HYDRAIN--Integrated Drainage Design Computer System

Volume IV,

CDS--Culvert Design &
Analysis

U.S. Department of Transportation

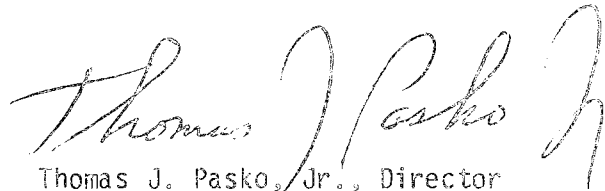**Federal Highway Administration**

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101-2296

FOREWORD

This report (Volume IV) is a technical supplement for the Culvert Design
System (CDS) microcomputer program of the HYDRAIN integrated drainage design
computer system. The HYDRAIN system which was developed under a pooled-fund
study, includes a system shell and five engineering microcomputer programs for
drainage design. The HYDRAIN documentation was published in 6 volumes so that
there would be a separate volume for each of the engineering programs. This
report will be of interest to hydraulic engineers for State highway agencies,
consultants, and other Government agencies who deal with drainage design.

The HYDRAIN microcomputer programs, including CDS, which is the subject of
this volume, have been distributed to the 25 States that participated in the
pooled-fund study. Those States will evaluate the programs for a 6 to 12
month trial period after which the programs will be available through McTrans
at the University of Florida, located in Gainesville, Florida and the PC-TRANS
at the University of Kansas.

Sufficient copies of this report are being distributed by an FHWA transmittal
memorandum to provide a minimum of one copy to each regional office, division
office, and State highway agency. At least 10 copies are being distributed to
those State highway agencies that participated in the study. Direct
distribution is being made to the division offices. Additional copies may be
obtained from the National Technical Information Service, 5285 Port Royal
Road, Springfield, Virginia 22161.

Thomas J. Pasko, Jr., Director
Office of Engineering and Highway
Operations Research and Development

NOTICE

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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 IV is a technical, user, and program supplement to more extensive available documentation for CDS (Culvert Design and Analysis). It consists of three sections. The first section introduces CDS, describing its intent and providing a system overview. The second section investigates the technical and operational methods used by CDS to analyze a culvert. The final section provides user documentation, guiding the user through the steps required to design or review a culvert without detailed technical explanations.

This volume is one of a series. The entire series is:

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

To operate all the software, the user needs all six (6) volumes. To individually operate CDS, the user needs Volume I and Volume IV.

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
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

Symbol	When You Know	Multiply By	To Find	Symbol
in²	square inches	645.2	millimetres squared	mm²
ft²	square feet	0.0929	metres squared	m²
yd²	square yards	0.836	metres squared	m²
mi²	square miles	2.59	kilometres squared	km²
ac	acres	0.395	hectares	ha

MASS (weight)

Symbol	When You Know	Multiply By	To Find	Symbol
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft³	cubic feet	0.0328	metres cubed	m³
yd³	cubic yards	0.0765	metres cubed	m³

NOTE: Volumes greater than 1000 L shall be shown in m³.

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
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

Symbol	When You Know	Multiply By	To Find	Symbol
mm²	millimetres squared	0.0016	square inches	in²
m²	metres squared	10.764	square feet	ft²
km²	kilometres squared	0.39	square miles	mi²
ha	hectares (10 000 m²)	2.53	acres	ac

MASS (weight)

Symbol	When You Know	Multiply By	To Find	Symbol
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m³	metres cubed	35.315	cubic feet	ft³
m³	metres cubed	1.308	cubic yards	yd³

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

```
          °F                                    °F
         -40      32        98.6               212
          -40    0  40    80  120    160    200
          +--+--+--+--+--+--+--+--+--+--+--+--+
          -40  -20   0   20  40   60   80   100
          °C                   37               °C
```
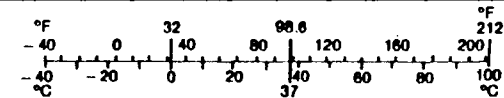
These factors conform to the requirement of FHWA Order 5190.1A.

* 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.

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- 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

FORTRAN 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.

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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.

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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 CDS program. There are a total of 6 such volumes for Hydrain.

Disclaimer

FHWA, the pooled fund States and their agents have, within the limits of their resources, tested and debugged the Hydrain shells. The engineering programs derive from several varied sources and were adapted to Hydrain and also underwent testing and debugging. However, this is a very large and somewhat complicated system of logic and 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 documentation is intended to serve as a technical, user and program supplement to the Culvert Design System (CDS) report.[1] It consists of three sections. The first section introduces CDS, describing its intent and providing a system overview. The second section investigates the technical and operational methods used by CDS to analyze a culvert. The final section provides user documentation, guiding the user through the steps required to design or review a culvert without detailed technical explanations.

The objective of this documentation will be to provide the user with an understanding of CDS as it has been implemented under the Pooled Fund Project. The CDS program has additional features (such as overflow and overtopping analysis, and upstream cross section propagation) that were not implemented under PFP at this time, but for the interested user, are discussed in the CDS report and its supplements.

The CDS model uses the USGS table look up method to predict how the culvert will hydraulically function. The CDS code was developed by the Wyoming State Highway Department[1] and has several years of operations to its credit within which bugs have been identified and eliminated. Hydraulic routing computations are a feature of this code; ponding analyses to downsize openings can be conducted. Additionally, the code can iterate through alternative sizes subject to headwater or pond surface area constraints to identify trial designs. Trial designs can be found for steady-state design flows or for design hydrographs representing a dynamic flow condition.

2. System Overview

System Background

The release of the Culvert Design System (CDS), in December, 1980, provided a generalized technology for the analysis of traditional issues in culvert design, as well as a state specific technology suitable for evaluating temporary upstream pond storage. CDS allowed the engineer to directly avoid using manually time consuming flood routing and improved culvert hydraulics techniques. These techniques were more easily applied by using an automated computer system than developing them by hand. CDS is written in FORTRAN, and constructed in a modular fashion to facilitate changes and enhancements.

CDS provides four distinct types of analysis that can be classified into two broad options: design and review. The design option selects a culvert size and number of barrels compatible with the engineering data, environmental constraints, and site geometry. With this option, the user can request that the program consider the following culvert types: round concrete, round metal, arch concrete, arch metal, oval concrete (horizontal placement only), and concrete box. There is an upper limit of six barrels for commercial culverts or five for concrete box culverts.

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

Additionally, the user must select one of two flow scenarios: the steady state (peak or irrigation flow design or review) method or dynamic (drainage design or review) method. The steady state method ignores any upstream pond storage and selects a culvert capable of passing the peak discharge. This precludes considerations of any available pond storage. The dynamic flow method uses temporary upstream pond storage resulting from the attenuating effects of routing a hydrograph through the site.

Provision has been made for the user to obtain data for manually plotting a culvert performance curve. This is accomplished by the user identifying the design discharge and five other performance discharges deemed suitable to define a performance curve. With these discharges, CDS will first size a culvert using the design option and then review this design culvert size using the five performance discharges. If the review option is selected, then CDS will review up to six peak discharges or hydrographs for the specified culvert size. This satisfies FHWA requirements for a culvert performance curve and assists in making a flood hazard assessment provided the base flood (100-year event) is one of the five performance discharges.[2] It is not necessary to input all five performance discharges in order to secure a culvert design; one discharge is sufficient. Additionally, this logic also provides a linkage for addressing economic (risk) analysis to identify the most theoretically cost effective culvert.

When considering the dynamic flow scenario, CDS has a choice of two hydrograph alternatives in both the design option or review option. The first alternative allows the user to input a hydrograph of their choice for a given discharge. Each of the six discharges that can be input to CDS will also require input of their own unique hydrograph. The second alternative is where the user does not elect to input a hydrograph, but to use a default, internal dimensionless hydrograph based on Wyoming's flood studies.[3]

System Operation

CDS develops tabular data for developing the stage discharge relationship needed to define the tailwater. The stage discharge relationship (sometimes referred to as a rating curve) identifies downstream flood stages. The user can override these internally computed stage storage and stage discharge tables by entering his own tabular relationships. This might be necessary in order to define a complex upstream storage geometry or to reflect complex tailwater situations such as backwater from existing culverts or bridges. When deemed advisable, a flow distribution can also be provided by CDS.

Having quantified the hydraulic site conditions, CDS selects an initial trial size culvert when in the design option (both steady-state and dynamic methods of design). This initial trial size is an 18-inch round or equivalent size commercial culvert. The minimum box culvert size is a 4-foot square opening (in accordance with Wyoming practices). The user may select an incremental hydrograph time interval (flood routing period) or use the internally generated time interval based on the hydrograph shape, thereby allowing the program to compute an incremental volume for routing. With this incremental volume selection, CDS computes an average discharge over the selected time interval for use in flood routing. A headwater rating curve is computed using the tabular stage discharge relationship for tailwater conditions. The computation considers both inlet and outlet control parameters and selects the governing control.[4] Having determined the headwater rating curve, CDS uses the stage storage relationship and the rating curve to apply the Storage Indication routing technique.[5]

From the hydrograph time interval an incremental flood volume arriving at the site during the selected time interval or routing period can be identified.

Mathematically, the basic flood routing equation is:

$$I - 0 = \frac{S}{t} \tag{1}$$

where:

I = the average hydrograph inflow to the pond,

0 = the average outflow of the pond,

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S = the upstream storage volume, and

t = the time interval.

This can be expanded as:

$$2 \frac{S_1}{\delta t} - O_1 + I_1 + I_2 = 2 \frac{S_2}{\delta t} + O_2 \qquad (2)$$

where:

S_1 = the storage volume in the pond at the beginning of the incremental time period, δt,

O_1 = the instantaneous outflow at the beginning of the incremental time period, δt,

I_1 = is the instantaneous inflow at the beginning of the incremental time period, δt,

I_2 = is the instantaneous inflow at the end of the incremental time period, δt,

S_2 = is the storage volume in the pond at the end of the incremental time period, δt,

O_2 = is the instantaneous outflow at the end of the incremental time period, δt, and

δt = the time interval.

The basic flood routing equation as used in CDS considers the accumulation of storage in a culvert's temporary upstream pond as depending upon the difference between the rates of inflow and outflow. For an interval of time, the basic flood routing equation can express this relationship as:

$$\delta S = Q_i \cdot \delta t - Q_i \cdot \delta t \qquad (3)$$

where:

δS = the change in pond storage during time period, δt, and

Q_i = the average rate of inflow flood discharge from the watershed.

This yields:

$$\frac{(I_1 + I_2)}{2} = \delta S + \frac{O_1}{2} + \frac{O_2}{2} \tag{4}$$

On the initial trial for a given culvert size, CDS assumes:

$$Q_d = (Q_i + Q_{i-1}) / 2 \tag{5}$$

where:

Q_d = the average outflow discharge being routed through a culvert occurring over time interval, δt.

Once these equations have been developed, upstream pond routing is accomplished using conventional reservoir routing techniques, specifically, the Storage Indication method.[5] A headwater rating table (upstream discharge versus stage curve) is first developed. Then the table is linked with the stage storage relationship. The routing equations utilize these tables at each time step to calculate the pond discharge at that time increment.

After an incremental volume balance is reached, the time is advanced another increment, δt, on the hydrograph. Each subsequent incremental volume balance must necessarily consider the amount of pond storage, S_2, occupied by the previous incremental volume balance.

This processing of the hydrograph through successive time increments continues until the outflow hydrograph drops below 0.5 ft^3/s. CDS monitors the increase in upstream pond depth to ensure it does not exceed a design maximum (termed design headwater). If the design headwater is exceeded, the program increments the culvert opening, returns to the beginning of the hydrograph and repeats the flood routing process until a culvert size is obtained that precluded the upstream pond from exceeding the design headwater. In addition, CDS also monitors the pond's surface area and the ratio of headwater over vertical culvert dimension (H_w/D), and similarly increments the culvert size should these optional input constraints be exceeded.

In the design mode, CDS will increase the number of culvert barrels if it cannot satisfy the design headwater, surface area, and H_w/D ratio limitations with a culvert having the greatest allowable vertical culvert dimension specified for the site. The greatest allowable culvert dimension is an input value to prevent CDS from selecting a culvert that is not compatible with embankment cover requirements. CDS increments the number of barrels when it reaches the upper limit for the greatest vertical dimension established by the available structure geometries. The maximum vertical barrel dimension for each culvert type are 10 feet for boxes, 21 feet for round metal, 8 feet for round concrete, 158 inches for metal arches, 54 inches for concrete arches and 116 inches for concrete ovals. CDS can be used for any size of culvert in the

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review mode. For example, a 22-foot round metal culvert or a 13-foot round concrete culvert could be reviewed.

Once a culvert size commensurate with the design headwater, pond surface area, H_w/D ratio and cover limitations has been determined, CDS proceeds to identify the flow type. Knowing the flow type allows CDS to quickly identify the outlet conditions and thus compute velocity, flow type, Froude number, and brink depth.

When the steady-state method is selected, CDS omits the flood routing process and only seeks to satisfy the design headwater limitation or to review the specified size, for the peak discharge, Qp.

Program logic can be subdivided into six general engineering catagories. These are: stage discharge, stage storage, hydrograph, headwater rating curve, flow types and outlet conditions, and flow distribution. These catagories are discussed in a technical and operational and engineering sense in the following chapters to facilitate understanding of CDS by the engineer.

3. Stage Technical and Operation Information

Stage Discharge

A unique site feature affecting a culvert's performance is the stage discharge relationship, often termed a rating curve. This relationship is portrayed graphically by plotting flow depth versus discharge. From this relationship, the program can obtain the various tailwater values necessary in evaluating flow characteristics immediately downstream of the culvert outlet.

The cross section profile and slope used to compute the stage discharge relationship must be typical of downstream conditions. This relationship predicts the natural flow depth of a flood for any particular discharge within the capacity limits of the channel cross section.

This program does not employ a water surface profile to compute the stage discharge relationship. Rather, a single section analysis that assumes the channel profile slope approximates the hydraulic gradient is used. A channel cross section located at a naturally constricted reach is recommended to avoid slack water conveyance. In other words, the cross section should not contain areas of slack water.

The various depth discharge relationships necessary in defining the stage discharge (or tailwater rating curve) are computed using Manning's equation:

$$V = \frac{1.486}{n} \cdot R_h^{0.667} \cdot S_o^{0.5} \qquad (6)$$

where:

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

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

S_o = the downstream channel slope, in ft/ft, and

n = Manning's friction value for a waterway.

Also;

$$Q = V \cdot A \qquad (7)$$

where:

Q = the total discharge occurring within a cross section of area a, in ft^3/s,

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

A = the channel's waterway cross sectional area, in square feet.

The stage discharge (and flow distribution) logic uses the channel cross section in one of two ways to compute hydraulic properties and the stage discharge relationship.

