

1. Report No. FHWA-RD-88-121		2. Government Accession No.		3. Recipient's Catalog No. PB90 120338/A																									
4. Title and Subtitle HYDRAIN - INTEGRATED DRAINAGE DESIGN COMPUTER SYSTEM VOLUME II. HYDRO - HYDROLOGY				5. Report Date November 1988																									
				6. Performing Organization Code																									
7. Author(s) G. Kenneth Young and Joseph S. Krolak				8. Performing Organization Report No.																									
9. Performing Organization Name and Address GKY & Associates, Inc. 5411-E Backlick Road Springfield, VA 22151				10. Work Unit No. (TRAIS) NCP 3D3b302																									
				11. Contract or Grant No. DTFH61-88-C-00083																									
12. Sponsoring Agency Name and Address Structures Division, HNR-10 Federal Highway Administration 6300 Georgetown Pike McLean, Virginia 22101-2296				13. Type of Report and Period Covered Final Report September 1984 - December 1987																									
				14. Sponsoring Agency Code																									
15. Supplementary Notes Contract Manager: J. Sterling Jones <u>Advisors</u> : Roy Trent, Phil Thompson, Stan Davis, Dennis Richards <u>Contributors</u> : James Adler, Roger Kilgore																													
16. Abstract This project report, in six volumes, documents a system of computer programs for the design of drainage components: culverts, storm drains, and open channels. The system includes an input generator to estimate design rain, hyetographs, design flow, and hydrographs. Programs are facilitated with semi-expert system shells that generate input data for engineering programs. The system is expandable and designed for personal computers that operate within an MS-DOS environment.  Volume II documents the computer program HYDRO. Written in FORTRAN, it is based on the Federal Highway Administration (FHWA) Highway Engineering Circular 19, HYDROLOGY, and is an effort to combine existing approaches for rainfall and runoff analysis into one system. HYDRO generates point estimates or a single design event. HYDRO uses the probabilistic distribution of natural events such as rainfall or stream flow, as a controlling variable. HYDRO should be considered as a computer based subset of Highway Engineering Circular (HEC) 19, with some areas of HEC-12 also included.  This volume is one of a series. The entire series is:  <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="text-align: left;">FHWA No.</th> <th style="text-align: left;">Vol. No.</th> <th style="text-align: left;">Short Title</th> <th style="text-align: left;">FHWA No.</th> <th style="text-align: left;">Vol. No.</th> <th style="text-align: left;">Short Title</th> </tr> </thead> <tbody> <tr> <td>RD-88-120</td> <td>I</td> <td>HYDRAIN</td> <td>RD-88-123</td> <td>IV</td> <td>CDS</td> </tr> <tr> <td>RD-88-121</td> <td>II</td> <td>HYDRO</td> <td>RD-88-124</td> <td>V</td> <td>WSPRO</td> </tr> <tr> <td>RD-88-122</td> <td>III</td> <td>PFP-HYDRA</td> <td>RD-88-125</td> <td>VI</td> <td>HY8</td> </tr> </tbody> </table> To operate all the software, the user needs all six (6) volumes. To individually operate HYDRO, one needs Volume I and Volume II.						FHWA No.	Vol. No.	Short Title	FHWA No.	Vol. No.	Short Title	RD-88-120	I	HYDRAIN	RD-88-123	IV	CDS	RD-88-121	II	HYDRO	RD-88-124	V	WSPRO	RD-88-122	III	PFP-HYDRA	RD-88-125	VI	HY8
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17. Key Words Backwater, Bridges, Culverts, Drainage, Expert System, Floods, Hydraulics, Hydrology, Open Channels, Sewers, Storm Drains, Personal Computers			18. Distribution Statement No Restrictions. This document is available to the public through the National Technical Information Services, Springfield, Virginia, 22161																										
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 67	22. Price																								

# METRIC (SI\*) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
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### LENGTH

in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

### AREA

in <sup>2</sup>	square inches	645.2	millimetres squared	mm <sup>2</sup>
ft <sup>2</sup>	square feet	0.0929	metres squared	m <sup>2</sup>
yd <sup>2</sup>	square yards	0.836	metres squared	m <sup>2</sup>
mi <sup>2</sup>	square miles	2.59	kilometres squared	km <sup>2</sup>
ac	acres	0.395	hectares	ha

### MASS (weight)

oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

### VOLUME

fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft <sup>3</sup>	cubic feet	0.0328	metres cubed	m <sup>3</sup>
yd <sup>3</sup>	cubic yards	0.0765	metres cubed	m <sup>3</sup>

NOTE: Volumes greater than 1000 L shall be shown in m<sup>3</sup>.

### TEMPERATURE (exact)

°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C
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## APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
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### LENGTH

mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi

### AREA

mm <sup>2</sup>	millimetres squared	0.0016	square inches	in <sup>2</sup>
m <sup>2</sup>	metres squared	10.764	square feet	ft <sup>2</sup>
km <sup>2</sup>	kilometres squared	0.39	square miles	mi <sup>2</sup>
ha	hectares (10 000 m <sup>2</sup> )	2.53	acres	ac

### MASS (weight)

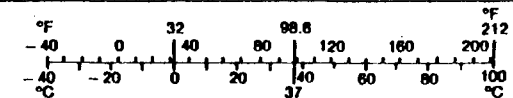
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

### VOLUME

mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m <sup>3</sup>	metres cubed	35.315	cubic feet	ft <sup>3</sup>
m <sup>3</sup>	metres cubed	1.308	cubic yards	yd <sup>3</sup>

### TEMPERATURE (exact)

°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F
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These factors conform to the requirement of FHWA Order 5190.1A.

\* SI is the symbol for the International System of Measurements

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## Preface

This report presents documentation for the Hydrain system. HYDRO, PFP-HYDRA, CDS, WSPRO and HY8 are five nonproprietary engineering programs incorporated in the Hydrain system. The Hydrain personal computer oriented system operates the first three of these engineering programs with an interactive program shell written in the C language. The last program, HY8, also has an interactive program interspersed with the analysis code. It is written in BASIC and FORTRAN. Each program is in turn controlled by a common system shell, also in C. The system and program shells are designed with an open architecture for expansion. Hydrain is sponsored as a Pooled Fund Project (PFP) of 23 State highway departments and is managed by the Federal Highway Administration (FHWA). The latest State to join is Texas. The system and its support are expanding.

Within the Hydrain program shell concept, the HYDRO, PFP-HYDRA and CDS program shells allow the user to easily input, edit and run input data files and to scroll through output files. With these three applications, "short" (one-line) and "long" (multiple line) help is provided within the program logic.

The other two applications are incorporated into Hydrain without the high level of help and without program shells. WSPRO has the same type of batch operations as the first three but the input file has to be created with an input file generator (word processor or line editor). Hydrain system shell allows entry to this file generator, and reentry to Hydrain, but the user must rely on hard-copy documentation for help. HY8 is a stand-alone interactive BASIC program that accepts inputs during processing and produces screen outputs that the user can capture with the print screen command. All engineering programs but HY8 are batch oriented, and three steps are built into the process of using them: input file generation, programs execution, and output file screen review or listing. HY8 accepts inputs and generates outputs as the engineering program logic is executing.

### HYDRO Program

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

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

- Design Rain Using Digitized NWS Information - Calculates the rainfall intensity for a specific return period, duration, and site.
- Design Hyetograph using Yen and Chow's method - Calculates the rain versus time plot for a return period, duration and site.

- Intensity-Duration-Frequency Curve - Analyzes a specific site and creates two graphs: a plot of points for durations up to 24 hours, and a detail graph of the first 2 hours.
- Design Flow by Rational Method - Uses a specific return period, duration and intensity to determine the peak flow for the site.
- Design Flow by USGS Regression Method - Uses USGS three or seven parameter regression equations or user supplied equations to determine design flow.
- Design Flow by log Pearson type III - Calculates the peak flow for given data.
- Design Hydrograph by Rational Method and Snyder's Unit Graph - The rainfall intensity for a return period is used to calculate the peak flow. A hydrograph is created using Constant's modification of Snyder's method.
- Design Hydrograph by USGS Regression and Snyder's Unit Graph - Develops a hydrograph for a site based on peak flow and a unit hydrograph.
- Design Hydrograph by log Pearson type III and Snyder's Unit Graph - Develops a hydrograph for a site based on peak flow and a unit hydrograph.
- Hydrograph - Develops a hydrograph for a site based on its unit graph for a given flow.

#### PFP-HYDRA Program

FORTTRAN code for PFP-HYDRA previously existed and the Pooled Fund work effort included substantial improvements. PFP-HYDRA is a storm and sanitary sewer system analysis and design program. It is used either to model an existing sewer system or to design a new system.

PFP-HYDRA generates storm flows by using either the Rational Method technique, hydrologic simulation techniques, or accepting a hydrograph generated by a HYDRO analysis. It can be used to design or analyze storm, sanitary or combined collection systems. PFP-HYDRA can handle up to 1,000 contributing drainage areas and 2,000 pipes. Additionally, PFP-HYDRA can be used for cost estimating. The Rational Method approximates the peak rate of runoff from a basin resulting from storms of a given return period. PFP-HYDRA's hydrologic simulation models the natural rainfall-runoff process. In the simulation, runoff hydrographs are generated, merged together and routed through the collection system. Inlet limitations can be analyzed: inlet overflow can be passed down a gutter system, while inlets in sumps can store water in ponds.



In the PFP-HYDRA design process, the program will select the pipe size, slope and invert elevations given certain design criteria. Additionally, PFP-HYDRA will perform analyses on an existing system of pipes (and/or ditches). When an existing system of pipes is overloaded, PFP-HYDRA will show suggested flow removal quantities as well as an increased pipe diameter size as an alternative remedy.

