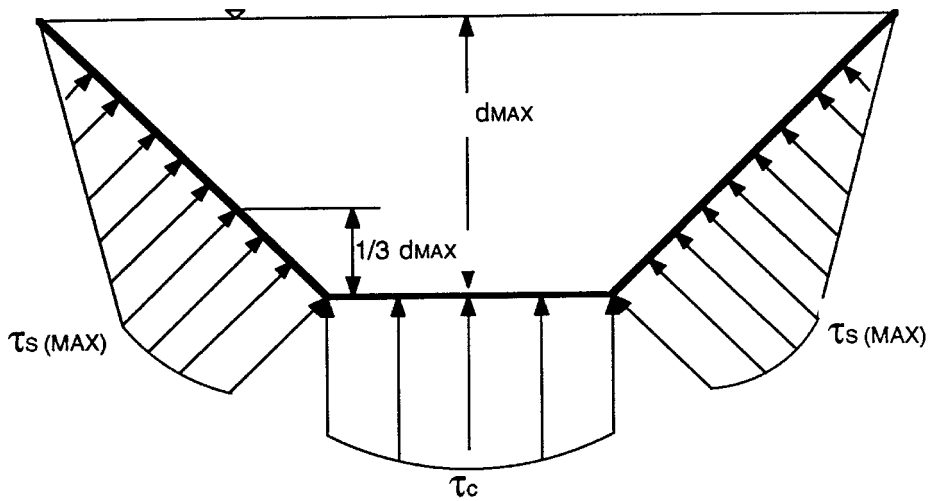


Figure 2. Assumed shear stress distribution.

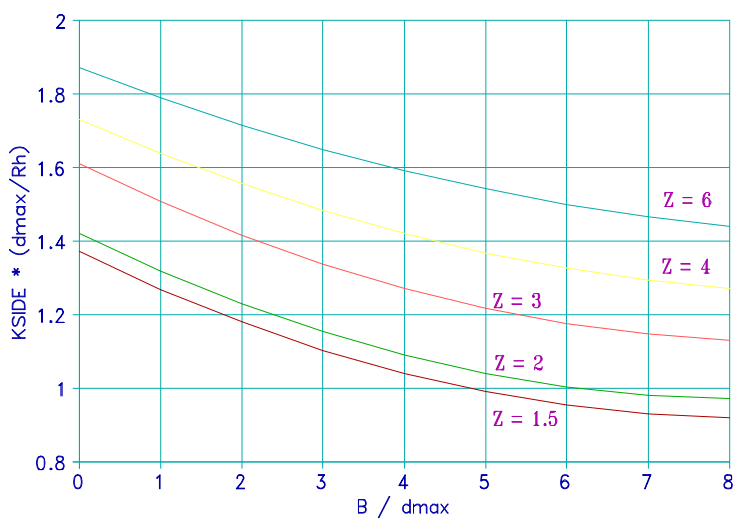


Figure 3. Maximum boundary shear stress on sides of trapezoidal channels.

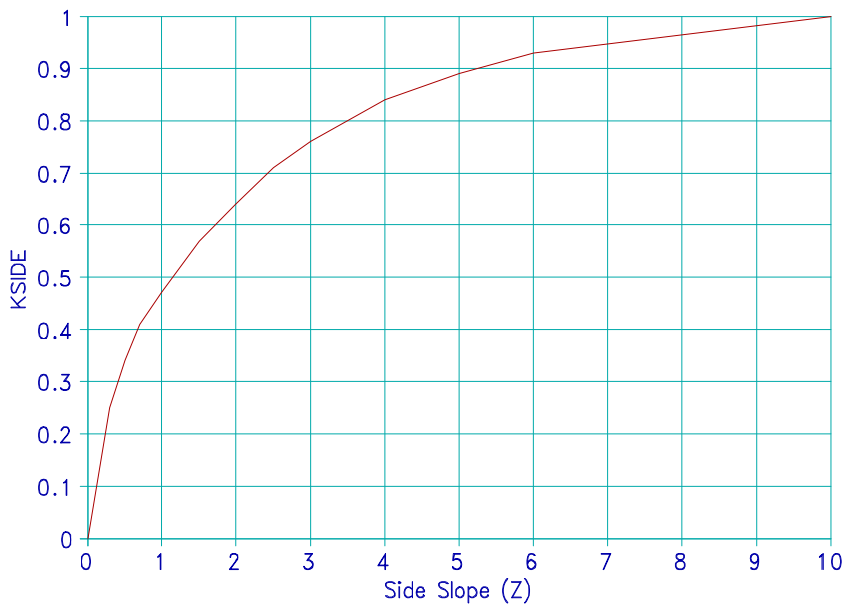


Figure 4. Ratio of side to bottom shear stress for triangular channels.

Since $\mathbf{K_{SIDE}}$ is always less than or equal to one, side shear does not limit the design of a single, rigid, vegetative, gabion, or temporary lining, but may affect the design of composite linings. For the side slope or upper lining in a composite design, the parameter $\mathbf{K_{SU}}$ must be defined. It is a function of both channel shape and lining transition height, $\mathbf{h_{TL}}$. Maximum side shear for the side slope lining occurs at the lining transition point (the most submerged point of the side slope lining).

Table 5 summarizes the derivation of side shear ratios for estimating side shear. For single linings or for channels with composite linings with a maximum flow depth less than the lining transition depth, the side shear ratio is developed as previous described. However, if the flow depth in a compositely lined channel is greater than the lining transition height, then the parameter $\mathbf{K_{SU}}$ must be calculated and used as the side shear ratio for evaluating the upper lining.

Table 5. Derivation of side shear ratios.

	Single Lining	Composite Lining		
Shape	All Cases	$d_{MAX} < h_{TL}$ Lower Lining	$d_{MAX} \geq h_{TL} \geq 1/3d_{MAX}$ Upper Lining	$1/3d_{MAX} > h_{TL}$ Upper Lining
Trapezoidal	K_{SIDE} from figure 3	K_{SIDE} from figure 3	K_{SU} from equation 14	$K_{SU} = K_{SIDE}$ from figure 3
V-Shaped	K_{SIDE} from figure 4	K_{SIDE} from figure 4	K_{SU} from equation 14	$K_{SU} = K_{SIDE}$ from figure 4
Parabolic	$K_{SIDE} = 1.0$	$K_{SIDE} = 1.0$	K_{SU} from equation 13	K_{SU} from equation 13
V-shaped w/rounded bottom	$K_{SIDE} = 1.0$	$K_{SIDE} = 1.0$	K_{SU} from equation 13	K_{SU} from equation 13

If the channel is parabolic or V-shaped with rounded bottom, shear stress at every point in the channel is a function of flow depth above that point where shear equals $\gamma \times \mathbf{d_{MAX}} \times \mathbf{S_F}$. Since the depth of water above the lining transition is ($\mathbf{d_{MAX}} - \mathbf{h_{TL}}$), then $\mathbf{K_{SU}}$ is defined by the following equation:

$$K_{SU} = \frac{\gamma \times (d_{MAX} - h_{TL}) \times S_F}{\gamma \times d_{MAX} \times S_F} = \frac{d_{MAX} - h_{TL}}{d_{MAX}} \tag{13}$$

For compositely lined trapezoidal or V-shaped channels with a submerged lining transition height, K_{SU} further depends on whether one third of d_{MAX} (see figure 2) is above or below the lining transition height. If the lining transition depth, h_{TL}, is below one third of the maximum depth, the lining at the transition experiences the maximum side shear and K_{SU} equals K_{SIDE}. However, if the lining transition depth is above the depth of maximum side shear (one third d_{max}), then K_{SU} is calculated using the following equation:

$$K_{SU} = \frac{3}{2} \times \left(\frac{d_{MAX} - h_{TL}}{d_{MAX}} \right) \times K_{SIDE} \tag{14}$$

$\mathbf{K_{SU}}$ is used to calculate the maximum shear on an upper lining. Stability is determined by comparing τ_s to τ_p for the side slope lining. The equation for τ_s is:

$$\tau_s = K_{SU} \times \gamma \times d_{MAX} \times S_F \tag{15}$$

Bends

A channel bend causes additional shear stresses because of centrifugal forces. These additional stresses are taken into account by calculating a bend factor, $\mathbf{K_B}$, to determine bend shear. This factor represents the ratio of bend shear to the amount of shear in the same straight channel section. $\mathbf{K_B}$ is a function of a characteristic width of the channel and its radius of curvature. Base width, **B**, is used as the characteristic width for trapezoidal channels. The bend shear curve is approximated by the following parabolic equation derived from HEC-15 (chart 10):

$$K_B = 2.38 - 0.206 \times \left(\frac{R_c}{B}\right) + 0.0073 \times \left(\frac{R_c}{B}\right)^2 \tag{16}$$

Where:

K_B	=	Bend shear factor, dimensionless.
R_c	=	Radius of curvature, m.
B	=	Characteristic width of channel, m.

Equation (16) is applicable for R_c/B values from 2.0 to 10.0. For values less than 2.0 and greater than 10.0, $\mathbf{K_B}$ is set to 2.00 and 1.05, respectively. For channel shapes other than trapezoids, the characteristic width, **B**, is calculated as the flow area divided by the maximum depth.

The calculated shear stress in the bend is computed by multiplying the shear stress value in the straight channel section by the bend shear factor:

$$\tau_{c,B} = \tau_{c,S} \times K_B \tag{17}$$

Where:

$\tau_{c,B}$	=	Calculated shear in the bend for the bottom or side slopes, N/m^2.
$\tau_{c,S}$	=	Calculated shear for bottom or side slopes in the straight channel section, N/m^2.

