INTRODUCTION

This User's Guide is intended as a guide for the first time KCBW user. The procedures presented herein guide the user through step-by-step procedures for creating and entering input data for pipe and catch basin, and open channel conveyance elements. It also provides limited theoretical background to help the user understand the concepts of design and analysis using standard step backwater methods.

This User's Guide is divided into the following eight sections.

- **Section I , Introduction.**
- **Section II , Standard Step Overview.** This section gives a brief overview of how the standard step method is applied in this program.
- **Section III , Creating a Pipe Data Input File.** This section describes how to input data gathered from survey, plan sheets and or maps that is required to analyze pipe and catch basin conveyance systems.
- **Section IV , Creating a Channel Data Input File.** This section covers how to input cross section data required for the analysis of open channels
- **Section V , Running the Pipe Routines.** This section presents step by step methods used to run and obtain output on pipe and catch basin systems. The section discuses upstream and downstream boundary values and the options available for their use.
- **Section VI , Running the Channel Routines.** This section presents a step-by-step procedure for running and obtaining output on open channels.
- **Section VII , Running the Culvert Routine.** This section presents a step-by-step procedure for running the interactive culvert routine.
- **Section VIII , Analyzing output Data.** This section covers the analysis of output from the program runs. Discussion of the limitations of the standard step method. Discusses the overflow warnings and interpretation of output data.

STANDARD STEP OVERVIEW

The term "standard step" refers to a computational method for determining gradually varied flow water surface profiles. V. T. Chow originally published the method in 1959 in Open-Channel Hydraulics. The method is an iterative procedure involving the energy equation (conservation of energy) and continuity (conservation of mass). The user is referred to open channel hydraulics textbooks for a more thorough derivation of the governing equations, the assumptions used in the derivation, and the limitations of the method.

The KCBW program calculates water surface profiles and elevations for culverts, pipe and catch basin systems, and open channels. The program is useful for designing new conveyance systems and analyzing existing ones. The program calculates headwater depths on culverts and individual pipes in a system with single steps between the outlet and the inlet. It calculates profiles between individual cross-sections for open channels.

Input and output definitions are included in the KCBW documentation section of this users guide.

The KCBW program has limited warning and error messages in the output. The output should be carefully analyzed to interpret the relationship to the assumptions and limitations of gradually varied flow analysis. In addition, an understanding of the application of the classification of flow profiles can be essential to interpreting the output from the model. The output from the model is sufficient to provide the information needed to make these analyses. Two good references for this material are Open Channel Hydraulics by Chow, 1959 and Open Channel Flow by Chaudry, 1993.

Culvert and pipe flow are equally complex situations. Inlet and outlet control can vary throughout ranges of flow and variations of headwater and tailwater conditions present in the field. Discussions and schematics of the various culvert flow situations possible are contained in FHWA Hydraulic Design Series #5, 1985, Chow, 1959, and Chaudry 1993. Once again the program provides the needed output to thoroughly analyze the physical situation being modeled.

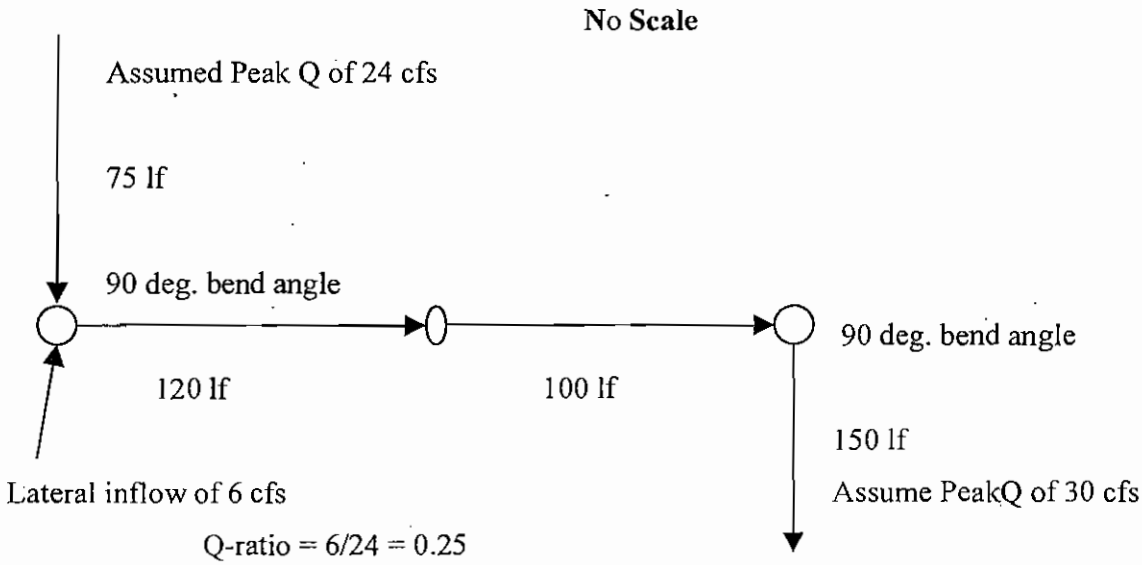
Linking of open channels, pipe systems and culverts using headwater/tailwater (.BWT) files is a very useful tool but requires careful characterization of site conditions through accurate survey information and thorough observation of the results of specific flow conditions.

All users should check output against observed conditions and assumptions. If discrepancies exist the input and flow condition assumptions should be reviewed.

CREATING A PIPE DATA INPUT FILE (EXAMPLE)

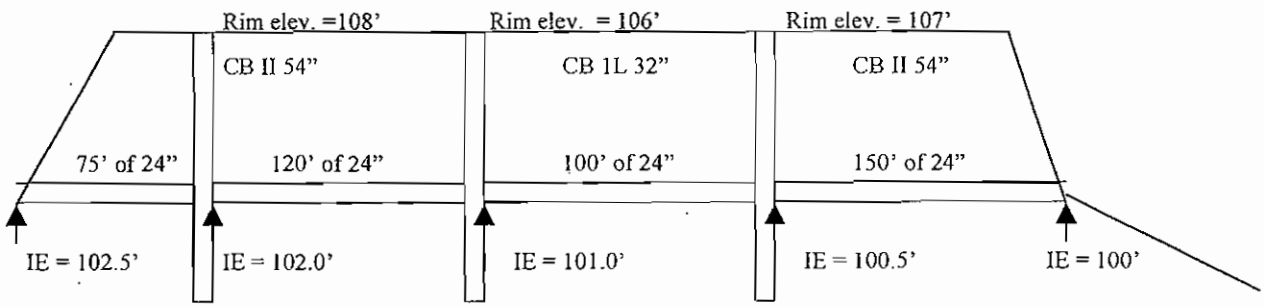
The following is an example of how to create an input data file for a pipe and catch basin system. **The input file must be created prior to running an analysis on the system.** The file created in this example is also contained in the KCBWEX folder/sub-directory included on the installation disk for the KCBW program. The input file will be used in section V, running pipe and culvert routines.

A schematic of the example pipe network is shown below and data input sheets for the problem are enclosed at the end of this section.



PLAN

Upstream Overflow Elevation = 107.5', All pipes are Circular Concrete

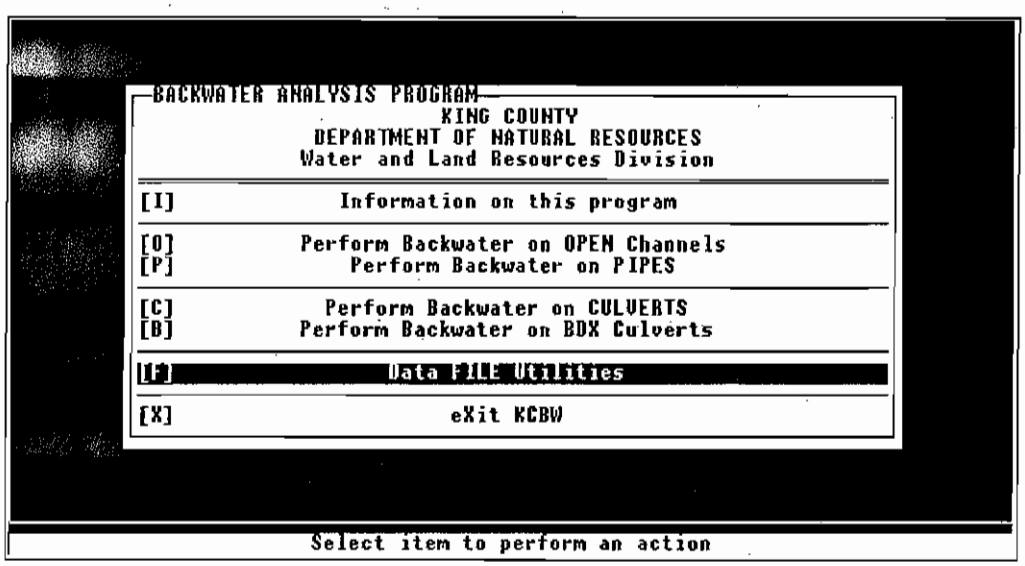


Projecting Inlet at Upstream end

Free Outfall at Downstream end.

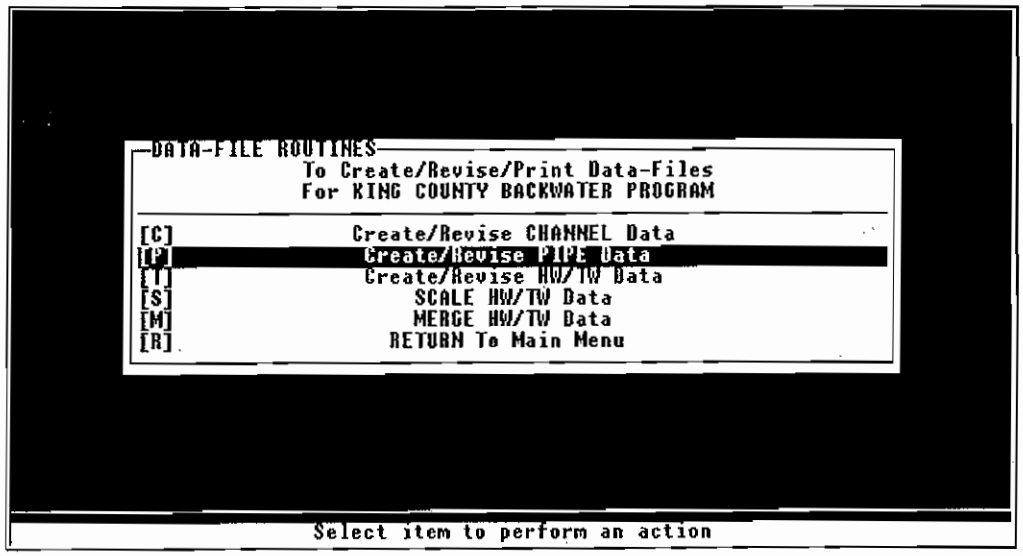
PROFILE

STEP 1. Start the program.



STEP 2. From the Main menu,

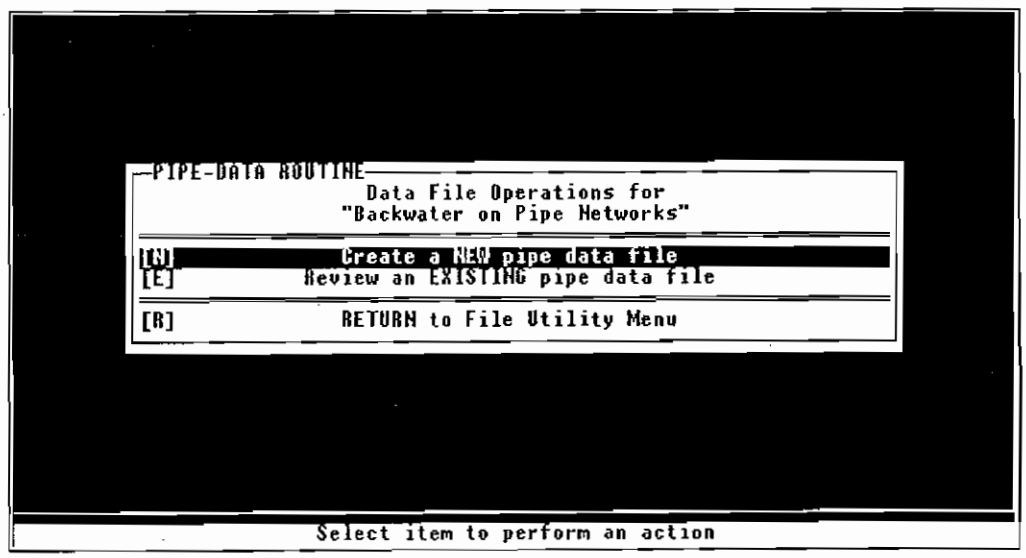
- ➔ Highlight **[F] Data FILE Utilities** and press **Enter**, OR
- ➔ Type **F** at the Main Menu.



STEP 3. Highlight **[P] Create/Revise Pipe Data** and press **Enter**

Or

Press **P**

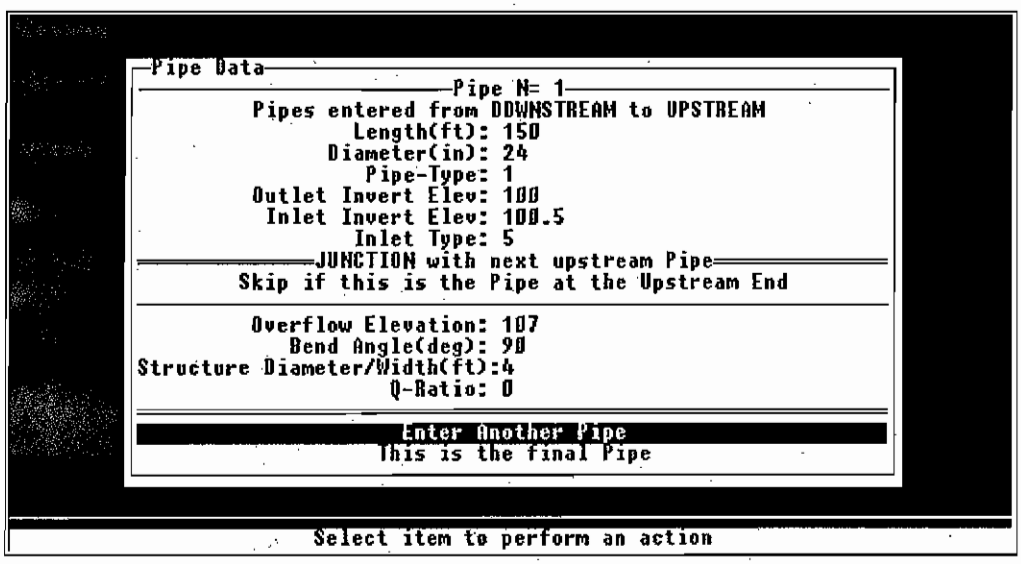


STEP 4. Highlight **[N] Create a NEW pipe data file** and press **Enter**

Or

Press **N**

The following menu screen will appear:



Input data for the pipe and catch basin system are entered at this menu.