PFP-HYDRA requires the forming of an input file of commands to describe the sewer system. The program shell facilitates this activity. The commands are placed in a logical sequence usually from upper to lower elevation. It is possible that several command sequences can produce the same result. An input file is established for a particular collection system by the engineer and then the PFP-HYDRA program is executed. To change the characteristics of the collection system, the input file can be edited using the program shell. The input file, in itself, is a line by line command language that identifies the computation and provides the required data. Each line of data is preceded with a three-letter command. A typical command is PDA, indicating the line contains the design parameters for pipe analysis (PIPE DATA). PFP-HYDRA reads the command line one line (command) at a time and executes each command individually. However, PFP-HYDRA maintains a memory of information, including prior command information and results. Error checking is performed on each command.

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

### CDS Program

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

The Design option selects a culvert size and number of barrels that are compatible with engineering data, environmental constraints, and site geometry. In this option, hydraulic performance data are calculated for each new culvert system design. The Review option provides hydraulic performance data for any preselected combination of culvert type and size, inlet type, slope, and number of barrels. The initial design and analysis options may be followed by up to five additional culvert types or flow frequencies so a full spectrum of risk scenarios or economic considerations can be simulated at the same time.

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

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

#### WSPRO Program

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

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

The United States Geologic Survey (USGS) originally developed WSPRO for the Federal Highway Administration. The model was a batch mode mainframe program, written in FORTRAN. The members of the Pooled Fund Project decided to use WSPRO as the bridge waterways analysis element of the Integrated Computerized Drainage Design System. WSPRO was downloaded to the microcomputer by the USGS and FHWA. The microcomputer version of WSPRO, is dated August 1987. As yet, WSPRO does not have a user friendly, interactive shell to aid in data input and manipulation, although this is planned as a future Hydrain enhancement. The result is that the user must create or edit an input file on a line editor or word processor.

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

### HY8 Program

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

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

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

There are three main groups of data to be entered into the program: initial culvert data, downstream channel data, and roadway data. Within the program, the user is sequentially led from one group to the next. From these sets of data, the program develops culvert performance data with or without overtopping. A performance curve can be plotted on a computer with graphics capabilities by typing a V for view. 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.

## Operation

To allow the software to be used by a wide audience, Hydrain operates on an IBM XT/PC or equivalent microcomputer with 640 K RAM, a hard disk, and a monochrome monitor. A math coprocessor is recommended. Engineering programs are in FORTRAN 77. Shells are in C. The HYDRO, HYDRA, and CDS programs are equipped with a "semi-expert" system that includes extensive input shells and "short" and "long" help files. The other programs available to the experienced to expert Hydrain user, WSPRO and HY8, have received a minimum level of development under the Hydrain system.

## Report Contents

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

## Disclaimer

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

## 1. Introduction

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

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

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

## 2. System Operation

HYDRO capabilities are divided into two major hydrological scenarios; rainfall analysis 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. The rainfall analysis also can calculate an Intensity-Duration-Frequency (IDF) curve. The rainfall analysis is a function of frequency, geographic location, and duration of the storm event. The second scenario, flow, permits the user to investigate several methods for determining peak flow. This peak flow can be the result of either runoff or gauged stream flow. As with the rainfall scenario, both steady-state (peak flow) and dynamic (hydrograph) flow conditions can be considered. The basic types of analysis available through use of HYDRO are shown in figure 1.

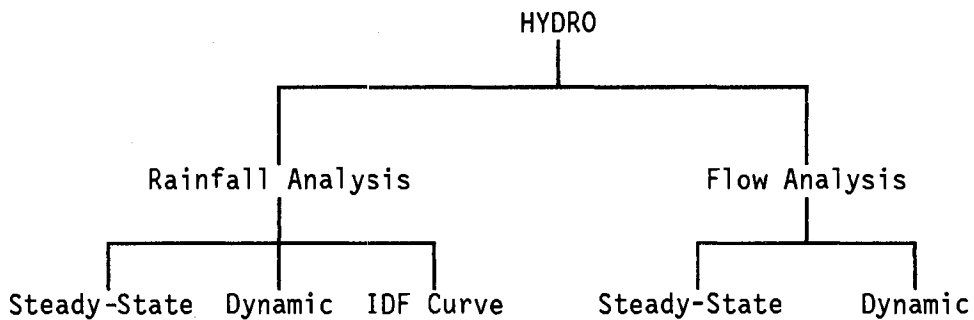


Figure 1. HYDRO flow chart.

### Rainfall

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

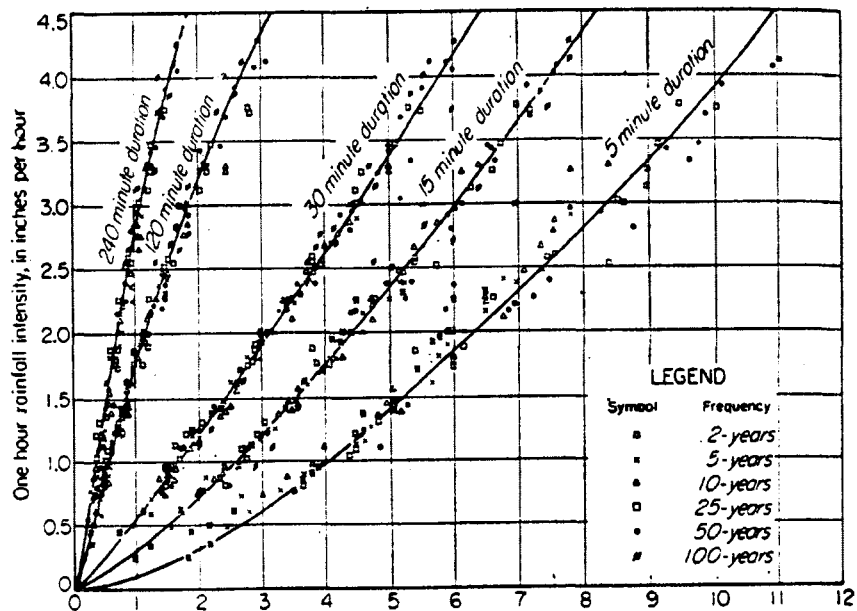
### Rainfall Database

The rainfall intensities are created from values in a unique database, developed specifically for the Pooled Fund. This database consists of the 1-hour rain durations for 2- and 100-year return periods for a total of 5597 latitude/longitude coordinate pairs. The database was developed from two sources; the National Weather Service (NWS) technical memorandum, HYDRO-35 and the National Oceanic and Atmospheric Administration (NOAA) Atlas 2 documents.

(3,4) The resolution of the data is as follows: 30 minutes for the eastern and midwest States covered by the HYDRO-35 document, 20 minutes for the eleven western States covered by the NOAA Atlas 2, and 10 minutes and for parts of Southern California.

## Peak Intensity

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



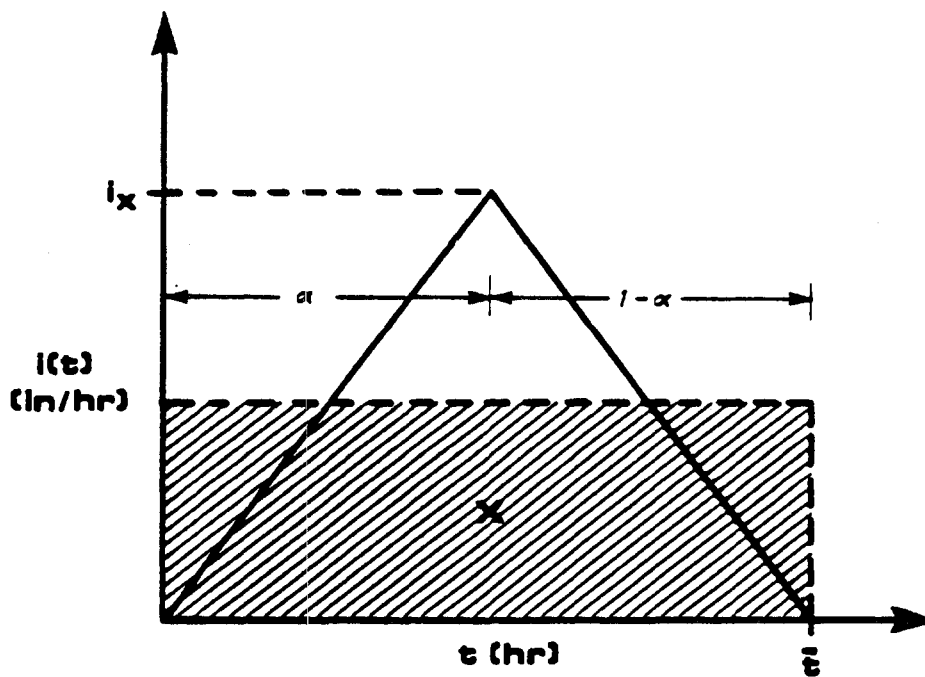
Rainfall intensity for durations indicated by parameter, in inches per hour

Figure 2. Rainfall Intensity relationships.<sup>(6)</sup>

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

## Hyetographs

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



$$X = \text{AREA} = \text{TOTAL RAIN [INCHES/EVENT]} = \frac{i_x \cdot t_r}{2}$$

- $i_x = \frac{2X}{t_r}$
- $\alpha$  tabulated in Yen & Chow, 1983

Figure 3. Yen and Chow's triangular hyetograph.



## IDF Curves

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

## User Supplied Rainfall Values

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

## Peak Flow

HYDRO allows the user to investigate three flow methods; the rational method, user supplied regression equations, and stream flows using 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 these peak flows with Snyder's unit hydrograph method so as to consider hydrographic or dynamic flow conditions. The first two flow determination methods, rational and regression, are techniques that are used on ungauged watersheds where runoff is the primary source of flow. The log Pearson type III method requires gauged stream flow as the primary input. Each of the three flow methods will be discussed below.

## Rational Method

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

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

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

- The frequency of the peak flow is equal to the frequency of the rainfall intensity.