The added stress resulting from a bend does not require the use of more resistant linings for the entire straight portion of a channel. The necessary length of protection is defined by the following equation:

$$L_p = 0.7350 \times \left[\frac{R_h^{\frac{7}{6}}}{n}\right] \tag{18}$$

Where:

R_h	=	Hydraulic radius, m.
n	=	Manning's **n**.
L_p	=	Length of protection, m.

Since the water surface is no longer level across the channel in a bend, additional freeboard must be provided. The minimum necessary freeboard is calculated using the following equation for superelevation.

$$SE = \frac{V^2 \times T}{g \times R_c} \tag{19}$$

Where:

V	=	Average velocity, m/s.
T	=	Top width, m.
R_c	=	Radius of curvature, m.
SE	=	Superelevation, m.
g	=	Gravitational constant, m/s^2.

<u>Maximum Discharge</u>

The stability of rigid, vegetative, gabion, and temporary linings is evaluated based on a comparison of permissible and calculated shear stress. The maximum discharge a channel can convey for a given lining is calculated by setting calculated shear equal to permissible shear. The allowable flow depth for the lining is then found from the following equation:

$$d_{QMAX} = \frac{\tau_p}{\gamma \times S_F} \tag{20}$$

Where:

d_{QMAX}	=	The largest flow depth that the lining can support, m.

At this depth, the calculated shear stress is exactly equal to the permissible shear stress. This depth is used to calculate flow from Manning's equation, which is combined with the continuity equation, Q = A × V, to compute maximum discharge.

$$Q_{MAX} = \frac{1.49}{n_E} \times A \times R_h^{\frac{2}{3}} \times S_F^{\frac{1}{2}} \tag{21}$$

Where:

Q_{MAX}	=	Maximum discharge, m^3/s.
A	=	Flow area, m^2.
R_h	=	Hydraulic radius, m.
S_F	=	Friction slope, m/m.
n_E	=	Effective Manning's **n**.

If a channel is compositely lined, the limiting flow depths corresponding to each of the two linings are estimated. The maximum depth for the low flow lining is defined by equation (20). The maximum depth for the side slope lining must also be calculated. If the channel is V-shaped or trapezoidal, then the maximum depth of water is dependent on $\mathbf{K_{SIDE}}$, the side shear ratio. The shapes are differentiated because parabolic and V-shaped with rounded bottom channels have gradually varying cross sections. The following equation calculates a maximum depth for stability of V-shaped or trapezoidal channels if lining transition height, h_{TL}, is greater than one third the maximum flow depth:

$$d_{SIDE} = h_{TL} + \frac{\tau_{p,ss}}{\gamma \times S_F \times \frac{3}{2} \times K_{SIDE}} \tag{22}$$

Where:

d_{SIDE}	=	Maximum depth of channel for side slope lining stability, m.
h_{TL}	=	Lining transition height, m.
$\tau_{p,ss}$	=	Side slope permissible shear stress, N/m^2.
γ	=	Unit weight of water, N/m^3.
S_F	=	Friction slope, m/m.
K_{SIDE}	=	Side shear ratio.

For V-shaped or trapezoidal channels whose lining transition depth is less than one third the flow depth, the maximum depth for side slope stability is calculated as:

$$d_{SIDE} = \frac{\tau_{p,s}}{\gamma \times S_F \times K_{SIDE}} \tag{23}$$

If the shape is parabolic or V-shaped with a rounded bottom, then the depth of water is calculated by the following equation:

$$d_{SIDE} = h_{TL} + \frac{\tau_{p,s}}{\gamma \times S_F} \tag{24}$$

Once the maximum flow depths of both linings are computed, $\mathbf{Q_{MAX}}$, is computed from Manning's equation using that value for the limiting (shallower) depth. From $\mathbf{Q_{MAX}}$, the maximum stable length of a channel is calculated for a given lateral inflow, **q**. Lateral inflow

contribution is an optional input, and if given, then maximum length, $\mathbf{L_{MAX}}$, is calculated according to the following equation:

$$L_{MAX} = \frac{Q_{MAX}}{q} \tag{25}$$

RIPRAP LININGS

Although based on the same underlying principles of tractive force theory, riprap linings have been presented by themselves to highlight their design process. Both HEC-11 and HEC-15 address components of riprap lining design under different flow conditions and channel types. HYCHL assists the designer by automatically recognizing the appropriate conditions and employing the applicable lining design procedures for riprap-lined channels. This section discusses topics which are specific to riprap linings.

Estimating Manning's Roughness Coefficient

Manning's roughness coefficient, **n**, is based on the channel flow regime and user preferences. HYCHL default calculations determine an **n** value based on the ratio of the average depth to the median riprap size. However, if d_a/D_{50} is greater than 30,000, the procedures may not apply. For ratios greater than or equal to 2 and less than or equal to 185 then equation (26) applies:[4]

$$n = \frac{4.657 \times R_h^{\frac{1}{6}}}{32.25 + 5.23 \times \log\left(\frac{R_h}{D_{50}}\right)} \tag{26}$$

Where:

n	=	Manning's **n**.
R_h	=	Hydraulic radius, m.
D_{50}	=	Median riprap size, m.
d_a	=	Average flow depth, m.

For values of R_h/D_{50} less than one, **n** becomes negative when using equation (26). To avoid this situation, an upper limit is placed on **n**. For a given riprap size, the maximum **n** is computed when the hydraulic radius is 10 percent greater than the hydraulic radius which would result in the denominator of equation (26) equaling zero. This quantity is denoted as R_o. Therefore, for all values of hydraulic radius less than $1.1 \times R_o$, Manning's **n** remains the same.

For ratios of d_a/D_{50} of greater than 185, equation (27) applies:

$$n = 0.0232 \times d_a^{\frac{1}{6}} \tag{27}$$

If a riprap or gabion-lined channel has a value of $\mathbf{d_a}/D_{50}$ less than two, then the Bathurst procedure is used to estimate the hydraulic conditions.[5] When riprap protrudes into the flow field, very complex flow conditions are created which significantly increases flow resistance due to Froude number effects, i.e., standing waves, hydraulic jumps, and free surface drag. The Bathurst resistance equation is used in the program to quantify these effects in computing channel hydraulics. Bathurst's work is based on laboratory experiments with d_a/D_{50} values ranging from 0.3 to 8.0.

The following form of the Bathurst equation is used:

$$\frac{V}{\sqrt{g \times d_a \times S_F}} = f_n(FR) \times f_n(REG) \times f_n(CG) \tag{28}$$

Where:

V	=	Mean velocity, m/s.
g	=	Gravity constant which equals 9.81 m/s^2.
S_F	=	Friction slope, m/m.
d_a	=	Average flow depth, m.
FR	=	Froude number = $V/(g \times d_a)^{1/2}$.
REG	=	Roughness element geometry.
CG	=	Channel geometry.

The functions of Froude number, roughness element geometry, and channel geometry are given by the following equations:

$$f_n(FR) = \left[\frac{0.28}{b} \times FR\right]^{\log\left(\frac{0.755}{b}\right)} \tag{29}$$

$$f_n(REG) = 13.434 \times \left[\frac{T}{D_{50}}\right]^{0.492} \times b^{\left[1.025 \times \left(\frac{T}{D_{50}}\right)^{0.118}\right]} \tag{30}$$

$$f_n(CG) = \left[\frac{T}{d_a}\right]^{-b} \tag{31}$$

Where:

T	=	Channel top width, m.
b	=	Parameter describing the effective roughness concentration.
D_{50}	=	Median diameter of riprap, m.

The parameter, **b**, describes the relationship between effective roughness concentration and relative submergence of the roughness bed. This relationship is given by:

$$b = a \times \left[\frac{d_a}{D_{50}}\right]^c \tag{32}$$

Where:

a	=	Parameter varying with channel shape and bed material gradation.
c	=	Parameter varying with bed material gradation.

The parameter, **c**, is a function of the roughness size distribution and varies with respect to the bed-material gradation, , where:

$$c = 0.648 \times \quad ^{-0.134} \tag{33}$$

The bed-material gradation is calculated as the log standard deviation of the size distribution. For standard riprap gradations, it is assumed to be constant at a value of 0.182, giving a **c** value of 0.814.

The parameter, **a**, is a function of channel width and bed material size in the cross stream direction, and defined by equation (34):

$$a^{\frac{1}{c}} = 1.175 \times \left[\frac{D_{50}}{T}\right]^{0.557} \tag{34}$$

Since mean velocity, **V**, Froude number, **FR**, roughness element geometry, **REG**, and channel geometry, **CG**, are all implicit functions of mean flow depth, the flow depth must be calculated through iterative solutions of the Bathurst equation. A convergence criterion, similar to the normal depth convergence scheme, is used such that convergence is reached when the left hand side of equation (28) is within 0.1 percent of the right-hand side of the equation. If they are not equal, then depth is incremented or decremented according to the ratio of left side to right side.

HYCHL allows the user to override the default calculations of Manning's **n**. Regardless of the d_a/D_{50} ratio, the user may specify that a user-supplied value, equation (26), or the Anderson equation be used.[6] The Anderson equation is as follows:

$$n = 0.0481 \times D_{50}^{\frac{1}{6}} \tag{35}$$

The stability of the riprap is not determined using the moment analysis which is illustrated in appendix C of HEC-15. Riprap stability is based on the tractive force theory and is calculated according to the equations in the Channel Bottom Shear and Side Shear sections.