1. With a homogeneous channel cross section, the program provides hydraulic characteristics for the entire cross section. The output reflects only average values for the entire cross section. A homogeneous cross section is defined as having uniform Manning's roughness coefficient and geometry across the entire cross section.

2. When the cross section is subdivided to reflect irregular shapes or different vegetal and friction patterns, the output will reflect the hydraulic properties from each individual subsection. The program can accommodate up to nine subsections per cross section. In the analysis, program logic subdivides each subsection further into relatively equal increments.

The computational procedure is similar for both of the above applications. Both applications use equations 6 and 7 for the discharge and velocity relationships. The application of these equations is accomplished by starting at the lowest point within a subsection and using simple geometry relationships, compute the initial incremental cross sectional area and wetted perimeter as well as an incremental discharge. Next, the depth is incremented to a higher elevation level and the process repeated.

The Froude number evaluates the gravitational and momentum effects on the flow and is computed using the equation below:

$$F_r = V / (g \cdot H_d)^{0.5} \qquad (8)$$

where:

F_r = the Froude number (a dimensionless measure of gravity's effect on the state of flow),

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

g = the gravitational acceleration (32.2 ft/sec^2), and

H_d = the channel's cross section hydraulic depth, in feet.

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The program evaluates the streambed stability by estimating the tractive shear occurring on the bed. This is a gross estimate found in most texts.[6] It is computed using the equation below:

$$Tau = \quad \cdot S_f \cdot T_w \qquad (9)$$

where:

Tau = the tractive shear, in lbs per square foot,

$\quad$ = the unit weight of water (62.4 lbs/ft^3),

S_f = the friction slope in the downstream reach, in ft/ft. CDS assumes that this equals to the downstream channel slope, in ($S_f = S_o$), and

T_w = the tailwater depth, or the maximum depth of flow occurring in the natural channel just beyond the culvert outlet, in feet.

Comparing the tractive shear with allowable values for various streambed materials as found in modern open channel texts provides the user with an estimate of channel stability.

Stage Storage

Routing flood hydrographs through a culvert requires quantification of upstream storage. The program accomplishes this by generating an internal stage storage table. In this case, stage is the upstream pond depth above the culvert inlet flow line and not the natural flow depth discussed under stage discharge. Storage is the volumetric storage occurring upstream from the culvert for a given stage or pond depth. CDS provides two alternative means of computing the stage storage relationship. One method uses a cross section and channel slope which are input to the program. If it is believed the upstream stage storage relationship can not be reasonably identified with a cross section (i.e. complex reservoirs, channel confluences), the user can manually compute a separate stage storage curve. This externally computed stage storage table will override the internally computed stage storage table computed by the cross-section option. In either alternative, this table of incremental values for storage versus stage (depth) are used by the program.

If the upstream cross section is not located at the culvert entrance, (i.e. the cross section is "offset" from the culvert entrance) the program will internally assume the upstream cross section that is provided also defines the cross section at the culvert inlet. In other words, if the cross section is offset, CDS will propagate the cross section downstream until it reaches the culvert location. This is depicted in figure 1.

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TOP

x

FRONT

SIDE

$\leftarrow x \rightarrow$

Downstream

Offset-x

Cross Section Coordinates
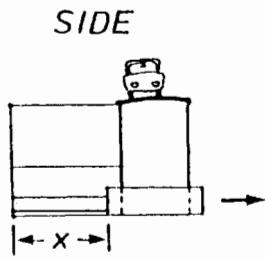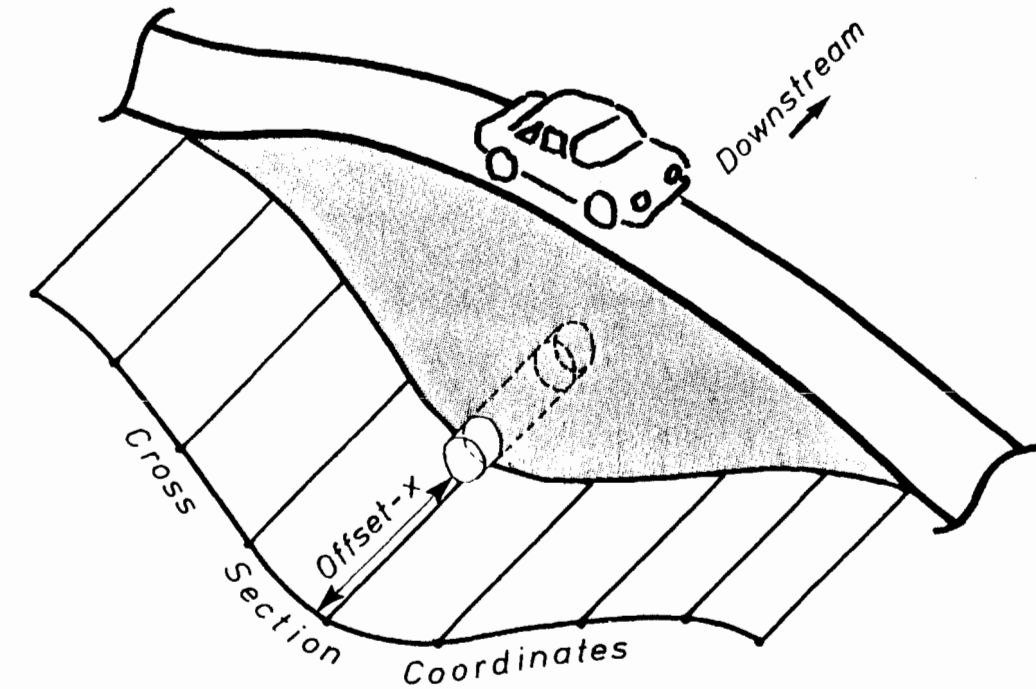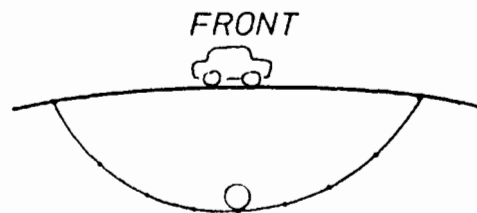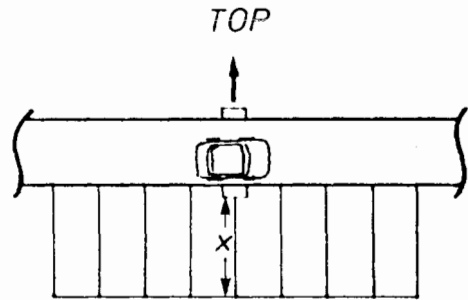
Figure 1. Culvert offset

If no upstream cross section is available, a downstream cross section may be input to serve as the cross section reflecting upstream storage provided the elevations are adjusted accordingly. The user is cautioned that in this simplistic solution, the downstream section must be typical of upstream storage capacities.

The internal logic procedure for computing the stage storage relationship is based on the average end area method commonly associated with earthwork computations. Using the cross section and upstream slope, the profile is propagated upstream. In other words, the program assumes that the upstream storage can be represented by a triangularly shaped prism that projects the upstream stream slope to where it intercepts the incremental pond level. This projection identifies the length of the storage pond and computes the corresponding volume. The prism shape, when internally incremented through the elevation levels (stages) identified on the cross section, results in a table of stage storage relationships. The surface area for any incremental level of ponding (inundated area) is computed in a similar manner.

If it is believed the upstream stage storage relationship cannot be reasonably identified with cross sections, then the user should manually compute a separate stage storage relationship.

The user can do several things to improve the accuracy of the stage storage relationships:

1. When using the downstream cross section to define the upstream storage pond is justified, be sure to raise all cross section elevations so they are relative to the streambed elevation at the culvert entrance.

2. Always use the average channel slope occurring upstream from the cross section to compute the stage storage relationship.

3. Use the externally supplied stage storage table input on very complex sites.

Hydrograph

In order to route floods through the culvert, roadway, and site geometry, it is necessary to define a hydrograph; the time versus discharge relationship for flood.

As stated earlier, CDS has the capability of considering two hydrograph alternatives in both the design option or review option. The first alternative allows the user to input a hydrograph of his choice for a given discharge. The second alternative is where the user does not elect to input a hydrograph, but to use a default, internal dimensionless hydrograph based on Wyoming's flood studies.[3] These studies are for semiarid regions having watersheds ranging from 0 to 15 square miles.

Producing data for the first hydrograph alternative is left to the user. Any appropriate procedure for developing a hydrograph can be used. The FHWA

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report, HEC-19, outlines several different methods for creating a hydro-graph.[5] Additionally, most States have their own practices that can be used. The HYDRO model can also be used to generate a hydrograph.

Input data consists of a series of incremental discharges and their corresponding incremental time values. The minimum number of discharge and time values needed to describe a hydrograph would be three (as in the commonly used "triangular" hydrograph). The maximum number of discharge and time values is 100. This alternative makes CDS viable in any geographic region in the world provided a reasonable hydrograph can be synthesized.

The rest of the hydrograph portion will dwell on the second hydrograph alternative. It is the result of research, conducted by the USGS in Wyoming, that produced a dimensionless hydrograph curve.

The total volume contained under the hydrograph curve for a given frequency is identified by the USGS report as a function of drainage area.[3] The standard error of estimate for the volume relationship can be significantly improved by also including such watershed parameters as maximum basin relief, basin slope, and channel slope in the expression used to compute the hydrograph volume. Therefore, because the flood volume varies with the standard error for various combinations of watershed variables, the user must identify and input the desired volume, such that the user is confident that a permissable level of accuracy has been achieved.

From the USGS study report, it was possible to identify a simple hydrograph shape that provided a reasonable simulation of the time/discharge relationship for watersheds in semiarid regions having approximately 15 or fewer square miles in contributing area. This shape is a function of volume and peak discharge.

Headwater

The logic for computing the partial full flow headwater does not make use of water surface profile procedures between the culvert outlet and inlet. Rather a more simplistic methodology is used.[4,7]

This methodology determines the upstream pond depth, identifies flow types, and computes the culvert barrel's outlet properties: velocity, depth, and Froude number. The governing headwater within Zone 1, depicted in figure 2, is identified by first comparing the headwater that would result if the culvert were in inlet control to the headwater that would result if the culvert were in outlet control. The greater of the two headwaters governs within Zone 1. Either inlet or outlet control can occur within Zone 1 depending on the culvert geometry, discharge, and other site characteristics. Of course, the same holds true if water surface profile calculations are used.

As the average outlet discharge is increased, the headwater increases to where the inlet becomes submerged (about where the Hw/D ratio is approximately 1.2). When 1.2 < Hw/D < 1.5, the culvert headwater tends to fluctuate,

vortexes form to introduce air into the culvert, and the discharge capacity
varies. This is depicted as the shaded region of figure 2. This phenomenon
occurs as the culvert approaches and is able to sustain its full barrel flow
capacity. Zone 2, the region of fluctuation bounded by points a and c in
figure 2 reflects this visually.
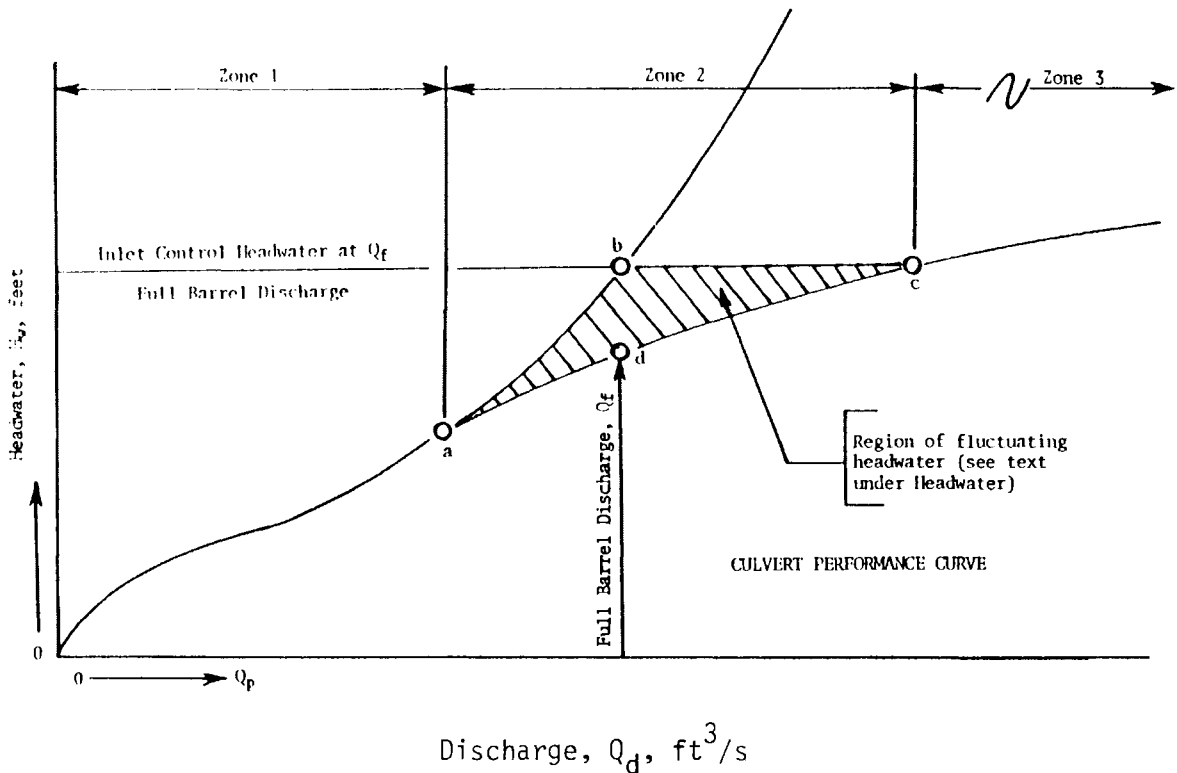
Figure 2. Governing headwater / discharge zones.[1]

The fluctuation was circumvented by arbitrarily considering only the worst
case. This is done by computing the full barrel headwater associated with the
full barrel discharge. This establishes point b on figure 2. Line bc is the
minimum headwater used in Zone 2. Zone 3 is recognized by the computer as that
region where the computed headwater exceeds the full flow headwater. In this
region, Manning's equation for full pipe flow is used to calculate headwater.

Functions used in culvert hydraulics have many discontinuities. These
discontinuities must be "smoothed" before flood routing is performed to allow
the flood routing equations to "balance". The same discontinuities would also
occur if the program used water surface profiles, again making "smoothing"
procedures necessary if flood routing is used. These three zones are a means
of describing the technical solution used in linking partially full barrel flow

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to full barrel flow to smooth these discontinuous hydraulic functions used in culvert hydraulics. They do not specifically exists, as such, in the program.