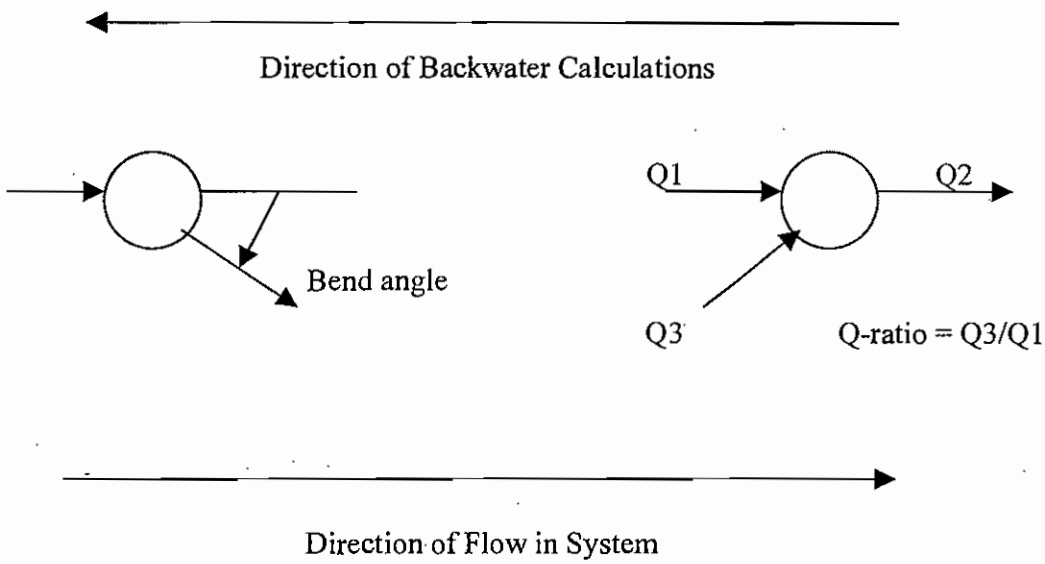
STEP 5.

- ➔ Input **Lengths** and **Diameters** or equivalent diameters.
- ➔ Input the **Pipe Type.** Press **F-10** for a list of pipe and inlet type codes.
- ➔ Input the **Outlet Invert Elevation.**
- ➔ Input the **Inlet Invert Elevation.**
- ➔ Input the **Inlet Type.** Press **F-10** for a list of pipe and inlet type codes.
- ➔ Input the **Overflow Elevation.** This is generally the CB rim elev.
- ➔ **Bend Angle** is the deflection angle measured in the direction of flow. See **Figure III-1**.
- ➔ **Q-Ratio** is the ratio of the lateral upstream inflow to the inflow for the upstream pipe being analyzed. See **Fig III-1**. For no lateral inflow, the **Q-ratio = 0**.

Continue entering data for each pipe and catch basin in the system being analyzed by highlighting **Enter Another Pipe** and pressing **Enter**. Once the data for the last pipe in the system is entered, highlight **This is the Final Pipe** and press **Enter**.

NOTE: The upstream end overflow is entered while running the **Perform Backwater on Pipes**. Bend angle, Structure properties and Q-ratio are not required for the upstream end.

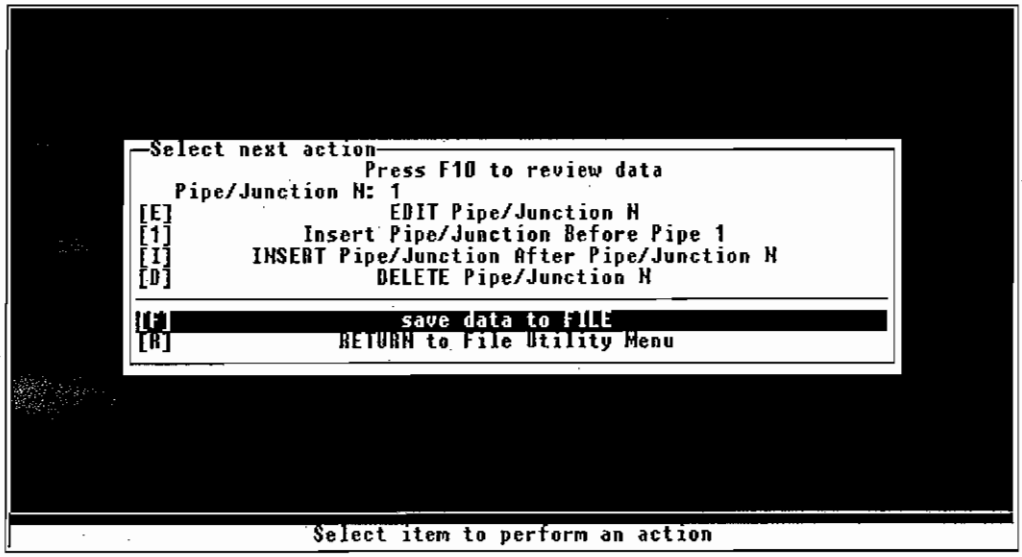
Figure III-1



To view the Pipe and Inlet coding table; Press **F-10** at **Pipe Data Menu.**

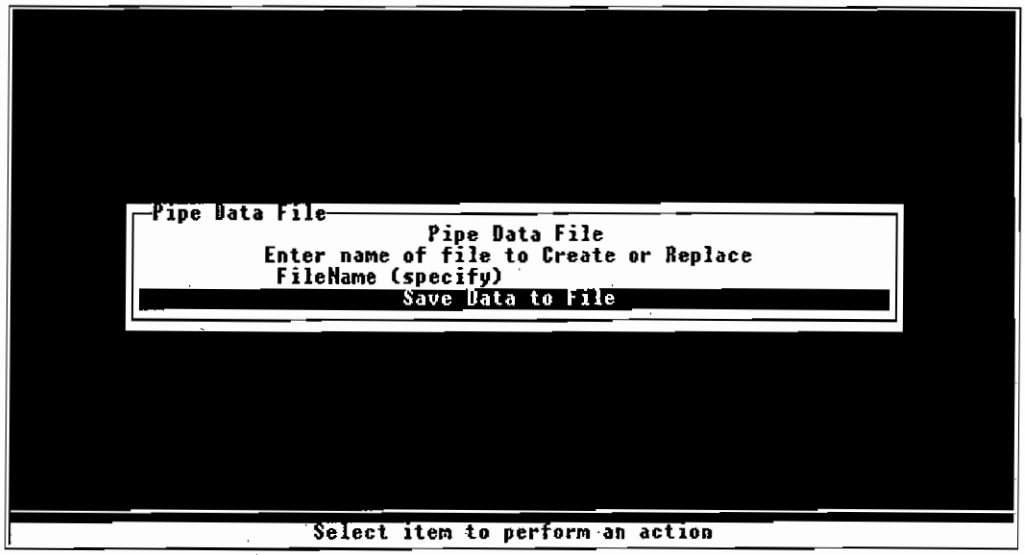
```
                    BACKWATER ANALYSIS PROGRAM

                         Version 5.05

ROUND/ARCH PIPE INPUT CODING INFORMATION:

PIPE TYPE CODING:
     1 - CONC/SMOOTH BORE (n=0.012)            5 - CMP ARCH (NEW GEOMETRY)
     2 - CORRUGATED METAL (n=0.024)            6 - CONC/SMOOTH ARCH (OLD)
     3 - HELICAL CMP (n-fac varies)            7 - CONC/SMOOTH ARCH (NEW)
     4 - CMP ARCH (OLD GEOMETRY)               8 - ROUND (user sets n-fac)

ARCH PIPE CODING - EQUIVALENT ROUND SIZE MUST BE INPUTTED PER FOLLOWING TABLE:
  EQUIV-DIAM.   OLD-ARCH   NEW-ARCH    *    EQUIV-DIAM.   OLD-ARCH   NEW-ARCH
      15"       18"X 11"   17"X 13"    *        42"       50"X 31"   49"X 33"
      18"       22"X 13"   21"X 13"    *        48"       58"X 36"   57"X 38"
      21"       25"X 16"   24"X 18"    *        54"       65"X 40"   64"X 43"
      24"       29"X 18"   28"X 20"    *        60"       72"X 44"   71"X 47"
      30"       36"X 22"   35"X 24"    *        66"       79"X 49"   77"X 52"
      36"       43"X 27"   42"X 29"    *        72"       85"X 54"   83"X 57"

INLET TYPE CODING:
  1 - CMP/PROJ.      4 - CP SOCKET/PROJ.      7 - CMAP/PROJ.     10 - OTHER (SEE
  2 - CMP/HDWALL     5 - CP SQ.EDGE/HDWALL    8 - CMAP/HDWALL        FHWA REPORT
  3 - CMP/MITER      6 - CP SOCKET/HDWALL     9 - CMAP/MITER         HDS NO.5)
```

After **This is the Final Pipe** is entered the following screen will appear:



STEP 6.

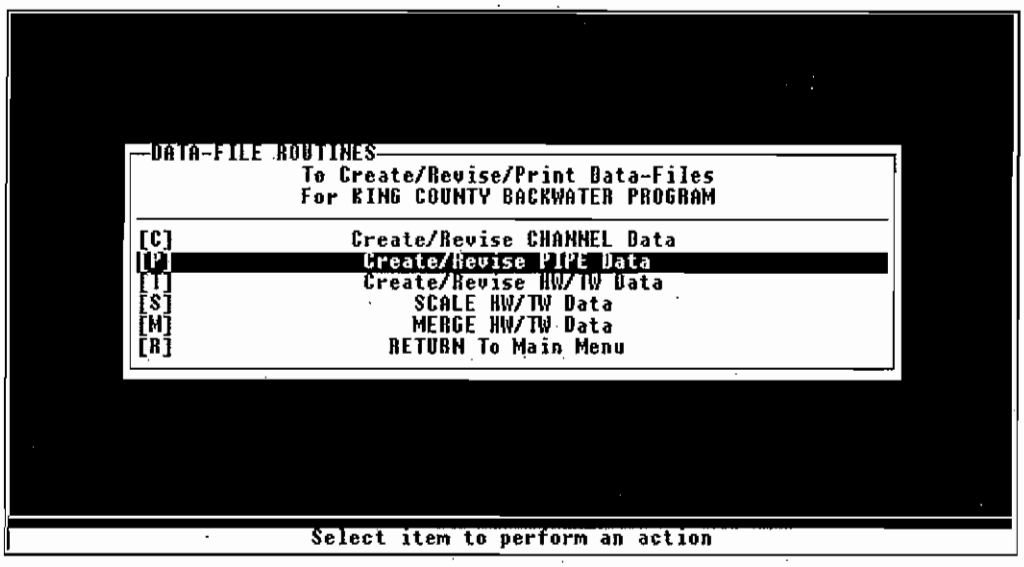
Highlight **Save Data to File** and press **Enter** or press **F** to continue with saving the pipe data file. The user also has the option of editing, inserting or deleting any of the pipes and structures by selecting the appropriate menu item or hot key.



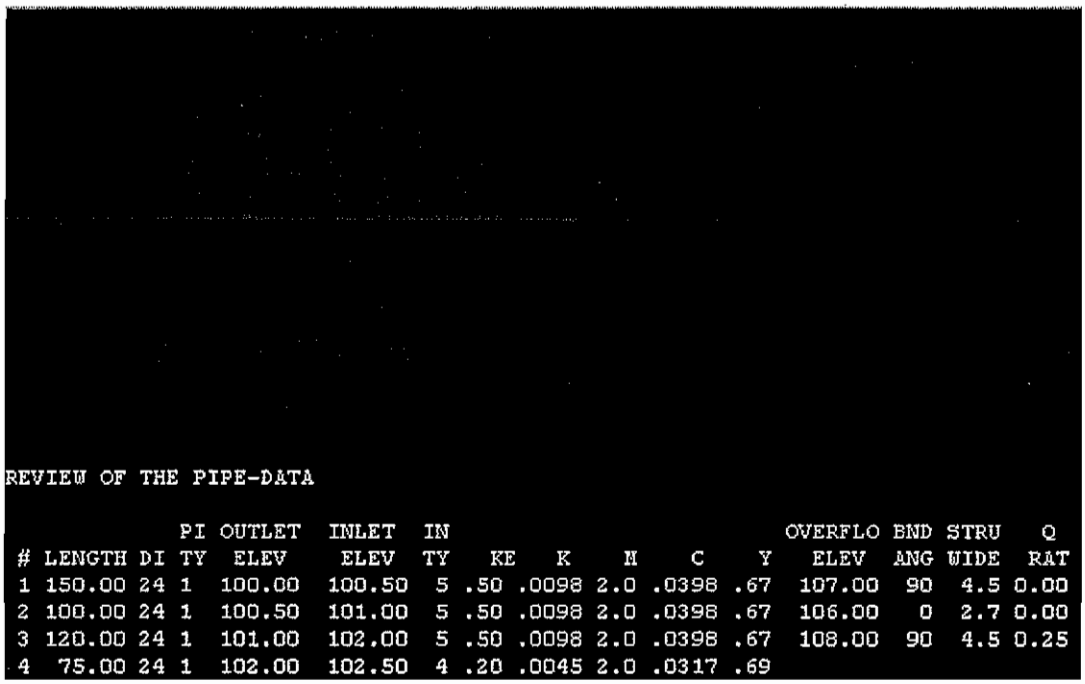
STEP 7.

Key in the appropriate file name in the **FileName** space, highlight **Save Data to File** and press **Enter**. To perform a backwater analysis in the saved pipe system see Section V of this manual.

Once the data is saved to a file, the user is returned to the **Data-File Routines** menu.



The user can view the input data by pressing **F-10.** The output screen will display the data as shown below. This is a convenient way to check data for keyboarding errors after entry.



REVIEW OF THE PIPE-DATA

#	LENGTH	DI	PI TY	OUTLET ELEV	INLET ELEV	IN TY	KE	K	N	C	Y	OVERFLO ELEV	BND ANG	STRU WIDE	Q RAT
1	150.00	24	1	100.00	100.50	5	.50	.0098	2.0	.0398	.67	107.00	90	4.5	0.00
2	100.00	24	1	100.50	101.00	5	.50	.0098	2.0	.0398	.67	106.00	0	2.7	0.00
3	120.00	24	1	101.00	102.00	5	.50	.0098	2.0	.0398	.67	108.00	90	4.5	0.25
4	75.00	24	1	102.00	102.50	4	.20	.0045	2.0	.0317	.69				

The following two pages contain completed data input sheets for the Example pipe network:

The following two pages contain completed data input sheets for the Example pipe network:

PROJECT: **EXAMPLE** PAGE 1 OF 2

PIPE DATA FILE NAME PIPEX .BWP

ROUND/ARCH PIPE INPUT CODING INFORMATION:

TYPE CODING:

1 - CONC/SMOOTH BORE (n=.012)
2 - CORRUGATED METAL (n=.024)
3 - HELICAL CMP (n-fac varies)
4 - CMP ARCH (OLD GEOMETRY)
5 - CMP ARCH (NEW GEOMETRY)
6 - CONC/SMOOTH ARCH (OLD)
7 - CONC/SMOOTH ARCH (NEW)
8 - ROUND (user sets n-fac)

PIPE CODING - EQUIVALENT ROUND SIZE MUST BE INPUTTED PER FOLLOWING TABLE:

IV-DIAM	OLD-ARCH	NEW-ARCH	*	EQUIV-DIAM.	OLD-ARCH	NEW-ARCH
15"	18"X 11"	17"X 13"	*	42"	50"X 31"	49"X 33"
18"	22"X 13"	21"X 13"	*	48"	58"X 36"	57"X 38"
21"	25"X 16"	24"X 18"	*	54"	65"X 40"	64"X 43"
24"	29"X 18"	28"X 20"	*	60"	72"X 44"	71"X 47"
30"	36"X 22"	35"X 24"	*	66"	79"X 49"	77"X 52"
36"	43"X 27"	42"X 29"	*	72"	85"X 54"	83"X 57"

TYPE CODING:

CMP/PROJ.
CMP/HDWALL
CMP/MITER

4 - CP SOCKET/PROJ
5 - CP SQ.EDGE/HDWALL
6 - CP SOCKET/HDWALL

7 - CMAP/PROJ
8 - CMAP/HDWALL
9 - CMAP/MITER

10 - OTHER (SEE FHWA REPORT HDS NO.5)

#	LENGTH(ft)	DIA(in)	PIPE-TYPE	OUTLET-IE	INLET-IE	INLET-TYPE
1	150	24	1	100.00	100.50	5

KE = _____ K = _____ M = _____ C = _____ Y = _____

OVERFLOW-ELEV	BEND-ANGLE(deg)	STRUCT.DIA/WIDTH(ft)	Q-RATIO
107.00	90	4.5	0

#	LENGTH(ft)	DIA(in)	PIPE-TYPE	OUTLET-IE	INLET-IE	INLET-TYPE
2	100	24	1	100.50	101.00	5

KE = _____ K = _____ M = _____ C = _____ Y = _____

OVERFLOW-ELEV	BEND-ANGLE(deg)	STRUCT.DIA/WIDTH(ft)	Q-RATIO
106.00	0	2.7	0

PROJECT: **EXAMPLE** PAGE 2 OF 2

PIPE DATA FILE NAME PIPEX .BWP

ROUND/ARCH PIPE INPUT CODING INFORMATION:

#	LENGTH(ft)	DIA(in)	PIPE-TYPE	OUTLET-IE	INLET-IE	INLET-TYPE
3	120	24	1	101.00	102.00	5

KE = ____ K = ____ M = ____ C = ____ Y = ____

OVERFLOW-ELEV	BEND-ANGLE(deg)	STRUCT.DIA/WIDTH(ft)	Q-RATIO
108.00	90	4.5	0.25

#	LENGTH(ft)	DIA(in)	PIPE-TYPE	OUTLET-IE	INLET-IE	INLET-TYPE
4	75	24	1	102.00	102.50	4

KE = ____ K = ____ M = ____ C = ____ Y = ____

OVERFLOW-ELEV	BEND-ANGLE(deg)	STRUCT.DIA/WIDTH(ft)	Q-RATIO
107.50			

#	LENGTH(ft)	DIA(in)	PIPE-TYPE	OUTLET-IE	INLET-IE	INLET-TYPE

KE = ____ K = ____ M = ____ C = ____ Y = ____

OVERFLOW-ELEV	BEND-ANGLE(deg)	STRUCT.DIA/WIDTH(ft)	Q-RATIO

#	LENGTH(ft)	DIA(in)	PIPE-TYPE	OUTLET-IE	INLET-IE	INLET-TYPE

KE = ____ K = ____ M = ____ C = ____ Y = ____

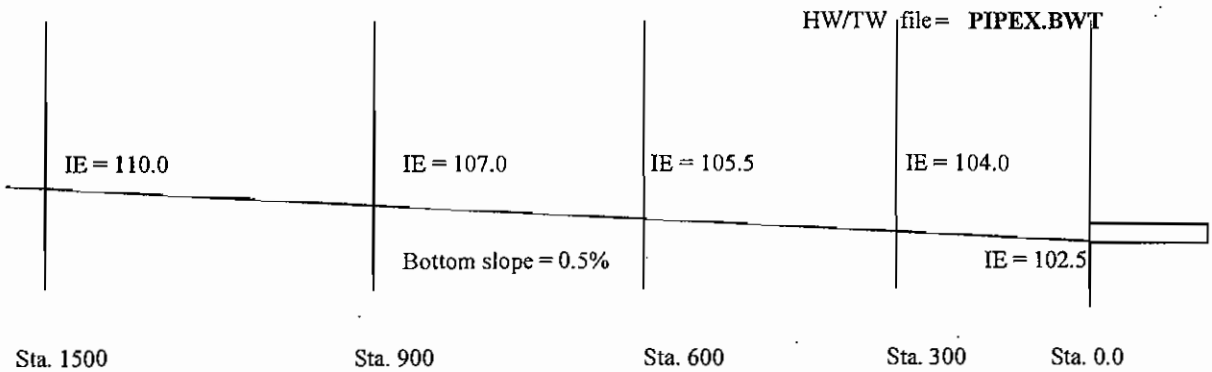
OVERFLOW-ELEV	BEND-ANGLE(deg)	STRUCT.DIA/WIDTH(ft)	Q-RATIO

CREATING A CHANNEL DATA INPUT FILE (EXAMPLE)

The following is an example of how to create an input data file for an open channel. **The input file must be created prior to running an analysis on the channel.** The file created in this example is also contained in the KCBWEX folder/sub-directory included on the installation disk for the KCBW program. The input file will be used in Section VI, Running the Open Channel Routine.

A schematic of the example channel is shown below and data input sheets for the problem are enclosed at the end of the section.

No Scale

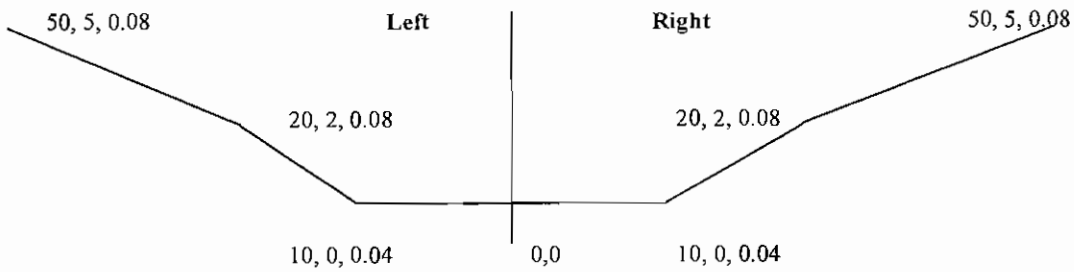


Profile

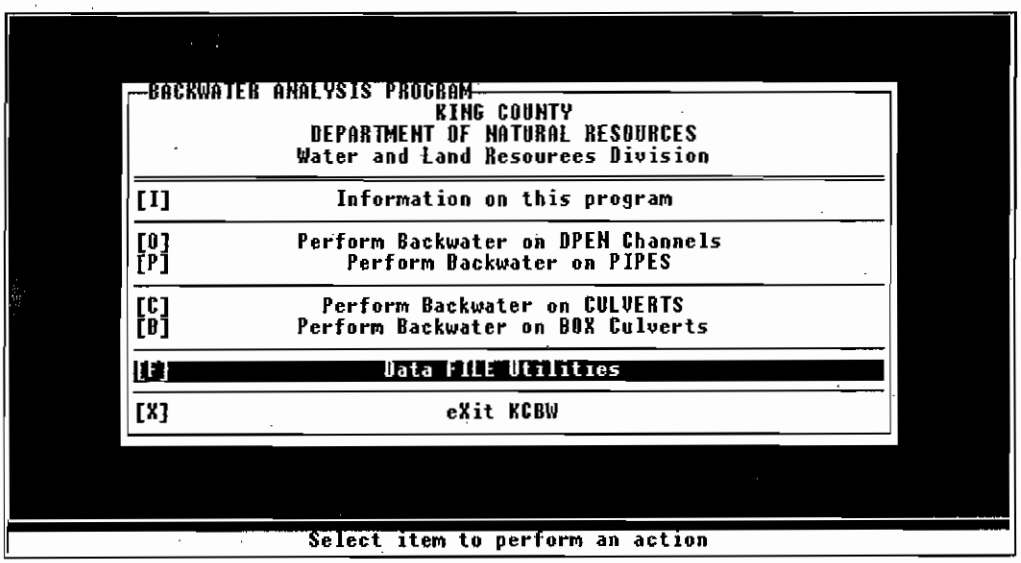
Cross Section #1, Station 0.00

Coordinates listed as X, Y, Manning N

Cross Section #'s 2, 3, 4, & 5, Station 300, 600, 900, 1500



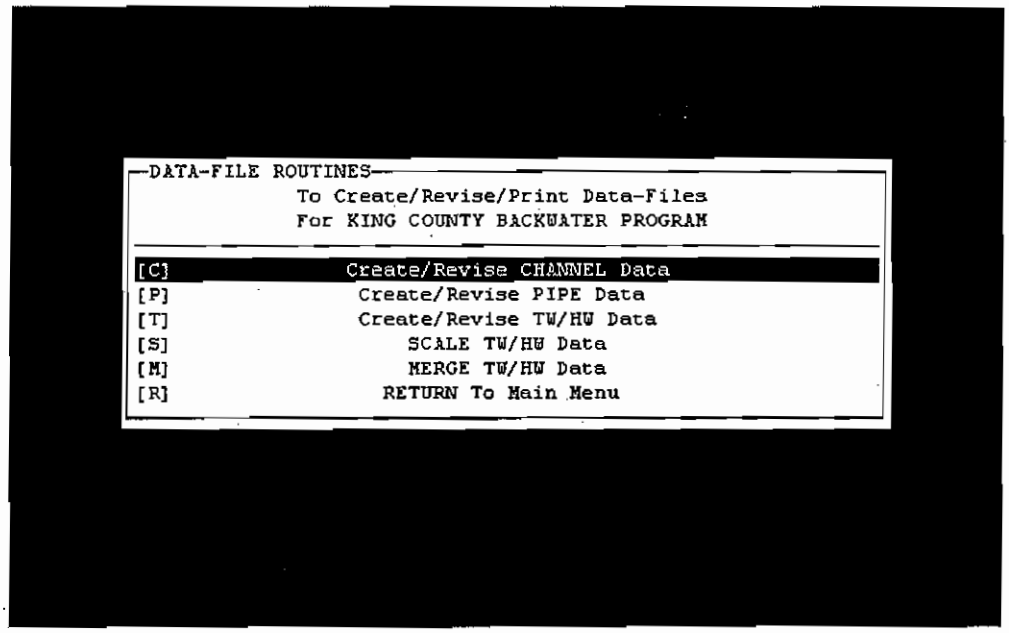
STEP 1. Start the program.



STEP 2. From the Main menu,

- ➔ Highlight **[F] Data File Utilities** and press **Enter**, OR
- ➔ Type **F** at the Main Menu.

This screen contains a variety of data file routines covered in section 6 of the KCBW Program Documentation.

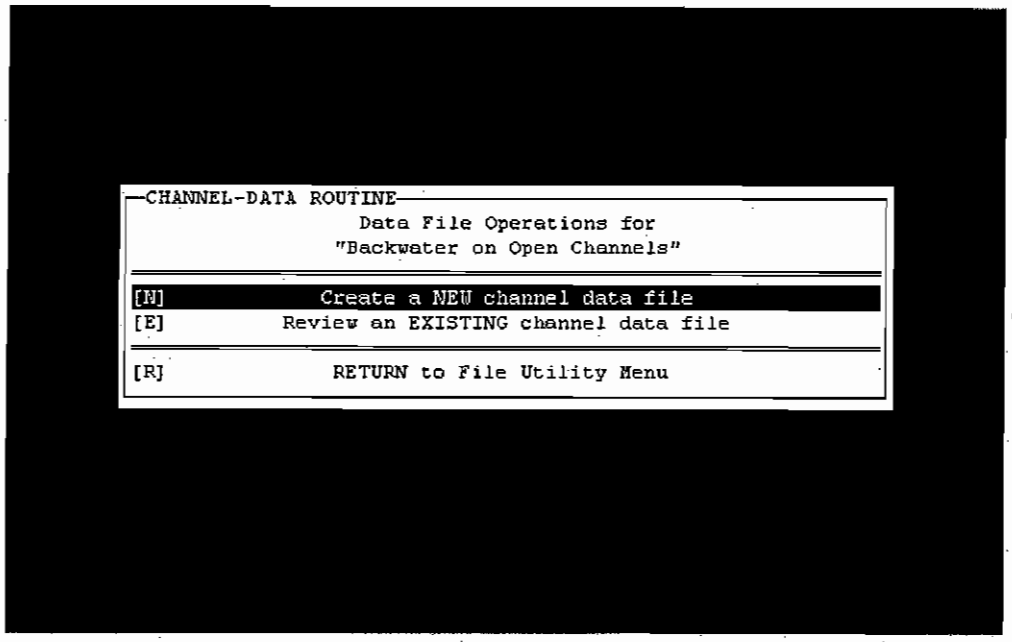


STEP 3. Highlight **[C] Create/Revise CHANNEL Data** and press ***Enter***

Or

Press **C**

The following menu screen will appear:

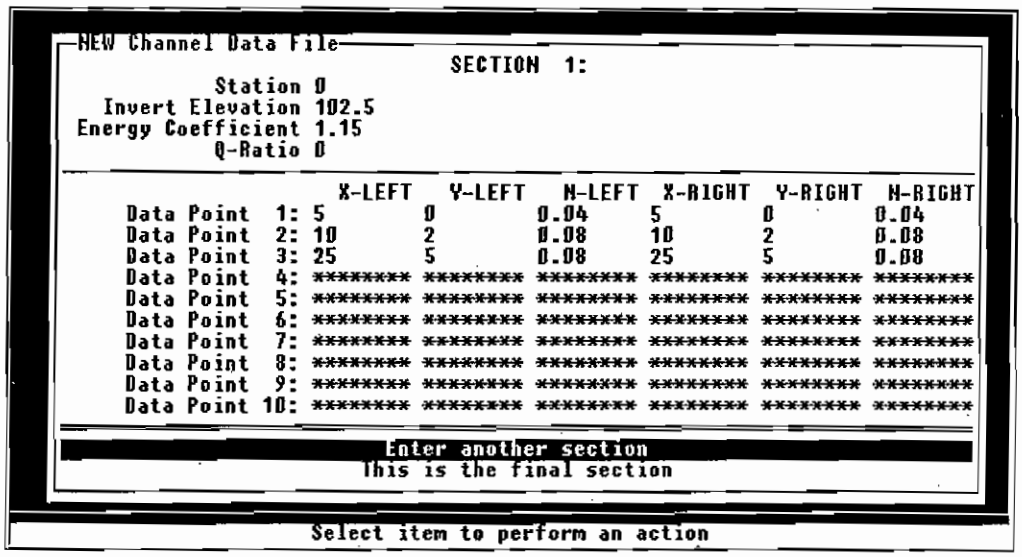


STEP 4. Highlight **[N] Create a NEW Channel Data File** and press ***Enter***

Or

Press **N**

The following menu screen will appear:



Data for the channel cross-section, station, and invert elevation are entered here.

STEP 5.

- ➔ Input the **Station** in units of feet. Stationing is used by the program to calculate the distance between cross-sections.
- ➔ Enter **Invert Elevation,** Corresponds to 0, 0 on cross section, See **Figure IV-2.**
- ➔ Enter **Energy Coefficient** often referred to as *alpha*. 1.15 is common value for constructed channels. Refer to Open channel text books for the theory related to the coefficient. Common values are listed in the table below.

Channels, regular section	1.15
Natural streams	1.3
Shallow vegetated flood fringes (includes channel)	1.75

- ➔ **Q-Ratio** is the ratio of the lateral upstream inflow to the inflow for the upstream channel being analyzed, see **Figure IV-1**. For no lateral inflow, **Q-ratio = 0.**
- ➔ Enter **Channel Cross Section Data** using the coordinate convention shown in **Figure IV-2**.

Continue entering data for each channel cross section being analyzed by highlighting **Enter Another Section** and pressing ***Enter***. Once the data for the last cross-section is entered, highlight **This is the final Section** and press ***Enter***.