Selection of a stability factor for riprap design is left to user judgment based on knowledge of the channel conditions. HEC-11 provides guidelines for the selection of a stability factor which are shown in table 6.

Table 6. Guidelines for the selection of stability factors.

Condition	Stability Factor Range
Uniform flow; Straight or mildly curving reach (curve radius/ channel width > 30); Impact from wave action and floating debris is minimal; Little or no uncertainty in design parameters.	1.0 - 1.2
Gradually varying flow; Moderate bend curvature (30 > curve radius/channel width > 10); Impact from waves or floating debris moderate.	1.3 - 1.6
Approaching rapidly varying flow; Sharp bend curvature (10 > curve radius/channel width); Significant impact potential from floating debris and/or ice; Significant wind and/or boat generated waves 0.30 - 0.61 m; High flow turbulence; Turbulently mixing flow at bridge abutments; significant uncertainty in design parameters.	1.6 - 2.0

Channel Bottom Shear

The stability factor is defined as the ratio of the riprap material's critical, or permissible, shear stress, τ_p, to the tractive force exerted by the flow, τ_c. The shear stresses are given as the following:

$$\tau_c = \gamma \times d_{MAX} \times S_F \tag{36}$$

$$\tau_p = F_* \times (\gamma_s - \gamma) \times D_{50} \tag{37}$$

Where:

γ_s = Unit weight of the riprap, N/m^3.

Shield's parameter, $\mathbf{F_*}$, has a default value of 0.047. This is the value used in HEC-11 and changes the basic permissible shear relationship for riprap in HEC-15. The user has the option of overriding the default Shields' parameter. To assist the user in selecting an $\mathbf{F_*}$ value, the particle shear velocity Reynolds' number is calculated and included in the output.

The Reynolds' number is calculated using equation (38):

$$R_e = \frac{U_* \times D_{50}}{} \tag{38}$$

Where:

U_*	=	Particle shear velocity, m/s.
	=	Kinematic viscosity of water at 15°C.

The Reynolds' number is important in assisting the user in interpreting the hydraulic regime. It has been documented that at high Reynolds' numbers (> 10^5), Shields' parameter significantly increases.[7] At Reynolds' numbers greater than 10^5, HEC-15 suggests an $\mathbf{F_*}$ value of 0.15. HYCHL defaults to $F_* = 0.047$ but allows a user to override the default.

In the case of riprap analysis for the channel bottom, the stability factor is calculated as follows:

$$SF_b = \frac{\tau_p}{\tau_c} = \frac{F_* \times (\gamma_s - \gamma) \times D_{50}}{\gamma \times d_{MAX} \times S_F} = \frac{F_* \times (S_g - 1) \times D_{50}}{d_{MAX} \times S_F} \tag{39}$$

Where:

SF_b	=	Stability Factor for the channel bottom.
S_g	=	Specific gravity of the riprap.

Manning's equation can be expressed as:

$$S_F = \frac{V^2 \times n^2}{0.455 \times R_h^{4/3}} \tag{40}$$

Substituting for slope in equation (39), the equation for calculating the stability factor for the channel bottom is given as:

$$SF_b = \frac{F_* \times (S_g - 1) \times D_{50}}{d_{MAX}} \times \frac{0.455 \times R_h^{\frac{4}{3}}}{V^2 \times n^2} \tag{41}$$

For the cases of riprap design of the channel bottom, equation (41) is solved for $\mathbf{D_{50}}$ to give equation (42):

$$D_{50,b} = \frac{SF_b \times d_{MAX} \times V^2 \times n^2}{F_* \times (S_g - 1) \times 0.455 \times R_h^{\frac{4}{3}}} \tag{42}$$

Where:

$D_{50,b}$ = Riprap size for the channel bottom.

<u>Side Shear</u>

The procedure for determining stability factor and riprap size can be extended to the analysis/design of the channel side slopes. The observed shear on the side slopes is calculated as:

$$\tau_c = \gamma \times d_{MAX} \times S_F \times K_{SIDE} \tag{43}$$

where $\mathbf{K_{SIDE}}$ is the ratio of side shear to bottom shear and is obtained in the same manner as described in the Side Shear section for the analysis and design of rigid, vegetative, gabion, and temporary linings. The critical, or permissible, shear is given as:

$$\tau_p = F_* \times (\gamma_s - \gamma) \times D_{50} \times K_2 \tag{44}$$

Where:

$$K_2 = \sqrt{1 - \frac{\sin^2}{\sin^2}} \tag{45}$$

and:

= Angle of side slope.
= Riprap angle of repose.
K_2 = Tractive force ratio.

The angle of repose can be user supplied, or, if it is omitted, a default value is determined as a function of $\mathbf{D_{50}}$ and the type of riprap based on chart 33 of HEC-11. Stability factor for the side slopes is then calculated as the ratio of calculated shear stress to permissible shear stress:

$$SF_{ss} = \frac{F_* \times (\gamma_s - \gamma) \times D_{50} \times K_2}{\gamma \times d_{MAX} \times S_F \times K_{SIDE}} \tag{46}$$

Where:

SF_{ss} = Stability factor for channel side slopes.

Again, applying Manning's equation and substituting for slope, the stability factor for side slopes becomes:

$$SF_{ss} = \frac{F_* \times (S_g - 1) \times D_{50} \times K_2}{d_{MAX} \times K_{SIDE}} \times \frac{0.455 \times R_h^{\frac{4}{3}}}{V^2 \times n^2} \tag{47}$$

This equation is similar to the $\mathbf{SF_b}$ equation with the exception of the $\mathbf{K_2/K_{SIDE}}$ term, and reduces to:

$$SF_{ss} = SF_b \times \frac{K_2}{K_{SIDE}} \tag{48}$$

For the case of riprap design of the side slope material, the mean riprap size for the channel side slopes is calculated as,

$$D_{50,ss} = \frac{SF_b \times d_{MAX} \times V^2 \times n^2}{F_* \times (S_g - 1) \times 0.455 \times R_h^{\frac{4}{3}}} \times \left[\frac{K_{SIDE}}{K_2}\right] \tag{49}$$

Where:

$D_{50,ss}$ = Stable riprap size for channel side slopes.

Substituting $D_{50,b}$, this equation reduces to:

$$D_{50,ss} = D_{50,b} \times \frac{K_{SIDE}}{K_2} \tag{50}$$

<u>Irregular Channels</u>

HEC-11 discusses design procedures for riprap revetments to be used as channel protection for large streams and rivers while HEC-15 outlines procedures for the design of small roadside channels of constant cross section and slope. HYCHL provides for the analysis or design of both general types of channels. In addition to allowing for the analysis of channels with a specific geometric shape, which are typically small roadside channels, large channel reaches can also be analyzed/designed using the irregular channel shape option.

HYCHL provides for the analysis or design of irregular channels which are lined with riprap. An irregular channel cross section is defined by the user through the input of a series of x-, y-coordinates. The x-coordinates must be in order, left to right, and a maximum of 50 x-, y-coordinates may be used to describe a channel cross section. The y-coordinates must be given as elevation values from any datum. A main channel within the irregular channel must be defined by four x-,y-coordinates or hinge points, as shown in figure 5. The main channel is bounded by points one and four on the left and right sides, and by points two and three on the bottom. From the given four main channel points, side slope z-values and a base width are estimated by connecting these points linearly in a trapezoidal shape. The side shear ratio is determined in the same manner as for a trapezoidal channel shape, which is described in the Side Shear section for the analysis and design of rigid, vegetative, gabion, and temporary linings.

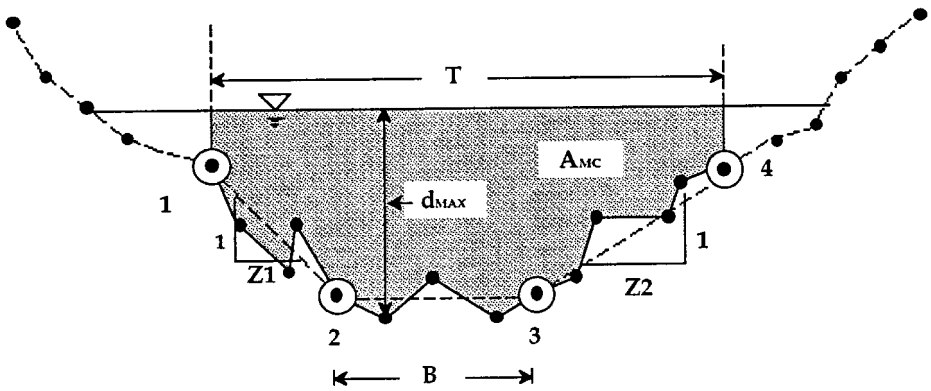


Figure 5. Example of an irregular channel cross section.

Channel area and wetted perimeter are calculated for the area between points 1 and 4. The irregular channel is broken up into a series of rectangular and triangular channel elements. Area and wetted perimeter for each element are calculated and the summation of these values is used in computing the overall hydraulic radius. If the depth, $\mathbf{d_{MAX}}$, exceeds the height bounded by the main channel, then hydraulic calculations for area, wetted perimeter, hydraulic radius, and top width are limited to the area above the main channel ($\mathbf{A_{mc}}$).

Riprap-lined irregular channels can be analyzed for stability given a $\mathbf{D_{50}}$ value or the $\mathbf{D_{50}}$ can be calculated given a stability factor. If the user inputs $\mathbf{S_F}$ and **Q**, and the calculated normal depth, $\mathbf{d_{MAX}}$, exceeds the height of the main channel, an error message results. In this case, a portion of an irregular channel is to be analyzed/designed, and the inputs, **S** and **Q**, must be replaced with $\mathbf{d_{MAX}}$ and velocity, **V**.