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

### Regression Equations

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

### Log Pearson Type III Flood Frequency

The third flow method, log Pearson type III, allows the user to contemplate the effects of frequency associated with gauged stream flows. The log Pearson type III distribution is a three parameter (i.e., mean, standard deviation, and skew coefficient) gamma distribution. A logarithmic transform of the independent variable is made so as to "flatten" the distribution, thus lending it to a variety of stream situations. It has been adopted by the Water Resource Council (WRC) as a standard flood frequency determination method for all Federal agencies.(9,10) The peak flow is assumed by HYDRO to be steady state. As with the other flow determination methods, the peak flow is combined with Snyder's method to create a 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 uses Constant's modification to Snyder's method to derive a hydrograph from a peak flow value. Constant recognized that Snyder's unit hydrograph could be simulated by a log normal curve for which the rising limb of the hydrograph is approximated mathematically as a parabolic function. The recession limb of the hydrograph is approximated by a exponential function.(11) The rationale for using this method is based on a preliminary study of different hydrograph methods.(12)

It has been suggested that a national effort should be made, using the methodology outlined in the study, to produce a national assessment of hydrograph methods. The goal would be to outline a method similar in scope to that which led the WRC to propose log Pearson type III as a flood frequency determination method. The authors do not suggest that Snyder's method is the most appropriate hydrograph method, but they do suggest that until national, or

even regional assessments, similar to those already completed in Wyoming and Georgia are conducted, engineers will use those methods with which they are most comfortable. (13,14)

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

### 3. Technical Operation

This section investigates the technical operation of the HYDRO program. The section will be organized in the following manner: Rainfall, including the rainfall database, 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, including a discussion of Snyder's method and Constant's modification to that method.

#### Rainfall Database

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

The information used to create the database came from:

1. The final base values used to compute isohyetal maps for eleven western States.<sup>(15)</sup> The eleven western States are: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Washington and Wyoming.
2. The tape E17383, obtained from the National Weather Service, that contains data for the remaining 37 midwestern and eastern States and the District of Columbia. This is the data that was used to create the HYDRO-35 document.<sup>(15)</sup>

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

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

#### Lookup and Weighted Averaging of the Data

After the user enters a site's latitude and longitude values, HYDRO will enter the database to find the coordinates most closely associated with those site values. This is done quickly by initiating a binary search to locate the approximate location of the site in the dataset. If the site corresponds to a specific data element, the 2- and 100-year, 1-hour storm duration, rainfall intensities associated with that data element are read in as variables, and the program moves to the next module (frequency adjustment). Otherwise, HYDRO

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

### Frequency Adjustment

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

5-Year Equation<sup>(3)</sup>

$$C = (0.278 \cdot A) + (0.674 \cdot B) \quad (1)$$

10-Year Equation<sup>(3)</sup>

$$C = (0.449 \cdot A) + (0.496 \cdot B) \quad (2)$$

25-Year Equation<sup>(3)</sup>

$$C = (0.669 \cdot A) + (0.293 \cdot B) \quad (3)$$

50-Year Equation<sup>(3)</sup>

$$C = (0.835 \cdot A) + (0.146 \cdot B) \quad (4)$$

General Equation<sup>(5)</sup>

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

where:

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

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

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

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

## Time of Concentration

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

### SCS Curve Number

The Soil Conservation Service, in Technical Release 55, describes a method for determining the overland time of concentration known as the curve number (CN) method.(16,17) This method is limited to small watersheds ( $\leq 2000$  acres) containing consistent land uses and climatological characteristics.

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

- A = a sandy soil, having deep sand and loess with aggregated silts. The composition is 90 to 100 percent sand/gravel. There is a high infiltration rate of 0.30 to 0.45 inches per hour.
- B = a sand/loam soil, having a shallow loess/sandy loam with a moderate infiltration rate of 0.15 to 0.30 inches per hour.
- C = a clay/loam soil, having low organic content and usually high in clay. It has a slow infiltration rate of 0.05 to 0.15 inches per hour.
- D = a clay soil, having a mixture of heavy plastic clay (90 to 100%) and certain saline soils that swells significantly when wet. Clay has a very low infiltration rate of 0 to 0.05 inches per hour.

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

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

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

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

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

Table 1. Curve Number matrix.

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

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

$$CN = \frac{\sum CN_i \cdot A_i}{\sum A_i} \quad (6)$$

where:

CN = the composite curve number for the watershed,

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

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

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

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

$$S = \frac{1000}{CN} - 10 \quad (7)$$

where:

$S$  = an intermediate empirical value, and

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

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

$$t_{co} = \frac{L_o^{0.8} \cdot (S + 1)^{0.7}}{1140 \cdot S_o^{0.5}} \quad (8)$$

where:

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

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

$S$  = the intermediate empirical coefficient, defined above, and

$S_o$  = the average overland slope, in percent.

#### Kinematic Wave

The alternative overland time of concentration method that is found in HYDRO is the kinematic wave approach. It is used as defined in HEC-12 (FHWA, 1984) and based on research by Regan conducted for the Maryland State Highway Administration and the FHWA.<sup>(18)</sup> Although the kinematic wave theory is not found in HEC-19, it was felt that it was appropriate to include it in HYDRO so as to provide the user with an alternative to the curve number method.



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

$$t_{co} = \frac{56 \cdot L_o^{0.6} \cdot n^{0.6}}{S_o^{0.3} \cdot i^{0.4}} \quad (9)$$

where:

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

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

$n$  = Manning's friction value for a waterway,

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

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

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

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

#### SCS Grassy Waterway

The SCS grassy waterway is a subset of the Upland Method described in the SCS handbook.<sup>(16)</sup> 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.<sup>(5)</sup> The SCS grassy waterway equation is given as:

$$V = 1.942 \cdot S_c^{0.504} \quad (10)$$

where:

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

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

#### Manning's Formula

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

$$V = \frac{1.486}{n} \cdot R_h^{0.667} \cdot S_c^{0.5} \quad (11)$$

where:

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

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

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

n = Manning's friction value for the channel.

#### Triangular Gutter Section

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

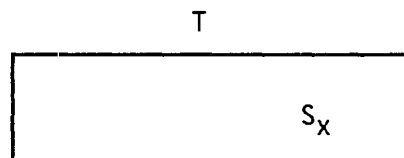


Figure 4. Triangular gutter section.

Substituting basic geometric relationships, derived from figure 4, into equation eleven yields:

$$V = \frac{1.12}{n} \cdot S_c^{0.5} \cdot S_x^{0.67} \cdot T^{0.67} \quad (12)$$

where:

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

n = Manning's friction value for the channel,

S<sub>c</sub> = the average channel slope, in ft/ft,

S<sub>x</sub> = the roadway cross slope, in ft/ft, and

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

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

$$t_{cc} = \frac{L_c}{(V \cdot 3600)} \quad (13)$$

where:

t<sub>cc</sub> = the channel time of concentration, in hours,

L<sub>c</sub> = the length of the channel, in feet,

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

3600 = conversion factor between seconds and hours.

#### Combining Overland and Channel Time of Concentrations

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

$$t_c = t_{co} + t_{cc} \quad (14)$$

where:

t<sub>c</sub> = the combined time of concentration of the watershed, in hours,

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

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

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

### Adjusting Rainfall Intensity for Duration

Transformation of the 1-hour rainfall intensity to the intensity associated with the time of concentration, just calculated, is achieved using NWS and GKY regression equations. The NWS equations are from the HYDRO-35 memorandum.<sup>(3)</sup> The GKY regression equations are based on figure 2 shown earlier.<sup>(6)</sup> There are four equations for transforming the 1-hour intensity to rainfall intensities less than 1 hour:

5 Minute Equation<sup>(5)</sup>

$$i_{5min} = 4.145 \cdot i_{1hr}^{0.635} \quad (15)$$

10 Minute Equation<sup>(3)</sup>

$$i_{10min} = 0.59 \cdot i_{15min} + 0.41 \cdot i_{5min} \quad (16)$$

15 Minute Equation<sup>(5)</sup>

$$i_{15min} = 2.47 \cdot i_{1hr}^{0.817} \quad (17)$$

30 Minute Equation<sup>(3)</sup>

$$i_{30min} = 0.49 \cdot i_{1hr} + 0.51 \cdot i_{15min} \quad (18)$$

where:

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

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

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

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

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

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

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

$$i = i_{1\text{hr}} / (0.4461 + 0.5520 \cdot t_c) \quad (19)$$

where:

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

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

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

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.<sup>(7)</sup> They felt that a typical rain event could be described using a triangular shape defined by three parameters. The first parameter is the "apex" of the triangle, equal to twice the peak rainfall intensity. The "base" of the triangle, equal to the duration of the storm, is the second parameter. The last parameter is the time to the peak intensity, and is based on a localized coefficient shown on a map in the Yen and Chow document. The total volume of rainfall is found by using basic geometric principles. The triangular hyetograph was shown earlier in figure 3.

To apply the methodology, HYDRO needs these three parameters. HYDRO will either use calculated or user supplied intensity and duration values to satisfy the need for the first two parameters. The final parameter is found using an internal table containing the appropriate coefficient for each State. Should a State contain two or more coefficients, the State is further broken down by latitude and longitude.

### IDF Curve

The Intensity Duration Frequency curve is produced, for a given frequency and location, by calculating the rainfall intensities associated with the 5, 10, 15, 30 minute, and 1, 2, 4, 8 and 24 hour durations. Specifically, a location and the rainfall database are used to retrieve 2 and 100, 1-hour rainfall intensities. Next, the rainfall intensities are adjusted to a user supplied frequency using equations 1 through 5. Finally, equations 15 through 19 are used to calculate the rainfall intensities.

### Rational Method

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

$$Q = C \cdot i \cdot A, \quad (22)$$

where:

Q = the peak flow, in ft<sup>3</sup>/s,

C = the runoff coefficient,

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

A = the area of the watershed, in acres.