In Zone 1, the inlet control headwater for various culvert and inlet types is defined by headwater equations obtained through regression of data generated by laboratory studies conducted by the National Bureau of Standards between 1955 and 1967. An example of such an equation is shown below:

$$H_{wi} = (A + B \cdot X + C \cdot X^2 + D \cdot X^3 + E \cdot X^4 + F \cdot X^5) \cdot D \qquad (10)$$

where:

H_{wi} = the inlet control headwater, in feet,

D = the height of the culvert barrel, in feet,

A to F = regression coefficients for each type of culvert, and

X = a function of the average outflow discharge being routed through a culvert, culvert barrel height and for box and pipe arch culverts, the width of the barrel.

A complete table of coefficients used for each culvert type is found in the publication, "Culvert Design System" referenced in the bibliography.[1]

The headwater for outlet control is computed using a form of Bernoulli's equation as shown below:

$$H_{wo} = H + h_0 - \left[L \cdot S_0 \right] \qquad (11)$$

where:

H_{wo} = the outlet control headwater, in feet,

H = the head loss through the culvert including barrel friction, entrance losses, and outlet velocity head, in feet,

h_0 = the vertical distance from the outlet culvert invert to the hydraulic grade line, in feet,

L = the length of the culvert barrel, and

S_0 = the downstream channel slope.

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The vertical distance for part full flow at the outlet, h_o, has been approximated by using the larger of either the tailwater or the hypothetical value below:

$$(d_c + d) / 2 \qquad\qquad (12)$$

where:

d_c = the critical culvert flow depth for a specific discharge, in feet, and

d = the normal flow depth that would occur within a culvert assuming uniform flow, in feet. HEC-5 discusses a similar variable, D, the culvert height.[4] For part full flow, these variables do not have the same meaning, although, as the culvert approaches full flow, d becomes equal to D.

This situation is considered to be tailwater control which is one type of outlet control.

When the culvert reaches full flow, the outlet energy line is defined by using the larger of either the tailwater or the outlet energy (which as mentioned above is expressed only as the vertical culvert height). This situation is considered to be barrel control, another form of outlet control.

The product of culvert length and slope defines the elevation difference between the culvert inlet and outlet as required by Bernoulli's equation.

Any time the average outflow discharge is equal to or greater than the full barrel flow, a full barrel condition is used.

The head or energy, H, required to pass a given quantity of water through a culvert consists of three components, a velocity head, H_v, an entrance loss, H_e, and a barrel friction loss, H_f. This energy is obtained through ponding water at the entrance and the energy equation may be expressed as:

$$H = H_v + H_e + H_f \qquad\qquad (13)$$

The velocity head is, in turn, governed by flow in the barrel. Full flow gives a velocity head of:

$$H_v = V_f^2 / 2g \qquad\qquad (14)$$

where:

H_v = the velocity head,

V_f = the full flow velocity, in ft/s, and

g = the gravitational acceleration (32.2 ft/sec^2).

In the case where barrel flow is not full, a partial flow area is used to generate a velocity, V, which is bounded by the velocity at critical depth, V_c, and the full flowing velocity, V_f such that $V_c \geq V \geq V_f$.

These cases are dependent upon inlet control and/or the ability of the culvert slope to generate this velocity. Outlet control will require yet another velocity head consideration.

If the tailwater momentum is greater than the pipe flow, the velocity head is computed using the velocity associated with either the tailwater depth or the culvert barrel height, whichever is less. If tailwater momentum governs and the tailwater depth is less than the flow depth that would occur in the culvert barrel due to uniform flow (exclusive of inlet/tailwater/culvert length), then the velocity associated with this flow depth governs and is used to compute the velocity head.

The second part of the energy equation is the entrance head loss. This loss is expressed in terms of the velocity and an entrance loss coefficient that is unique for various types of commonly used culvert entrances. The following expression is used to compute the entrance head loss for all cases:

$$H_e = k_e \cdot V^2 / 2g \qquad (15)$$

where:

H_e = the entrance loss,

k_e = the entrance loss coefficient,

V = the unique flow velocity (such that $V_c \geq V \geq V_f$), and

g = the gravitational acceleration (32.2 ft/sec^2).

The final part of the energy equation, barrel friction loss, is obtained through manipulation of Manning's equation. The expression for barrel friction loss, seen below, is continuous between full and full flows.

$$H_f = \left| \frac{29.1 \cdot n^2 \cdot L}{R_h^{1.33}} \right| \left| \frac{V_f}{V_o} \right|^{0.667} \frac{V^2}{2g} \qquad (16)$$

where:

H_f = the barrel friction loss,

R_h = the hydraulic radius of the culvert, in feet,

n = Manning's friction value for the culvert,

L = the length of the culvert barrel, in feet,

V_f = the velocity when the culvert is flowing full, in ft/s,

V_o = the outlet velocity ($V_c \geq V_o \geq V_f$), in ft/s,

V = the flow velocity ($V_c \geq V \geq V_f$), in ft/s, and

g = the gravitational acceleration (32.2 ft/sec^2).

The hydraulic radius is subject to the same boundary scheme as velocity. It corresponds to the barrel flow conditions bounded by critical and full flow conditions such that $R_c \leq R_n \leq R_f$.

Flow Types and Outlet Conditions

This section discusses the methods for determining the flow types used to compute the hydraulic conditions at the culvert outlet. CDS does not presently contain the logic to evaluate the need for outlet protection or the protection requirements, but does generate the necessary input to such logic.

CDS internally identifies the flow types shown in figures 3 and 4 using the criteria presented in table 1. Once the flow types have been identified, the program then computes the hydraulic properties existing at the outlet. These properties include outlet flow depth, brink depth, velocity, specific force, and Froude number. These are the essential properties necessary to input into a separate culvert outlet protection program. The flow types are useful in determining the location of hydraulic jumps, if any occur.

As mentioned earlier, CDS does not develop a water surface profile, but instead uses regression equations, similar to work done by the USGS, to determine, for a given flow type, the area and depth of a culvert flowing partially full.

Flow Distribution

Flow distribution, by itself, does not aid in designing or reviewing a culvert, rather, when combined with a stage discharge analysis, generates and accumulates incremental discharges across a typical cross sectional profile. This will illustrate, for a given elevation or discharge, what percentage of the flow will be found at any point in the cross section.

Other information provided by the flow distribution for each of the incremental segments used in computing the stage discharge relationship include

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Froude number, tractive shear, velocity, and discharge. The flow distribution also sums the incremental discharges to obtain the total subsection and hence channel discharge. In addition, the flow distribution provides the average depth, velocity, and Froude number. The nonuniform velocity coefficient, and nonuniform momentum coefficient, for the cross section are also provided by this option. The flow distribution option also identifies the maximum velocity occurring within the cross section, the specific force of the cross section, and the cross section's specific head.
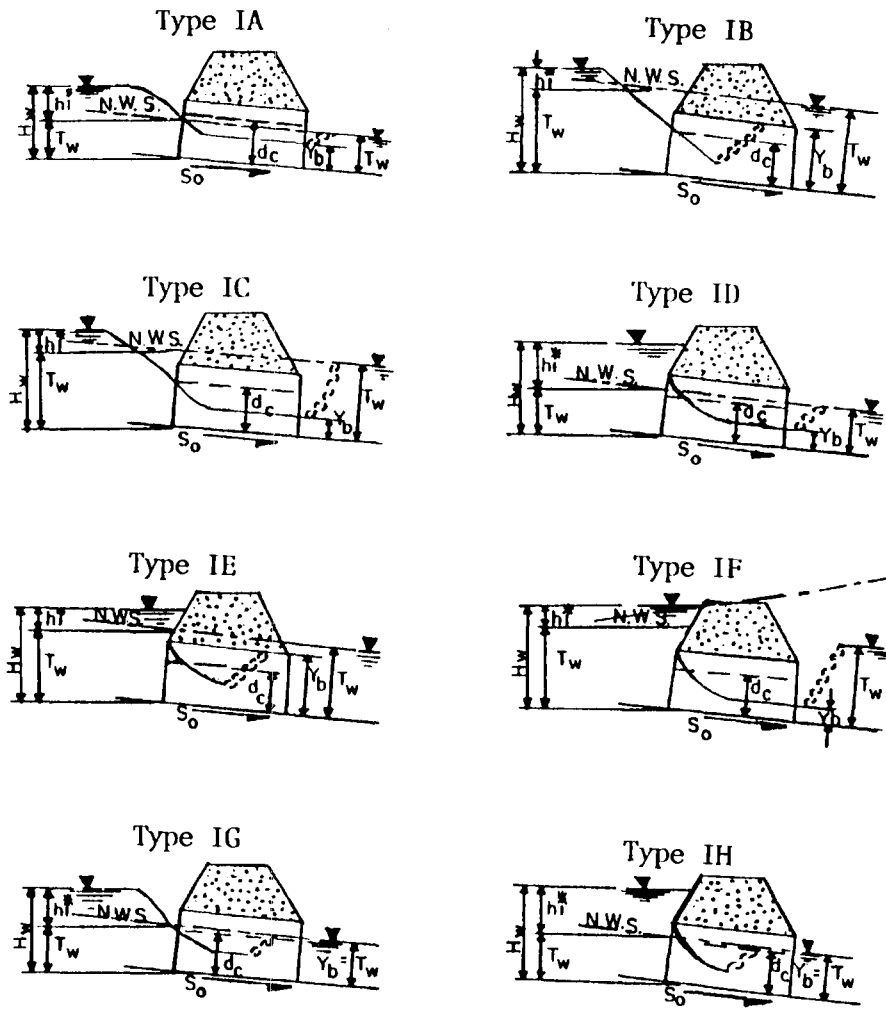
Figure 3. Inlet control flow types.[1]

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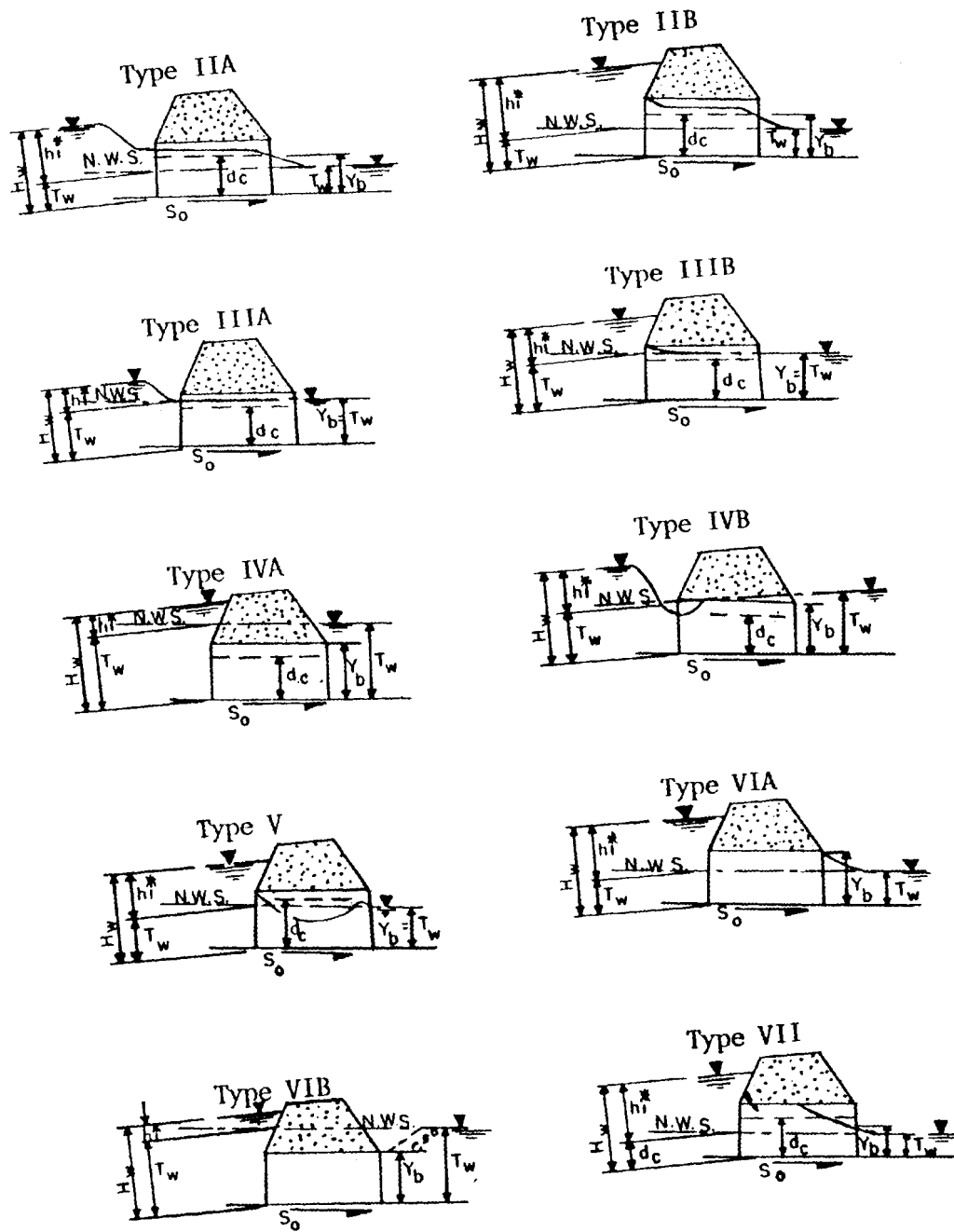
Figure 4. Outlet control flow types.[1]

Table 1. Flow type variables.[1]

Inlet Control	H_w/D	d/d_c	Q_d/Q_f	$\dfrac{(S_o \cdot L + D)}{T_w}$	S_o/S_c	T_w/D	M_b/M_{TW}	d/D	d_c/T_w	d_c/D	Y_b
IA	<1.5	<1.0	<1.0	–	>1.0	<1.0	>1.0	<1.0	–	<1.0	d
IB	<1.5	<1.0	<1.0	>1.0	–	>1.0	<1.0	<1.0	–	<1.0	D
IC	<1.5	<1.0	<1.0	>1.0	>1.0	>1.0	>1.0	<1.0	–	<1.0	d
ID	>1.5	<1.0	<1.0	–	>1.0	<1.0	>1.0	<1.0	–	<1.0	d
IE	<1.5	<1.0	<1.0	>1.0	>1.0	>1.0	<1.0	<1.0	<1.0	<1.0	D
IF	>1.5	<1.0	<1.0	>1.0	>1.0	>1.0	>1.0	<1.0	<1.0	<1.0	d
IG	<1.5	<1.0	<1.0	–	>1.0	<1.0	<1.0	<1.0	>1.0	<1.0	T_w
IH	>1.5	<1.0	<1.0	–	>1.0	<1.0	<1.0	<1.0	>1.0	<1.0	T_w

Outlet Control	H_w/D	d/d_c	Q_d/Q_f	$\dfrac{(S_o \cdot L + D)}{T_w}$	S_o/S_c	T_w/D	M_b/M_{TW}	d/D	d_c/T_w	d_c/D	Y_b
IIA	<1.5	>1.0	<1.0	–	<1.0	<1.0	–	<1.0	>1.0	<1.0	d_c
IIB	>1.5	>1.0	<1.0	–	<1.0	<1.0	–	<1.0	>1.0	<1.0	d_c
IIIA	<1.5	>1.0	<1.0	–	<1.0	<1.0	–	<1.0	<1.0	<1.0	T_w
IIIB	>1.5	>1.0	<1.0	–	<1.0	<1.0	–	<1.0	<1.0	<1.0	T_w
IVA	>1.5	>1.0	<1.0	<1.0	<1.0	>1.0	–	–	<1.0	<1.0	D
IVB	<1.5	>1.0	<1.0	>1.0	<1.0	>1.0	–	–	<1.0	<1.0	D
V	–	–	>1.0	–	–	<1.0	–	–	–	<1.0	d_c
VIA	–	–	>1.0	–	–	<1.0	–	>1.0	–	>1.0	D
VIB	–	–	>1.0	–	–	>1.0	>1.0	>1.0	–	>1.0	D
VII	–	–	>1.0	–	–	<1.0	–	>1.0	>1.0	<1.0	$(d_c + T_w)/2$

H_w = Headwater pond, feet
D = Vertical Culvert height, feet
d = Normal flow depth in culvert without tailwater influence, feet
d_c = Critical flow depth in culvert, feet
Q_d = Barrel discharge, ft^3/s
S_o = Culvert slope, feet/feet
L = Culvert length
T_w = Flow depth in natural channel downstream
S_c = Critical culvert slope, feet/feet
M_b = Specific force at culvert outlet, lbs
M_{TW} = Specific force at culvert outlet due to tailwater, lbs
Y_b = Brink depth, feet

4. User Documentation

The Work Deck Concept

The Culvert Design System Input Program has four work options available for the design and review of flow systems relevant to culvert analysis. These work options are; stage discharge, stage storage, culvert design or review, and flow distribution. Each of the four work options has a corresponding data file structure, called a **Work Deck**.