Analysis and Design Options

A channel lined with riprap may be analyzed for stability based on a user-supplied riprap size ($\mathbf{D_{50}}$), or a riprap size can be determined by HYCHL given a stability factor (**SF**). The user has the option, based on the provided inputs, to either analyze or design a riprap-lined channel. Stability Factors are calculated for both the channel bottom and side slopes, and if a bend exists, **SF** is calculated for the channel bottom and sides in the bend. For the case of riprap design, $\mathbf{D_{50}}$ is

also calculated for both the channel bottom and side slopes in the straight channel reach and in the bend.

There are four input scenarios the user can choose for the analysis or design of a riprap-lined channel. The user must supply either:

1. Slope, Design Flow, D_{50}.
2. Velocity, d_{MAX}, D_{50}.
3. Slope, Design Flow, Stability Factor.
4. Velocity, d_{MAX}, Stability Factor.

The channel will be analyzed for stability given scenarios 1 and 2, and riprap size is designed in scenarios 3 and 4. If only the main channel portion of an irregular channel is to be considered, one of the choices must be either 2 or 4.

USER DOCUMENTATION

Effective use of HYCHL requires an understanding of the interaction between user and the software. While the previous chapter describes the functions of HYCHL, this chapter explains how the user communicates with the software to achieve desired results.

THE INTERACTIVE HYCHL EDITOR

The HYCHL program can be executed through the interactive HYCHL editor (version 6.1) which provides full-screen input and output of data. The user is guided through a series of menus which prompt the user for required inputs for the analysis or design of a channel lining. The HYCHL interactive editor can be accessed either from DOS or from the HYDRAIN system shell.

Executing the HYCHL Interactive Editor

From DOS, execute the interactive editor by changing to the HYCHL directory (typically C:\HYCHL). Type the program name, **CHSHL**, and depress the carriage return (or enter) key (denoted as <Enter>). The interactive menu will appear on the screen. Alternatively, access the HYCHL interactive editor from the HYDRAIN system. To enter HYDRAIN, change to the HYDRAIN directory (typically C:\HYDRAIN), type **HYDRAIN**, and strike <Enter>. A screen will appear showing the member sponsors of the Pooled Fund Project. Another <Enter> reveals a disclaimer message and a third <Enter> will place the user in the Main Menu. Selection of an option within the main menu is done by using the left and right ARROWS to move the cursor to the desired procedure or by striking the highlighted letter of the desired option. From the Main Menu at the Analyze choice, select the HYCHL option. After selecting an input file, HYDRAIN calls CHSHL and the interactive menu will appear. It is a very good idea to add both HYDRAIN and HYCHL directories to the PATH statement in the AUTOEXEC.BAT file.

Using the HYCHL Interactive Editor

When the interactive editor is entered, a screen appears with the following main heading choices: Analyze, Shapes, Lining, Options, and Select. The upper right hand corner (below the HYDRAIN version number) contains information describing the current operations of the editor. The information includes the mode, input file name, and units used in the analysis (English or metric). The information also shows whether the CapsLock, NumLock, and Insert/Replace keys are active. CapsLock is indicated by the capitalization of the mode and units information displayed: all capitals indicates CapsLock is on, initial capitals indicates CapsLock is off. Insert is indicated by "in" or "IN" following units information. Replace is indicated by "rp" or "RP" following units information. NumLock is indicated by presence or absence of "#" following Insert/Replace information. The editor mode can be either guided or edit. The guided mode

automatically progresses through the program options and prompts. The guided mode is activated when creating a new file. The edit mode allows changes to information already entered into an existing input data file. The HYCHL input data set typically has a **.CHL** extension. This helps the program to distinguish the input files.

The screen initially appears in the **Shapes** section with the pulldown menu of all channel shape options. A channel shape must be selected regardless of the type of analysis desired. A shape is chosen by using the ARROW keys to highlight the desired channel shape and striking <Enter>, upon which another menu appears prompting the user for inputs specific to the channel shape. Certain input values are checked and must be within certain limits which appear in the short help descriptions. Short helps appear at the bottom of the screen which give descriptions of the highlighted choices. Once the channel shape data are entered, <Enter> returns the editor to the **Shapes** menu and <Esc> places the editor in the main heading choices (**Shapes** is highlighted).

The **Lining** section displays a menu which gives the user three options of lining type analysis, including analyzing a single lining, a composite lining, or all linings. If a single or composite lining is chosen, menus appear which prompt the user to select a lining type(s) and its associated parameters. When all lining data have been input, <Enter> returns the editor to **Lining** menu and <Esc> places the editor in the main heading choices. ***Note: If the user selects to check all linings, no Manning's values should be specified. If any have been entered, they should be removed prior to analysis.***

The **Options** section allows the user to add optional input criteria or to change program defaults in the channel lining analysis. Again, for each option, a menu appears prompting the user for the required data. <Enter> and <Esc> returns the editor to the main heading choices.

The **Select** option allows the user to retrieve, save, or print a file and to temporarily exit to DOS or to Quit. The Quit option terminates the interactive editor and returns to the C:\HYDRAIN prompt. The DOS option allows a temporary exit from the editor to DOS. The interactive editor is reactivated by typing EXIT.

Once all necessary data are supplied by the user, the **Analyze** option must be enacted in order to carry out the analysis. After the **Analysis** parameters are chosen, <Enter> will display a **GO** menu. When <Enter> is struck, analysis is performed by HYCHL using the inputs provided in the interactive editor and numerical and graphical results are displayed. Graphical output assists the user to visualize whether the selected lining is stable or unstable. The user then has the option of viewing the output file for a complete, detailed listing of the results by striking <Enter>, or returning to the interactive editor by striking <Esc>. Upon completion of the run, the output file is automatically assigned an **.LST** filename extension. The file prefix (or node) remains the same as the input file name.

THE COMMAND APPROACH - ORGANIZING THE DATA

HYCHL also functions within the HYDRAIN system through the command language concept. Data entry and data analysis are all dictated by user-supplied commands. A command describes a basic task that HYCHL can recognize. There is only a set number of commands in HYCHL's vocabulary and they must each follow a specific format. A complete list of these commands, along with brief definitions, is shown in table 7. A more detailed description, including format specifications, is included in appendix C. On-line descriptions are also available in the form of long helps (activated by the <F1> key).

Table 7. Glossary of commands.

Command		Description
BEN	-	indicates channel **BEN**d and its radius of curvature.
CHL	-	specifies **CH**anne**L** information such as slope and flow rate.
CPS	-	indicates **C**om**P**o**S**ite channel and its lining transition depth.
END	-	**END**s a command string.
GR	-	cross-section coordinates for an irregular channel.
JOB	-	indicates **JOB** and enters **JOB** title.
LBC	-	indicates **L**ining to be **B**are soil, **C**ohesive.
LBN	-	indicates **L**ining to be **B**are soil, **N**on-cohesive.
LGB	-	indicates **L**ining to be **G**a**B**ion.
LRG	-	indicates **L**ining to be **R**i**G**id.
LRR	-	indicates **L**ining to be **R**ip**R**ap.
LTM	-	indicates **L**ining to be **T**e**M**porary.
LVG	-	indicates **L**ining to be **V**e**G**etative.
N	-	allows input of Ma**N**ning's n-value(s).
NEQ	-	allows for override of Manning's **N EQ**uations.
PAR	-	specifies a **PAR**abolic shaped channel and its associated parameters.
PSS	-	allows input of **P**ermissible **S**hear **S**tress value(s).
REM	-	allows a line for **REM**arks or comments.
SA	-	specifies the main channel boundaries of an irregular channel.
TRP	-	specifies a **TR**a**P**ezoidal shaped channel and its associated parameters.
UNI	-	allows data input/output in metric **UNI**ts.
VRB	-	specifies a **V**-shaped with **R**ounded **B**ottom channel.
VSH	-	specifies a **V**-**SH**aped channel and its associated parameters.

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 the guidelines provided in the command descriptions. Once these commands are arranged in their final working order, they are collectively referred to as a command string. The command string is what HYCHL needs for analysis.

Figure 6 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 HYCHL command string is a relatively easily acquired skill. For instance, using figure 6 as an example, note that the **JOB** command is first. This establishes a labeling header used in the output.

HYCHL Command	Data	Comments
JOB	Command Example	The title of the HYCHL job.
UNI	1	Sets units to metric for both input and output data.
CHL	0.01 1.2	Slope equals 0.01 m/m and flow rate equals 1.2 m^3/s.
CPS	0.2	Lining is composite with lining transition height occurring at 0.2 m from the channel bottom.
LRG	2	Low flow lining is grouted riprap.
LVG	C	Side slope lining is vegetative, class "C".
TRP	1 3	Trapezoidal shape with 1-m base and 3:1 side slopes.
N	0.031 0.040	Manning's roughness value for low flow lining and side slope lining, respectively.
END		Terminates the HYDRO input file

Figure 6. Example of a command string.

Commands operate in "free format" fashion; that is, a space [ ], or a comma [,] are parameter subfield separators that may be used in any amount between each parameter value (spacing between subfields is not critical).

THE HYDRAIN ENVIRONMENT

For those users who have obtained HYCHL as part of the FHWA's HYDRAIN package, consult the HYDRAIN documentation for information on how to use the software system.

The interactive editor allows the user to input data with more visual interaction than the HYDRAIN editor. It is accessible through the HYDRAIN system or directly from DOS. Its operation was described earlier.