Figure IV-1

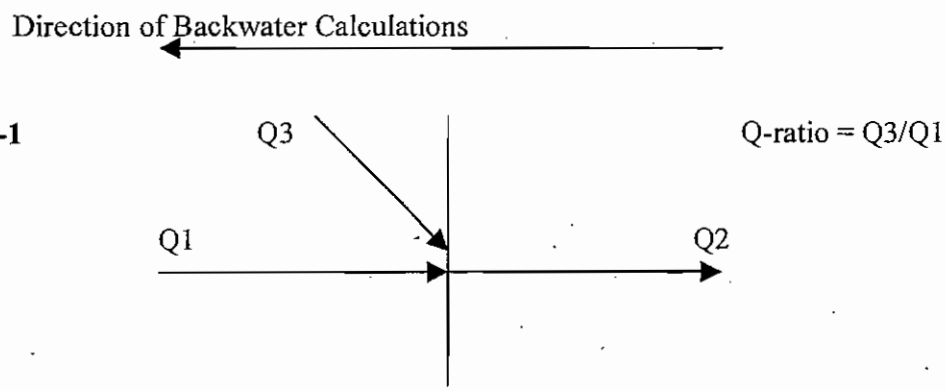
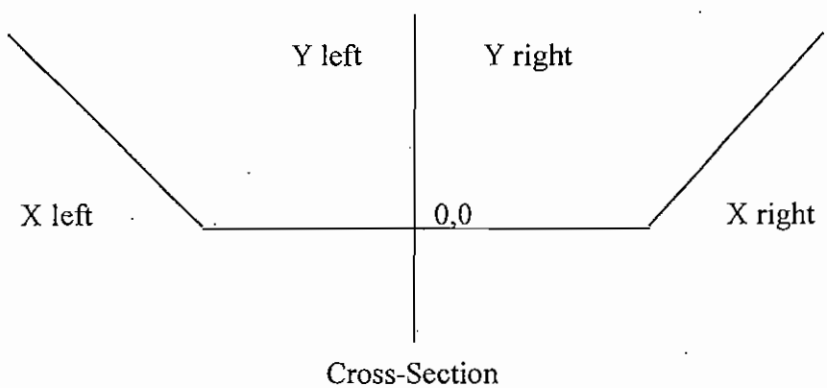
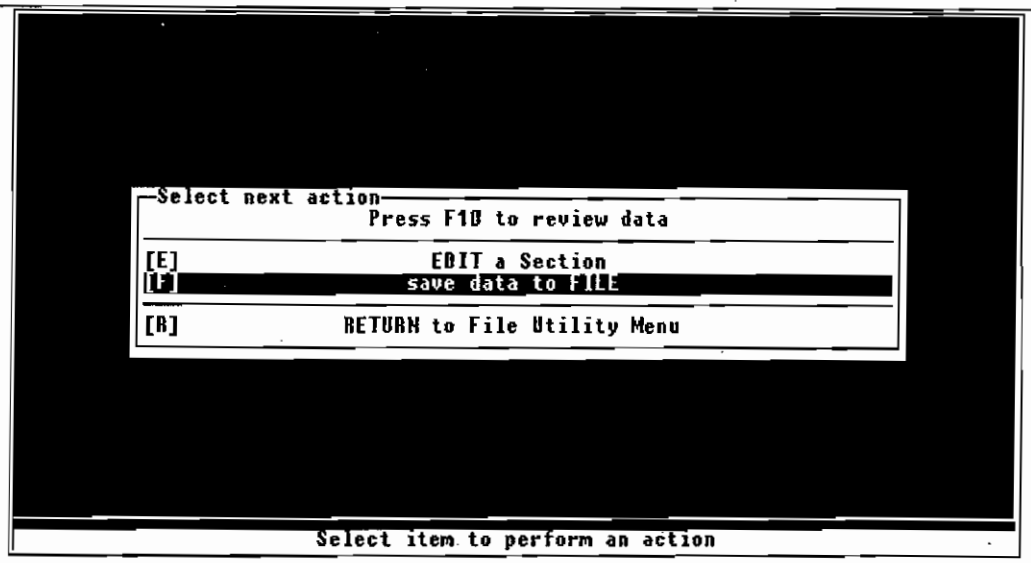


Figure IV-2



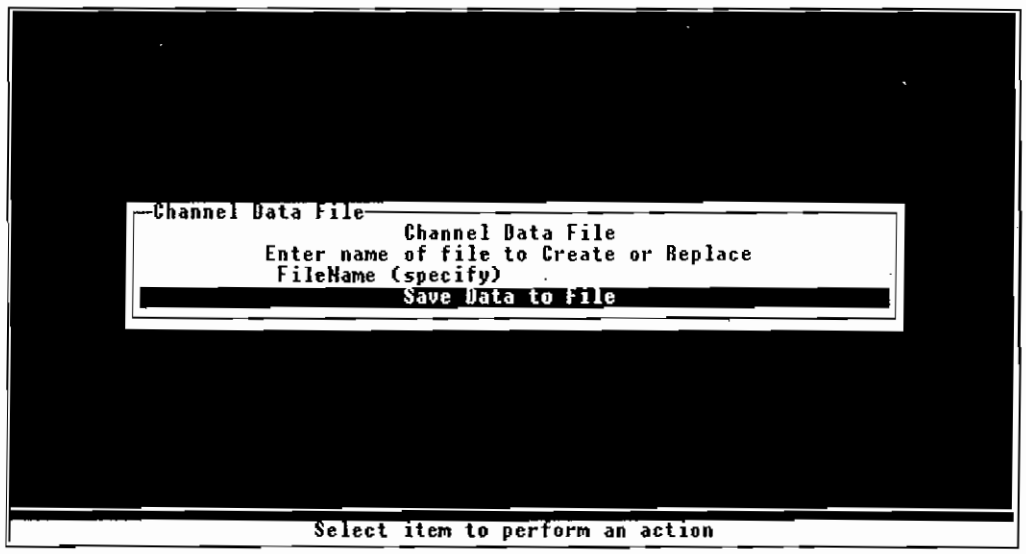
Once the Last cross section is entered the following menu will appear:



STEP 6.

Highlight **Save Data to File** and press enter or press **F** to continue with saving the channel data file.

The following menu screen will appear:



STEP 7.

Key in the appropriate **File Name** in the file name space, highlight **Save Data to File** and press **Enter**. To perform a backwater analysis in the channel system see Section V of this manual.

The following menu screen will appear:

```
DATA-FILE ROUTINES
To Create/Revise/Print Data-Files
For KING COUNTY BACKWATER PROGRAM

[C]   Create/Revise CHANNEL Data
[P]   Create/Revise PIPE Data
[T]   Create/Revise HW/TW Data
[S]   SCALE HW/TW Data
[M]   MERGE HW/TW Data
[R]   RETURN to Main Menu

Select item to perform an action
```

The user can return to the Main Menu by pressing **[R] Return to Main Menu**. There the user will be able to perform Backwater Analysis. The user can view the input data by pressing **F10**. The output screen will display the data as shown below.

REVIEW OF THIS 5 SECTION CHANNEL-DATA FILE

SEC	STATION	INVERT	X-LT	Y-LT	N-LT	X-RT	Y-RT	N-RT	EC	XQ
1	0.00	102.50	5.00	0.00	.040	5.00	0.00	.040		
			10.00	2.00	.080	10.00	2.00	.080		
			25.00	5.00	.080	25.00	5.00	.080	1.25	0.00
2	300.00	104.00	10.00	0.00	.040	10.00	0.00	.040		
			20.00	2.00	.080	20.00	2.00	.080		
			50.00	5.00	.080	50.00	5.00	.080	1.25	0.00
3	600.00	105.50	10.00	0.00	.040	10.00	0.00	.040		
			20.00	2.00	.080	20.00	2.00	.080		
			50.00	5.00	.080	50.00	5.00	.080	1.25	0.00
4	900.00	107.00	10.00	0.00	.040	10.00	0.00	.040		
			20.00	2.00	.080	20.00	2.00	.080		
			50.00	5.00	.080	50.00	5.00	.080	1.25	0.00
5	1500.00	110.00	10.00	0.00	.040	10.00	0.00	.040		
			20.00	2.00	.080	20.00	2.00	.080		
			50.00	5.00	.080	50.00	5.00	.080	1.25	0.00

PROJECT: EXAMPLE **PAGE 1 OF 3**

CHANNEL DATA **FILE NAME Chanex .BWC**

SECTION 1 STATION 0 INVERT ELEV 102.5

	X-LT (ft)	Y-LT (ft)	N-LT	X-RT (ft)	Y-RT (ft)	N-RT
1	5	0	0.04	5	0	0.04
2	10	2	0.08	10	2	0.08
3	25	5	0.08	25	5	0.08
4						
5						
6						
7						
8						
9						
10						

EC = 1.15 Q-Ratio = 0

SECTION 2 STATION 300 INVERT ELEV 104.00

	X-LT (ft)	Y-LT (ft)	N-LT	X-RT (ft)	Y-RT (ft)	N-RT
1	10	0	0.04	10	0	0.04
2	20	2	0.08	20	2	0.08
3	50	5	0.08	50	5	0.08
4						
5						
6						
7						
8						
9						
10						

EC = 1.15 Q-Ratio = 0

PROJECT: EXAMPLE **PAGE 2 OF 3**

CHANNEL DATA **FILE NAME** Chanex .BWC

SECTION 3 STATION 600 INVERT ELEV 105.5

	X-LT (ft)	Y-LT (ft)	N-LT	X-RT (ft)	Y-RT (ft)	N-RT
1	10	0	0.04	10	0	0.04
2	20	2	0.08	20	2	0.08
3	50	5	0.08	50	5	0.08
4						
5						
6						
7						
8						
9						
10						

EC = 1.15 Q-Ratio = 0

SECTION 4 STATION 900 INVERT ELEV 107.00

	X-LT (ft)	Y-LT (ft)	N-LT	X-RT (ft)	Y-RT (ft)	N-RT
1	10	0	0.04	10	0	0.04
2	20	2	0.08	20	2	0.08
3	50	5	0.08	50	5	0.08
4						
5						
6						
7						
8						
9						
10						

EC = 1.15 Q-Ratio = 0

PROJECT: EXAMPLE **PAGE 3 OF 3**

CHANNEL DATA **FILE NAME Chanex .BWC**

SECTION 5 STATION 1500 INVERT ELEV 110.00

	X-LT (ft)	Y-LT (ft)	N-LT	X-RT (ft)	Y-RT (ft)	N-RT
1	10	0	0.04	10	0	0.04
2	20	2	0.08	20	2	0.08
3	50	5	0.08	50	5	0.08
4						
5						
6						
7						
8						
9						
10						

EC = 1.15 Q-Ratio = 0

SECTION ___ STATION ____ INVERT ELEV_____

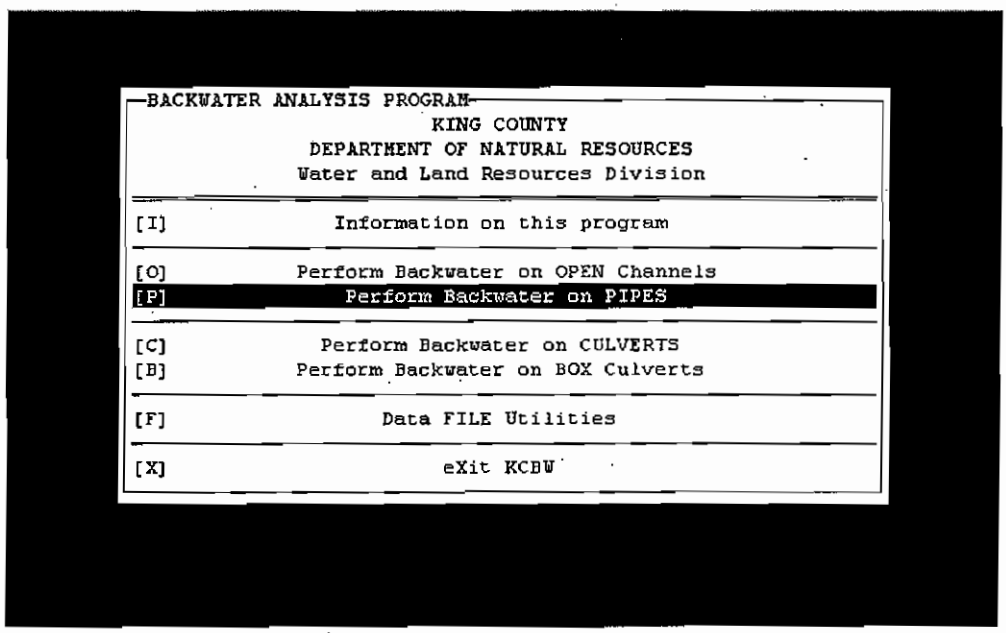
	X-LT (ft)	Y-LT (ft)	N-LT	X-RT (ft)	Y-RT (ft)	N-RT
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

EC =_____ Q-Ratio = ____

RUNNING THE PIPE ROUTINE (EXAMPLE)

The following is an example of how to perform an analysis on a previously entered pipe data file. **The pipe data input file must be created prior to running an analysis on the pipe system.** The file created in this example is contained in the KCBWEX folder/sub-directory included on the installation disk for the KCBW program.

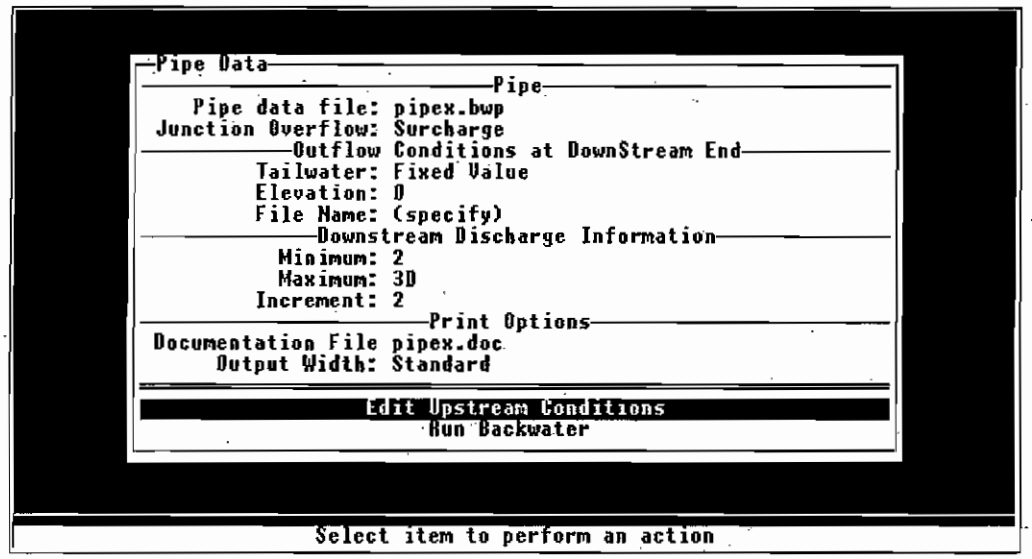
STEP 1. Start the program,



STEP 2. From the Main menu,

- ➔ Highlight **[P] Perform Backwater on PIPES** and press **Enter**, OR
- ➔ Type **P** at the Main Menu.

The user is then presented with the following screen:



STEP 3.