The generation of the stage discharge relationship from a typical cross section is created using the stage discharge work deck. To determine the volume of storage upstream of a culvert (independent of a culvert design or review) or behind a dam, the stage storage work deck is used. The culvert design or review work deck stipulates the flow conditions, the type of culvert, inlet type, design methodology and various culvert and flow parameters. The flow distribution work deck allows the user to analyze the proportional flow and velocity increment as a function of elevation of discharge.

For most common applications, CDS work decks are combined into one of the nine combinations shown in table 2 below. For example, if upstream storage is to be considered in the design or review of a culvert, a stage discharge, stage storage and culvert decks are required. If the peak flow (steady-state) design or review method is to be used, the stage storage deck is unnecessary, and configuration 4 is used. These work deck configurations form the CDS input dataset that is used by the CDS analysis program.

Table 2. Common CDS work deck configurations

1) Data review
    · Stage Discharge Work Deck

   This deck will run alone to generate a stage discharge (rating) curve from downstream cross sectional data.

2) Data review
    · Stage Storage Work Deck

   This deck will run alone to determine upstream storage volumes.

3) Dynamic Flow Design or Review
    · Stage Discharge Work Deck
    · Stage Storage Work Deck
    · Culvert Work Deck

   This combination designs or reviews a culvert with upstream storage and routes a hydrograph through the culvert.

4) Steady State Flow Design or Review
    · Stage Discharge Work Deck
    · Culvert Work Deck

   This combination designs or reviews a culvert with steady state (peak) flow.

5) Flow Distribution
    · Stage Discharge Work Deck
    · Flow Distribution Work Deck

   This combination reviews the downstream channel hydraulics (independent of any culvert analyses).

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6) Stage Discharge & Storage   This combination calculates
   • Stage Discharge Work Deck   the stage discharge and stage
   • Stage Storage Work Deck   storage curves (independent
                                      of culvert analyses).

7) Data Review   This option combines the two
   • Stage Discharge Work Deck   previous options; both stage
   • Stage Storage Work Deck   discharge & storage curves with
   • Flow Distribution Work Deck   flow distribution.

8) Dynamic Flow Design or Review with This combination designs or
   Flow Distribution   reviews a culvert with upstream
   • Stage Discharge Work Deck   storage and routes a hydrograph
   • Stage Storage Work Deck   through the culvert. A flow
   • Culvert Work Deck   distribution is done on the
   • Flow Distribution Work Deck   downstream channel.

9) Steady State Design or Review with This combination designs or
   Flow Distribution   reviews a culvert with steady
   • Stage Discharge Work Deck   state (peak) flow. A flow
   • Culvert Work Deck   distribution is done on the
   • Flow Distribution Work Deck   downstream channel.

     A final program option allows for the design or review of more than one
culvert. This may be accomplished by first creating a stage discharge work
deck, then a stage storage work deck, then several culvert decks. In this
manner, it becomes clear that once the stage discharge and stage storage work
deck have been created for a site, a virtually unlimited number of culvert
configurations can be analyzed; even within a single job.

     The following section describes how input of data to these decks is
achieved through the use of the CDS Input Program.

The CDS Input Program

     Data is entered into the four CDS work decks by using the CDS Input
Program. This program was written for the Pooled Fund Project to provide user
friendly, interactive assistance for entering data and managing work decks.
The program was written in the C language. The integrated computerized
drainage design system, of which CDS 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 CDS Input Program by leading the user through an example
problem.

Example Problem: Perform a culvert analysis for a 634 foot section of a
secondary road, Twin Bridges Road, crossing over the Glade in Reston, Virginia.
A dynamic (hydrograph) flow condition, representing a 10-year storm event will

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be routed through the culvert. This roadway was the subject of an FHWA report on risk analysis in box culverts and provided the physical data.[8]

Basin Characteristics:

Long, narrow drainage area consisting of residential (40%) and wooded (60%) land uses.

Area: 830 acres	Channel Slope: 0.0143 ft/ft
Length: 16,250 feet	Width: 2,000 feet

Manning's n: 0.03 for natural watercourses, 0.05 for banks

Culvert and Roadway Characteristics:

Roadway width: 54 feet   Roadway length: 634 feet

Culvert location: at station 15+86.4
          type: Concrete box (with Manning's ≈ 0.012)
         inlet: 1 : 1 top bevel headwall (k_e = 0.2)
         slope: 0.010 ft/ft
        length: 54 feet (width of roadway)

Hydrograph Information:

Triangular Hydrograph with a Peak Flow of 1,193.00 ft^3/s (10-year storm).

time (min)	flow (ft^3/s)	time (min)	flow (ft^3/s)
0	0.00	180	903.79
30	298.25	210	723.03
60	596.50	240	542.27
90	894.75	270	361.52
120	1,193.00	300	180.76
150	1,084.55	318	0.00

Upstream Cross-Sectional Representation of Channel (not to scale):

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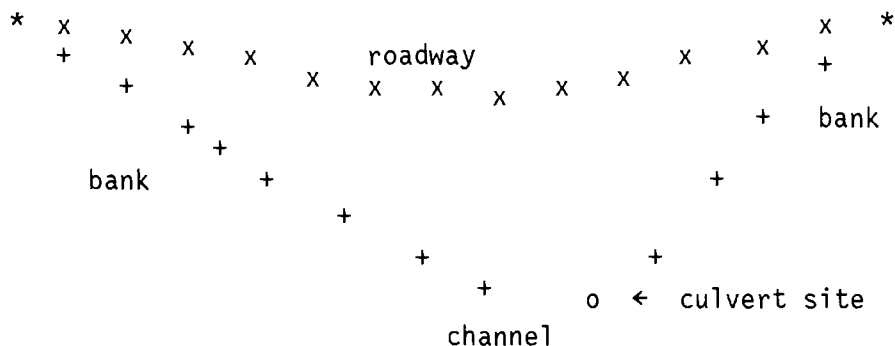
Cross-Sectional Coordinates:

Station	Upstream Channel Elevation	Downstream Channel Elevation	Roadway Elevation	Manning's Roughness
11 + 50	344.25	343.70	344.25	
12 + 00	337.50	336.95	341.25	
12 + 50	328.50	327.95	338.25	
13 + 00	317.90	317.35	335.25	
13 + 50	306.00	305.45	332.25	
14 + 00	294.00	293.45	329.35	
14 + 50	282.50	281.95	327.15	0.05
15 + 00	272.00	271.45	325.75	
15 + 50	272.40	271.85	325.15	
15 + 86.38	273.00	273.95	325.22	
16 + 00	274.50	280.45	325.35	0.03
16 + 50	281.00	295.70	326.25	
17 + 00	296.25	295.70	326.18	
17 + 50	315.00	314.45	328.18	
17 + 84	328.86	328.31	328.86	0.05

The object of the exercise will be to enter the CDS Input Program and create a combination of work decks described in configuration 3 in table 2. These work decks will be a stage discharge work deck, a stage storage work deck (as we will be considering storage, and will be routing a hydrograph through the culvert), and a culvert work deck.

Entering the CDS Input Program

The first step in entering into the CDS input program is to type **HYDRAIN** and strike <u>Enter</u> or <u>Carriage Return</u>, denoted by <CR>. Two preliminary screens provide the user with information on the sponsors of the Hydrain software. After these screens, the user reaches the <u>Hydrain Primary Menu</u>. This menu is represented in figure 5. The primary menu allows the user to access the programs in the Pooled Fund Project. Select the CDS program option either by moving to the <u>CDS</u> option with the cursor and striking <CR>, or by simply typing **C**. By choosing this option, the user moves into the culvert design and review section of the Pooled Fund Project.

```
┌─────────────────────────────────────────────────────────────────────────┐
│┌───────────────────────────────────────────────────────────────────────┐│
││ HYDRAIN - DRAINAGE DESIGN SYSTEM → PRIMARY MENU                        ││
│├───────────────────────────────────────────────────────────────────────┤│
││┌─────────────────────────────────────────────────────────────────────┐││
│││                                                                     │││
││└─────────────────────────────────────────────────────────────────────┘││
││                                                                        ││
││  HYDRO   CDS   PFP-HYDRA   WSPRO   HY8   DOS   FILES   INFO PFP   QUIT  ││
││                                                                        ││
││  Access Culvert Design System (CDS) Program                           ││
││                                                                        ││
││                                                                        ││
││                                                                        ││
││                                                                        ││
││                                                                        ││
││                                                                        ││
││                                                                        ││
││                                                                        ││
││                                                                        ││
││                                                                        ││
│├───────────────────────────────────────────────────────────────────────┤│
││                    F6-MENU   F10-HELP                                  ││
│└───────────────────────────────────────────────────────────────────────┘│
└─────────────────────────────────────────────────────────────────────────┘
```

Figure 5. Hydrain primary menu.

For assistance at <u>any time</u> within the Hydrain programs, the user can take advantage of active short helps, or, by striking <F10>, enter into long help. In the CDS Input Program, this long help will not only give information about a specified field, but will give advice on how to progress most efficiently through the program.

The next screen that the user will encounter is the job option menu. This is the menu that the user will employ to create or edit a CDS input data set and work decks as well as execute the actual CDS analytical program. A screen illustrating the job option menu is shown in figure 6. To begin entering data,

select the **Input / Edit Data File** option, by either striking **I** or moving the cursor to this entry through use of the cursor keys and striking <CR>.

```
┌─────────────────────────────────────────────────────────────────────┐
│ HYDRAIN - DRAINAGE DESIGN SYSTEM → CDS PROGRAM                        │
├─────────────────────────────────────────────────────────────────────┤
│ Access Culvert Design System (CDS) Program                           │
│ Job Option Menu -- Select job option choice from list                │
├─────────────────────────────────────────────────────────────────────┤
│                                                                       │
│                                                                       │
│                                                                       │
│                       Input / Edit Data File                          │
│                       Run Program / Review File                       │
│                                                                       │
│                       Quit (return to primary menu)                   │
│                                                                       │
│                                                                       │
│                                                                       │
│ Create or edit data for analysis program                             │
│                                                                       │
├─────────────────────────────────────────────────────────────────────┤
│                       F6-MENU   F10-HELP                              │
└─────────────────────────────────────────────────────────────────────┘
```

Figure 6. Job option menu.

The user will be creating three work decks for this example; stage discharge, stage storage, and culvert design and review. To differentiate between these work decks (and the flow distribution work deck), the following file extension convention was adopted:

.SD =   **STAGE DISCHARGE** - This deck contains the headwater stage discharge or downstream channel cross-section tables.

.SS =   **STAGE STORAGE** - This deck contains table of stage versus storage or a table describing the upstream cross section.

.CD =   **CULVERT DESIGN** - This deck contains data to select culvert types and characteristics, and peak flows. The user can also determine whether to review an existing culvert or to design a culvert.

.FD =   **FLOW DISTRIBUTION** - This deck is included to obtain the flow-distribution for a channel.

The actual input file submitted to the CDS analysis program uses a .CDS extension. To help further differentiate the files used in the example, a descriptive filename "prefix" (or node) is selected by the user. The name chosen for this example is a reference to the site being analyzed. Therefore, the four data files that will be produced in this example are:

GLADE.SD - stage discharge work deck
GLADE.SS - stage storage work deck
GLADE.CD - culvert design and review work deck

When the data files are combined, they must be in the same order as shown above and in table 2. Therefore it is good practice (and illustrative for the example) to create them in that order.   The file that will result when the files are combined is:

GLADE.CDS - CDS Input File.

After the user has selected the Input/Edit Data File option, they will be, as shown in figure 7, prompted for a filename.

```
HYDRAIN - DRAINAGE DESIGN SYSTEM → CDS PROGRAM

Access Culvert Design System (CDS) Program
Type file name (wildcard character ? or * will invoke file menu)

        Data File Name   - C:\HDN\CDS\*.*_____




                   F5-CLEAR-F   F6-MENU   F10-HELP
```

Figure 7. Filename prompt.

Three alternatives can be selected:

1)   Simply type in **GLADE.SD** and strike <CR>. This will take the user into
      the CDS Input Program, where stage discharge data is entered. (This
      option will occur only if one of the four valid work deck extensions is
      appended to the filename.)

2)   Type in **GLADE** and strike <CR>. This will take the user into the CDS
      Input Program where the user selects the desired work option.

3)   Strike <CR> without entering a filename. This will take the user to the
      Hydrain Data Manager Program, which displays a list of existing CDS work
      decks (see the Hydrain System Shell documentation for more details on
      this option). The user selects an appropriate file and enters the CDS
      Input Program.

      In the case of the example, select the second alternative by entering
GLADE at the prompt and striking <CR>. After a few seconds, the program will
enter the CDS Input program shown below in figure 8.

WORK Deck: CULVERT DESIGN SYSTEM   Rev 710.A

```
 ┌──────────────────────┐
 │ Edit Indicated Work Deck │
 │ Select Another Work Deck │
 │ Combine Decks into File  │
 │ Return to System Shell   │
 └──────────────────────┘
►┌──────────────────────┐
 │ Stage Discharge Deck     │
 │ Stage Storage Deck       │
 │ Culvert Design and Review │
 │ Flow-Distribution        │
 └──────────────────────┘
```


Enter / edit stage-discharge deck data
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

Figure 8. The CDS input program.