There are four methods by which HYCHL can be run. Three of these are within the HYDRAIN environment. The first method is to run HYCHL from the HYDRAIN editor. This allows the user the option of immediate review, editing capabilities. As discussed earlier, the second and third methods execute HYCHL from the interactive editor. The final method executes HYCHL from the DOS prompt. Further discussion of these options is in the HYDRAIN documentation.

APPENDIX A: BENCHMARK EXAMPLES

The following examples are hypothetical systems modeled by HYCHL 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 C 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.
4. Demonstrate what to expect for output.

The examples offered here collectively make use of most of the available commands. Some examples include a figure to schematically represent a given problem. Each example provides the input data set for the run and its corresponding output. Each of the six examples provides a different type of HYCHL application. The applications are:

1. Designing temporary and permanent linings.
2. Analyzing a composite lining.
3. Designing rock riprap lining.
4. Analyzing rock riprap in a bend.
5. Analyzing a gabion lining.
6. Designing an irregular channel lining.

Example One: Designing Temporary and Permanent Linings

Problem:

This example shows a procedure for designing a temporary lining with a permanent grass cover. A roadside channel, with 0.015 m/m slope, is planned to carry 1.2 m^3/s on a temporary lining. A permanent vegetative lining must be designed to replace the temporary lining and carry 2.3 m^3/s. To solve the problem, the designer must first choose a channel geometry that will apply to both the temporary and permanent linings. The example uses the **PAR** command which is a parabolic shape with 5.2 m maximum top width, and 1.7 m maximum depth. The **CHL** command shows a slope of 0.015 m/m and the design flow rate for the temporary lining. By not specifying a lining type, all temporary and permanent flexible linings are analyzed.

Input File: HYCHL1.CHL

```
JOB Example One:  Designing Temporary & Permanent Linings
UNI 1
CHL 0.015  1.2
PAR 5.2  1.7
END
```

Discussion of output:

Interpreting the output allows selection of both the temporary and permanent lining. HYCHL yields three stable temporary linings: straw with net, curled wood mat, and synthetic mat. Examination of the MAX Q column also shows that only one permanent lining (vegetative Class A) will be stable when the flow is 2.3 m^3/s.

Output: HYCHL1.LST

```
          ******  HYCHL  ****** (Version 6.1) ******          Date 10-15-97

 Commands Read From File: hychl1.chl


       JOB EXAMPLE ONE:  DESIGNING TEMPORARY & PERMANENT LININGS
       UNI 1
 ** UNITS PARAMETER = 1  (METRIC)
       CHL 0.015  1.2
       PAR 5.2  1.7
 ** MAX TOP WIDTH (m)    5.200   MAX DEPTH (m)    1.700
       END
```

```
***************END OF COMMAND FILE************

 EXAMPLE ONE:  DESIGNING TEMPORARY & PERMANENT LININGS
 ------------
 INPUT REVIEW
 ------------
   DESIGN PARAMETERS:
       DESIGN DISCHARGE (m^3/s):           1.200
       CHANNEL SHAPE:                   PARABOLIC
       CHANNEL SLOPE (m/m):                 .015

 -------
 RESULTS
 -------
                 SHEAR STRESS (Pa) Len of Super                        ---DESIGN--
                  --------------- Protect Elev        Stab.   Max Q  Depth  Mann
 Lining Type      Permiss  Bottom   (m)   (mm) Remark Factor (m^3/s)  (m)    n
 ---------------- ------- ------- ------ ----- ------ ------ ------- ------ ----
     TEMPORARY (FLEXIBLE)

 WOVEN PAPER NET      7.2   41.9    .000     0 UNSTAB    .17    .024   .285 .013
 JUTE NET            21.5   53.5    .000     0 UNSTAB    .40    .143   .364 .022
 FIBERGLASS SINGLE   28.7   53.1    .000     0 UNSTAB    .54    .292   .361 .022
 FIBERGLASS DOUBLE   40.7   54.5    .000     0 UNSTAB    .75    .614   .371 .023
 STRAW WITH NET      69.4   65.1    .000     0 STABLE   1.07   1.397   .443 .034
 CURLED WOOD MAT     74.2   66.8    .000     0 STABLE   1.11   1.538   .454 .036
 SYNTHETIC MAT       95.8   57.1    .000     0 STABLE   1.68   3.882   .389 .026

     PERMANENT (FLEXIBLE)

 VEGETATIVE  A      177.2  128.6    .000     0 STABLE   1.38   3.235   .874 .143
 VEGETATIVE  B      100.5  101.2    .000     0 UNSTAB    .99   1.176   .689 .086
 VEGETATIVE  C       47.9   84.5    .000     0 UNSTAB    .57    .245   .575 .059
 VEGETATIVE  D       28.7   77.3    .000     0 UNSTAB    .37    .076   .526 .049
 VEGETATIVE  E       16.8   72.9    .000     0 UNSTAB    .23    .017   .496 .043

     RIGID

 CONCRETE         *******   41.5    .000     0 STABLE ******    .000   .282 .013
 GROUTED RIPRAP   *******   61.5    .000     0 STABLE ******    .000   .418 .030
 STONE MASONRY    *******   63.4    .000     0 STABLE ******    .000   .431 .032
 SOIL CEMENT      *******   53.1    .000     0 STABLE ******    .000   .361 .022
 ASPHALT          *******   45.8    .000     0 STABLE ******    .000   .311 .016

 SOME RIPRAP AND GABION LININGS MAY ALSO BE STABLE
 *** NORMAL END OF HYCHL ***
```

Example Two: Analyzing Composite Linings

Problem:

This example shows how to analyze a compositely lined channel. It is similar to example 13 of HEC-15. A trapezoidal channel on a 0.02 m/m slope has a 0.91-m base width and 3:1 (horizontal:vertical) side slopes. The flow is 0.28 m^3/s, the low-flow lining is concrete, and the side flow lining is vegetative (Class C). The lining transition depth is zero m, meaning the low flow lining only lines the channel bottom.

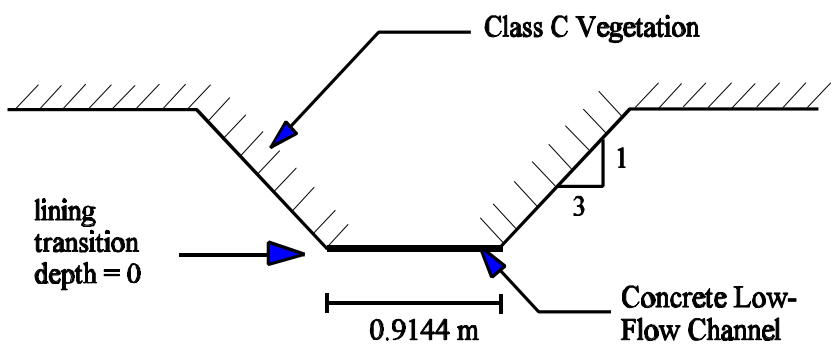


Figure 7. Composite lining example.

Input File: HYCHL2.CHL

```
JOB Example Two: Analyzing Composite Linings
UNI 1
CHL 0.02  0.28
TRP 0.91  3
LRG 1 0.30
CPS 0
LVG C
END
```

Discussion of output:

The output shows that both linings are stable with the vegetative lining having a safety factor of 1.11. It is almost flowing with maximum discharge, which is 0.34 m^3/s. The depth is 265 mm and the effective Manning's **n** value is 0.071. The final line shows that $\mathbf{K_{SU}}$–the ratio of side lining shear to bottom lining shear–is 0.86.

Output File: HYCHL2.LST

```
          ******  HYCHL  ****** (Version 6.1) ******          Date 10-15-97

 Commands Read From File: hychl2.chl


       JOB EXAMPLE TWO: ANALYZING COMPOSITE LININGS
       UNI 1
 ** UNITS PARAMETER = 1  (METRIC)
       CHL 0.02  0.28
       TRP 0.91  3
 ** LEFT SIDE SLOPE    3.0 AND RIGHT SIDE SLOPE    3.0
 ** THE BASE WIDTH OF THE TRAPEZOID (m)     .910
       LRG 1 0.30
 ** THE MAXIMUM CHANNEL DEPTH (m) IS     .300
       CPS 0
       LVG C
       END
***************END OF COMMAND FILE************
```

```
EXAMPLE TWO: ANALYZING COMPOSITE LININGS
------------
INPUT REVIEW
------------
  DESIGN PARAMETERS:
      DESIGN DISCHARGE (m^3/s):            .280
      CHANNEL SHAPE:                  TRAPEZOIDAL
      CHANNEL SLOPE (m/m):                 .020
      LINING TRANSITION HEIGHT (m):      .000
-----------------------------------------
HYDRAULIC CALCULATIONS USING NORMAL DEPTH
-----------------------------------------

                        DESIGN     MAXIMUM
                        ------     -------
FLOW (m^3/s)              .280        .338
DEPTH (m)                 .264        .284
AREA (m^2)                .449        .500
WETTED PERIMETER (m)     2.579       2.704
HYDRAULIC RADIUS (m)      .174        .185
VELOCITY (m/s)            .624        .677
MANNINGS N (LOW FLOW)     .013        .013
MANNINGS N (SIDE SLOPE)   .093        .087
EFFECTIVE MANNINGS N      .071        .068

------------------
STABILITY ANALYSIS
------------------

                     LINING       PERMIS SHR   CALC. SHR  STAB.
    CONDITION        TYPE          ( Pa )       ( Pa )    FACTOR   REMARKS
    ---------        ---------    ----------   ---------  ------   -------
LOW FLOW LINING
  BOTTOM; STRAIGHT   CONCRETE        *******     51.73    ******   STABLE
SIDE SLOPE LINING
  SIDE; STRAIGHT     VEGETATIVE  C     47.88     44.54      1.07   STABLE

RATIO OF SIDE SHEAR TO BOTTOM SHEAR =      .86

*** NORMAL END OF HYCHL ***
```

Example Three: Designing Rock Riprap Linings

Problem:

A riprap-lined trapezoidal channel is to be designed which can convey a design discharge of 2.5 m^3/s on a slope of 0.03 m/m. A stability factor of 1.2 is prescribed by the user in the **LRR** command.