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

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

Table 2. Default runoff coefficients.

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

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

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

$$C = \frac{\sum C_i A_i}{\sum A_i} \quad (23)$$

where:

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

$C_i$  = the runoff coefficient associated with each subarea, and

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

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

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

### Regression Equations

A more sophisticated analysis of flow at ungauged watershed can be achieved through the use of regression equations. These equations related peak

flow of a specified frequency to physical or site related factors. The typical regression equation is a log-log formula in the form:

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

where:

$Q_p$  = the regression equation peak flow, in ft<sup>3</sup>/s,

$a$  = the regression constant, usually a translation factor,

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

$b_i$  = the regression coefficients associated with each  
independent variable.

The regression equation is usually developed for a specific region or State. The FHWA has a document that describes regression equations used to calculate runoff from small watersheds in 24 hydrophysiographic regions.<sup>(1)</sup> The FHWA equations were developed for a 10-year flood frequency and have three, five, or seven independent variables. The USGS has conducted a nationwide study that developed three and seven parameter regression equations.<sup>(1)</sup> More recent work has concentrated on developing regional equations.<sup>(19)</sup> The interested reader is referred to the literature for more information on typical coefficients and variables to be used with these equations.

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

### Log Pearson Type III Flood Frequency

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

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



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

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

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

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

where:

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

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

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

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

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

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

where:

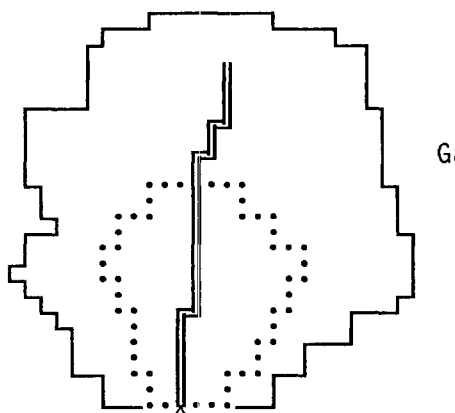
$Q_{ia}$  = the adjusted peak annual flow, in  $\text{ft}^3/\text{s}$ ,

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

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

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

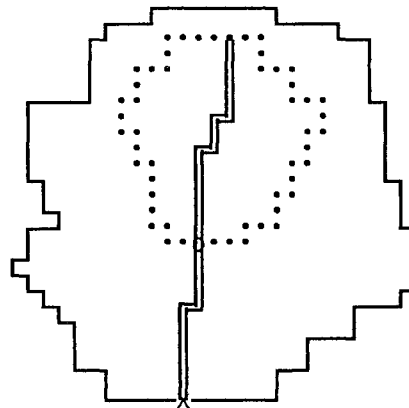
(a) At Location



Gauging Station  
Watershed

HYDRO  
Watershed

(b) UPSTREAM Location



Gauging Station  
Watershed

HYDRO  
Watershed

(c) DOWNSTREAM Location

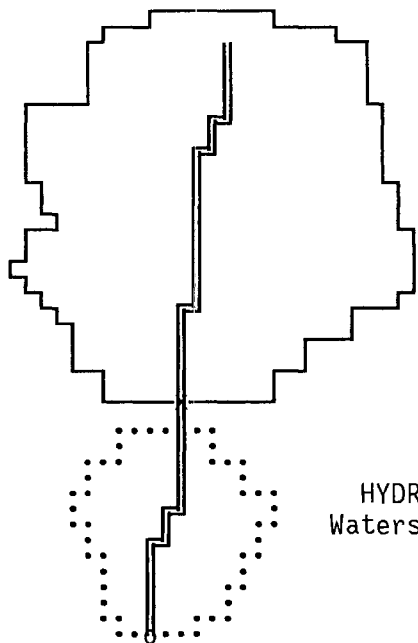


Figure 5. Relative watershed locations.

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

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

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

Sample Mean; (geometric mean).

$$\bar{Q}_L = \frac{\sum \log Q_i}{n} \quad (27)$$

Standard Deviation;

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

Skew Coefficient;

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

where:

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

$Q_i$  = the peak annual stream flow samples, in ft<sup>3</sup>/s,

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

$S_L$  = the standard deviation of the peak annual stream flow values, in ft<sup>3</sup>/s, and

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

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

HYDRO calculates a form of the Incomplete Gamma Function using the methodology outlined by Croley.(20) Simply put, Croley's methodology solves Pearson's integral for a probability that is a function of flow. To begin this analysis, HYDRO first defines three translation coefficients:

$$\alpha = (2 \cdot G_L)^2 \quad (30)$$

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

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

where:

$\alpha$  = the first Croley translation coefficient, alpha,

$\beta$  = the second Croley translation coefficient, beta,

$\delta$  = the third Croley translation coefficient, delta,

$G_L$  = the skew coefficient for the sample of peak annual stream flow values, in ft<sup>3</sup>/s, and

$S_L$  = the standard deviation of the peak annual stream flow values, in ft<sup>3</sup>/s.

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

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

where:

$t_\tau$  = the  $\tau$ -quantile point for some logarithmic transformed stream flow,  $Q_\tau$ ,

$Q_\tau$  = a stream flow in the distribution defined by  $\bar{Q}_L$ ,  $S_L$  and  $G_L$ , in ft<sup>3</sup>/s,

$\delta$  = the translation coefficient, delta, defined above, and

$\beta$  = the translation coefficient, beta, defined above.

Pearson's integral, is defined as:

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

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

$$P(Q \leq Q_\tau) \approx \left[ \frac{\alpha + 5}{2 \cdot \pi} \right]^{0.5} \cdot \frac{(\alpha + 4)! \cdot \alpha}{\alpha!} \cdot \left[ \frac{t_\tau}{\alpha + 5} \right]^\alpha \cdot \left[ \frac{1}{\alpha + 5} \right]^5 \cdot \exp \left[ -t_\tau + \alpha + 5 - \frac{1}{12 \cdot (\alpha + 5)} + \frac{1}{(360 \cdot (\alpha + 5))^3} \right] \cdot \sum_{j=0}^{14} \frac{t_\tau^j}{\alpha \cdot (\alpha + 1) \cdots (\alpha + j)} \quad (35)$$

where:

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

$\alpha$  = Croley's translation coefficient, defined above,

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

$t_\tau$  = the upper bounds of Pearson's integral, defined above, and

$j$  = a integer variable used in the summation.

HYDRO will enter two values for  $Q_\tau$  into equation 35 (with the two values of  $Q_\tau$  initially equalling the maximum and minimum values for the range of  $Q_i$ ),

which will return two associated probabilities. Since the user defined return period for the peak flow can be expressed as a probability:

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

where:

$P(Q_p)$  = the probability associated with the user defined return period, in years<sup>-1</sup>, and

$n$  = the user defined return period, in years,

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

There are two potential areas of trouble when using equation 35. First, the upper interval of the integral must satisfy the condition  $0 \leq t_{\tau} \leq \infty$ . 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  $Q_{\tau}$  will converge towards infinity. Should either occur, HYDRO will use an alternative peak flow equation.

HYDRO uses another approximation to calculate a default peak flow value. (21) The value for peak flow is usually within 5 percent of a value derived by a table. The function relates the skew coefficient to the normal deviate, and produces a skew based on a user defined probability:

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

where:

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

$G_L$  = the skew coefficient for the sample of peak annual stream flow values, in ft<sup>3</sup>/s,

$Z$  = the normal deviate, that is approximated by:

$$Z = 4.91 \cdot ((1 - p)^{0.14} - p^{0.14}) \quad (38)$$

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

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

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

where:

$Q_p$  = the peak flow for the stream, in  $\text{ft}^3/\text{s}$ , based on a user defined return period,

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

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

$S_L$  = the standard deviation of the peak annual stream flow values, in  $\text{ft}^3/\text{s}$ .

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

### Hydrograph Formation

HYDRO uses an adaptation of Snyder's unit hydrograph formulation developed by Constant to generate the hydrograph associated with a peak flow estimate for a drainage area.<sup>(11)</sup> The hydrograph computed by HYDRO represents the runoff associated with a rainfall duration equal to the concentration time of the drainage area.

As described earlier, HYDRO can determine the peak flow of a watershed using three methods: the rational method, regression equations and log Pearson type III.

Constant's technique allows the user to use one of these three methods, or a flow selected by a user, to create a hydrograph. The means used for determining peak flow for each of the four methods are summarized below:

- Rational -  $Q_p$  is calculated using equation 22; the intensity being dependent upon the time of concentration and return period. The time of concentration is determined by either by the summation of overland and channel time of concentration or selection by the user.
- Regression -  $Q_p$  is determined by log-log relationships developed by the FHWA and USGS for specific localities.
- Log Pearson type III -  $Q_p$  is calculated using a statistical fit to stream flow data for a desired return period.

User Input -  $Q_p$  and time to concentration,  $t_c$  are directly provided to HYDRO by the user.

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

Constant's method estimates coordinates of a synthetic unit hydrograph associated with a 1-hour, 1-inch rainfall. The basic assumption is that the unit graph is a log normal distribution; with this assumption the rising limb, to the median, is approximately parabolic and the falling limb, past the median, is approximately exponential.

Constant's unit graph needs a value for peak runoff,  $q_1$ , associated with a 1-inch, 1-hour storm and a value,  $t_1$ , that represents the time from the start of the runoff to peak runoff. Constant's method also requires the standard deviation of the associated log normal distribution, sigma. In the HYDRO implementation, this is estimated from  $t_1$  and  $q_1$ .

The  $q_1$  value is estimated by using the rational formula with a one inch per hour rainfall intensity:

$$q_1 = C \cdot A \cdot 1.0 \quad (39)$$

where:

$q_1$  = the peak runoff associated with a 1-inch, 1-hour storm, or, for user supplied peak flows, equal to  $Q_p$ , in  $\text{ft}^3/\text{s}$ ,

$C$  = the composite value associated with the rational method for small areas with known land use, or equal to 0.5, as an approximation, for large areas (regression or log Pearson type III areas), and

$A$  = the drainage area of the watershed, in acres.