The user has entered the CDS Input Program. Note that the first screen has underlined (or highlighted) the **Select Another Work Deck** option and the user is in the second screen. In the program, the user can tell which screen is active by the presence of a small character "▸" pointing to the top left corner of the screen. Note the one line of "active" short help near the bottom left of the screen. Also, at any time within the Input Program, strike <F10> for more specific "long" help. As mentioned earlier, the example will first enter data into the stage discharge work deck. Position the cursor at **Stage Discharge Deck** field using the cursor or <F2> keys and strike <CR> or <F4>.

The user will encounter the third screen (New deck / Existing Deck), shown in figure 9 below. Since a new work deck is going to be created, the user should select the **New Deck** option and strike <CR> or <F4>.

WORK Deck: CULVERT DESIGN SYSTEM   Rev 710.A

```
 ┌─────────────────────────┐
 │Edit Indicated Work Deck │
 │Select Another Work Deck │
 │Combine Decks into File  │
 │Return to System Shell   │
 └─────────────────────────┘
```

```
 ┌──────────────────────────┐
 │Stage Discharge Deck      │
 │Stage Storage Deck        │
 │Culvert Design and Review │
 │Flow-Distribution         │
 └──────────────────────────┘
```

```
▸┌──────────────┐
 │New Deck      │
 │Existing Deck │
 └──────────────┘
```

Enter new deck (do not add file extension - program will add it)
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

Figure 9. The new deck / existing deck screen.

The **Existing Deck** option would be selected if there were stage discharge work decks already existing, and the user wished to edit the data. In that case, a small screen showing the existing files would appear and the user could select a file to edit (without leaving the program).

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At the **New Deck** prompt, enter the name **GLADE** <u>without any extensions</u> (they will be added by the program). Figure 10 illustrates this screen. Strike <CR> or <F4> to continue.

WORK Deck: CULVERT DESIGN SYSTEM   Rev 710.A

```
┌─────────────────────────┐          New Deck
│Edit Indicated Work Deck │
│Select Another Work Deck │      ┌───────────────────────┐
│Combine Decks into File  │      │glade                  │
│Return to System Shell   │      └───────────────────────┘
└─────────────────────────┘

┌─────────────────────────┐
│Stage Discharge Deck     │
│Stage Storage Deck       │
│Culvert Design and Review│
│Flow-Distribution        │
└─────────────────────────┘
```


Enter new deck (do not add file extension - program will add it)
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

Figure 10. New deck prompt.

Note that the work deck filename **GLADE.SD** will appear in the upper left hand corner of the screen. The current work deck is <u>always</u> displayed in this position.

Since the user specified a stage discharge work deck, as seen below in figure 11, the program goes directly to the program control card field for stage discharge.

WORK Deck: glade.SD   CULVERT DESIGN SYSTEM   Rev 710.A

```
┌──────────────────────────┐
│Edit Indicated Work Deck  │
│Select Another Work Deck  │
│Combine Decks into File   │
│Return to System Shell    │
└──────────────────────────┘

  ┌──────────────────────────┐
  │Stage Discharge Deck      │
  │Stage Storage Deck        │
  │Culvert Design and Review │
  │Flow-Distribution         │
  └──────────────────────────┘

►
  ┌──────────────────────────────┐
  │Program Control Card          │
  │Tailwater Rating Curve Table  │
  │Cross Section Coordinate Card │
  └──────────────────────────────┘
```

Directs CDS to execute stage-discharge program segment
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

Figure 11. Program control card field.

The user is placed in the third screen (notice the ► character) on the first field - **Program Control Card**. This is always the first option to be selected in any work deck option. Strike <CR> or <F4> to continue.

The other two fields in this screen (**Tailwater Rating Curve Table**, and **Cross Section Coordinate Card**) would only be selected if the user is editing an existing work deck. By selecting the **Program Control Card** option, the program will automatically consider these two options.

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The user must determine whether or not they desire output that will echo all the information in the stage discharge deck, as well as any calculated values. The screen is shown in figure 12. Depending on the data, this output can be quite lengthy and if the user already knows that it is valid, it may be advisable to ignore it. Selecting **Yes** will echo the data, **No** will not. For this example, select Yes, and strike <CR> or <F4> to continue.

Work Deck: GLADE.SD   CULVERT DESIGN SYSTEM   Rev 710.A

```
┌──────────────────────┐       ►┌──────────────────────┐
│ Edit Indicated Work Deck│     │ Printed          YES │
│ Select Another Work Deck│     │ Listing          NO  │
│ Combine Decks into File │     └──────────────────────┘
│ Return to System Shell  │
└──────────────────────┘

┌──────────────────────────┐
│ Stage Discharge Deck     │
│ Stage Storage Deck       │
│ Culvert Design and Review│
│ Flow-Distribution        │
└──────────────────────────┘

┌──────────────────────────────┐
│ Program Control Card         │
│ Tailwater Rating Curve Table │
│ Cross Section Coordinate Card│
└──────────────────────────────┘
```

Listings will be printed
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

Figure 12. Printed listing screen.

The user may now select profile data input format. The information given in this example develops a stage discharge curve using the downstream cross sectional profile (that we obtained earlier from the Glade report). This is shown in figure 13 below. Move the cursor to the **Cross-Section Data** option and strike <CR> or <F4> to continue.

Work Deck: GLADE.SD   CULVERT DESIGN SYSTEM   Rev 710.A

```
┌─────────────────────────┐
│ Edit Indicated Work Deck│        ┌────────────────────┐  ▶ ┌────────────────────┐
│ Select Another Work Deck│        │ Printed      YES   │    │ Stage-Discharge Table│
│ Combine Decks into File │        │ Listing      NO    │    │ Cross-Section Data  │
│ Return to System Shell  │        └────────────────────┘    └────────────────────┘
└─────────────────────────┘

┌─────────────────────────┐
│ Stage Discharge Deck    │
│ Stage Storage Deck      │
│ Culvert Design and Review│
│ Flow-Distribution       │
└─────────────────────────┘

┌─────────────────────────┐
│ Program Control Card    │
│ Tailwater Rating Curve Table│
│ Cross-Section Coordinate Card│
└─────────────────────────┘
```

Enter downstream cross sectional coordinates
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

Figure 13. Stage discharge / cross-section screen.

If the user already has created a tailwater rating curve, they may wish to use the other option (**Stage Discharge Table**).

Finally, the user may start entering data pertinent to this example. As illustrated in figure 14, the data to be entered is the natural channel slope. For more information on what this field indicates, strike <F10>. Enter the appropriate value (0.0143 for the example), in feet per feet and strike <F4> or <CR> to continue.

```
Work Deck: GLADE.SD          CULVERT DESIGN SYSTEM                    Rev 710.A
 ┌─────────────────────────┐
 │Edit Indicated Work Deck │      ┌──────────────────┐   ┌──────────────────────┐
 │Select Another Work Deck │      │Printed      YES  │   │Stage-Discharge Table │
 │Combine Decks into File  │      │Listing      NO   │   │Cross-Section Data    │
 │Return to System Shell   │      └──────────────────┘   └──────────────────────┘
 └─────────────────────────┘
                                          ┌──────────────────────┐
 ┌─────────────────────────┐              │Natural Channel Slope │
 │Stage Discharge Deck     │              │        FT/FT         │
 │Stage Storage Deck       │              │        0.0143        │
 │Culvert Design and Review│              └──────────────────────┘
 │Flow-Distribution        │
 └─────────────────────────┘


 ┌─────────────────────────────┐
 │Program Control Card         │
 │Tailwater Rating Curve Table │
 │Cross-Section Coordinate Card│
 └─────────────────────────────┘




Enter natural channel slope (in ft/ft)                                       I
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP
```

Figure 14. Downstream slope screen.

Two interesting events have occurred; first when we previously choose the **Cross-Section Data** option and struck <CR>, this was reflected by the program by moving the cursor in the third screen from the **Program Control Card** field to the **Cross-Section Coordinate Card** field.

The second event is that the screen marker character, ►, is no longer visible. This is because the user is in a screen where data is entered. The CDS Input Program will display an I (for Input) in the lower right hand corner whenever data entry is called for.

The next input requested are the actual downstream cross section X and Y coordinates and the Manning's n associated with the channel, shown in figure 15 below. Input the appropriate values either row-wise, striking <F2> or <CR> after each value, or column-wise, using the up and down arrow keys and <CR> to change columns. Manning's number is input at the last coordinate before that value would change (use <F10> for more information). When all of the data is in, strike <F6>. This will save the data in **GLADE.SD** and return the user to the first screen in the CDS programming sequence.

Work Deck: GLADE.SD   CULVERT DESIGN SYSTEM   Rev 710.A

| Edit Indicated Work Deck |
| Select Another Work Deck |
| Combine Decks into File |
| Return to System Shell |

| Printed | YES | | Stage-Discharge Table |
| Listing | NO | | Cross-Section Data |

| Stage Discharge Deck |
| Stage Storage Deck |
| Culvert Design and Review |
| Flow-Distribution |

| Program Control Card |
| Tailwater Rating Curve Table |
| Cross-Section Coordinate Card |

| ----- Coordinates ----- | | Manning's |
X	Y	n
1150	343.70	
1200	336.95	
1250	327.95	
1300	317.35	
1350	305.45	
1400	293.45	
1450	281.95	0.05
1500	271.45	
1550	271.85	
1586.38	272.45	
1600	273.95	0.03

Enter X coordinate of channel section(in feet)   I
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

Figure 15. Cross-section coordinate screen.

Note that the coordinates scroll as the screen "fills up". The program will accept up to 50 sets of coordinates. Another point to remember, input Manning's n, in this case, 0.05, as the final entry.

The user now wishes to create a stage storage deck. This is done by returning to the file management screen. Move the cursor to the **Select Another Work Deck** option with either the cursor keys or <F2>. Strike <F4> or <CR> to continue.

WORK Deck: CULVERT DESIGN SYSTEM   Rev 710.A

```
┌─────────────────────────┐
│ Edit Indicated Work Deck│
│ Select Another Work Deck│
│ Combine Decks into File │
│ Return to System Shell  │
└─────────────────────────┘
▶
 ┌─────────────────────────┐
 │ Stage Discharge Deck    │
 │ Stage Storage Deck      │
 │ Culvert Design and Review│
 │ Flow-Distribution       │
 └─────────────────────────┘
```

Enter / edit stage storage deck data
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

Figure 16.   CDS input program screen.

    As seen in figure 16. the user is in the same CDS Input Program screen that they began in. This time, choose the **Stage Storage Deck** using either the cursor keys or <F2>. Strike <F4> or <CR> to continue.

Once again, the program will ask whether a new file will be created or an existing file will be edited. Select the **New File** option and strike <F4> or <CR> to continue.

The system will ask for a filename for the new deck. Once again enter **GLADE**. The extension will automatically be added by the system. Strike <CR> or <F4> to begin entering stage storage data.

Notice that the indicated work deck in the top left corner has now changed to **GLADE.SS**. The system has returned to the first screen, and then will quickly "move" to the stage storage program control screen seen below in figure 17.

As with the case with the stage discharge option, the first option in the Stage Storage Deck is the **Program Control Card**. This is seen below in figure 17. Select this option and strike <f4> or <CR> to continue.

```
WORK Deck: glade.SS          CULVERT DESIGN SYSTEM                    Rev 710.A

  ┌───────────────────────────┐
  │ Edit Indicated Work Deck  │
  │ Select Another Work Deck  │
  │ Combine Decks into File   │
  │ Return to System Shell    │
  └───────────────────────────┘

    ┌─────────────────────────────┐
    │ Stage Discharge Deck        │
    │ Stage Storage Deck          │
    │ Culvert Design and Review   │
    │ Flow-Distribution           │
    └─────────────────────────────┘

  ▶ ┌─────────────────────────────┐
    │ Program Control Card        │
    │ Cross-Section Coordinate Card│
    │ Upstream Stage Storage Table│
    └─────────────────────────────┘
```

Directs CDS to execute stage-storage program segment
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

Figure 17. Stage storage program control screen.

As can be seen in figure 18, once again print options are displayed. As
before in stage discharge, the user has the option to receive a printed copy of
Stage Storage input or to forego the printed copy. Select **Yes** and strike <CR>
or <F4> to continue.

WORK Deck: glade.SS   CULVERT DESIGN SYSTEM   Rev 710.A

```
┌────────────────────────┐        ►┌──────────────────────┐
│Edit Indicated Work Deck│         │Printed          YES  │
│Select Another Work Deck│         │Listing          NO   │
│Combine Decks into File │         └──────────────────────┘
│Return to System Shell  │
└────────────────────────┘

┌────────────────────────┐
│Stage Discharge Deck    │
│Stage Storage Deck      │
│Culvert Design and Review│
│Flow-Distribution       │
└────────────────────────┘


┌──────────────────────────┐
│Program Control Card      │
│Cross Section Coordinate Card│
│Upstream Stage Storage Table│
└──────────────────────────┘
```


Listings will be printed
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

Figure 18. Print options for stage storage.

The next set of options, displayed below in figure 19, allow the user to select the format for data input. Since the example uses the upstream Cross Sectional profile to determine the storage, choose the Cross Section option and strike <F4> or <CR> to continue.

WORK Deck: glade.SS   CULVERT DESIGN SYSTEM   Rev 710.A

```
Edit Indicated Work Deck
Select Another Work Deck          Printed       YES   ▸  Cross-Section Data
Combine Decks into File           Listing       NO       Stage-Storage Table
Return to System Shell

Stage Discharge Deck
Stage Storage Deck
Culvert Design and Review
Flow-Distribution

Program Control Card
Cross-Section Coordinate Card
Upstream Stage Storage Table
```

Enter upstream cross-section data
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

Figure 19. Cross section versus stage storage table screen.

Note that in a similar manner to what occurred in the stage discharge option, when the Cross-Section Data was selected, the cursor line in the Program Control Card screen automatically moved to Cross-Section Coordinate Card Field. The user is automatically led through the appropriate decisions.

At this point, input for this particular problem are entered. The first entry is the natural channel slope in ft/ft. This is illustrated in figure 20.

WORK Deck: glade.SS   CULVERT DESIGN SYSTEM   Rev 710.A

```
┌─────────────────────────┐
│Edit Indicated Work Deck │
│Select Another Work Deck │
│Combine Decks into File  │
│Return to System Shell   │
└─────────────────────────┘
```

```
┌──────────────────┐   ┌─────────────────────┐
│Printed      YES  │   │Cross-Section Data   │
│Listing      NO   │   │Stage-Storage Table  │
└──────────────────┘   └─────────────────────┘
```

```
┌──────────────────────┐
│Natural Channel Slope │
│       FT/FT          │
│       0.0143         │
└──────────────────────┘
```

```
┌──────────────────────────┐
│Stage Discharge Deck      │
│Stage Storage Deck        │
│Culvert Design and Review │
│Flow-Distribution         │
└──────────────────────────┘
```

```
┌──────────────────────────────┐
│Program Control Card          │
│Cross-Section Coordinate Card │
│Upstream Stage Storage Table  │
└──────────────────────────────┘
```

Enter channel slope (in ft/ft) upstream from culvert site   I
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

Figure 20. Upstream natural channel slope.