- Enter the filename of the **Pipe Data File** created earlier in Section III. The program assumes the file has a **.BWP** extension.
- Toggle between **Surcharge** and **Broad Weir**. See Section 3-2 of the KCBW Documentation for **Junction Overflow** characteristics. This example uses **Surcharge**.
- Toggle the **Tailwater** item to **Fixed Value** for the example problem or to **From HW/TW file** to use an existing HW/TW file.
- Enter the tailwater **Elevation.** For the example problem use an elevation of **0.0** for free outfall.
- Enter the downstream discharge information. These values specify the range in cfs of flows that will be analyzed. For the example problem set the **Minimum** to **0.0** , the **Maximum** to **30**, and the **Increment** to **2**.
- Enter a file name for the **Documentation File**. This file is where the output from the run will be sent by the program. The program automatically adds a .DOC extension on the file. Enter **Pipex.doc** for this example.
- **Output Width** is a toggle that has three options, **Standard, Condensed,** and **Expanded**. For the example problem use the **Standard** output.
- Highlight **Edit Upstream Conditions** and press **Enter.**

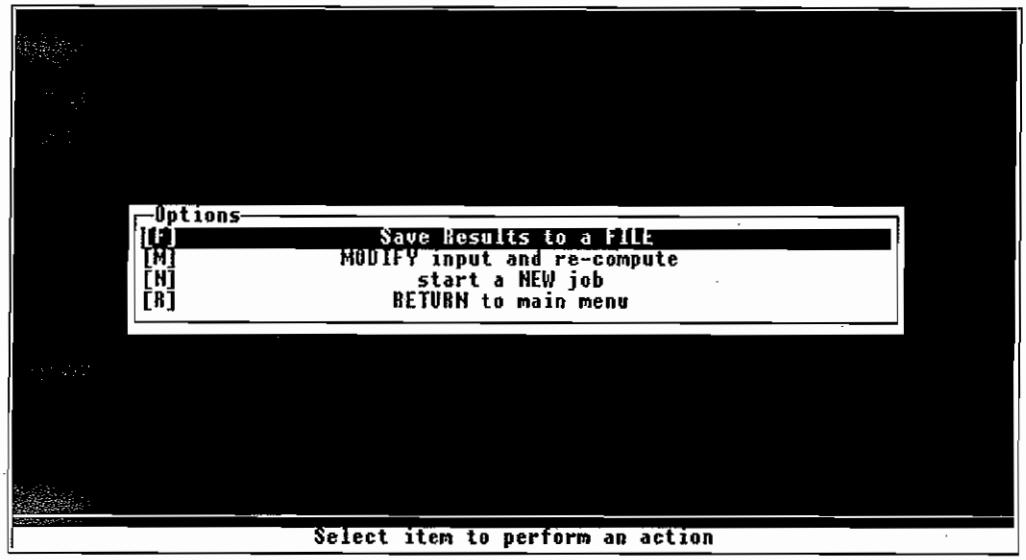
The following menu screen will appear:

```
Upstream Boundary Conditions for Pipes
                    Inlet Overflow Data
     Overflow Type: None
Overflow Elevation: 107.50
       Weir Length: ********
       Weir Height: ********
                  Upstream Velocity Data
 Upstream Velocity: Fixed Velocity
    Fixed Vel(fps): 1.0
 Channel Width(ft): ********
                 Return to Pipe Data Menu
                      Run Backwater

Select item to perform an action
```

STEP 4.

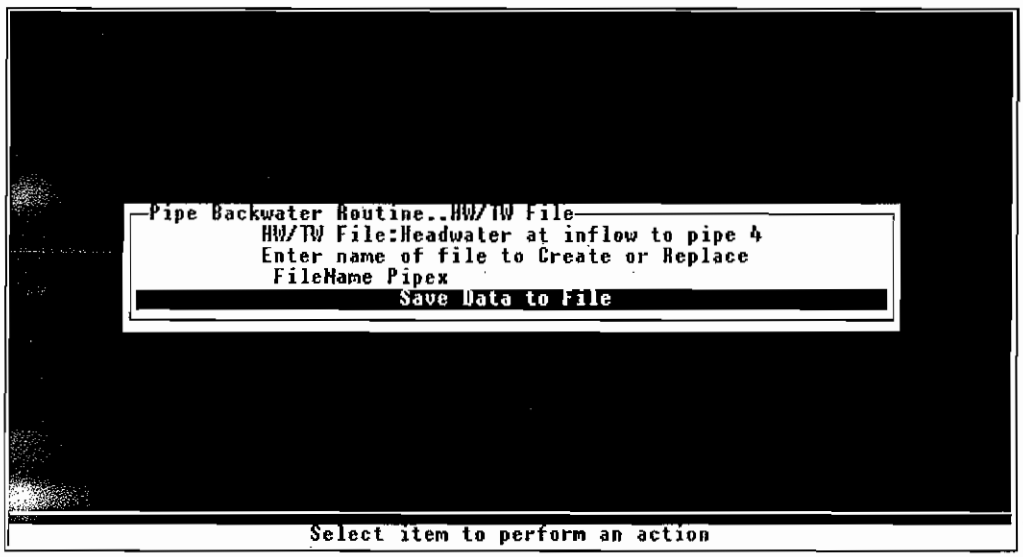
- Enter the overflow conditions for the most upstream pipe in the system. Recall that this information was not entered in the pipe data file.
- **Overflow Type** is a toggle that has three options: **None, Broad Crested Weir,** and **Sharp Crested Weir.** Leave the toggle set at **None.**
- Enter the **Overflow Elevation**. For the example problem this value is **107.5.**
- **Upstream Velocity** is a toggle that has two options, **Fixed Velocity** and **Vary as V=Q/A**, for the example set at **Fixed Vel** and enter **1.0** ft/s.
- Highlight **Run Backwater** and press ***Enter***. The output screen will flash by quickly. The output from the run has been sent to the documentation file if specified earlier.

The following menu screen will appear:



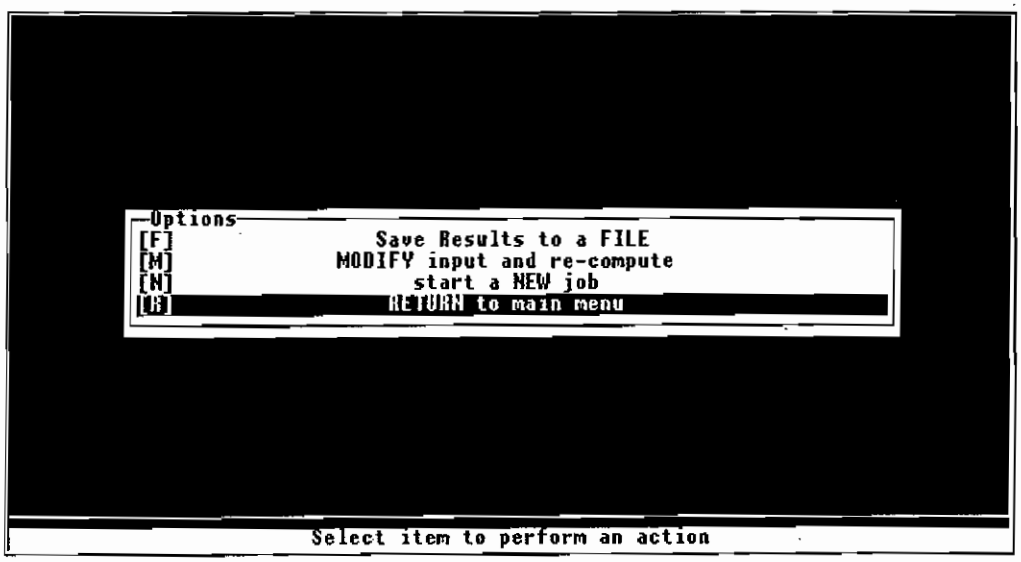
STEP 5.

Highlight **Save Data to File** and press **Enter** or press **F** to save the HW/TW file associated with the inflow at the upstream end of the system. The following menu screen will appear:



STEP 6.

Enter the **FileName** for the HW/TW file. For the example use **Pipex** the program will add a **.BWT** extension to the file name. Highlight **Save Data to File** and press **E*nter*.** We will use the HW/TW file as the tailwater condition for the open channel in the next section of the example problem. Once the file is saved the program will return to ***Options Menu.***



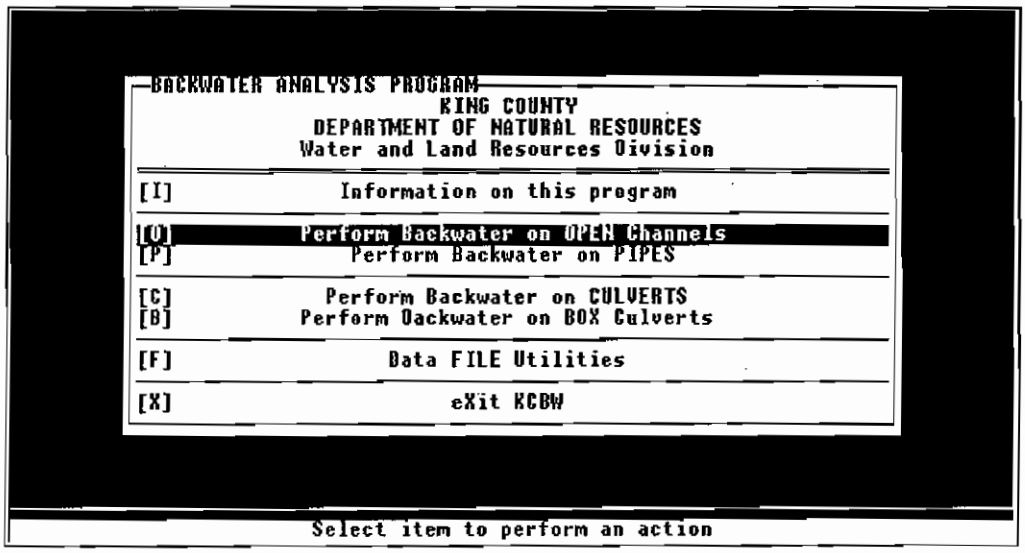
This screen allows the user to change the upstream and/or downstream conditions to the pipe file in memory by using the **Modify input and re-compute** option, start a new pipe job by using the **start a New job** or simply **Return to the main menu**.

Review and analysis of the out put from the pipe run is covered in section VIII of the Users Guide.

RUNNING THE OPEN CHANNEL ROUTINE (EXAMPLE)

The following is an example of how to perform an analysis on a previously entered channel data file. **The channel data input file must be created prior to running an analysis on the open channel.** The file created in this example is also contained in the KCBWEX folder/sub-directory included on the installation disk for the KCBW program.

STEP 1. Start the program,



STEP 2. From the Main menu,

- ➔ Highlight **[O] Perform Backwater on OPEN CHANNELS** and press **Enter**, OR
- ➔ Type **O** at the Main Menu.

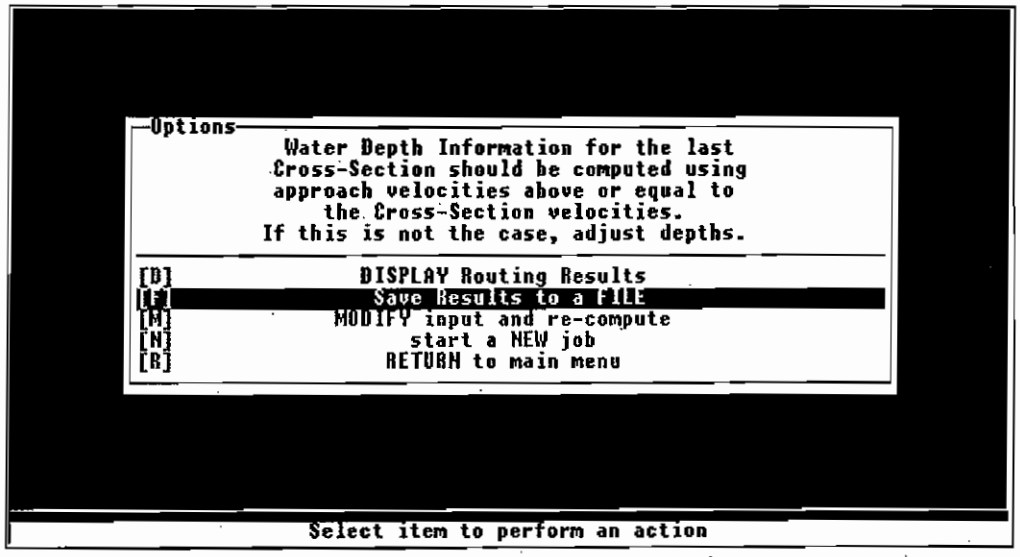
The user is then presented with the following screen:

```
Channel Data
                    Channel Data File
        File Name: Chanex.bwc
          Outflow Conditions at DownStream End
        Tailwater: From HW/TW File
        Elevation: ********
        File Name: pipex.bwt
          Downstream Discharge Information
          Minimum: 2
          Maximum: 30
        Increment: 2
                    Print Options
Documentation File chanex
     Output Width: Standard
                Run Backwater in Channel
Select item to perform an action
```

STEP 3.

- Enter the **File Name** of the **Channel Data File** created earlier in Section IV. The program assumes the file has a **.BWC** extension.
- Toggle the **Tailwater** item to **From HW/TW file.**
- Enter the tailwater **File Name** from the upstream end of the pipe system, *Pipex*.
- Enter the downstream discharge information. These values specify the range in cfs of flows that will be analyzed. For the example problem the **Minimum** is **0.0**, the **Maximum** is **30** and the **Increment** is **2** cfs.
- Enter a file name for the **Documentation File.** This file is where the program will send the output from the run. The program automatically adds a **.DOC** extension on the file. This example uses **chanex** as the documentation file name.
- **Output Width** is a toggle that has three options, **Standard, Condensed, and Expanded**. For the example problem use the **Standard** output.
- Highlight **Run Backwater in Channel** and press *Enter*. The output screen will flash by quickly. The output from the run has been sent to the documentation file if specified earlier.

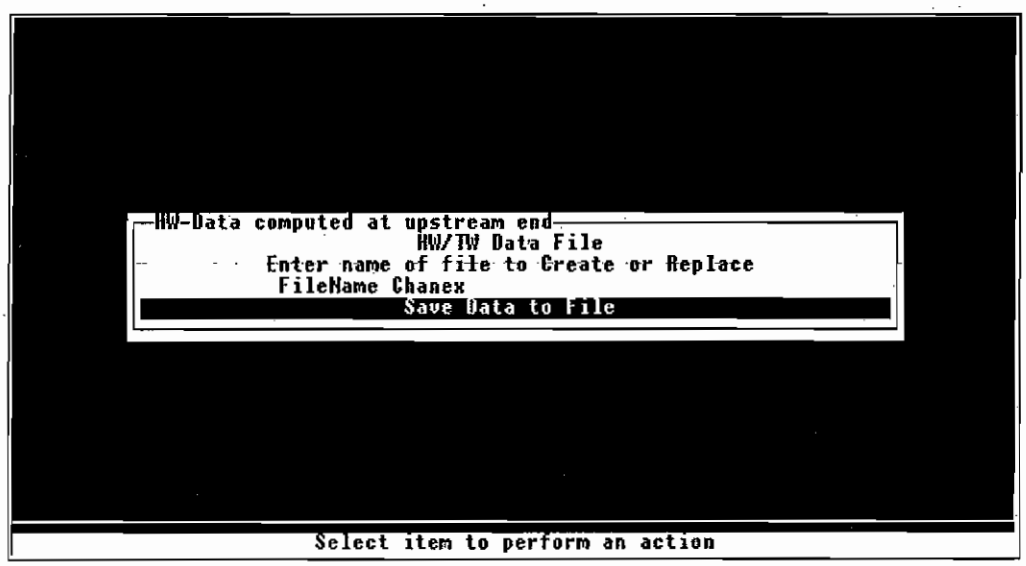
The following menu screen will appear:



STEP 4.