Given the peak runoff,  $q_1$ , the value of  $t_1$  is estimated with the SCS equation:

$$t_1 = \frac{K \cdot A}{q_1} \quad (40)$$

where:

$t_1$  = the value that represents the time from start of runoff to peak runoff, in hours, for user supplied peak flows, it is assigned a value of  $t_c$ ,



K = the SCS coefficient, that for one inch of rainfall excess, is equal to 484 in typical watersheds, 300 for flat and swampy watersheds, and 600 for steep watersheds,

A = the drainage area of the watershed, in acres, and

q<sub>1</sub> = the peak runoff associated with a 1-inch, 1-hour storm, in ft<sup>3</sup>/s.

For any time from the start of the hydrograph, t, Constant's method will calculate the corresponding scaled flow, q(t) (that is, adapted to the Q<sub>p</sub> and t<sub>c</sub>). The function is such that the coordinates form the hydrograph. There is a two step process required:

- 1) Estimate sigma, σ, using t<sub>1</sub>, q<sub>1</sub> and A by using Constant's normal distribution relationship:

$$\frac{\exp(-2.650949 \cdot \sigma^2)}{\sigma} = \frac{t_1 \cdot q_1}{111.8094 \cdot A} \quad (41)$$

where:

σ = the standard deviation of the log normal distribution,

t<sub>1</sub> = the value that represents the time from start of runoff to peak runoff, in hours,

q<sub>1</sub> = the peak runoff associated with a 1-inch, 1-hour storm, in ft<sup>3</sup>/s, and

A = the drainage area of the watershed, in square miles.

The solution requires either an iterative solution or solution by trial and error. HYDRO solves the equation by using Newton-Raphson root method.

- 2) Compute the scaled hydrograph coordinates as a function of hours, t, from the start of the runoff with the following equation:

$$q(t) = \left[ \frac{111.8094 \cdot A}{\sigma \cdot t \cdot (t_c / t_1)} \cdot \exp \left[ \frac{-\log_{10}(t \cdot (t_c / t_1))^2}{2 \cdot \sigma^2} \right] \right] \cdot \frac{Q_p}{q_1} \quad (42)$$

where:

$q(t)$  = the scaled flow, in  $\text{ft}^3/\text{s}$ , that along with a corresponding  $t$ , forms the coordinates of the hydrograph,

$t$  = some given time from the start of the hydrograph, in hours,

$A$  = the drainage area of the watershed, in square miles,

$\sigma$  = the standard deviation of the log normal distribution,

$t_c$  = the time of concentrations derived from the flow methods, or a user defined time of concentration, in hours,

$t_1$  = the value that represents the time from start of runoff to peak runoff, in hours,

$Q_p$  = the peak flow calculated by the HYDRO flow methods, or entered by the user, in  $\text{ft}^3/\text{s}$ , and

$q_1$  = the peak runoff associated with a 1-inch, 1-hour storm, in  $\text{ft}^3/\text{s}$ .

As can be seen in equation 42, the ordinate and abscissa values of Constant's equation are scaled to the  $Q_p$  and  $t_c$  that represent the problem at hand. The resulting hydrograph approximates the shape and characteristics of one developed using Snyder's method.

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

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

## 4. User Documentation

### Hydro Input and Output Files

The input data file used for the Hydro program is called a data worksheet. It is a single ASCII file. The worksheet provides a field for a variable, whether or not it is being used in a particular execution run. This makes the worksheet extremely flexible for data entry and editing. HYDRO uses an **HDO** extension for the input file. When submitting a file for execution, the Hydro input program will automatically append the correct extension.

HYDRO output files have a user specified prefix followed by the extension **LST**. Unlike other Hydrain programs, the output name does not necessarily need to have the same prefix as the input data file, although it may be advisable to do so for organizational and legal reasons.

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

- **QT** - This extension contains the ordinates of a hydrograph (ie: flow (Q) vs. time (T)). If desired, this file can be incorporated into the other engineering programs (i.e.: into CDS using the culvert design and review work deck, and into PFP-HYDRA using the **UHY** Command).
- **HYE** - This extension contains the ordinates of a hyetograph (ie: rainfall intensity (I) vs. time (T)). If desired, this file can be incorporated into PFP-HYDRA using the **HYE** command.
- **IDF** - This extension contains the ordinates of an intensity-duration-frequency (IDF) curve (for a duration from 5 minutes to 24 hours). If desired, this file can be incorporated into PFP-HYDRA using the **RAI** command.

### The Hydro Input Program

Data is entered into the Hydro data worksheet by using the Hydro Input Program. This program was written for the Pooled Fund Project to provide user friendly, interactive assistance for entering data and managing input files. The program was written in the C language. The integrated computerized drainage design system, of which HYDRO is one program, is known as the Hydrain program. The user is directed to other Hydrain documentation for direction in applying the system. The remainder of the documentation will attempt to demonstrate the HYDRO Input Program by leading the user through an example problem.

Example Problem: Perform a rational method analysis of a hypothetical watershed near Charlotte, North Carolina. The user wishes to investigate a flooding problem at the watershed outlet, which flows under (and sometimes across) a small country road. A culvert will resolve the problem, but the user

needs to determine the maximum flow that the culvert will need to pass. Local guidelines state that the design storm is to be 50 years. This problem is a slight modification of an example found in the rational method section of HEC-19.(1)

### Watershed Characteristics

The watershed is circular shaped, with a total area of 108.1 acres. It has the following land uses:

Land Use	C Value	Area (acres)
Park	0.20	53.9
Commercial	0.95	3.7
Residential	0.40	50.5

There are two constituents for flow, overland and channel with the following physical characteristics:

#### Overland Flow:

Length: 1,100 feet                      Roughness Factor: 0.1  
Slope: 0.02 ft/ft

#### Channel Flow:

Length: 2,150 feet                      Roughness Factor: 0.03  
Slope: 0.01 ft/ft

The user wants to use the Kinematic Wave approach for determining the overland time of concentration and will use the Grassy Waterway approach for determining the channel time of concentration.

The location of the watershed is at: 34°14' N Latitude  
80°50' E Longitude

The user also may wish to consider storage behind the culvert, so besides the Peak Flow, a hydrograph is also desired. This will create a QT output file that could be used as input to the CDS program.

The object of the exercise will be to enter the HYDRO Input Program and use the rational method capabilities to investigate this problem. One reason that a rational method example was selected for the example problem is that it shares many common screens with other options in the Hydro input program. This will allow the user to gain experience on not one, but many of the hydrology options.

## Entering the HYDRO Input Program

The first step in entering into the Hydro input program is to type **HYDRAIN** and strike Enter or Carriage Return, denoted by <CR>. The first screen provides the user with information on the sponsors of the Hydrain software. Strike any key to continue. The second screen provides a disclaimer. Again, strike any key to continue. After these preliminary screens, the user reaches the Hydrain Primary Menu. This menu is represented in figure 6. The primary menu allows the user to access the programs in the Pooled Fund Project. Select the HYDRO program option either by moving to the HYDRO option with the cursor and striking <CR>, or by simply typing **H**. By choosing this option, the user moves into the hydrology analysis module of the Pooled Fund Project.

HYDRAIN - DRAINAGE DESIGN SYSTEM → PRIMARY MENU									
<u>HYDRO</u>	CDS	PF-PHYDRA	WSPRO	HY8	DOS	FILES	INFO PFP	QUIT	
Access Hydrology (Design Event vs. Return Period) Program									
F6-MENU F10-HELP									

Figure 6. Hydrain primary menu.

For assistance at any time within the Hydrain programs, the user can take advantage of active short helps, or, by striking <F10>, enter into long help. In the Hydro input program, this long help will provide information about a specified screen.

After selecting the HYDRO option and hitting <CR>, the user will wait for a few seconds (actually, about 20) while the Hydro input program initializes the worksheet, and loads error and range checking and short help files into memory. One reason that it takes HYDRO longer to load than other programs in

the Hydrain system is that the Hydro module is totally self contained. This means that the user will not be required to move back and forth between the Hydro input program and Hydrain system shell until the user is finished with all hydrological analyses and wants to move on to another element of the Hydrain system. The user can retrieve and store data, enter and edit data, and execute the HYDRO analysis program all from the Hydro input program. When the program has finished loading, the Hydro input program primary menu will appear, as seen below in figure 7.

HYDRAIN - DRAINAGE DESIGN SYSTEM → HYDRO PROGRAM
————— Hydro input program primary menu —————
<u>Retrieve HYDRO data worksheet</u>
Edit HYDRO data worksheet
Store HYDRO data worksheet
Quit (Return to HYDRAIN)
Retrieve Hydro Worksheet file from the disk and place into data pages
F6-MENU  F10-HELP

Figure 7. Hydro Input Program primary menu.

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

- RETRIEVE data from an existing input dataset (worksheet). If an input dataset is being created, the user does not need to use this option, but can simply go to the EDIT option.
- EDIT and Enter design rainfall or design flow input data. This is the option that will be used to access the hydrological analysis selections and to execute the input datasets.

- STORE data into a worksheet file. If the user forgets to save the data before leaving the input program, it is automatically saved in a file called **LASTIME.HDO** that can be retrieved the next time the user enters the program.
- QUIT the Hydro input program and return to the Hydrain System Shell. Save all data in a file called **LASTIME.HDO**.

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

Since the example is a new data file, the user does not have to **Retrieve** any files, but can move the cursor to the **Edit HYDRO data worksheet** option and strike <CR>, or press E. This action will direct the program to go to the Rainfall/Flow Menu, depicted in figure 8 below. Within the menu, the user can choose to investigate one of the hydrological options listed below.