Input File: HYCHL3.CHL

```
JOB Example Three: Designing Rock Riprap Linings
UNI 1
CHL 0.03  2.5
TRP 1.8  3
LRR -1.2 2
END
```

Discussion of Output:

The Bathurst hydraulic procedure was enacted in this run due to rock protrusion, i.e., the value of $\mathbf{d_a} / \mathbf{D_{50}}$ was less than 2. Maximum discharge is not computed for the channel and does not appear in the hydraulic calculations. In the riprap design section, a $\mathbf{D_{50}}$ value is given for both the bottom and sides of the channel.

Output File: HYCHL3.LST

```
          ******  HYCHL  ****** (Version 6.1) ******          Date 10-15-97

 Commands Read From File: hychl3.chl


       JOB EXAMPLE THREE: DESIGNING ROCK RIPRAP LININGS
       UNI 1
 ** UNITS PARAMETER = 1  (METRIC)
       CHL 0.03  2.5
       TRP 1.8  3
 ** LEFT SIDE SLOPE    3.0 AND RIGHT SIDE SLOPE    3.0
 ** THE BASE WIDTH OF THE TRAPEZOID (m)    1.800
       LRR -1.2 2
 ** STABILITY FACTOR    1.20
       END
***************END OF COMMAND FILE************

 EXAMPLE THREE: DESIGNING ROCK RIPRAP LININGS
 ------------
 INPUT REVIEW
 ------------
   DESIGN PARAMETERS:
       DESIGN DISCHARGE (m^3/s):           2.500
       CHANNEL SHAPE:                  TRAPEZOIDAL
       CHANNEL SLOPE (m/m):                 .030
 -------------------------------------
 HYDRAULIC CALCULATIONS USING BATHURST
 -------------------------------------

 FLOW (m^3/s)              2.500
```

```
MAX DEPTH (m)              .508
AREA (m^2)                1.680
WETTED PERIMETER (m)      5.001
HYDRAULIC RADIUS (m)       .336
AVG VELOCITY (m/s)        1.489
MANNINGS EQUIVALENT        .058
Davg / D50                 1.48
FROUDE NUMBER               .67
REYNOLDS NUMBER (10^5)      .86
-------------
RIPRAP DESIGN
-------------

                      LINING    PERMIS SHR   CALC. SHR  STAB.
    CONDITION         TYPE       ( Pa )       ( Pa )    FACTOR   D50(m)
    ---------          ------    ----------   ---------  ------   -------
  BOTTOM; STRAIGHT   RIPRAP         177.86    149.26      1.20     .234
  SIDE; STRAIGHT     RIPRAP         152.92    128.32      1.20     .229

*** NORMAL END OF HYCHL ***
```

Example Four: Rock Riprap Analysis in a Bend

Problem:

This example illustrates the rock riprap analysis procedure in a bend. A trapezoidal channel is to carry a design flow of 0.91 m^3/s on a longitudinal slope of m/m. The user-supplied riprap size is 0.08 m. The channel is to have a bend with a radius of curvature of 18.3 m. The trapezoidal channel section has a base width of 3.1 m and unequal side slopes (2.7 to 1 and 3 to 1, horizontal to vertical).

Input File: HYCHL4.CHL

```
JOB Example Four: Analysis of Rock Riprap in a Bend
UNI 1
BEN 18.3
CHL 0.01  0.91
TRP 3.1 2.7 3
LRR 0.08
END
```

Discussion of Output:

Input parameters are echoed in the first section of output and the hydraulic calculations follow. Reynolds' number is included in the hydraulic calculations to assist the user in determining a value for Shields' parameter (0.047 is the default). Maximum discharge is computed but it is applicable only to the straight channel section. The stability analysis includes stability factor calculations for both the bottom and sides of the straight channel section and the bend. The given riprap size was determined to be stable (SF > 1.0) for all channel areas.

Output File: HYCHL4.LST

```
          ******  HYCHL  ****** (Version 6.1) ******          Date 10-15-97

 Commands Read From File: hychl4.chl


       JOB EXAMPLE FOUR: ANALYSIS OF ROCK RIPRAP IN A BEND
       UNI 1
 ** UNITS PARAMETER = 1  (METRIC)
       BEN 18.3
       CHL 0.01  0.91
       TRP 3.1 2.7 3
 ** LEFT SIDE SLOPE    2.7 AND RIGHT SIDE SLOPE    3.0
 ** THE BASE WIDTH OF THE TRAPEZOID (m)    3.100
       LRR 0.08
 ** D50 (m)    .080
       END
***************END OF COMMAND FILE************
```

```
EXAMPLE FOUR: ANALYSIS OF ROCK RIPRAP IN A BEND
------------
INPUT REVIEW
------------
  DEFAULT ANGLE OF REPOSE (degrees):     40.70
  DESIGN PARAMETERS:
      DESIGN DISCHARGE (m^3/s):            .910
      CHANNEL SHAPE:                  TRAPEZOIDAL
      CHANNEL SLOPE (m/m):                 .010
      RADIUS OF CURV. FOR BEND (m):    18.301
-----------------------------------------
HYDRAULIC CALCULATIONS USING NORMAL DEPTH
-----------------------------------------

                                   MAXIMUM
                         DESIGN    (NO BEND)
                         ------     -------
FLOW (m^3/s)               .910       2.730
DEPTH (m)                  .307        .525
AREA (m^2)                1.219       2.414
WETTED PERIMETER (m)      4.953       6.272
HYDRAULIC RADIUS (m)       .246        .385
VELOCITY (m/s)             .746       1.131
MANNINGS N (LOW FLOW)      .053        .047
REYNOLDS NUMBER (10^5)      .17

------------------
STABILITY ANALYSIS
------------------

                      LINING    PERMIS SHR   CALC. SHR  STAB.
    CONDITION         TYPE       ( Pa )       ( Pa )     FACTOR   REMARKS
    ---------          ------    ----------   ---------  ------   -------
  BOTTOM; STRAIGHT   RIPRAP          60.81     30.07      2.02   STABLE
  BOTTOM; BEND       RIPRAP          60.81     42.73      1.42   STABLE
  SIDE; STRAIGHT     RIPRAP          51.47     25.56      2.01   STABLE
  SIDE; BEND         RIPRAP          51.47     36.32      1.42   STABLE

       SUPER ELEVATION (m)          .015
       LENGTH OF PROTECTION (m)    5.165

RATIO OF SHEAR IN BEND TO SHEAR IN STRAIGHT CHANNEL =    1.42

*** NORMAL END OF HYCHL ***
```

Example Five: Gabion Lining Analysis

Problem:

The example shows the analysis of a gabion-lined channel. The gabion lining command (**LGB**) indicates a gabion lining with a riprap size of 0.08 m and a mattress thickness of 0.16 m. The slope is 0.05 m/m (0.05 ft/ft) and the trapezoid has a base width of 1.3 m. The flow rate is 0.5 m^3/s.

Input File: HYCHL5.CHL

```
JOB Example Five: Gabion Lining Analysis
UNI 1
CHL 0.05   0.5
TRP 1.3  2.7  3
LGB 0.08  0.16
END
```

Discussion of Output:

The output shows the normal depth computation results and the maximum discharge. Since the calculated shear stress is less than the permissible shear stress of the gabion mattress, the channel lining is stable.

Output File: HYCHL5.LST

```
          ******  HYCHL  ****** (Version 6.1) ******          Date 10-15-97

 Commands Read From File: hychl5.chl


       JOB EXAMPLE FIVE: GABION LINING ANALYSIS
       UNI 1
 ** UNITS PARAMETER = 1  (METRIC)
       CHL 0.05   0.5
       TRP 1.3  2.7  3
 ** LEFT SIDE SLOPE    2.7 AND RIGHT SIDE SLOPE    3.0
 ** THE BASE WIDTH OF THE TRAPEZOID (m)    1.300
       LGB 0.08  0.16
 ** MEAN STONE SIZE (m)       .080
 ** MATTRESS THICKNESS (m)    .160
 ** SPECIFIC GRAVITY EQUALS   2.65
       END
***************END OF COMMAND FILE************
```

```
EXAMPLE FIVE: GABION LINING ANALYSIS
------------
INPUT REVIEW
------------
  DEFAULT ANGLE OF REPOSE (degrees):     37.20
  DESIGN PARAMETERS:
      DESIGN DISCHARGE (m^3/s):            .500
      CHANNEL SHAPE:                  TRAPEZOIDAL
      CHANNEL SLOPE (m/m):                 .050
-----------------------------------------
HYDRAULIC CALCULATIONS USING NORMAL DEPTH
-----------------------------------------

                        DESIGN     MAXIMUM
                        ------     -------
FLOW (m^3/s)              .500       1.899
DEPTH (m)                 .229        .416
AREA (m^2)                .447       1.036
WETTED PERIMETER (m)     2.683       3.815
HYDRAULIC RADIUS (m)      .167        .271
VELOCITY (m/s)           1.119       1.834
MANNINGS N (LOW FLOW)     .060        .051

------------------
STABILITY ANALYSIS
------------------

                     LINING       PERMIS SHR   CALC. SHR  STAB.
    CONDITION        TYPE          ( Pa )       ( Pa )    FACTOR   REMARKS
    ---------        ---------    ----------   ---------  ------   -------
LOW FLOW LINING
  BOTTOM; STRAIGHT   GABION           204.05    112.15      1.82   STABLE

*** NORMAL END OF HYCHL ***
```

Example Six: Irregular Channel Lining Design

Problem:

This example illustrates the design of a riprap-lined channel for an irregular cross section. Figure 8 shows a sketch of the cross section detailing the main channel and the left and right floodplains. Inputs include a field measured maximum depth of 3.8 m and a main channel velocity of 2.1 m/s. The design incorporates a stability factor of 1.2.