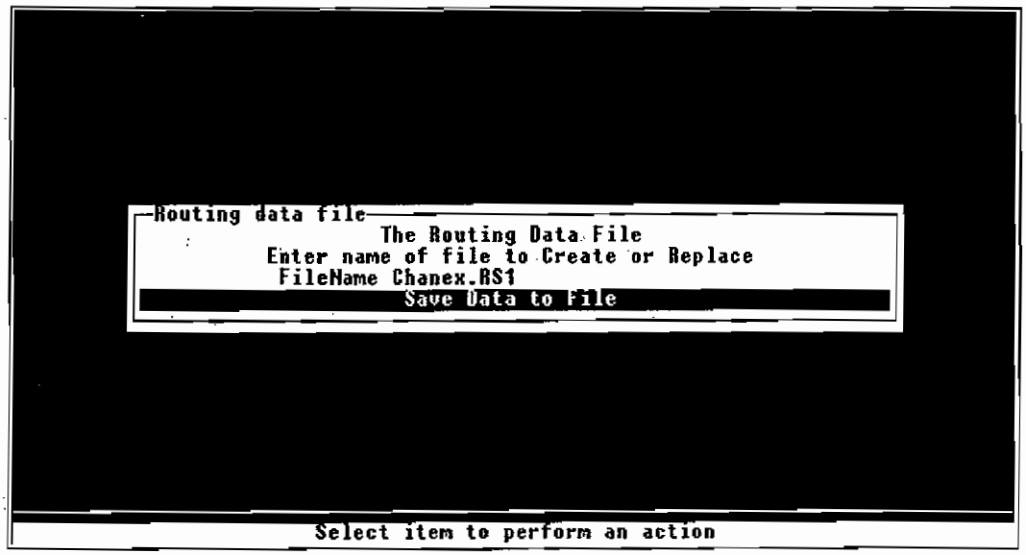
Highlight **[F] Save Results to a FILE** and press ***Enter*** or press **F** to save the HW/TW and routing information associated with the open channel.

The following screen will appear:



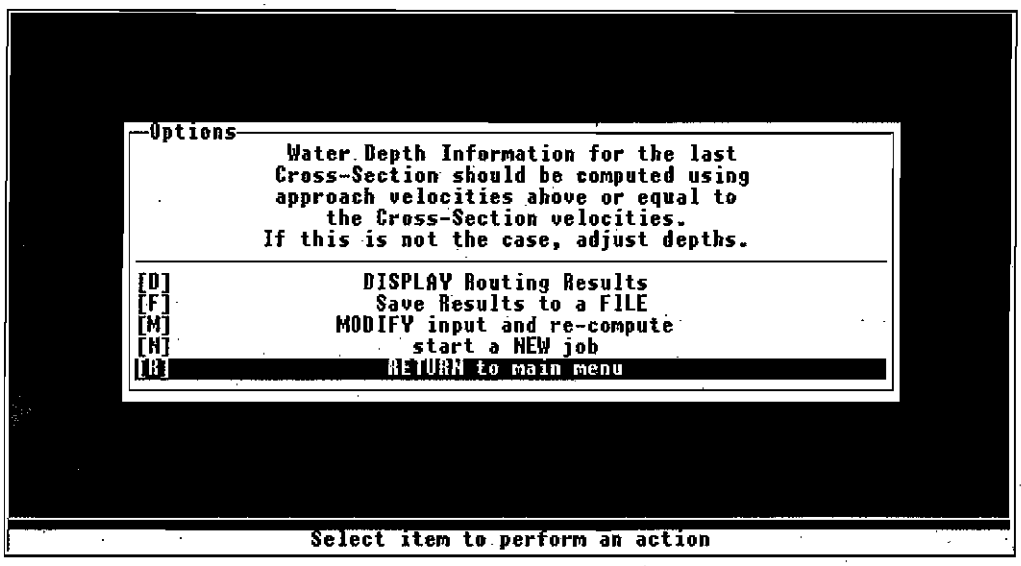
STEP 5.

Enter the file name for the HW/TW file. For the example use **Chanex**. The program will add a **.BWT** extension to the file name. Then highlight **Save Data to File** and press ***Enter***. The following screen will appear:



STEP 6.

The program will default to the same name as the HW/TW file for the RS1 file. The RS1 file is a Stage Storage Discharge table that can be used directly by KCRTS for hydrologic channel routing. Highlight **Save Data to File** and press enter. The program will return to the following screen:



Any adjustments or modifications to the run can be carried out from this menu or the user can return to the main menu.

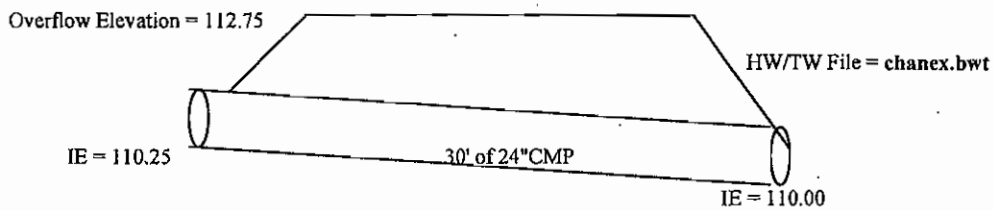
Review and analysis of the output data is covered in section VIII of the Users Guide.

RUNNING THE CULVERT ROUTINE (EXAMPLE)

The following is an example of how to perform an analysis on a culvert. Unlike the pipe and open ditch routines the culvert data is entered interactively within the **Perform Backwater on Culverts** default found on the main menu of the backwater program.

A schematic of the example culvert is shown below and data input sheets for the problem are enclosed at the end of the section.

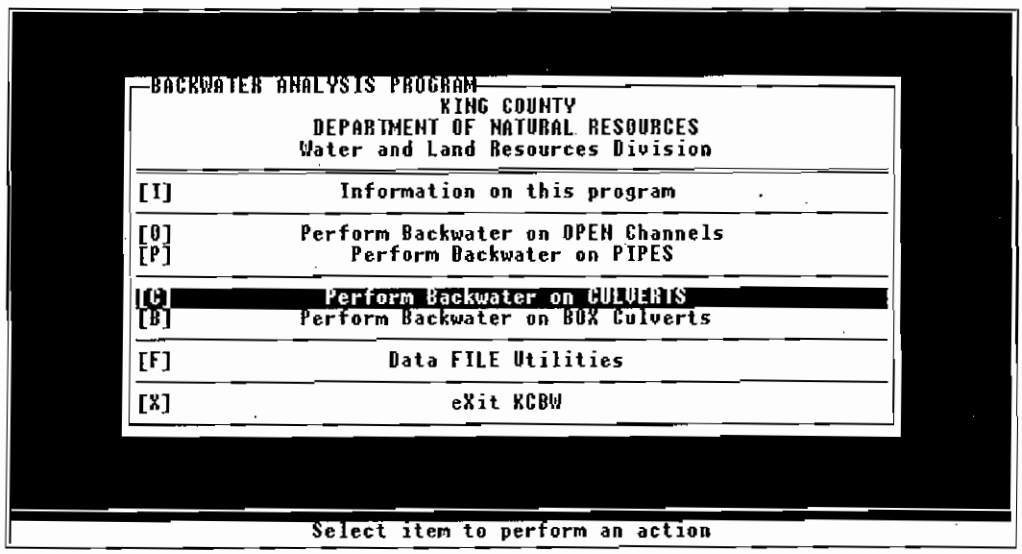
No Scale



Target PeakQ of 20cfs

Profile

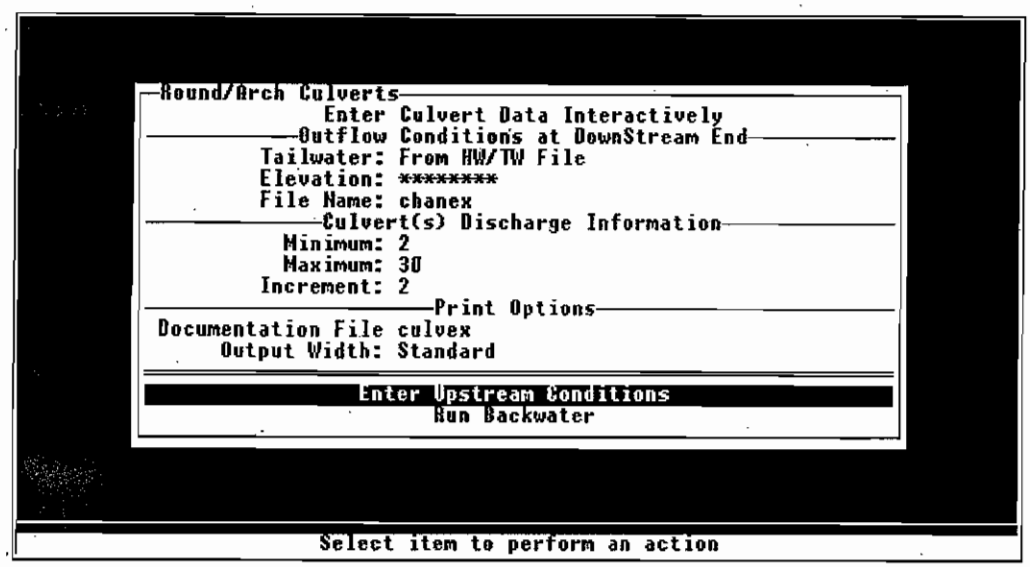
STEP 1. Start the program,



STEP 2. From the Main menu,

- ➔ Highlight **[C] Perform Backwater on Culverts** and press **Enter**, OR
- ➔ Type C at the Main Menu.

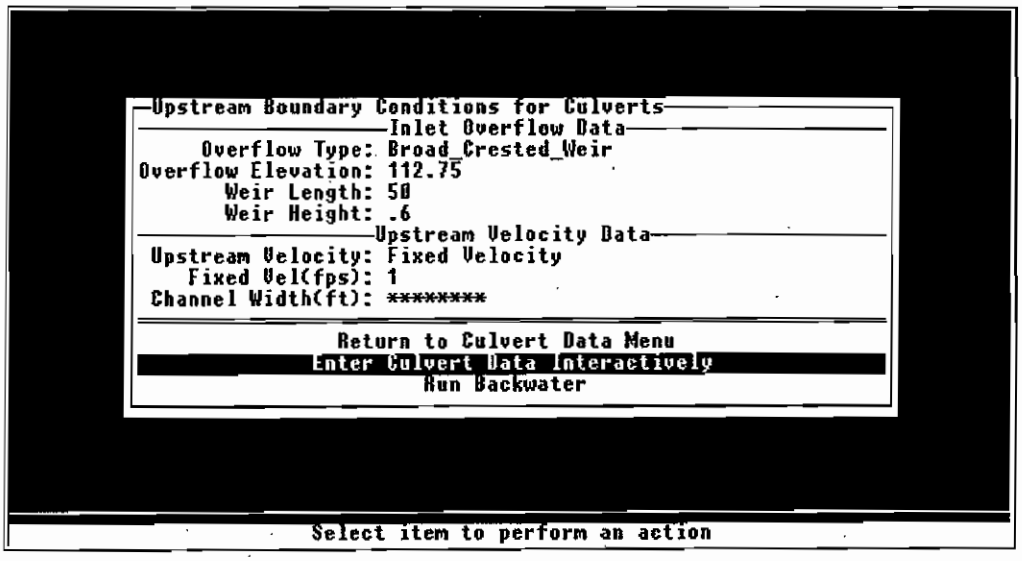
The user is then presented with the following screen:



STEP 3.

- Toggle the **Tailwater** item to **From HW/TW file.**
- Enter the tailwater **File Name** from the upstream end of the channel system, **chanex.**
- Enter the downstream discharge information. These values specify the range in cfs of flows that will be analyzed. For the example problem the **Minimum** is **0.0**, the **Maximum** is **30** and the **Increment** is **2** cfs.
- Enter a file name for the **Documentation File**. This file is where the program will send the output from the run. The program automatically adds a **.DOC** extension on the file. This example uses **culvex** as the documentation file name.
- **Output Width** is a toggle that has three options, **Standard, Condensed, and Expanded.** For the example problem use the **Standard** output.
- Highlight **Enter Upstream Conditions** and press ***Enter***.

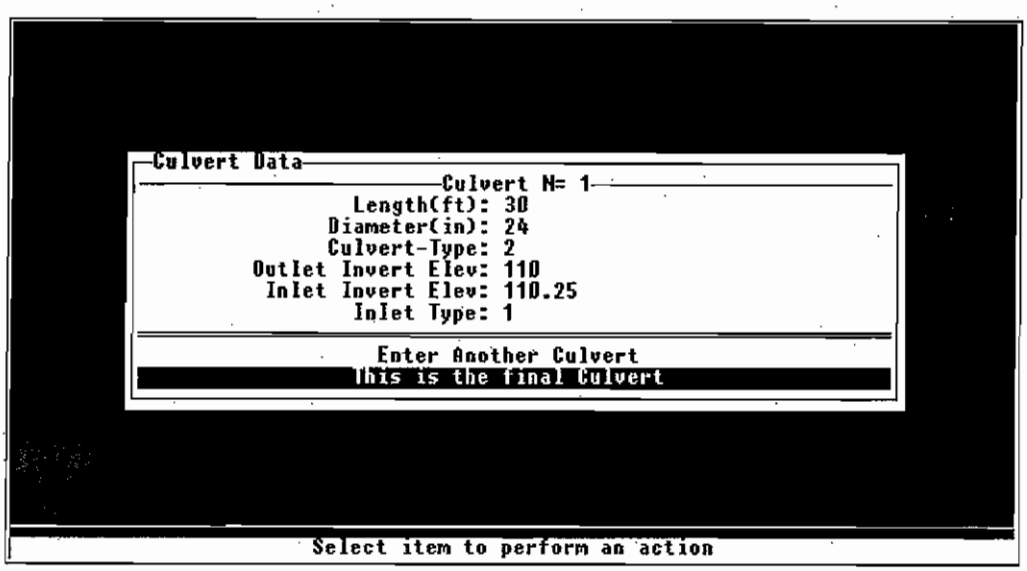
The following menu screen will appear:



STEP 4.

- Toggle the **Overflow Type** to **Broad Crested Weir**.
- Enter the **Overflow Elevation** at **112.75**.
- Enter the **Weir Elevation** to **50** feet.
- Enter the **Weir Height** to **0.6**.
- Leave the **Upstream Velocity** at **Fixed Velocity**.
- Enter the **Fixed Vel(fps)** at **1**.
- Highlight **Enter Culvert Data Interactively** and press **Enter**.

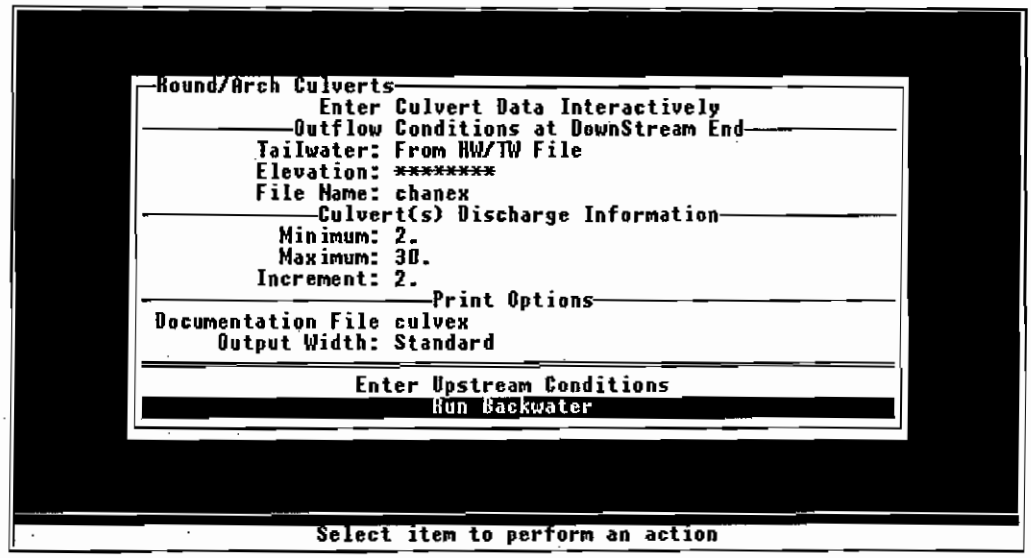
The following screen will appear:



STEP 5.