#### Design Rainfall Options

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

- **Rainfall Intensity Determination** - This option calculates the rainfall intensity (inches/hour) for a desired return period and a duration (assumed to be time of concentration in hours) at a site. Additionally, this option can use Yen and Chow's Method to create a triangular hyetograph (intensity-vs-time) for the site. The resulting output includes a file of the hyetograph ordinates that can be used by other Hydrain programs as input. An IDF Curve can also be developed as a subset of this option. If desired, users can input their own storm duration (time of concentration) and/or intensity.
- **Intensity-Duration-Frequency Curve** - The second design rainfall option creates an intensity duration frequency (IDF) curve for the desired site and return period. The duration ranges from 5 minutes up to 24 hours. The frequency (return period) ranges from 2 to 100 years. A plotting routine puts these IDF ordinates on a graph where the y-axis is intensity (inches/hour) and the x-axis is duration (hours). Two graphs are created: one plots all points for durations up to 24 hours; the second details the first two hours of the first curve. Like the rainfall intensity option, an output file containing the coordinates of the IDF curve is produced for use by other Hydrain programs.

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

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

HYDRAIN - DRAINAGE DESIGN SYSTEM → HYDRO PROGRAM
----- Rainfall Options -----
Hyetograph / Intensity Intensity-Duration-Frequency Curve
----- Hydrology Options -----
<u>Rational Method Flows</u> User Supplied Equation Flows Log Pearson III Flows Constants Hydrograph
Quit (return to prior screen)
Use Rational Method Flow Analysis (Steady State / Hydrograph)
F6-MENU  F10-HELP

Figure 8. Rainfall/Flow options screen.

#### Design Flow Options

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

- **Rational Method** - This option uses the rational method equation ( $Q = CiA$ ) to calculate the peak flow (in  $\text{ft}^3/\text{s}$ ) at a site. The rainfall intensity is calculated for a specific return period and duration (time of concentration) using a unique rainfall database (RAIN.PFP), or it can be entered by the user. The area variable is developed using seven land use



conditions as subareas. Default runoff coefficients are provided (or can be replaced at the users option). A unit hydrograph can be developed using Constant's (Constant, 1970) modification of Snyder's method. An IDF Curve can also be developed as a subset of this option.

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

$$Q25 = \text{SLOPE} * \text{AREA} ** 0.147 + \text{INTENSITY} * \text{DURATION} \dots$$

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

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

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

- **Design Hydrograph** - This option develops a unit hydrograph for a given flow across a specific site. The option uses Constant's method (a version of Snyder's method) to create the unit hydrograph.

As can be seen in the figure 8 above, each of these options has an equivalent field in the menu. Additionally, the final option, QUIT, will return the user to the HYDRO input program menu.

To continue with the rational method example, the user should move the cursor to the **Rational Method Flows** field and strike <CR> (or press R). The next screen, depicted in figure 9, is the time of concentration menu. Notice that the previous short help - "Use Rational Method Flow Analysis (Steady State/Hydrograph)" - has been placed in the top section of the screen. This enables the user to know at all times which options have been previously selected.

As stated earlier in this chapter, the rainfall intensity used in the rational method is a function of the duration or time of concentration of the storm event. As applied in the Hydro input program, there are two constituents that form the time of concentration, overland and channel flows. There are two options for entering the overland time of concentration - the **SCS Curve Number** and the **Kinematic wave** approaches. Selecting either of these first two options will eventually lead the user to a screen where channel flow methods can be chosen. The third option provides the user with the opportunity to enter a user supplied time of concentration and/or a user defined rainfall intensity.

HYDRAIN - DRAINAGE DESIGN SYSTEM → HYDRO PROGRAM
Use Rational Method Flow Analysis (Steady State / Hydrograph)
<p style="text-align: center;">Time of Concentration Calculation Method</p> <p style="text-align: center;">SCS Curve Number  <u>Kinematic Wave</u>  User Supplied</p> <p style="text-align: center;">Quit</p> <p style="text-align: center;">Time of Concentration (duration) Calculated using Kinematic Wave Method</p>
F6-MENU F10-HELP

Figure 9. Time of Concentration menu screen.

Select the second option, **Kinematic Wave**, with the cursor keys and press <CR>. Notice once again that the short help has been placed in the upper section of the screen.

The first data entry screen, shown below in figure 10, prompts the user for the respective land use areas and their corresponding runoff coefficients. Notice that in the upper right corner of the screen a message, **Page 1 of 5**, is displayed. This is indicating to the user that for this sequence of input options, this is the first of five screens to enter data in. The last "input page" screen, in any of the hydrological options (except the user defined equation generator), will contain the information and prompts necessary for the actual execution of the HYDRO analysis program. The last information that a user will enter will always be whether or not to execute the HYDRO program.

In the example, recall that there are three land uses in the hypothetical watershed: Park, Commercial and Residential. Although the land uses corresponding to the park are not found under the same name, the park can be assumed to consist of meadow and/or woods for land uses.

For the example, assume that the park is entirely meadow. Notice the default runoff coefficient values are already in the proper field. These can be changed as the user desires to reflect conditions within a study watershed. In the case of the park, the default runoff coefficient is already equal to the

coefficient in the example. Enter the appropriate area for the park in the meadows field by moving to that field and typing in the value.

There is a residential field as one of the HYDRO land use types. Enter the area from the residential segment of the example into this field by moving the cursor to the field with the arrows keys and entering the value. Again notice that the default runoff coefficient matches that from the example.

As with the park, there is not a specific land use corresponding to commercial in the data screen. Additionally, none of the default runoff coefficients are equal to that of the example. The solution to this dilemma, is to assume that the commercial most closely is associated with the pavement land use (partially because both have high runoff coefficients). Enter the area as was done above, but instead move to the next screen using the right arrow key to move across to the coefficient column. Once there, clear the default value from the field by either using the deletion key, or striking <F5>, the clear field function key. When the field is clear, enter the new value of 0.95.

HYDRAIN - DRAINAGE DESIGN SYSTEM → HYDRO PROGRAM		
Use Rational Method Flow Analysis (Steady State / Hydrograph)		
Time of Concentration (duration) Calculated using Kinematic Wave Method		
		Page 1 of 5
Basin Description		
Land Use	-acres-	Coefficients
Meadow	53.90	0.200
Woods	0.00	0.200
Pasture	0.00	0.300
Crops	0.00	0.300
Residential	50.50	0.400
Urban	0.00	0.700
Pavement	3.70	.95
Total	108.10	
Enter pavement runoff coefficient or use default (0.9)		
F3-PGUP F4-PGDN F5-CLEAR-F F6-MENU F10-HELP		

Figure 10. First data entry screen.

Realistically, when using the Kinematic wave option, placement of land uses not found on the screen is not a critical issue. The data will only be

used to calculate the composite runoff coefficient. The only important element may be to change the default runoff coefficient to an appropriate value. If the SCS Curve number method was used instead, where the data not only determines the composite runoff coefficient, but is also used in the Curve Number analysis, the user can hopefully see where judgement in deciding the placement of the land uses may be important.

Using the down arrow will move the user to the second data input screen (figure 11). This is the Overland Flow Constituent screen. Enter the appropriate values from the example. Note that in all the Hydro input program fields, there are error and range checking elements (try to enter a negative slope into the second field). The range checking values are based on parameters found in the literature.

HYDRAIN - DRAINAGE DESIGN SYSTEM → HYDRO PROGRAM	
Use Rational Method Flow Analysis (Steady State / Hydrograph) Time of Concentration (duration) Calculated using Kinematic Wave Method	
Overland Flow Constituent	Page 2 of 5
<p>Overland Flow Length - <u>1100.0</u></p> <p>Overland Slope - <u>0.02</u></p> <p>Manning Roughness Coefficient - <u>0.1</u></p>	
Enter Manning's roughness coefficient for the basin area (0.01 - 0.4)	
F3-PGUP F4-PGDN F5-CLEAR-F F6-MENU F10-HELP	

Figure 11. Overland flow constituent screen.

When all the data values have been entered, strike <CR> at the last field in the screen to move "forward" to subsequent screens. This can also be achieved by using the down or right arrow key, or striking the PgDn or <F4> keys. The user can move "backwards" through the data input screens by using the up and left arrow keys or pressing PgUp or <F3> keys. The Home key will take the user to the first data field on the present screen and the End key will take the user to the last field on the present screen.

The Channel Flow Constituent is the next screen, illustrated below in figure 12. This screen prompts the user for data related to the channel constituent for determining time of concentration. The three channel flow methods active in HYDRO are: Grassy Waterway, Manning's formula, and Triangular Gutter.

Required data entry for each option is as follows. Data in the first two fields, **Channel Flow Length** and **Channel Slope**, are necessary for all three alternatives (although this entire screen could be left blank if there was not a channel constituent of time of concentration).

- The Grassy Waterway alternative requires only the first two fields, **Channel Flow Length** and **Channel Slope**. After entering this information, the user can strike the <F4> or PgDn keys to skip the other fields and progress to the next screen.
- The Manning's formula alternative requires the data to be placed in the top two fields **Channel Flow Length** and **Channel Slope**. Additionally, the hydraulic radius (in feet) is placed in the fourth field, **Gutter Spread**, and the roughness coefficient is placed in the last field. The **Gutter Side Slope** field is left blank.

HYDRAIN - DRAINAGE DESIGN SYSTEM → HYDRO PROGRAM	
Use Rational Method Flow Analysis (Steady State / Hydrograph) Time of Concentration (duration) Calculated using Kinematic Wave Method	
Page 3 of 5	
Channel Flow Constituent	
Channel Flow Length - <u>2150.0</u>	Channel Slope - <u>0.01</u>
OPTIONAL - Triangular Gutter Channel	
Gutter Side Slope - _____	Gutter Spread - _____
Manning Roughness Coefficient - <u>0.016</u>	
OPTIONAL - Enter Manning's "n" for the channel or use default (0.016)	
F3-PGUP F4-PGDN F5-CLEAR-F F6-MENU F10-HELP	

Figure 12. Channel flow constituent screen.