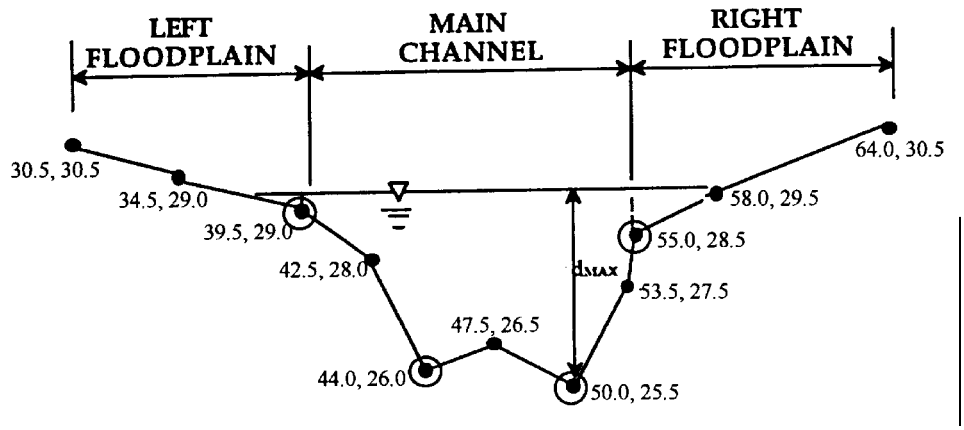


Figure 8. Irregular channel example.

Input File: HYCHL6.CHL

```
JOB Example Six: Riprap Lined Irregularly Shaped Channel
UNI 1
CHL -3.8  -2.1
GR  30.5,30.5 34.5,29.0 39.5,29.0 42.5,28.0 44.0,26.0 47.5,26.5 50.0,25.5
    53.5,27.5 55.0,28.5 58.0,29.0 64.0,30.5
SA  39.5  44.0  50.0  55.0
LRR -1.2 2
END
```

Discussion of Output:

The x-, y-coordinates describing the cross section are printed along with the x-value of the four coordinates which bound the main channel. Due to a high Reynolds' number, HYCHL has provided a message so that the user can consider increasing Shields' parameter. In the riprap design section, $\mathbf{D_{50}}$ was sized for both the channel bottom and the channel side slope for a stability factor of 1.2.

Output File: HYCHL6.LST

```
          ******  HYCHL  ****** (Version 6.1) ******          Date 10-15-97

 Commands Read From File: hychl6.chl


       JOB EXAMPLE SIX: RIPRAP LINED IRREGULARLY SHAPED CHANNEL
       UNI 1
 ** UNITS PARAMETER = 1  (METRIC)
       CHL -3.8  -2.1
       GR  30.5,30.5 34.5,29.0 39.5,29.0 42.5,28.0 44.0,26.0 47.5,26.5
50.0,25.5
 ** NUMBER  X-COORD( m)  Y-COORD( m)
 **    1        30.500       30.500
 **    2        34.500       29.000
 **    3        39.500       29.000
 **    4        42.500       28.000
 **    5        44.000       26.000
 **    6        47.500       26.500
 **    7        50.000       25.500
 **    8        53.500       27.500
 **    9        55.000       28.500
 **   10        58.000       29.000
 **   11        64.000       30.500
       SA  39.5  44.0  50.0  55.0
 **   LOCATION    X COORD ( m)
 **  LEFT BANK         39.500
 **  LEFT BASE         44.000
 **  RIGHT BASE        50.000
 **  RIGHT BANK        55.000
       LRR -1.2 2
 ** STABILITY FACTOR    1.20
       END
***************END OF COMMAND FILE************
```

```
EXAMPLE SIX: RIPRAP LINED IRREGULARLY SHAPED CHANNEL
------------
INPUT REVIEW
------------
  IRREGULAR CHANNEL CALCULATIONS:
      LEFT SIDE SLOPE EQUIVALENT:         1.5
      RIGHT SIDE SLOPE EQUIVALENT:        1.7
      BASE WIDTH EQUIVALENT (m):          6.000
  DESIGN PARAMETERS:
      DESIGN VELOCITY (m/s):             2.100
      CHANNEL SHAPE:                  IRREGULAR
      CHANNEL SLOPE (m/m):                 .000
      MAXIMUM FLOW DEPTH (m):            3.800
------------------------------------------------------------
HYDRAULIC CALCULATIONS USING NORMAL DEPTH FOR MAIN CHANNEL
------------------------------------------------------------

                         DESIGN
                         ------
FLOW (m^3/s)             76.714
MAX DEPTH (m)             3.800
AREA (m^2)               36.539
WETTED PERIMETER (m)     17.725
HYDRAULIC RADIUS (m)      2.061
AVG VELOCITY (m/s)        2.100
MANNINGS N (LOW FLOW)      .052
Davg / D50                8.94
EQUIVALENT SLOPE (m/m)     .005
REYNOLDS NUMBER (10^5)    1.03
*** WARNING *** REYNOLDS NUMBER IS LARGER THAN 10^5

-------------
RIPRAP DESIGN
-------------

                      LINING    PERMIS SHR   CALC. SHR  STAB.
    CONDITION         TYPE       ( Pa )       ( Pa )    FACTOR   D50(m)
    ---------          ------    ----------   ---------  ------   -------
  BOTTOM; STRAIGHT   RIPRAP         200.27    168.51      1.20     .263
  SIDE; STRAIGHT     RIPRAP         133.73    112.52      1.20     .319

*** NORMAL END OF HYCHL ***
```

APPENDIX B: FOOTPRINTS FOR TYPICAL APPLICATIONS

This section presents two basic HYCHL applications represented by an arrangement of command strings. These command strings, or footprints, are depicted in this section for the following typical applications:

1. Riprap channel design.
2. Analysis of a non-riprap channel.

These two footprints are contained in files on the HYDRAIN diskettes. These files are comprised of command lines with empty data fields for which the user may supply the appropriate data (footprint files should be copied and renamed before any editing is done).

1. Riprap Channel Design

Filename: RRCH˜FP.CHL

HYCHL determines the stability factor given the flow and slope (or depth and velocity) and mean particle diameter, D_{50}. Another function of HYCHL is to determine the mean particle diameter given the flow and slope (or velocity and depth) and stability factor. The typical footprint of this application is as follows:

```
rem--->Riprap Channel Design
rem--->REMOVE all unused command lines (Alt + D)
rem--->REQUIRED first command, JOB
JOB
CHL
LRR
rem--->Cross section geometry---Select <TRP>, <PAR>, <VRB>, <VSH>, or <GR and
rem--->SA>:
TRP
PAR
VRB
VSH
GR
SA
rem--->OPTIONAL:  BEN, N, and PSS commands
BEN
N
PSS
END
```

2. Analysis of Non-riprap Channel

Filename: ANCHL~FP.CHL

HYCHL determines the maximum flow in a channel given the cross section geometry and channel slope. The typical footprint of this application is as follows:

```
rem--->Analysis of Non-riprap Channel
rem--->REMOVE all unused command lines (Alt + D)
rem--->REQUIRED first command, JOB
JOB
rem--->Command UNI, if used, must be the first active command
UNI 1
CHL
rem--->Channel lining types---<LBC>, <LBN>, <LGB>, <LRG>, <LTM>, or <LVG>
LBC
LBN
LGB
LRG
LTM
LVG
rem--->Cross section geometry---<PAR>, <TRP>, <VRB>, or <VSH>
PAR
TRP
VRB
VSH
rem--->OPTIONAL---BEN, N, and PSS commands
BEN
N
PSS
END
```

APPENDIX C: HYCHL COMMANDS

This appendix details the meaning and syntax of each command available in HYCHL. The descriptions are ordered alphabetically and include information on the command name, its purpose, and its structure. It also includes important notes pertaining to the command. Those commands designated as "required" must be included in any run.

COMMAND BEN - BENd information

Purpose: To analyze a channel BENd.

Structure:

BEN Rc

Rc - radius of curvature, m

Note: The channel radius of curvature is measured to the middle of the channel.

COMMAND CHL - CHanneL information (required)

Purpose: To specify design or analysis conditions.

Structure: (2 options)

CHL slope (, qd, qlin)

-- OR --

CHL -dmax, -v, (, qlin)

1) slope - Slope of channel, ft/ft (m/m)
2) qd - OPTIONAL - Design discharge, (optional), ft^3/s (m^3)
3) qlin - OPTIONAL - Lateral flow contribution, $ft^3/s/ft$ (m^3/m)

-- OR --

1) -dmax - maximum depth of flow in main channel, m, expressed as a negative number to distinguish it from "slope".
2) -v - average velocity of flow in main channel, ft/s, (m/s), expressed as a negative number to distinguish it from "slope".
3) qlin - OPTIONAL - Lateral flow contribution, $ft^3/s/ft$ (m^3/m)

Notes:

1) For a riprap-lined channel, the user may supply maximum depth, dmax, and average velocity, v rather than slope and design discharge. If a portion of an irregular riprap-lined channel is to be analyzed, dmax and v must be input. Both dmax and v values are preceded by a minus sign to distinguish them from slope and qd.