    In the example, the upstream and downstream channel slopes are assumed to be equal. The user can enter different values for these slopes.

As demonstrated in figure 21, the next required data are the culvert offset (in feet) and the X-Y coordinates of the upstream section. Enter an offset of zero (because we will assume that the cross-section data is at the culvert inlet). When the final coordinate has been entered strike <F6> to save this information in **GLADE.SS** and to leave this section.

WORK Deck: glade.SS   CULVERT DESIGN SYSTEM   Rev 710.A

```
┌─────────────────────────┐
│Edit Indicated Work Deck │
│Select Another Work Deck │       ┌──────────────────┐   ┌──────────────────────┐
│Combine Decks into File  │       │Printed      YES  │   │Cross-Section Data    │
│Return to System Shell   │       │Listing      NO   │   │Stage-Storage Table   │
└─────────────────────────┘       └──────────────────┘   └──────────────────────┘

┌─────────────────────────┐                    ┌────────────────────────────────┐
│Stage Discharge Deck     │                    │CROSS SECTION At         0.0    │
│Stage Storage Deck       │                    │  ----- Coordinates -----       │
│Culvert Design and Review│                    │     X                   Y      │
│Flow-Distribution        │                    │     1150             344.25    │
└─────────────────────────┘                    │     1200             337.50    │
                                               │     1250             328.50    │
                                               │     1300             317.90    │
┌─────────────────────────┐                    │     1350             306.00    │
│Program Control Card     │                    │     1400             294.00    │
│Cross-Section Coordinate Card│                │     1450             282.50    │
│Upstream Stage Storage Table│                 │     1500             272.00    │
└─────────────────────────┘                    │     1550             272.40    │
                                               │  1586.38            273.00    │
                                               │     1600             274.50    │
                                               └────────────────────────────────┘
```

Enter Y coordinate of upstream cross section (in feet)   I
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

Figure 21. Upstream cross-section data.

Select a new work deck, **Culvert Design and Review,** in the same manner as previously described in the sequences on page 36 and page 37.

In this case, the user will select a culvert work deck instead of a stage storage work deck. Use the filename **GLADE** at the new deck prompt as the name of the example work deck for culvert design or review.

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The Culvert Design and Review section is a little more involved than the
two previous decks. Several options are available with many selections for
each option, as shown below in the initial screen as figure 22. The first
step, as with the previous decks, is to start with the "Program Control Card".
Strike <F4> or <CR> to continue.

WORK Deck: glade.CD   CULVERT DESIGN SYSTEM   Rev 710.A

```
┌─────────────────────┐
│Edit Indicated Work Deck│
│Select Another Work Deck│
│Combine Decks into File │
│Return to System Shell  │
└─────────────────────┘

┌─────────────────────┐
│Stage Discharge Deck  │
│Stage Storage Deck    │
│Culvert Design and Review │
│Flow-Distribution     │
└─────────────────────┘

►┌─────────────────────┐
 │Program control       │
 │Culvert Type          │
 │Work Options          │
 │Flow Data             │
 │Input Hydrograph      │
 └─────────────────────┘
```


Directs CDS to execute culvert design & review program segment
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

Figure 22. Initial culvert design and review screen.

In the case below (figure 23), the print options are more sophisticated. See the long help <F10> for a specific explanation of what these options mean. One hint, since the example considers a dynamic (hydrograph) flow scenario, select **Flood Routing Output** so that inflow and outflow hydrograph data can be seen.

WORK Deck: glade.CD   CULVERT DESIGN SYSTEM   Rev 710.A

```
┌──────────────────────────┐
│ Edit Indicated Work Deck │              PRINTOUT OPTIONS
│ Select Another Work Deck │      ▶ ┌──────────────────────────────────┐
│ Combine Decks into File  │        │ No culvert output                │
│ Return to System Shell   │        │ Maximum headwater output only    │
└──────────────────────────┘        │ Flood routing output             │
                                     └──────────────────────────────────┘
┌──────────────────────────┐
│ Stage Discharge Deck     │
│ Stage Storage Deck       │
│ Culvert Design and Review│
│ Flow-Distribution        │
└──────────────────────────┘


┌──────────────────────────┐
│ Program control          │
│ Culvert Type             │
│ Work Options             │
│ Flow Data                │
│ Input Hydrograph         │
└──────────────────────────┘
```

Printout of all culvert data
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

Figure 23. Culvert design or review print options.

Figure 24 shows specific culvert information to be entered. The values are from the example data developed above. Strike <CR> or <F2> after each entry and <F4> at the end of the input. This may initially seem awkward, but makes sense if the user considers that within a screen where the user is entering data (as opposed to simply making a choice) the definition of <CR> or <F2> is simply "go to next field in the screen" and <F4> means "go to the next screen". For example, if the user presses <CR> after entering data into the **Culvert Slope** field, the CDS Input Program interprets this as meaning "go to the next field in this screen, that is, back to **Culvert Site**". Hopefully, it becomes clear that to move to the next screen, the Next Screen key, or <F4> must be pressed.

WORK Deck: glade.CD   CULVERT DESIGN SYSTEM   Rev 710.A

```
┌─────────────────────────┐              PRINTOUT OPTIONS
│ Edit Indicated Work Deck │
│ Select Another Work Deck │        ┌──────────────────────────────────┐
│ Combine Decks into File  │        │ No culvert output                │
│ Return to System Shell   │        │ Maximum headwater output only    │
└─────────────────────────┘         │ Flood routing output             │
                                     └──────────────────────────────────┘
┌──────────────────────────────┐
│ Stage Discharge Deck         │
│ Stage Storage Deck           │     ┌──────────────────────────────────────┐
│ Culvert Design and Review    │     │ CULVERT INFORMATION                    │
│ Flow-Distribution            │     │ Culvert        Culvert       Culvert   │
└──────────────────────────────┘     │  Site          Length        Slope     │
                                      │ (feet)         (feet)      (feet/feet) │
┌──────────────────────────┐         │   1586.38        54.0         0.010     │
│ Program control          │         └──────────────────────────────────────┘
│ Culvert Type             │
│ Work Options             │
│ Flow Data                │
│ Input Hydrograph         │
└──────────────────────────┘
```

Enter slope of culvert (in ft/ft)   I
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

                       Figure 24. Culvert information screen.

        Notice that the I in the lower right hand corner is telling the user that this is a data input screen. As before, the ► character will disappear when a input screen appears.

Striking <F4> has placed the user back to the initial culvert design and
review screen (figure 25). The next input required is the culvert type.
Select this option and strike <F4> or <CR> to continue. Notice that in this
case, since the user is making a decision (as opposed to entering data), <CR>
will mean "go to Next Screen".

WORK Deck: glade.CD   CULVERT DESIGN SYSTEM   Rev 710.A

```
┌─────────────────────┐
│Edit Indicated Work Deck│
│Select Another Work Deck│
│Combine Decks into File │
│Return to System Shell  │
└─────────────────────┘

┌─────────────────────────┐
│Stage Discharge Deck     │
│Stage Storage Deck       │
│Culvert Design and Review│
│Flow-Distribution        │
└─────────────────────────┘

►┌──────────────────────┐
 │Program control       │
 │Culvert Type          │
 │Work Options          │
 │Flow Data             │
 │Input Hydrograph      │
 └──────────────────────┘
```

Select a Culvert Type for the analysis
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

Figure 25. Culvert type selection.

As portrayed in figure 26, the user is given a choice of six general types of culverts. Use the long help <F10> to get more information on each culvert type. A culvert can be selected by using either the cursor arrows or <F2>. Strike <F4> or <CR> to continue. For the example, choose **Concrete Box (RCB)**.

WORK Deck: glade.CD   CULVERT DESIGN SYSTEM   Rev 710.A

```
┌─────────────────────────┐
│Edit Indicated Work Deck │
│Select Another Work Deck │
│Combine Decks into File  │
│Return to System Shell   │
└─────────────────────────┘

 ┌─────────────────────────┐
 │Stage Discharge Deck     │
 │Stage Storage Deck       │
 │Culvert Design and Review│
 │Flow-Distribution        │
 └─────────────────────────┘

►┌──────────────────────────────┐
 │Circular Concrete Culvert (RCP)│
 │Circular Metal Pipe (CMP)     │
 │Elliptical Concrete Pipe (ECP)│
 │Corrugated Metal Pipe Arch (CMPA)│
 │Concrete Pipe Arch (RCPA)     │
 │Concrete Box (RCB)            │
 └──────────────────────────────┘
```

Design or review a concrete box culvert
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

Figure 26. Culvert type screen.

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Figure 27 reveals several inlet conditions for a box culvert that the user can consider when reviewing or designing a culvert. The long help will provide more information on each of the inlet options.

The opening type for the example is a Headwall with a 1:1 top bevel angle and a entrance loss (Ke) of 0.2. Move the cursor to this option and press <F4> or <CR> to continue.

WORK Deck: glade.CD   CULVERT DESIGN SYSTEM   Rev 710.A

```
┌─────────────────────────┐          BOX CULVERT INLET MENU
│Edit Indicated Work Deck │             Inlet Type            Ke
│Select Another Work Deck │       ▶ ┌────────────────────────────────┐
│Combine Decks into File  │         │Wingwalls 30 to 75 deg.    0.4  │
│Return to System Shell   │         │Wingwalls 90 and 15 deg.   0.5  │
└─────────────────────────┘         │Wingwalls parallel         0.7  │
                                    │Wingwalls 30 to 75 deg.    0.2  │
┌─────────────────────────┐         │Headwalls Square top edge  0.5  │
│Stage Discharge Deck     │         │Headwalls 1:1 top bevel    0.2  │
│Stage Storage Deck       │         │Headwalls 1.5:1 top bevel  0.2  │
│Culvert Design and Review│         └────────────────────────────────┘
│Flow-Distribution        │
└─────────────────────────┘

┌─────────────────────────────┐
│Circular Concrete Culvert (RCP)│
│Circular Metal Pipe (CMP)    │
│Elliptical Concrete Pipe (ECP)│
│Corrugated Metal Pipe Arch (CMPA)│
│Concrete Pipe Arch (RCPA)    │
│Concrete Box (RCB)           │
└─────────────────────────────┘
```

Inlet type is 1:1 top bevel headwall / loss is 0.2
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

Figure 27. Box culvert inlet types.

After selecting the culvert information, the user is back in the initial culvert design and review screen. Select the **Work Option** selection. Strike <F4> or <CR> to continue. As revealed in figure 28, four Design/Review options are displayed. Each option corresponds to a specific analysis type and flow scenario. Since the goal of the example is to design a culvert for the Glade, considering hydrographic flow and storage, select the **Design Culvert with Dynamic Flow** option. Strike <F4> or <CR> to continue.

WORK Deck: glade.CD   CULVERT DESIGN SYSTEM   Rev 710.A

```
Edit Indicated Work Deck                    WORK OPTIONS
Select Another Work Deck    ▶
Combine Decks into File        Design culvert with steady-state flow
Return to System Shell         Review culvert with steady-state flow
                               Design culvert with dynamic flow
                               Review culvert with dynamic flow

Stage Discharge Deck
Stage Storage Deck
Culvert Design and Review
Flow-Distribution


Program control
Culvert Type
Work Options
Flow Data
Input Hydrograph
```

Design culvert system for drainage crossing (dynamic flow)
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

Figure 28.   Design / review and flow type screen.

```
┌─────────────────────────┐
│ Edit Indicated Work Deck│              WORK OPTIONS
│ Select Another Work Deck│
│ Combine Decks into File │    ┌──────────────────────────────────────┐
│ Return to System Shell  │    │ Design culvert with steady-state flow│
└─────────────────────────┘    │ Review culvert with steady-state flow│
                               │ Design culvert with dynamic flow     │
┌─────────────────────────┐    │ Review culvert with dynamic flow     │
│ Stage Discharge Deck    │    └──────────────────────────────────────┘
│ Stage Storage Deck      │
│ Culvert Design and Review│   ┌──────────────────────────────────────────┐
│ Flow-Distribution       │   │   Maximum      Greatest         Time       │
└─────────────────────────┘   │   Headwater   Culvert Height  Increment    │
                              │    (feet)       (feet)         (min)       │
                              │     25.0          10.0          30.0       │
┌─────────────────────────┐   │                                            │
│ Program control         │   │    Input     Maximum Pond      Maximum     │
│ Culvert Type            │   │  Hydrograph     size          Hw/D Ratio   │
│ Work Options            │   │    (Y/N)       (acres)     (improved inlets)│
│ Flow Data               │   │      Y        _____        _____     │
│ Input Hydrograph        │   └──────────────────────────────────────────┘
└─────────────────────────┘
```

Enter the maximum headwater before overtopping (in feet)   I
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

Figure 29. Control information.

Enter the appropriate data. Notice that from the example data, we can
calculate the max headwater to be about 45 feet (the difference between the
roadway and upstream cross section coordinates). Since the user would probably
want some factor of safety, arbitrarily choose 25 feet instead. Select a
maximum culvert height of 10 feet (the maximum allowed for design in CDS).

The Input Hydrograph (Y/N) field may be confusing at first, but consider,
since a dynamic flow scenario has already been selected the user already has
made the decision to use a hydrograph. This field asks the question: "Is this
hydrograph going to be input by the user (the Yes response), or will CDS fit
some peak flow and volume with the internal, dimensionless hydrograph?" (the No
response). Since the example has site specific hydrograph values, the user
will be entering a hydrograph and therefore will answer Y.

The last two fields are optional. In this example, leave them blank and
strike <F4> to continue.

Since a **Y** was input for the hydrograph data, the system requires more data. First, will the hydrograph be a user supplied file or will it be entered using a keyboard? As depicted in figure 30, choose **User Keyboard Input** and press <CR> or <F4> to continue.

WORK Deck: glade.CD   CULVERT DESIGN SYSTEM   Rev 710.A

```
┌──────────────────────────┐         Hydrograph Input
│ Edit Indicated Work Deck │
│ Select Another Work Deck │    ▶ ┌────────────────────────┐
│ Combine Decks into File  │      │ User supplied files    │
│ Return to System Shell   │      │ User keyboard input    │
└──────────────────────────┘      └────────────────────────┘


┌──────────────────────────┐
│ Stage Discharge Deck     │
│ Stage Storage Deck       │
│ Culvert Design and Review│
│ Flow-Distribution        │
└──────────────────────────┘


┌──────────────────────────┐
│ Program control          │
│ Culvert Type             │
│ Work Options             │
│ Flow Data                │
│ Input Hydrograph         │
└──────────────────────────┘
```

Enter hydrograph data from keyboard (user supplied)
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

Figure 30. Hydrograph input screen.