- The Triangular Gutter Channel alternative requires that data be placed in every field in the screen: **Channel Flow Length, Channel Slope, Gutter Side Slope, Gutter Spread and Manning Roughness Coefficient.**

Note the default roughness coefficient is for a typical gutter. The user can override this value, when appropriate, by using the <F5> function key and entering another value.

For the example, only the first two fields will be used. Enter the values for channel length and slope, and press <F4> or PgDn to continue.

The next screen requires location and return period (storm frequency) information and is depicted in figure 13. It is the last screen that will prompt the user for physical data. The required data are the latitude and longitude of the watershed and the value for the return period.

HYDRAIN - DRAINAGE DESIGN SYSTEM → HYDRO PROGRAM			
Use Rational Method Flow Analysis (Steady State / Hydrograph) Time of Concentration (duration) Calculated using Kinematic Wave Method			
			Page 4 of 5
Location / Storm Information			
Latitude		Longitude	
_____	_____	_____	_____
Degrees	Minutes	Degrees	Minutes
<u>34</u>	<u>14</u>	<u>80</u>	<u>50</u>
Return Period - <u>50</u>			
Enter desired return period in whole years (range - 2 to 100 years)			
F3-PGUP F4-PGDN F5-CLEAR-F F6-MENU F10-HELP			

Figure 13. Location/Storm information screen.

The latitude/longitude will be used by HYDRO to retrieve the 2- and 100-year, 1-hour rainfall intensities from the **RAIN.PFP** database. Care should be taken that the coordinates are within continental U.S. boundaries. Range checking is provided to assist the user in this.

The return period field requires a whole number value between 2 and 100 years. The range checking module will prevent a value greater than 100 or less than 2 from being accepted by the Hydro input program.

After entering the values from the example into the fields, continue to the next screen, represented by figure 14, where execution related variables will be entered and HYDRO will be run.

HYDRAIN - DRAINAGE DESIGN SYSTEM → HYDRO PROGRAM	
Use Rational Method Flow Analysis (Steady State / Hydrograph) Time of Concentration (duration) Calculated using Kinematic Wave Method	
Page 5 of 5	
Hydro Analysis Execution Parameters	
Generate a Hydrograph ?	→ Yes No
Generate an IDF Curve ?	→ Yes No
Comments - <u>Rational Method Example for Charlotte, NC - 10/1/87</u>	
Analysis Output Name - C:\HYDRAIN\OUT\CNC50 .LST	
Execute Analysis ?	<u>Yes</u>
Hydro will create a Hydrograph	
F3-PGUP F4-PGDN	F6-MENU F10-HELP

Figure 14. Hydro analysis execution parameters screen.

To use this screen, simply select the desired prompts for the type of analysis desired. In the example problem, it was decided that besides calculating the rational method peak flow, that a hydrograph would be fitted to the flow data. Although the example did not call for it, generate an IDF curve.

The comments field can be left blank, or filled with a description of the analysis, date of the execution, or anything the user desires.

The **Analysis Output Name** prompts the user for the output file name. As discussed earlier, this does not necessarily need to be the name of the input file. For example, in order to derive performance curve data for the culvert review programs, the user may desire to make six runs of the same rational method data, varying only the return period between each execution. Instead of

entering data, executing, and saving the input file for each execution. This option allows the user, after initially entering the data, to create six different output listings, each with a slightly different filename and make the runs sequentially. Only after the runs have been made would the user save the "initial" input file. Of course, there are very good reasons to save the data set after each execution.

For the example, the conservative approach will be used. Enter the filename **CNC50** (an acronym for Charlotte, NC - 50-year storm) and continue to the next field.

To execute the HYDRO, strike <CR> at the last field. If the user does not wish to execute the analysis program, use the cursor or function keys to progress out of the input screens. In particular, pressing <F6>, will take the user back to the Rainfall/Flow Screen.

For the example, execute HYDRO by striking <CR> or pressing **Y** at the last field. Note - The execution time will vary based on problem complexity and type of microcomputer used (and whether it has a math coprocessor). Benchmark data are presented in the appendix.

HYDRAIN - DRAINAGE DESIGN SYSTEM → HYDRO PROGRAM		
Hydro Analysis Results Use ↑, ↓, Pg Up, Pg Dn, keys to move text - Hit F6 to exit report		
Rational Method Example for Charlotte, NC - 10/1/87		
OPTION 11 SELECTED		
THE BASIN AREA = 108.10 ACRES		
THE SUBAREAS (IN ACRES) AND USER SUPPLIED RUNOFF COEFFICIENTS ARE:		
MEADOW.....	53.90	C - .200
WOODS.....	.00	C - .200
PASTURE.....	.00	C - .300
CROPS.....	.00	C - .300
RESIDENTIAL.....	50.50	C - .400
URBAN/HIGHWAY.....	.00	C - .700
PAVEMENT.....	3.70	C - .950
THE OVERLAND RUNOFF LENGTH IS 1100.0 FEET ON A .020 FT/FT GRADE AND HAS A MANNINGS COEFFICIENT OF .10000		
F6-EXIT REPORT SCREEN		

Figure 15. HYDRO output in review program.



When the HYDRO engineering program has finished execution, program control is passed to the Hydro input program. The input program immediately calls a file review program which loads the output file (or an error file if the program fails) for the Users perusal. An example of the output presented in the review program is shown above in figure 15. As described earlier in the Hydrain documentation, the review program allows the user to move vertically through the output by using the arrow, PgUp, PgDn, Home and End keys.

In the output, the calculated peak flow is determined to be 140.0 ft<sup>3</sup>/s. A complete listing of the input and output files is found in the appendix.

To leave the review program, press <F6> to return to the Rainfall/Flow menu. There the user can continue analyses or move the cursor to **QUIT** and hit <CR> or strike **Q** to return to the Hydro Input Program primary menu.

In the case of the example, return to the primary menu by striking **Q**, move the cursor to **Store HYDRO data worksheet** and press <CR> (or strike **S**).

This will result in a screen where the user is prompted for a filename. The filename screen is shown in figure 16. If the user had retrieved a file earlier, that filename would be the present as default, otherwise the default is a wildcard. Note the default extension (**HDO**).

HYDRAIN - DRAINAGE DESIGN SYSTEM → HYDRO PROGRAM	
Type file name (wildcard character ? or * will invoke file menu)	
Source File Name	- C:\HYDRAIN\HDO\*_____.HDO
F5-CLEAR-F F6-MENU F10-HELP	

Figure 16. Filename prompt screen.

The alternatives open to the user are as follows:

- Enter a filename (or use the retrieved filename) and strike <CR>. The Hydro input program will save the file in the HYDRO subdirectory.
- Enter the Hydro File Management Module to select an existing input file on the HYDRO subdirectory to overwrite the data on. This is possible because of the initial default "\*" wildcard character (see the MS-DOS Reference for more information on what a wildcard is). The File Management Module is accessed by simply striking <CR>. Users will find themselves in a screen, depicted by figure 17, with a listing of all the files in the appropriate subdirectory. The user can move the cursor through the file listings (using the arrow keys), until a desired filename is reached. Striking <CR> will "flag" this filename as the one to save the data on. Should the user enter a filename within the module, it will override the listings and will be the file saved.

Note - This is the same procedure that a user would follow to Retrieve an input file. The user is initially prompted for a filename, and can use either one of the two alternatives described above.

#### Returning to the Hydrain System Shell

Upon returning to the primary menu, return to the Hydrain System Shell by moving the cursor to **QUIT** and pressing <CR> (or striking the **Q** key). As mentioned before, as a precautionary measure, all data is saved in an input file, **LASTIME.HDO**. There the user is free to investigate the other Hydrain system programs or again select **QUIT** to return to DOS.

HYDRAIN - DRAINAGE DESIGN SYSTEM → HYDRO PROGRAM									
Choose Hydro worksheet source file name from list									
Volume: has no label					Drive : C				
Path : \HYDRAIN\HDO\									
Search: *.HDO					Found : 5 file(s)				
Free : 23000001 bytes									
Choice: <u>INTST95</u> HDO									
LASTIME	HDO	1711	10-01-87	8:00	CNC50	HDO	1711	10-01-87	8:00
GLADE	HDO	1711	10-01-87	8:00	<u>INTST95</u>	HDO	1711	10-01-87	8:00
RT198	HDO	1711	10-01-87	8:00					
F6-MENU									

Figure 17. Hydro file management module.