2) If the qd or -v parameter is left blank or a zero is input, then the program calculates the maximum discharge for the channel but does not evaluate stability.

COMMAND CPS - ComPoSite lining information

Purpose: To analyze a compositely-lined channel.

Structure:

CPS htl

htl - Lining transition depth, m

Notes:

1) The lining transition height is measured from the channel bottom to the point of transition from low flow lining to side slope lining.

2) If this command is used, two lining cards must be specified, one for the low flow lining and one for the side slope lining.

COMMAND END - END of run (required)

Purpose: To signal the end of the command string.

Structure:

END (no fields)

Note: An END command must be present and must be the last command.

COMMAND GR - cross section GRound geometry

Purpose: To specify x-, y-coordinates that define cross section geometry.

Structure:

GR x(1), y(1), x(2), y(2),..., x(n), y(n)

nx) x(i) - x-coordinate, from an arbitrary horizontal datum, the ith ground point, m

ny) y(i) - y-coordinate, above common elevation datum of the ith ground point, m

Notes:

1) The parenthetical notation is for illustration purposes only.

2) The maximum number of x-, -y coordinates is 50.

3) x-, y-coordinates are oriented from left bank to right bank looking upstream (n is the total number of coordinates).

COMMAND JOB - JOB start (required)

Purpose: To initiate a job and specify a job title.

Structure:

JOB jobtitle

jobtitle - (optional) alphanumeric characters describing the job

Note: JOB must be the first command. Only one JOB command per command string is permitted. Only 15 characters describing the job are permitted in data sets intended for use with the interactive graphics shell. Longer strings cause an error.

COMMAND LBC - Lining Bare soil, Cohesive

Purpose: To analyze a channel lined with cohesive bare soil.

Structure

LBC PI, Looseness

1) PI - Plasticity index, dimensionless
2) looseness - OPTIONAL - measure of cohesiveness; 1 = "loose," 2 = "medium" (default), 3 = "compact"

Notes:

1) The plasticity index value is a measure of the cohesiveness of the soil and must have a value greater than 3 and less than 50.

2) The soil "looseness" can be one of three values:

   1 - "loose" - soil is loose in consistency.
   2 - "medium" - soil has a medium consistency.
   3 - "compact" - soil is dense or compact.

3) The default looseness value is "medium."

COMMAND LBN - Lining Bare soil, Non-cohesive

Purpose: To analyze a channel lined with non-cohesive soil.

Structure:

LBN D_{50}

D_{50} - mean particle size of the soil, m

COMMAND LGB - Lining GaBion

Purpose: To analyze a gabion lined channel.

Structure:

LGB D_{50}, mt (, spgrav)

1) D_{50} - Mean gabion rock diameter, m
2) mt - Gabion mattress thickness, m
3) spgrav - OPTIONAL - Specify gravity (default = 2.65).

COMMAND LRG - Lining RiGid information

Purpose: To analyze a channel with a rigid lining.

Structure:

LRG num, dmx

1) num - rigid lining type number:
   - 1 - concrete.
   - 2 - grouted riprap.
   - 3 - stone masonry.
   - 4 - soil cement.
   - 5 - asphalt.
2) dmx - maximum channel depth, m

Note: Since permissible shear of rigid linings is considered to be infinite, dmx acts as a limitation on depth of flow for the calculation of maximum discharge.

COMMAND LRR - Lining RipRap

Purpose: To specify the analysis of a riprap lined channel.

Structure: (2 options)

LRR D50, type (, angrep, spgrav, shields)

-- OR --

LRR -sf, type (, angrep, spgrav, shields)

1) D_{50} - Mean riprap diameter, m

-- OR --

1) -(sf) - Stability factor

2) type - Number corresponding to riprap type:
1 - crushed rock.
2 - very angular (default).
3 - very rounded.

3) angrep - OPTIONAL - Angle of repose, degrees

4) spgrav - OPTIONAL - Specific gravity of riprap (default = 2.65)

5) shields - OPTIONAL - Shields' parameter, F_* (default = 0.047)

Notes:

1) D_{50} is input if stability analysis is required for a given riprap size. Stability factor is input if a riprap design procedure is to be performed. sf is preceded by a minus sign to distinguish it from D_{50}.

2) The parameter angrep is optional and should only be entered as an override variable. If angrep is left blank or a zero is entered, the program calculates this value based on type and D_{50} (chart 12 in HEC-15).

3) The user may override Shields' parameter at any time but for Reynolds' number greater than 10^5, the user may want to choose 0.15 as Shields' number (p. 87 of HEC-15).

COMMAND LTM - Lining TeMporary information

Purpose: To analyze a channel with a temporary lining type.

Structure:

LTM num

num - number corresponding to the temporary lining type:

1 - woven paper net.
2 - jute net.
3 - fiberglass single.
4 - fiberglass double.
5 - straw with net.
6 - curled wood mat.
7 - synthetic mat.

COMMAND LVG - Lining VeGetative

Purpose: To analyze a vegetative lined channel.

Structure:

LVG class

class - Retardance class of the vegetation. There are 5 classes of vegetation with varying degrees of grass height and thickness:

A - Vegetation Class A, which is the tallest in height.
B - Vegetation Class B, which is tall in height.
C - Vegetation Class C, which is medium in height.
D - Vegetation Class D, which is short in height.
E - Vegetation Class E, which is shortest in height.

COMMAND N - optional user-supplied value for Manning's **N**

Purpose: To allow user to override default Manning's **N**.

Structure:

N n(1), n(2)

1) n(1) - Manning's **N** value for low flow lining
2) n(2) - Manning's **N** value for side slope lining

Notes:

1) The side slope lining Manning's **N** value, n(2) is omitted if the lining is not composite.

2) When using the interactive graphics shell, this command should not be used when all linings are to be checked. Any values for **N** should be removed prior to analysis.

3) If this command is used, **NEQ** cannot be used.

COMMAND NEQ - optional override of equations for Manning's **N**

Purpose: To allow user to employ the Anderson or Blodgett equations for Manning's **N**.

Structure:

NEQ select

select - override selection (1 = Anderson, 2 = Blodgett)

Notes:

1) Command is only valid for riprap or gabion linings.

2) If this command is used, **N** cannot be used.

COMMAND PAR - PARabolic channel information

Purpose: Specifies a parabolic channel shape for analysis.

Structure

PAR tm, dm

1)	tm	-	Maximum top width of the channel, m
2)	dm	-	Maximum depth corresponding to the maximum top width, m

Note: Both parameters, tm and dm, are used to define the parabola. Any channel width along with its corresponding depth may be entered instead of the widths and depths at the maximum.

COMMAND PSS - Permissible Shear Stress

Purpose: To allow the user the option of overriding the default shear value.

Structure:

PSS tp(1), tp(2)

1)	tp(1)	-	Permissible shear stress value for low flow lining, N/m^2
2)	tp(2)	-	Permissible shear stress value for side slope lining, N/m^2

Note: The side slope shear stress value, tp(2) is omitted if the lining is not composite.

COMMAND REM - REMark

Purpose: To provide remarks or comments.

Structure:

REM (any alphanumeric characters).

COMMAND SA - SubAreal hinge points

Purpose: To specify main channel boundaries of an irregular channel.

Structure:

SA x_{lc}, x_{lb}, x_{rb}, x_{rc}

1) x_{lc} - x-coordinate of the left bank of a main channel, m
2) x_{lb} - x-coordinate of the left base of a main channel, m
3) x_{rb} - x-coordinate of the right base of a main channel, m
4) x_{rc} - x-coordinate of the right bank of a main channel, m

Notes:

1) This command must be used for irregular channels.

2) The x-values have the same arbitrary horizontal datum as the irregular channel.

3) The x-values must be in ascending order left to right, looking upstream, and must be in the same range as the x-coordinates for the irregular channel.

COMMAND TRP - TRaPezoidal channel shape

Purpose: Specifies a trapezoidal channel shape for analysis.

Structure:

TRP b, z1 (, z2)

1)	b	-	Bottom width of the channel, m
2)	z1	-	Left side slope, horizontal:vertical (z1:1)
3)	z2	-	OPTIONAL - Right side slope, horizontal:vertical (z2:1) if different from left slope.

Note: If a right side slope value, z2, is not entered, the program sets the left and right side slopes equal to z1.

COMMAND UNI - UNIt conversion

Purpose: To allow data input in metric units.

Structure:

UNI units

units - 0 = English system of units (default)
1 = metric system of units

Note: This command is optional if the English system of units is desired.

COMMAND VRB - V-shaped with Rounded Bottom channel shape

Purpose: Specifies a V-shaped with rounded bottom channel for analysis.

Structure:

VRB z1

z1 - Left and right side slope, horizontal:vertical (1)

Note: By definition, the left and right side slopes must be equal for a V-shaped with rounded bottom channel.

COMMAND VSH - V-SHape channel information

Purpose: Specifies a V-shaped channel for analysis.

Structure:

VSH z1, z2

1) z1 - Left side slope, horizontal:vertical (1)
2) z2 - Right side slope, horizontal:vertical (1)

Note: If the right side slope value, z2, is not entered, the program sets the left and right side slopes equal to z1.

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