Further input will be required in the form of Flow Data and Hydrograph data shown below in figure 31. Up to six hydrographs could be entered so that a performance curve could be developed. The first hydrograph will be used to design the culvert, and the other five will be routed through the designed culvert. See the long help for more details. After entering the flow data information strike <F4> to enter hydrograph data sections. After entering the flow data information strike <F4> to enter hydrograph data input screen.

WORK Deck: glade.CD   CULVERT DESIGN SYSTEM   Rev 710.A

```
┌──────────────────────────┐     ┌─────────────────────────────────────────────┐
│Edit Indicated Work Deck  │     │              FLOW DATA                        │
│Select Another Work Deck  │     │ Discharge       Volume        Frequency       │
│Combine Decks into File   │     │ (Qp) in cfs   (Vi) acre-feet   (years)        │
│Return to System Shell    │     │     1193          523             10          │
└──────────────────────────┘     │                                               │
                                 │                                               │
┌──────────────────────────┐     │                                               │
│Stage Discharge Deck      │     │                                               │
│Stage Storage Deck        │     │                                               │
│Culvert Design and Review │     │                                               │
│Flow-Distribution         │     └─────────────────────────────────────────────┘
└──────────────────────────┘

┌──────────────────────────┐
│Program control           │
│Culvert Type              │
│Work Options              │
│Flow Data                 │
│Input Hydrograph          │
└──────────────────────────┘
```

Enter peak discharge or irrigation water right (in CFS)   I
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

Figure 31. Flow data.

The user is in the Hydrograph Data screen, which is the last data entry screen (figure 32) that will be used when designing a culvert and considering only one design condition (the 10-year hydrograph). Enter the example hydrograph data.

When data entry is completed, strike <F6> to save the information and leave the culvert design and review section.

WORK Deck: glade.CD   CULVERT DESIGN SYSTEM   Rev 710.A

```
┌─────────────────────────┐      ┌──────────────────────────────────────────┐
│Edit Indicated Work Deck │      │              FLOW DATA                     │
│Select Another Work Deck │      │  Discharge        Volume       Frequency   │
│Combine Decks into File  │      │  (Qp) in cfs   (Vi) acre-feet   (years)    │
│Return to System Shell   │      │     1193            523             10      │
└─────────────────────────┘      │                                            │
                                 │                                            │
┌─────────────────────────┐      │                                            │
│Stage Discharge Deck     │      │                                            │
│Stage Storage Deck       │      │                                            │
│Culvert Design and Review│      │                                            │
│Flow-Distribution        │      └──────────────────────────────────────────┘
└─────────────────────────┘                  Hydrograph data

                                 ┌────────────────────────────┐
┌─────────────────────────┐      │   Time        Flow Rate    │
│Program control          │      │ (minutes)       (cfs)      │
│Culvert Type             │      │    210.0        723.03     │
│Work Options             │      │    240.0        542.27     │
│Flow Data                │      │    270.0        361.52     │
│Input Hydrograph         │      │    300.0        180.76     │
└─────────────────────────┘      │    318.0          0.0      │
                                 └────────────────────────────┘
```

Enter the hydrograph abscissa (x value) in minutes   I
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

Figure 32. Hydrograph data screen.

If the user had additional hydrograph data with which they wished to create a performance curve, they would press <CR> or <F4>, returning them to the second row of the flow data screen seen above in figure 31. They would enter additional peak discharge, volume, and frequency values and would be placed again into the hydrograph data screen. This procedure would be repeated until six hydrographs were entered. At that time, the user would strike <F6> to leave the culvert design or review section.

The user is ready to combine the three work decks just created into a single CDS input file that will be executed. Select the **Combine decks into file** option in the initial CDS input screen and strike <F4> or <CR> to continue.

The user will observe the screen depicted by figure 33 below. Remembering the order that the files must combined from table 2, select **Stage Discharge** first and strike <CR> or <F4>.

WORK Deck: CULVERT DESIGN SYSTEM   Rev 710.A

```
┌─────────────────────────┐
│Edit Indicated Work Deck │
│Select Another Work Deck │
│Combine Decks into File  │
│Return to System Shell   │
└─────────────────────────┘

┌───────────────────────────────┐
│Stage Discharge Deck           │
│Stage Storage Deck             │
│Culvert Design and Review      │
│Flow-Distribution              │
└───────────────────────────────┘
```

Select deck that will be placed into CDS input file
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

Figure 33. Work deck type screen.

If the user forgets the order that was depicted in table 2, remember that the long help keys are always available to provide information.

As illustrated in figure 34, choose the **Select from available decks**
option. Strike <CR> or <F4> to continue.

WORK Deck: CULVERT DESIGN SYSTEM   Rev 710.A

```
┌───────────────────────────┐
│Edit Indicated Work Deck│
│Select Another Work Deck│
│Combine Decks into File │
│Return to System Shell  │
└───────────────────────────┘


┌───────────────────────────┐
│Stage Discharge Deck       │
│Stage Storage Deck         │
│Culvert Design and Review  │
│Flow-Distribution          │
└───────────────────────────┘


▶┌───────────────────────────┐
 │Select from available decks │
 │Assemble into CDS input file│
 └───────────────────────────┘
```


Select deck that will be placed into CDS input file
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

Figure 34. Select / Assemble screen.

     Do not choose the **Assemble into CDS input file** option until all the work
decks have been selected.

Choose a deck from the displayed entries in figure 35 and strike <CR>. If there are multiple entries, use the arrow keys to scroll down to the appropriate work deck before pressing <CR>. In the example, the user moves the cursor to **GLADE.SD** and strikes <CR>.

WORK Deck: CULVERT DESIGN SYSTEM   Rev 710.A

```
Edit Indicated Work Deck
Select Another Work Deck
Combine Decks into File
Return to System Shell
```

```
RT198.SD
GLADE.SD
```

```
Stage Discharge Deck
Stage Storage Deck
Culvert Design and Review
Flow-Distribution
```

```
Select from available decks
Assemble into CDS input file
```

Select deck that you want to combine into a input file
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8 9 10 HELP

Figure 35. Choosing the stage discharge work deck.

After hitting <CR>, the user will return to figure 33 where they will select the second work deck for the input file configuration (in this case, the **Stage Storage Deck**) and strike <CR>. The user will again see a situation as depicted in figure 36. Again the selection process is repeated for **GLADE.SS** and **GLADE.CD**.

WORK Deck: CULVERT DESIGN SYSTEM   Rev 710.A

```
┌─────────────────────────┐                    Deck Selection
│Edit Indicated Work Deck │            ┌───────────────────────┐
│Select Another Work Deck │            │ GLADE.SD              │
│Combine Decks into File  │            │                       │
│Return to System Shell   │            │                       │
└─────────────────────────┘            │                       │
 ┌─────────────────────────┐           │                       │
 │Stage Discharge Deck     │           │                       │
 │Stage Storage Deck       │           │                       │
 │Culvert Design and Review│           │                       │
 │Flow-Distribution        │           └───────────────────────┘
 └─────────────────────────┘


 ┌─────────────────────────┐
 │Select from available decks │
 │Assemble into CDS input file│
 └─────────────────────────┘
```

Select deck that will be placed into CDS input file
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

Figure 36. Select / Assemble for stage storage.

The process is repeated a third time for the culvert design and review deck. Figure 37 displays all the deck selections prior to assembling into a single CDS input file.

WORK Deck: CULVERT DESIGN SYSTEM   Rev 710.A

```
 _____                      Deck Selection
|Edit Indicated Work Deck|
|Select Another Work Deck|               _____
|Combine Decks into File |              |GLADE.SD                |
|Return to System Shell  |              |GLADE.SS                |
 _____                 |GLADE.CD                |
                                        |                        |
 _____                 |                        |
|Stage Discharge Deck    |              |                        |
|Stage Storage Deck      |              |_____|
|Culvert Design and Review |
|Flow-Distribution       |
 _____

 _____
|Select from available decks |
|Assemble into CDS input file|
 _____
```

Assemble Work Decks into CDS input file
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

Figure 37. Assemble option selected.

It is now appropriate to move the cursor to the **Assemble into CDS input file** field and strike <F4> or <CR>.

As illustrated in figure 38, two fields are provided for the user to enter identifying comments. These comments will appear in the output. The comment will automatically move to the second field if space is required. Enter a comment and strike <CR> to continue.

WORK Deck: CULVERT DESIGN SYSTEM   Rev 710.A

```
┌─────────────────────────┐
│Edit Indicated Work Deck │
│Select Another Work Deck │
│Combine Decks into File  │
│Return to System Shell   │
└─────────────────────────┘

┌─────────────────────────┐
│Stage Discharge Deck     │
│Stage Storage Deck     __│
│Culvert Design and Review│
│Flow-Distribution        │
└─────────────────────────┘
```

                                         Comments
                              Design of a box culvert over
                              the Glade - October 1, 1987

Enter the file name you wish to use (do not enter file extension)
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

Figure 38.   Comment screen.

At the file name prompt (figure 39), enter the input file name **GLADE** and strike <CR>. The CDS input program will automatically add the correct **CDS** extension to the file. The program will take a few moments to build the input data file from the three work decks. When this is achieved the program will place the user back into the initial CDS input program screen.

WORK Deck: CULVERT DESIGN SYSTEM   Rev 710.A

```
Edit Indicated Work Deck
Select Another Work Deck
Combine Decks into File
Return to System Shell
```

```
Stage Discharge Deck
Stage Storage Deck
Culvert Design and Review
Flow-Distribution
```

Comments
Design of a box culvert over
the Glade - October 1, 1987

File Name
GLADE

Enter the file name you wish to use (do not enter file extension)
1 PRIOR-F 2 NEXT-F 3 PRIOR-S 4 NEXT-S 5 CLEAR-F 6 LEAVE 7 ABORT 8   9   10 HELP

Figure 39. CDS input file name prompt.

To run the CDS analysis program, return to the Hydrain System Shell by selecting the **Return to System Shell** option.

Executing CDS from Hydrain

Upon returning from the CDS Input Program, CDS can be run by moving to the **Run Program / Review File** option, pressing <CR>, and entering the filename.

The extension, **CDS**, is automatically added by the program. The execution time will take several minutes to complete. A good rule of thumb is that the more complex the hydraulic/hydrologic situation, the longer the run.

Upon completion of the run, the CDS output file, that is automatically assigned an **LST** filename extension, will placed in the review module and will be displayed on the screen. Movement through this screen can be accomplished with the cursor, PgUp, PgDn, Home and End keys. Note that the user can scroll both vertically and <u>horizontally</u> through the output file. This allows the user to view the entire 132 character width of CDS output.

After reviewing the file, pressing <F6> will return the user to the **Job Option Menu.** From here, the user can the edit the just created work decks (or any other work deck). If it is desirable to run one of the other PFP programs, the primary menu can be brought up by pressing **Q.** Striking **Q** once more will enable the user to exit the Hydrain Shell to DOS.

Appendix: Benchmark Examples

CDS Example

The example problem for the glade is included in this section for the appendix. There will be a total of six files: GLADE.SD, GLADE.SS, GLADE.CD, GLADE.QT1, GLADE.CDS (the input file), and GLADE.LST (the output file).

GLADE.SD

```
HF002
    001      1.0                    0.0    0.0143
    020     1150    343.70    1200    336.95    1250    327.951
    020     1300    317.35    1350    305.45    1400    293.451
    020     1450    281.95    1500    271.45    1550    271.851
    020  1586.38    272.45    1600    273.95    1650    280.451
    020     1700    295.70    1750    314.45    1784    328.31
    030     1450     0.05     1600     0.03     1784     0.05
```

GLADE.SS

```
HS001
    001      1.0      1.0             0.0143
    005      0.0
    010     1150    344.25    1200     337.5    1250    328.51
    010     1300     317.9    1350     306.0    1400    294.01
    010     1450     282.5    1500     272.0    1550    272.41
    010  1586.38     273.0    1600     274.5    1650    281.01
    010     1700    296.25    1750     315.0    1784    328.86
```

GLADE.CD

```
HC001
    001     30.0      2.0             1586.38      54       .01
    000     30.0      050      1.0
    002                                                      61
    004
    005
    006
    030      25       10        30
    050.qtl
```

GLADE.QT1 (The temporary file that contains the hydrograph data)

```
    12     1193      523       10
            0          0
           30     298.25
           60      596.5
           90     894.75
```

```
                     120     1193.0
                     150     1084.5
                     180      903.8
                     210      723.0
                     240      542.3
                     270      361.5
                     300     180.76
                     318        0
```

GLADE.CDS

```
100Design of a box culvert over the Glade - October 1, 1987
HF002
   001      1.0                   0.0    0.0143
   020     1150     343.70       1200    336.95      1250    327.951
   020     1300     317.35       1350    305.45      1400    293.451
   020     1450     281.95       1500    271.45      1550    271.851
   020   1586.38    272.45       1600    273.95      1650    280.451
   020     1700     295.70       1750    314.45      1784    328.31
   030     1450      0.05        1600     0.03       1784     0.05
HS001
   001      1.0      1.0                 0.0143
   005      0.0
   010     1150     344.25       1200    337.5       1250    328.51
   010     1300     317.9        1350    306.0       1400    294.01
   010     1450     282.5        1500    272.0       1550    272.41
   010   1586.38    273.0        1600    274.5       1650    281.01
   010     1700     296.25       1750    315.0       1784    328.86
HC001
   001     30.0      2.0                1586.38       54      .01
   002                                                         61
   004     1193
   005      523
   006       10
   030       25       10          30
   050        0        0          30    298.25        60     596.51
   050       90     894.75       120    1193.0       150    1084.51
   050      180     903.8        210     723.0       240     542.31
   050      270     361.5        300    180.76       318        0
999
```

GLADE.LST

```
************************************************************************
************************************************************************
**                                                                  **
**                                                                  **
**                                                                  **
**     CCCCCCCCCC        DDDDDDDD        SSSSSSSSSS                  **
**     CCCCCCCCCCCC       DDDDDDDDD       SSSSSSSSSSSS                **
**     CC       CC      DD      DD      SS       SS                 **
**     CC                DD      DD      SS                          **
**     CC                DD      DD      SSS                         **
**     CC                DD      DD       SSSSSSSS                   **
**     CC      CULVERT   DD      DD DESIGN  SSSSSSSS SYSTEM          **
**     CC                DD      DD                SSS               **
**     CC                DD      DD                 SS               **
**     CC       CC      DD      DD      SS       SS                 **
**     CCCCCCCCCCCC       DDDDDDDDD       SSSSSSSSSSSS                **
**      CCCCCCCCCC        DDDDDDDD        SSSSSSSSSS                  **
**                                                                  **
**                                                                  **
**     VERSION 2.0    LEVEL 1        RELEASE DATE  2/11/86          **
**                                                                  **
**                                                                  **
************************************************************************
************************************************************************
```

MAIN ==> CARD= 100Design of a box culvert over the Glade - October 1, 1987
MAIN ==> CARD= HF002

WYOMING HIGHWAY DEPARTMENT

PRECONSTRUCTION DIVISION   HYDRAULICS SECTION

CHANNEL STAGE DISCHARGE RELATIONSHIP

100Design of a box culvert over the Glade - October 1, 1987

CHANNEL SLOPE =   .01430FT/FT

STAGE DISCHARGE INPUT VERIFICATION

INPUT VERIFIED?
DESIGNER_____   CHECKER_____

```
X( 1) = 1150.0  Y( 1) =  343.7  MANNINGS NUMBER = .050
X( 2) = 1200.0  Y( 2) =  337.0  MANNINGS NUMBER = .050
X( 3) = 1250.0  Y( 3) =  328.0  MANNINGS NUMBER = .050
X( 4) = 1300.0  Y( 4) =  317.4  MANNINGS NUMBER = .050
X( 5) = 1350.0  Y( 5) =  305.5  MANNINGS NUMBER = .050
X( 6) = 1400.0  Y( 6) =  293.5  MANNINGS NUMBER = .050
X( 7) = 1450.0  Y( 7) =  282.0  MANNINGS NUMBER = .050
X( 8) = 1500.0  Y( 8) =  271.5  MANNINGS NUMBER = .030
X( 9) = 1550.0  Y( 9) =  271.9  MANNINGS NUMBER = .030
X(10) = 1586.4  Y(10) =  272.5  MANNINGS NUMBER = .030
X(11) = 1600.0  Y(11) =  274.0  MANNINGS NUMBER = .030
X(12) = 1650.0  Y(12) =  280.5  MANNINGS NUMBER = .050
X(13) = 1700.0  Y(13) =  295.7  MANNINGS NUMBER = .050
X(14) = 1750.0  Y(14) =  314.5  MANNINGS NUMBER = .050
X(15) = 1784.0  Y(15) =  328.3  MANNINGS NUMBER = .050
X(16) = 1821.8  Y(16) =  343.7  MANNINGS NUMBER = .050
```
*** NOTE *** LAST POINT WAS EXTRAPOLATED

GLADE.LST (Cont.)