## Appendix: Benchmark Examples

### Hydro Example

#### Input Worksheet

Rational Method Example for Charlotte, NC - 10/01/87

1  
35            14  
80            50  
50  
53.90        0.200  
0.00        0.200  
0.00        0.300  
0.00        0.300  
50.50        0.400  
0.00        0.700  
3.70        0.950  
108.10  
1100.0       0.0200  
2150.0       0.0100  
  
             0.100  
  
0.0160

#### Hydro Output

Rational Method Example for Charlotte, NC - 10/01/87

OPTION 11 SELECTED

THE BASIN AREA = 108.10 ACRES

THE SUBAREAS (IN ACRES) AND USER SUPPLIED RUNOFF COEFFICIENTS ARE:

MEADOW.....	53.90	C - .200
WOODS.....	.00	C - .200
PASTURE.....	.00	C - .300
CROPS.....	.00	C - .300
RESIDENTIAL.....	50.50	C - .400
URBAN/HIGHWAY.....	.00	C - .700
PAVEMENT.....	3.70	C - .950

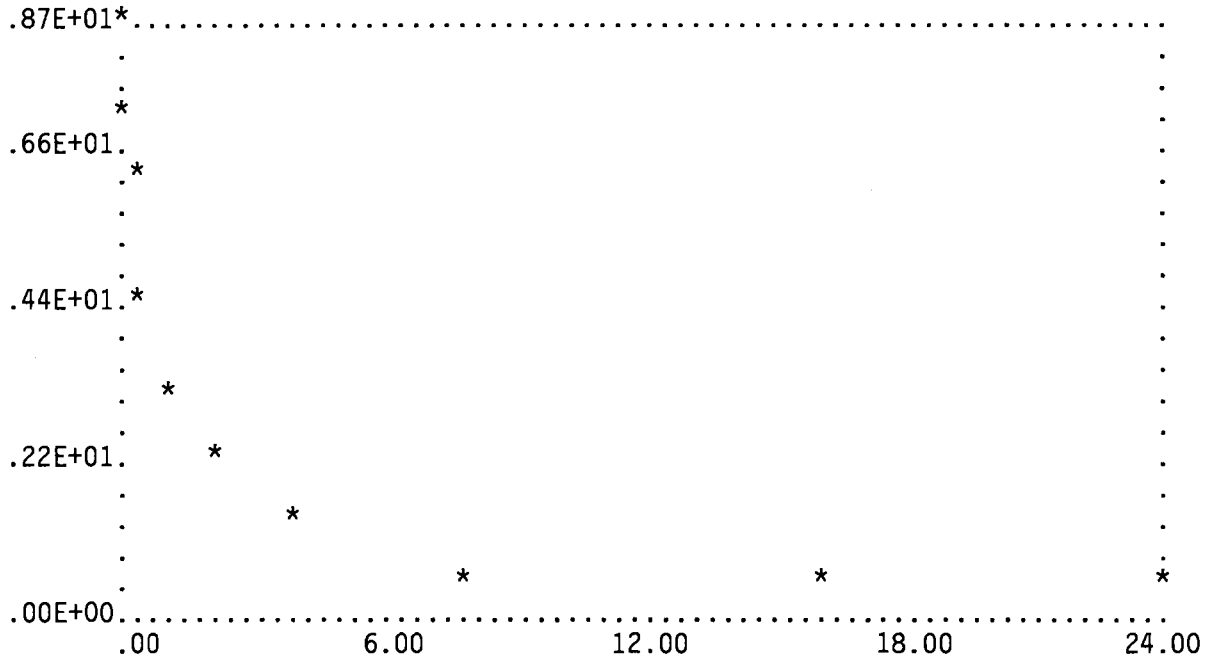
THE OVERLAND RUNOFF LENGTH IS 1100.0 FEET ON A .020 FT/FT GRADE  
AND HAS A MANNINGS COEFFICIENT OF .10000

THE CHANNEL IS 2150.0 FEET LONG AND HAS AN AVERAGE SLOPE OF .01000 FT/FT

THE LATITUDE IS 35 DEGREES, 14 MINUTES  
THE LONGITUDE IS 80 DEGREES, 50 MINUTES  
THE RETURN PERIOD IS 50 YEARS

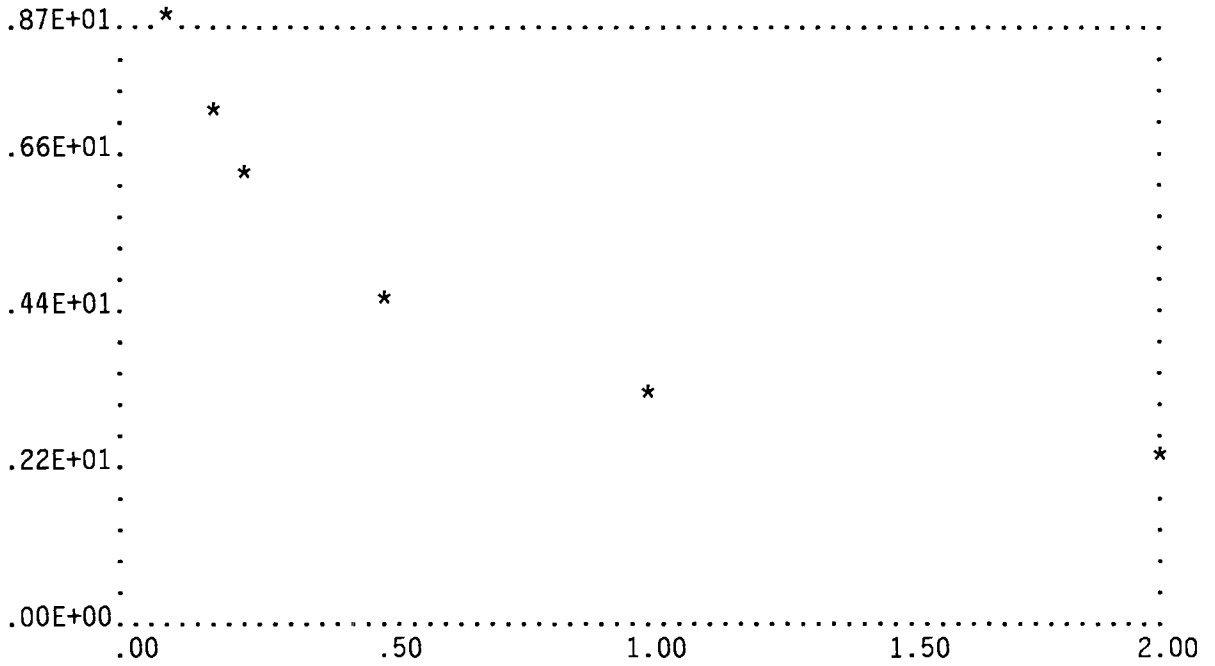
\*\*\*\*\*  
 \* TIME OF CONCENTRATION EQUALS .74 HOURS \*  
 \* INTENSITY EQUALS 4.06 INCHES/HOUR \*  
 \*\*\*\*\*

INTENSITY CURVE FOR 50 YEAR RETURN PERIOD  
 RAINFALL INTENSITY(INCHES/HOUR)-VS-DURATION(HOURS)



POINT	DURATION (HRS)	INTENSITY (IN/HR)
1	.08330	8.74200
2	.16670	7.39069
3	.25000	6.45165
4	.50000	4.82557
5	1.00000	3.23871
6	2.00000	2.08935
7	4.00000	1.22027
8	8.00000	.66611
9	16.00000	.34907
10	24.00000	.23650

IDF CURVE DETAIL

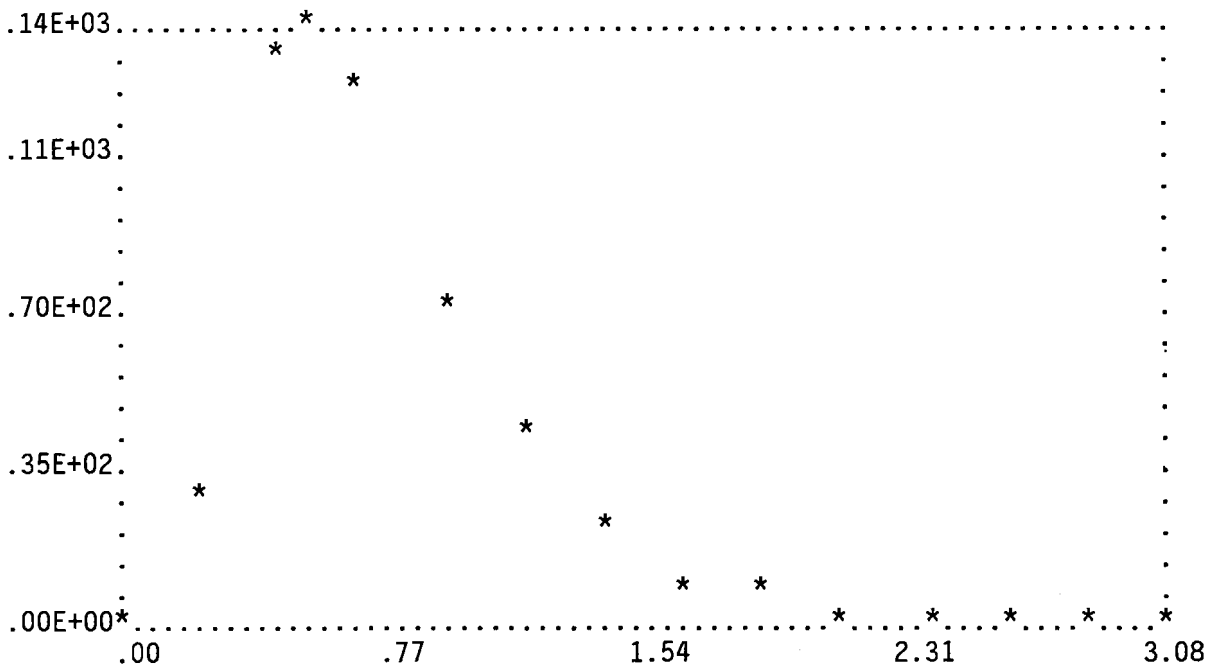


\*\*\*\*\*  
\* THE PEAK FLOW IS 140.04 CFS \*  
\*\*\*\*\*

THE VOLUME OF THE UNIT HYDROGRAPH IS EQUAL TO .99724 INCHES

THE TIME TO PEAK EQUALS .56061 HOURS

GRAPH OF CONSTANTS (MODIFIED SNYDER) HYDROGRAPH  
FLOW(CFS)-VS-TIME(HOURS)



POINT	TIME (HRS)	FLOW (CFS)
1	.00000	.00000
2	.23655	26.92541
3	.47310	131.38820
4	.56061	140.04140
5	.70965	123.82110
6	.94620	76.33469
7	1.18275	40.75118
8	1.41930	20.71674
9	1.65585	10.42349
10	1.89240	5.28030
11	2.12895	2.71436
12	2.36550	1.42083
13	2.60205	.75829
14	2.83860	.41269
15	3.07515	.00000

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