- For **Length(ft)** enter **30**.
- For **Diameter(in)** enter **24**.
- For **Outlet Culvert Elev** enter **110**.
- For **Inlet Culvert Elev** enter **110.25**.
- For **Inlet Type** enter **1**.
- Highlight **This is the Final Culvert** and press **Enter**.

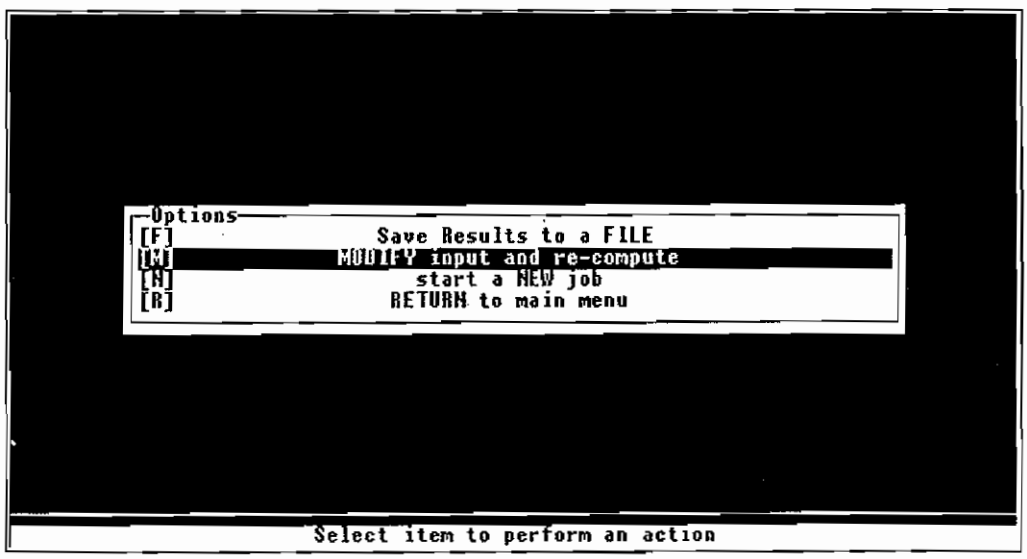
The following screen will appear:



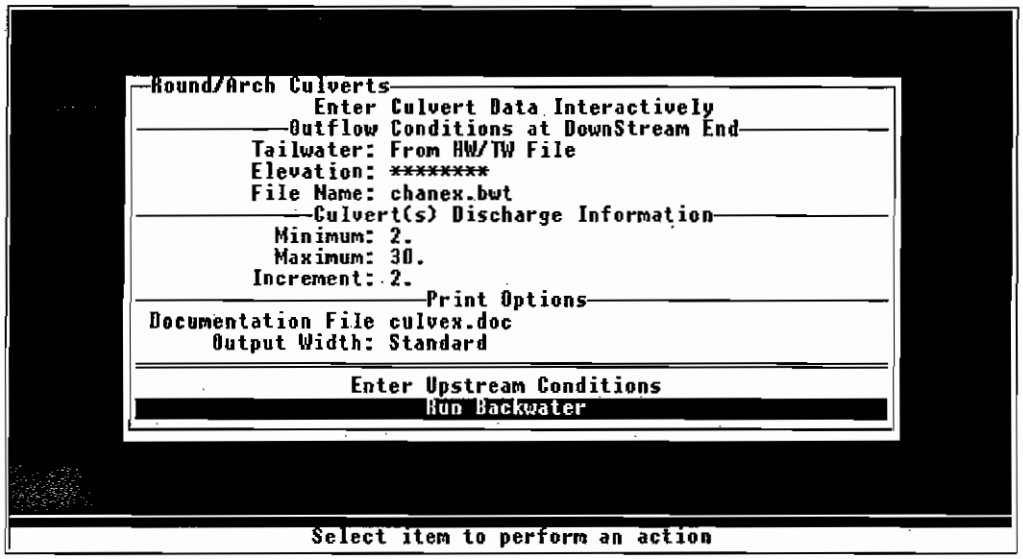
STEP 6.

Highlight **Run Backwater** and push **Enter**. The program runs the backwater calculations and outputs the results to the output screen (press **F10**) and to the text data file, **culvex.doc**, specified under the **Documentation File** heading of the **Print Options** screen. The program will use the default filename extension DOC, if not specified.

This example has a targeted capacity of 20cfs for the culvert. After reviewing the documentation file changes to the culvert will be required to meet the 20cfs threshold. The output file shows the culvert capacity is less than 16cfs. To change the data inputs of the culvert highlight [M] **Modify input and re-compute** and press **Enter**.

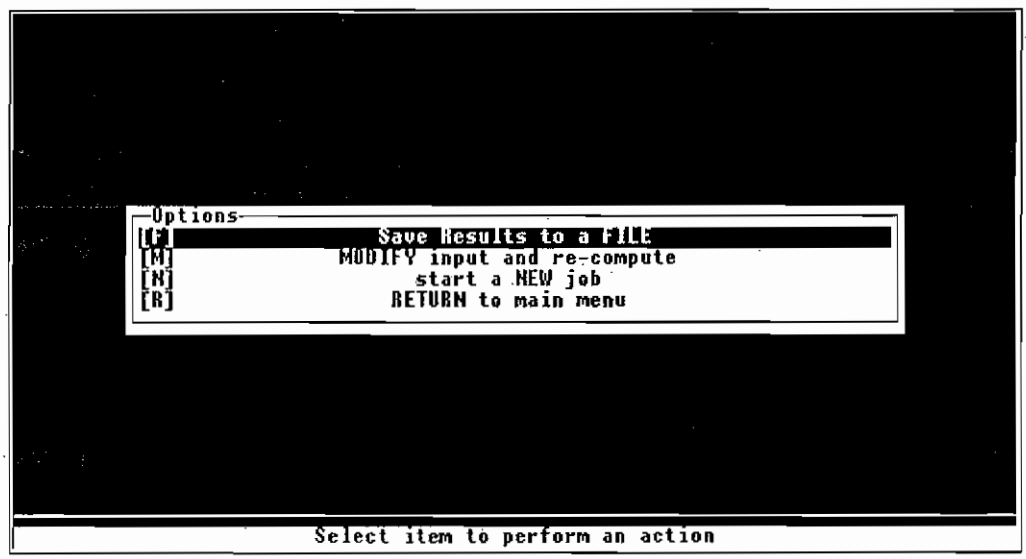


The following screen will appear:

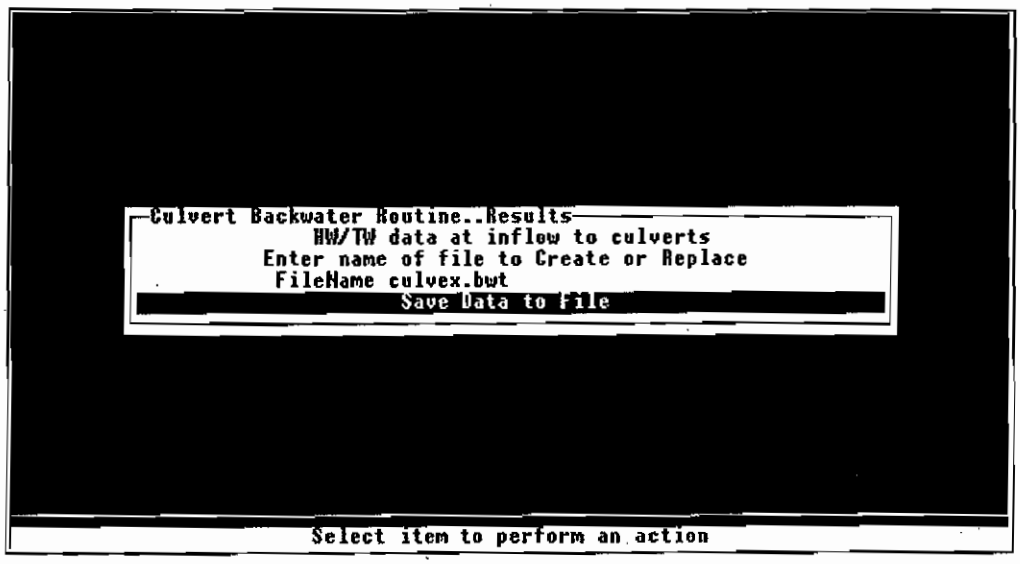


To make changes to the culvert data file to achieve the targeted capacity requirements return to **Steps 3-6.**

Once the design criteria have been matched highlight **[F] Save Results to a FILE** and push **Enter**.



The following screen will appear:



Enter **culvex** under **Filename** and toggle down to **Save Data to File** and press **Enter**. The program will automatically assign a **.bwt** default extension if one is not entered. To exit the program return to the main menu.

Review and analysis of the output data is covered in section VIII of the Users Guide.

The new version of the King County Backwater Program (KCBW) simplifies the access to the output data. The output from the specific runs is sent to the *.DOC files specified in section V and VI of the Users Guide. The files are created and stored in the Working Directory specified in the properties section of the Shortcut Icon on the Windows Desktop. The files can be viewed and printed using any text editor. If the files are simply double clicked in a Windows file viewer(My Computer, File Manager, Windows Explorer), Windows will assume they are MS Word files due to their .DOC file extension. As long as the font in the document is specified as any of the Courier group the columns in the file will be correctly aligned.

The variable descriptions for the pipe and open channel routines are contained in the Program Documentation, and in Chapter 4 of the King County Surface Water Design Manual. They are also attached to the example problem output for quick reference. These descriptions are very helpful in analyzing the output from the model. Some of the output variables listed are only available if the expanded output for the documentation file is specified during the running of the open channel, pipe, or culvert routines.

Analysis of Pipe Output Data

The pipe output from the example problem is enclosed. Included below are some notable conditions in the pipe run that the user should be aware of.

Note # 1

Pipe #'s 2 and 3 overflowed at less than the assumed flow. The program notes this but continues calculating water surface versus flow information assuming that the elevations can be achieved. Depending upon field conditions this may or may not be the case.

If the overflowing CB has a locking solid lid the excess head would be converted to pressure and the results are likely accurate although if the head is great enough the entire frame may be displaced.

If there is a grated lid the water will likely overflow or pond depending on the surrounding site topography. If the water simply overflows out of the grate the upstream capacity of the system will be underestimated at flows greater than those of the overflow.

Note # 2

The flow range and increment of the last pipe (#4) of the analysis was reduced. This is due to the Q-ratio introduced at junction/CB #3. Flow ranges must be over estimated at the downstream end to cover introduced flow along the network.

Additional Sources of Information

Schematics of inlet and outlet control conditions from FHWA HDS #5 can be very helpful in verifying the flow conditions being modeled.

BACKWATER COMPUTER PROGRAM FOR PIPES
Pipe data from file:pipex.bwp

Surcharge condition at intermediate junctions
Tailwater Elevation:0. feet
Discharge Range:2. to 30. Step of 2. [cfs]
Overflow Elevation:107.5 feet
Weir:NONE
Upstream Velocity:1. feet/sec

PIPE NO. 1: 150 LF - 24"CP @ 0.33% OUTLET: 100.00 INLET: 100.50 INTYP: 5
JUNC NO. 1: OVERFLOW-EL: 107.00 BEND: 90 DEG DIA/WIDTH: 4.0 Q-RATIO: 0.00

Q(CFS)	HW(FT)	HW ELEV.	*	N-FAC	DC	DN	TW	DO	DE	HWO	HWI
2.00	0.75	101.25	*	0.012	0.50	0.51	0.00	0.50	0.51	0.75	0.67
4.00	1.08	101.58	*	0.012	0.71	0.73	0.00	0.71	0.73	1.08	0.98
6.00	1.36	101.86	*	0.012	0.87	0.91	0.00	0.87	0.91	1.36	1.25
8.00	1.61	102.11	*	0.012	1.01	1.08	0.00	1.01	1.08	1.61	1.50
10.00	1.85	102.35	*	0.012	1.14	1.25	0.00	1.14	1.25	1.85	1.74
12.00	2.08	102.58	*	0.012	1.25	1.42	0.00	1.25	1.42	2.08	1.99
14.00	2.34	102.84	*	0.012	1.35	1.63	0.00	1.35	1.63	2.34	2.24
16.00	2.65	103.15	*	0.012	1.45	2.00	0.00	1.45	1.89	2.65	2.50
18.00	3.08	103.58	*	0.012	1.53	2.00	0.00	1.53	2.15	3.08	2.81
20.00	3.50	104.00	*	0.012	1.61	2.00	0.00	1.61	2.35	3.50	3.15
22.00	3.94	104.44	*	0.012	1.68	2.00	0.00	1.68	2.55	3.94	3.53
24.00	4.43	104.93	*	0.012	1.74	2.00	0.00	1.74	2.78	4.43	3.95
26.00	4.96	105.46	*	0.012	1.79	2.00	0.00	1.79	3.02	4.96	4.40
28.00	5.52	106.02	*	0.012	1.83	2.00	0.00	1.83	3.27	5.52	4.89
30.00	6.13	106.63	*	0.012	1.87	2.00	0.00	1.87	3.55	6.13	5.42

PIPE NO. 2: 100 LF - 24"CP @ 0.50% OUTLET: 100.50 INLET: 101.00 INTYP: 5
JUNC NO. 2: OVERFLOW-EL: 106.00 BEND: 0 DEG DIA/WIDTH: 2.0 Q-RATIO: 0.00

Q(CFS)	HW(FT)	HW ELEV.	*	N-FAC	DC	DN	TW	DO	DE	HWO	HWI
2.00	0.66	101.66	*	0.012	0.50	0.46	0.75	0.75	0.50	*****	0.66
4.00	0.95	101.95	*	0.012	0.71	0.66	1.08	1.08	0.71	*****	0.95
6.00	1.29	102.29	*	0.012	0.87	0.82	1.36	1.36	0.89	1.29	1.17
8.00	1.48	102.48	*	0.012	1.01	0.96	1.61	1.61	1.16	1.48	1.36
10.00	1.68	102.68	*	0.012	1.14	1.09	1.85	1.85	1.44	1.68	1.53
12.00	1.94	102.94	*	0.012	1.25	1.23	2.08	2.08	1.78	1.94	1.69
14.00	2.33	103.33	*	0.012	1.35	1.37	2.34	2.34	2.17	2.33	1.84
16.00	2.79	103.79	*	0.012	1.45	1.52	2.65	2.65	2.58	2.79	1.97
18.00	3.38	104.38	*	0.012	1.53	1.72	3.08	3.08	3.12	3.38	2.14
20.00	3.99	104.99	*	0.012	1.61	2.00	3.50	3.50	3.66	3.99	2.33
22.00	4.64	105.64	*	0.012	1.68	2.00	3.94	3.94	4.24	4.64	2.54

********** OVERFLOW ENCOUNTERED AT 24.00 CFS DISCHARGE **********
******** OVERFLOW CONDITIONS CALCULATED ASSUMING SURCHARGE CONDITIONS *********