CHANNEL STAGE DISCHARGE RELATIONSHIP

100Design of a box culvert over the Glade - October 1, 1987

CHANNEL SLOPE =   .01430FT/FT

ELEVATION	DEPTH	DISCHARGE	VELOCITY	MAX. VELOCITY
271.45	.00	.00	.00	.00
271.85	.40	20.98	2.02	2.02
272.15	.70	93.41	3.23	3.43
272.45	1.00	220.52	4.14	4.55
272.75	1.30	432.28	5.32	5.88
273.05	1.60	700.80	6.34	6.99
273.35	1.90	1023.06	7.26	7.96
273.65	2.20	1397.32	8.09	8.86
273.95	2.50	1822.69	8.87	9.69
274.25	2.80	2329.01	9.72	10.61
274.55	3.10	2887.00	10.50	11.47
274.85	3.40	3496.03	11.23	12.29
275.15	3.70	4155.56	11.91	13.06
275.45	4.00	4865.21	12.56	13.80
275.75	4.30	5624.72	13.17	14.51
276.05	4.60	6433.89	13.75	15.20
276.35	4.90	7292.63	14.30	15.87
276.65	5.20	8200.91	14.83	16.51
276.95	5.50	9158.76	15.33	17.14
277.25	5.80	10166.26	15.82	17.75
277.55	6.10	11223.51	16.29	18.35
277.85	6.40	12330.68	16.74	18.93
278.15	6.70	13487.95	17.17	19.51
278.45	7.00	14695.51	17.60	20.07
278.75	7.30	15953.61	18.00	20.62
279.05	7.60	17262.53	18.40	21.15
279.35	7.90	18622.48	18.78	21.68
279.65	8.20	20033.80	19.16	22.20
279.95	8.50	21496.78	19.52	22.72
280.25	8.80	23011.71	19.88	23.22
280.45	9.00	24052.10	20.11	23.55
280.75	9.30	25675.57	20.47	24.07
281.05	9.60	27350.61	20.83	24.57
281.35	9.90	29077.17	21.18	25.07
281.65	10.20	30855.23	21.53	25.55
281.95	10.50	32685.18	21.87	26.03
282.25	10.80	34763.61	22.34	26.66
282.55	11.10	36896.87	22.79	27.27
282.85	11.40	39085.02	23.24	27.87
283.15	11.70	41328.04	23.67	28.46
283.45	12.00	43625.92	24.10	29.03
283.75	12.30	45978.62	24.51	29.60
284.05	12.60	48386.10	24.92	30.15
284.35	12.90	50848.30	25.32	30.70
284.65	13.20	53365.23	25.71	31.24

GLADE.LST (Cont.)

ELEVATION	DEPTH	DISCHARGE	VELOCITY	MAX. VELOCITY
284.95	13.50	55936.84	26.10	31.77
285.25	13.80	58563.10	26.47	32.29
285.55	14.10	61244.02	26.84	32.81
285.85	14.40	63979.58	27.21	33.32
286.15	14.70	66769.76	27.57	33.82
286.45	15.00	69614.59	27.92	34.32
286.75	15.30	72514.05	28.26	34.82
287.05	15.60	75468.19	28.60	35.30
287.35	15.90	78477.01	28.94	35.78
287.65	16.20	81540.50	29.27	36.26
287.95	16.50	84658.75	29.59	36.73
288.25	16.80	87831.80	29.91	37.20
288.55	17.10	91059.62	30.22	37.66
288.85	17.40	94342.29	30.53	38.12
289.15	17.70	97679.86	30.84	38.58
289.45	18.00	101072.40	31.14	39.03
289.75	18.30	104519.90	31.44	39.48
290.05	18.60	108022.40	31.73	39.92
290.35	18.90	111580.10	32.02	40.36
290.65	19.20	115192.90	32.31	40.79
290.95	19.50	118861.00	32.59	41.23
291.25	19.80	122584.40	32.87	41.66
291.55	20.10	126363.20	33.14	42.08
291.85	20.40	130197.50	33.41	42.51
292.15	20.70	134087.30	33.68	42.93
292.45	21.00	138032.70	33.95	43.35
292.75	21.30	142033.90	34.21	43.76
293.05	21.60	146090.80	34.47	44.17
293.45	22.00	151593.40	34.81	44.72
293.75	22.30	155783.00	35.06	45.12
294.05	22.60	160028.70	35.31	45.53
294.35	22.90	164330.40	35.56	45.93
294.65	23.20	168688.20	35.80	46.33
294.95	23.50	173102.20	36.04	46.72
295.25	23.80	177572.50	36.28	47.12
295.70	24.25	184385.10	36.64	47.71
296.00	24.55	189024.90	36.88	48.10

MAIN ==> CARD= HS001

STAGE STORAGE

100Design of a box culvert over the Glade - October 1, 1987
INPUT VERIFICATION

INPUT VERIFIED ?

DESIGNER _____   CHECKER _____

UPSTREAM SLOPE =   .01430 FEET/FOOT
CROSS SECTION STATION =   .00

X (DISTANCE-FEET)	Y (ELEVATION-FEET)
1150.00	344.25
1200.00	337.50
1250.00	328.50
1300.00	317.90
1350.00	306.00
1400.00	294.00
1450.00	282.50
1500.00	272.00
1550.00	272.40
1586.38	273.00
1600.00	274.50
1650.00	281.00
1700.00	296.25
1750.00	315.00
1784.00	328.86

GLADE.LST (Cont.)

STAGE STORAGE

100Design of a box culvert over the Glade - October 1, 1987
COMPUTATIONAL RESULTS

DEPTH (FT)	STORAGE (ACRE-FT)	AREA INUNDATED (ACRES)
.00	.00	.00
.40	.00	.02
1.00	.03	.07
2.50	.28	.22
9.00	5.76	1.39
10.50	8.40	1.73
22.00	51.27	5.17
24.25	65.31	6.02
34.00	152.35	10.26
43.00	276.95	15.11
45.90	327.50	16.84
56.50	561.81	24.18
56.86	571.24	24.46

WYOMING HIGHWAY DEPARTMENT
ENGINEERING DIRECTORATE ✶✶✶✶✶✶✶ HYDRAULICS SECTION
CULVERT   PRINT OPTION NO. 2
        FLOOD ROUTING
STATION: 15+86.38 PROJECT: 100Design of a box culvert over the Glade - October 1, 1987
        ============

CULV SIZE: 1- 6.0X 5.0 CONCRETE BOX/HEADWALL INLET & 1:1 BEVEL
        ================
ANALYSIS TYPE: DRAINAGE DESIGN   Q:1193CFS FREQ: 10YR DHW:25.00FT   DHWO: .00FT
        ===
BARREL GEOMETRY: LENGTH: 54FT SLOPE: 1.00000% GVD:10.0FT
        ======   ==========   ======
✶ ✶ ✶ ✶ ✶ ✶ ✶ ✶ C U L V E R T F L O O D R O U T I N G ✶ ✶ ✶ ✶ ✶ ✶ ✶ ✶ ✶ ✶ ✶ ✶CULVERT FLOOD ROUTING

ROUTING	✶✶✶DISCHARGES✶✶✶		✶✶✶✶VOLUMES(AF)✶✶✶✶			HEAD	OUTLET	FROUDE	BRINK	FLOW	TAIL-	POND
TIME	INFLOW	OUTFLOW	IN	OUT	STORE	HW,FT	VELOCITY	NO.	DEPTH	TYPE	WATER	AREA
12MIN	127CFS	77CFS	1.3	.8	.5	2.7	10.4FPS	1.7	1.2FT	IA	.6FT	.3AC
25MIN	255CFS	159CFS	4.9	2.9	1.9	4.4	13.0FPS	1.6	2.0FT	IA	.9FT	.6AC
34MIN	340CFS	234CFS	8.6	5.3	3.1	5.8	14.5FPS	1.5	2.7FT	IA	1.0FT	.8AC
42MIN	426CFS	309CFS	13.2	8.7	4.4	7.4	15.5FPS	1.5	3.3FT	IA	1.1FT	1.1AC
51MIN	511CFS	375CFS	18.9	12.8	5.7	9.0	16.2FPS	1.5	3.9FT	ID	1.2FT	1.4AC
64MIN	639CFS	433CFS	29.2	20.1	8.8	10.6	16.7FPS	1.4	4.3FT	ID	1.3FT	1.8AC
85MIN	852CFS	501CFS	51.6	33.9	17.1	12.8	17.2FPS	1.4	4.8FT	VIA	1.4FT	2.4AC
94MIN	937CFS	645CFS	62.3	40.7	21.1	13.9	21.5FPS	1.7	5.0FT	VIA	1.5FT	2.7AC
109MIN	1086CFS	705CFS	83.4	54.8	28.0	15.8	23.5FPS	1.9	5.0FT	VIA	1.6FT	3.3AC
124MIN	1177CFS	774CFS	107.3	70.2	36.6	18.1	25.8FPS	2.0	5.0FT	VIA	1.7FT	4.0AC
141MIN	1115CFS	833CFS	134.3	89.3	44.6	20.2	27.8FPS	2.2	5.0FT	VIA	1.7FT	4.6AC
173MIN	942CFS	883CFS	179.9	127.6	52.2	22.2	29.4FPS	2.3	5.0FT	VIA	1.8FT	5.2AC
237MIN	555CFS	814CFS	245.7	204.1	42.0	19.5	27.1FPS	2.1	5.0FT	VIA	1.7FT	4.4AC
259MIN	426CFS	748CFS	260.0	227.1	33.3	17.2	25.0FPS	2.0	5.0FT	VIA	1.6FT	3.7AC
276MIN	322CFS	682CFS	268.7	244.0	25.2	15.0	22.7FPS	1.8	5.0FT	VIA	1.6FT	3.1AC
289MIN	245CFS	517CFS	273.6	255.1	18.9	13.3	17.4FPS	1.4	5.0FT	VIA	1.4FT	2.6AC
291MIN	232CFS	510CFS	274.3	256.6	18.1	13.1	17.3FPS	1.4	4.9FT	VIA	1.4FT	2.5AC
310MIN	73CFS	441CFS	278.3	269.2	9.7	10.8	16.8FPS	1.4	4.4FT	ID	1.3FT	1.8AC
319MIN	0CFS	353CFS	278.6	273.9	5.3	8.4	16.0FPS	1.5	3.7FT	ID	1.2FT	1.3AC
323MIN	0CFS	258CFS	278.6	275.5	3.5	6.3	14.8FPS	1.5	2.9FT	IA	1.1FT	.9AC
327MIN	0CFS	180CFS	278.6	276.7	2.2	4.8	13.5FPS	1.6	2.2FT	IA	.9FT	.6AC
332MIN	0CFS	124CFS	278.6	277.5	1.3	3.7	12.1FPS	1.6	1.7FT	IA	.8FT	.4AC
338MIN	0CFS	74CFS	278.6	278.3	.4	2.7	10.3FPS	1.7	1.2FT	IA	.6FT	.3AC
344MIN	0CFS	13CFS	278.6	278.6	.0	.8	4.0FPS	1.2	.3FT	IA	.3FT	.1AC
357MIN	0CFS	0CFS	278.6	278.6	.0	.0	.1FPS	.1	.0FT	IA	.0FT	.0AC

TOTAL VOLUMES   279   279
TIME TO PEAK= 120MIN.   TIME TO MAX OUTFLO= 182MIN.   TIME TO MAX HW= 182MIN.

ALL CULVERT TYPES REQUESTED HAVE BEEN DESIGNED

References

1) Wyoming State Highway Department, "Culvert Design System", FHWA Report FHWA Number FHWA-TS-80-245, Washington DC, December 1980.

2) Federal Highway Administration, "Federal Highway Program Manual", Volume 6, Chapter 7, Section 3, Subsection 2, Attachment 2, Section (2)(b), Washington DC, 1979.

3) Craig, G., and J. Rankle, "Analysis of Runoff from Small Drainage Basins in Wyoming", USGS Water Supply Paper 2056, Washington DC, 1978.

4) Federal Highway Administration, "Hydraulic Charts for the Selection of Highway Culverts", FHWA Hydraulic Engineering Circular Number 5, Washington DC, 1965.

5) Masch, Frank D., "Hydrology", Hydraulic Engineering Circular Number 19, FHWA-1P-84-15, Washington DC, August 1985.

6) Chow, V.T., Open Channel Hydraulics, New York, NY, McGraw Hill, 1959.

7) Federal Highway Administration, "Hydraulic Design of Improved Inlets for Culverts", FHWA Hydraulic Engineering Circular Number 13, Washington DC, 1972.

8) Federal Highway Administration, "Impact of Economic Risks on Box Culverts Designs -- an Application To 22 Virginia Sites", Report Number FHWA-RD-75-49, Washington DC, 1974.