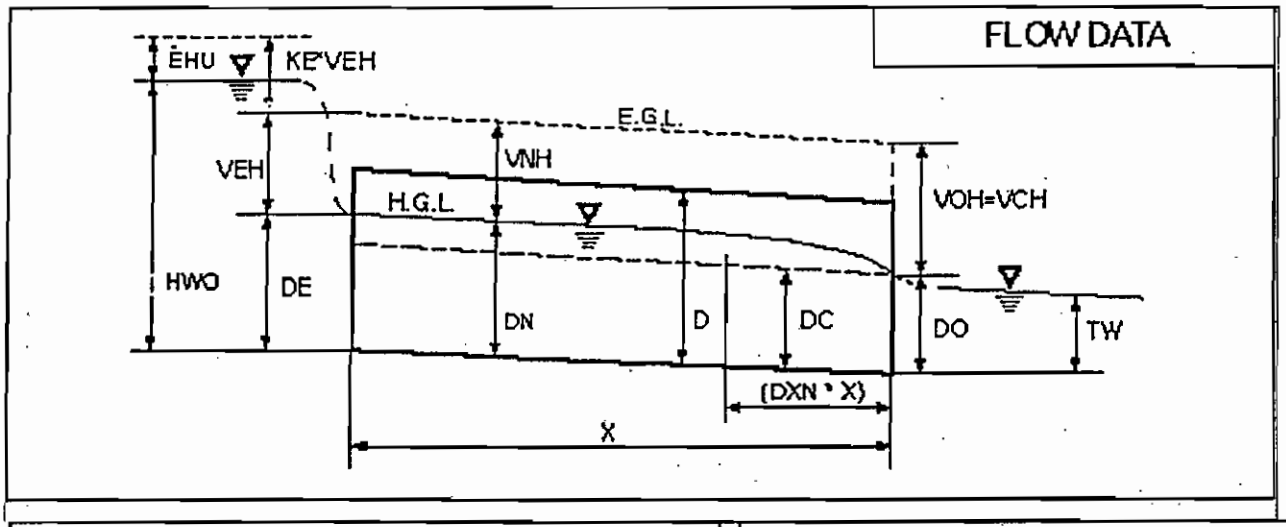
26.00	6.14	107.14	*	0.012	1.79	2.00	4.96	4.96	5.58	6.14	3.02
28.00	6.97	107.97	*	0.012	1.83	2.00	5.52	5.52	6.32	6.97	3.29
30.00	7.87	108.87	*	0.012	1.87	2.00	6.13	6.13	7.13	7.87	3.57

PIPE NO. 3: 120 LF - 24"CP @ 0.83% OUTLET: 101.00 INLET: 102.00 INTYP: 5
JUNC NO. 3: OVERFLOW-EL: 108.00 BEND: 90 DEG DIA/WIDTH: 4.0 Q-RATIO: 0.25

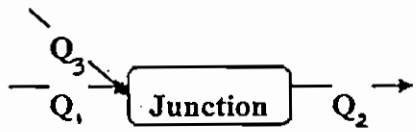
Q(CFS)	HW(FT)	HW ELEV.	* N-FAC	DC	DN	TW	DO	DE	HWO	HWI
2.00	0.66	102.66	* 0.012	0.50	0.41	0.66	0.66	0.50	*****	0.66
4.00	0.97	102.97	* 0.012	0.71	0.58	0.95	0.95	0.71	*****	0.97
6.00	1.24	103.24	* 0.012	0.87	0.71	1.29	1.29	0.87	*****	1.24
8.00	1.49	103.49	* 0.012	1.01	0.83	1.48	1.48	1.01	*****	1.49
10.00	1.74	103.74	* 0.012	1.14	0.94	1.68	1.68	1.14	*****	1.74
12.00	1.98	103.98	* 0.012	1.25	1.05	1.94	1.94	1.25	*****	1.98
14.00	2.34	104.34	* 0.012	1.35	1.15	2.33	2.33	1.63	2.34	2.24
16.00	3.04	105.04	* 0.012	1.45	1.26	2.79	2.79	2.30	3.04	2.50
18.00	3.96	105.96	* 0.012	1.53	1.36	3.38	3.38	3.03	3.96	2.80
20.00	4.94	106.94	* 0.012	1.61	1.48	3.99	3.99	3.79	4.94	3.15
********** OVERFLOW ENCOUNTERED AT 22.00 CFS DISCHARGE **********										
******** OVERFLOW CONDITIONS CALCULATED ASSUMING SURCHARGE CONDITIONS *********										
24.00	7.17	109.17	* 0.012	1.74	1.84	5.36	5.36	5.51	7.17	3.95
26.00	8.43	110.43	* 0.012	1.79	2.00	6.14	6.14	6.49	8.43	4.40
28.00	9.79	111.79	* 0.012	1.83	2.00	6.97	6.97	7.53	9.79	4.89
30.00	11.25	113.25	* 0.012	1.87	2.00	7.87	7.87	8.66	11.25	5.42

PIPE NO. 4: 75 LF - 24"CP @ 0.67% OUTLET: 102.00 INLET: 102.50 INTYP: 4

Q(CFS)	HW(FT)	HW ELEV.	* N-FAC	DC	DN	TW	DO	DE	HWO	HWI
1.60	0.57	103.07	* 0.012	0.44	0.39	0.66	0.66	0.44	*****	0.57
3.20	0.83	103.33	* 0.012	0.63	0.55	0.97	0.97	0.63	*****	0.83
4.80	1.05	103.55	* 0.012	0.78	0.67	1.24	1.24	0.78	*****	1.05
6.40	1.29	103.79	* 0.012	0.90	0.78	1.49	1.49	0.96	1.29	1.24
8.00	1.51	104.01	* 0.012	1.01	0.88	1.74	1.74	1.24	1.51	1.41
9.60	1.78	104.28	* 0.012	1.11	0.98	1.98	1.98	1.54	1.78	1.58
11.20	2.22	104.72	* 0.012	1.21	1.07	2.34	2.34	2.00	2.22	1.74
12.80	3.04	105.54	* 0.012	1.29	1.17	3.04	3.04	2.75	3.04	1.90
14.40	4.10	106.60	* 0.012	1.37	1.26	3.96	3.96	3.72	4.10	2.06
********** OVERFLOW ENCOUNTERED AT 16.00 CFS DISCHARGE **********										
16.00	5.23	107.73	* 0.012	1.45	1.36	4.94	4.94	4.76	5.23	2.20
17.60	6.45	108.95	* 0.012	1.52	1.46	6.00	6.00	5.88	6.45	2.36
19.20	7.81	110.31	* 0.012	1.58	1.58	7.17	7.17	7.13	7.81	2.54
20.80	9.27	111.77	* 0.012	1.64	1.73	8.43	8.43	8.47	9.27	2.75
22.40	10.84	113.34	* 0.012	1.69	2.00	9.79	9.79	9.91	10.84	2.97
24.00	12.54	115.04	* 0.012	1.74	2.00	11.25	11.25	11.47	12.54	3.21



FLOW DATA	COEFFICIENTS/INLET DATA
DC - Critical Depth (ft)	KE - Entrance Coefficient under Outlet Control
DN - Normal Depth (ft)	KB - Bend Loss Coefficient
TW - Tailwater Depth (ft)	KJ - Junction Loss Coefficient
DO - Outlet Depth (ft)	K - Inlet Control Equation parameter
DE - Entrance Depth (ft)	M - Inlet Control Equation parameter
HWO - Headwater (ft) assuming Outlet Control	C - Inlet Control Equation parameter (
HWI - Headwater (ft) assuming Inlet Control	Y - Inlet Control Equation parameter
DXN - Distance (expressed as a fraction of the pipe length) from the outlet to where the flow profile intersects with normal depth. DXN will equal one under full-flow conditions and will equal zero when a hydraulic jump occurs at the outlet or when normal depth equals zero (normal depth will equal zero when the pipe grade is flat or reversed).	Q-Ratio Ratio of tributary flow to main upstream flow of Q3/Q1
VBH - Barrel Velocity Head (ft) based on the average velocity determined by V=Q/Afull	
VUH - Upstream Velocity Head (ft) based on an inputted velocity.	
EHU - Upstream Energy Head (ft) available after bend losses and junction losses have been subtracted from VUH.	
VCH - Critical Depth Velocity Head (ft)	
VNH - Normal Depth Velocity Head (ft)	
VEH - Entrance Depth Velocity Head (ft)	
VOH - Outlet Depth Velocity Head (ft)	



Analysis of Open Channel Output Data

The output data from the open channel example problem is enclosed. Open channel data should always be checked carefully to see if the flows pass through critical depth.

Note # 1

The channel overflowed at various flow rates. If the channel overflows the program will assume that the channel has vertical walls and will continuing computing water surface depths based on the assumption. If there is a floodplain capable of storing, conveying or overflowing the excess flows it should be included in the cross section data.

Note # 2

The flow range was exceeded in the tailwater file. If the flow range is exceeded in the tailwater file the program extrapolates linearly from the last two points inn the HW/TW file. Over flow conditions should be confirmed to see if the extrapolated data is valid. The Headwater/Tailwater file can be modified to reflect field conditions.

Additional Information

The routing file that is created is a Stage/Storage/Discharge/Surface area table that can be used directly by the KCRTS program. The stage is relative to the invert at the downstream station/section of the reach.

Additional Sources

Flow profile classifications and their use in qualitative analysis of water surface profiles can be very useful in verifying open channel flow conditions present in existing systems or anticipated in the design of new systems. The use of these descriptive profiles is covered extensively in Open Channel Hydraulics by Chow.

```
BACKWATER COMPUTER PROGRAM FOR OPEN CHANNELS
    Channel Data Filename:chanex.bwc
Tailwater from HW/TW File:pipex.bwt
          Discharge Range:2. to 30. Step of 2. [cfs]

STATION    0.00:    INVERT= 102.50 FT    EC=1.25    Q-RATIO=0.00

CROSS-SECTION DATA:
  DIST/STAGE IS MEASURED FROM INVERT; N-FAC IS MEASURED BETWEEN STAGES

  LEFT(FT)  STAGE(FT)   N-FACTOR   *   RIGHT(FT)  STAGE(FT)   N-FACTOR
    5.00       0.00      0.080     *     5.00       0.00       0.080
   10.00       2.00      0.080     *    10.00       2.00       0.080
   25.00       5.00      0.080     *    25.00       5.00       0.080

 Q(CFS)   Y1(FT)   WS ELEV. * YC-IN YN-IN  Q-TW TW-HT  N-Y1   A-Y1  WP-Y1  V-Y1
*******************************************************************************
   2.00    0.63     103.14  *  0.12  0.32  2.00  0.63 0.080   7.36  13.42  0.27
   4.00    0.94     103.44  *  0.19  0.48  4.00  0.94 0.080  11.61  15.06  0.34
   6.00    1.23     103.73  *  0.24  0.61  6.00  1.23 0.080  16.08  16.62  0.37
   8.00    1.51     104.01  *  0.29  0.72  8.00  1.51 0.080  20.80  18.13  0.38
  10.00    1.89     104.39  *  0.33  0.82 10.00  1.89 0.080  27.83  20.18  0.36
  12.00    2.63     105.13  *  0.38  0.91 12.00  2.63 0.080  44.58  27.20  0.27
  14.00    3.84     106.33  *  0.41  0.99 14.00  3.84 0.080  83.54  39.48  0.17
**************** OVERFLOW ENCOUNTERED AT  16.00 CFS DISCHARGE ****************
  16.00    5.23     107.73  *  0.45  1.07 16.00  5.23 0.080 146.50  51.82  0.11
  18.00    6.79     109.29  *  0.49  1.14 18.00  6.79 0.080 224.50  54.94  0.08
  20.00    8.54     111.04  *  0.52  1.21 20.00  8.54 0.080 312.00  58.44  0.06
  22.00   10.45     112.95  *  0.55  1.28 22.00 10.45 0.080 407.38  62.26  0.05
  24.00   12.54     115.04  *  0.58  1.34 24.00 12.54 0.080 512.00  66.44  0.05
**************** RANGE EXCEEDED IN HW/TW FILE - DATA EXTRAPOLATED ****************
  26.00   14.66     117.17  *  0.61  1.40 26.00 14.66 0.080 618.25  70.69  0.04
  28.00   16.79     119.29  *  0.64  1.46 28.00 16.79 0.080 724.50  74.94  0.04
  30.00   18.91     121.41  *  0.67  1.52 30.00 18.91 0.080 830.75  79.19  0.04


****REACH NO. 1:    LENGTH= 300.00 FT    AVG.GRADE=  0.50% ****

STATION  300.00:    INVERT= 104.00 FT    EC=1.25    Q-RATIO=0.00

CROSS-SECTION DATA:
  DIST/STAGE IS MEASURED FROM INVERT; N-FAC IS MEASURED BETWEEN STAGES

  LEFT(FT)  STAGE(FT)   N-FACTOR   *   RIGHT(FT)  STAGE(FT)   N-FACTOR
   10.00       0.00      0.080     *    10.00       0.00       0.080
   20.00       2.00      0.080     *    20.00       2.00       0.080
   50.00       5.00      0.080     *    50.00       5.00       0.080

 Q(CFS)   Y1(FT)   WS ELEV. * YC-IN YN-IN YC-OT YN-OT  N-Y1   A-Y1  WP-Y1  V-Y1
*******************************************************************************
   2.00    0.22     104.22  *  0.08  0.22  0.08  0.22 0.080   4.64  22.24  0.43
   4.00    0.32     104.32  *  0.12  0.32  0.12  0.32 0.080   6.91  23.26  0.58
   6.00    0.43     104.43  *  0.15  0.41  0.15  0.41 0.080   9.52  24.39  0.63
   8.00    0.55     104.55  *  0.19  0.48  0.19  0.48 0.080  12.51  25.61  0.64
  10.00    0.72     104.72  *  0.21  0.55  0.21  0.55 0.080  16.99  27.34  0.59
  12.00    1.21     105.21  *  0.24  0.61  0.24  0.61 0.080  31.52  32.34  0.38
  14.00    2.35     106.35  *  0.27  0.67  0.27  0.67 0.080  75.22  47.43  0.19
  16.00    3.74     107.74  *  0.29  0.72  0.29  0.72 0.080 159.88  75.37  0.10
**************** OVERFLOW ENCOUNTERED AT  18.00 CFS DISCHARGE ****************
  18.00    5.30     109.30  *  0.31  0.77  0.31  0.77 0.080 300.00 101.30  0.06
  20.00    7.05     111.05  *  0.33  0.82  0.33  0.82 0.080 475.01 104.80  0.04
  22.00    8.95     112.95  *  0.36  0.86  0.36  0.86 0.080 665.01 108.60  0.03
  24.00   11.04     115.04  *  0.38  0.90  0.38  0.90 0.080 874.02 112.78  0.03
  26.00   13.17     117.17  *  0.40  0.95  0.40  0.95 0.0801087.02 117.04  0.02
  28.00   15.29     119.29  *  0.41  0.99  0.41  0.99 0.0801299.03 121.28  0.02
  30.00   17.42     121.42  *  0.43  1.03  0.43  1.03 0.0801512.03 125.54  0.02
```

****REACH NO. 2: LENGTH= 300.00 FT AVG.GRADE= 0.50% ****

STATION 600.00: INVERT= 105.50 FT EC=1.25 Q-RATIO=0.00

CROSS-SECTION DATA:
DIST/STAGE IS MEASURED FROM INVERT; N-FAC IS MEASURED BETWEEN STAGES

LEFT(FT)	STAGE(FT)	N-FACTOR	*	RIGHT(FT)	STAGE(FT)	N-FACTOR
10.00	0.00	0.080	*	10.00	0.00	0.080
20.00	2.00	0.080	*	20.00	2.00	0.080
50.00	5.00	0.080	*	50.00	5.00	0.080

Q(CFS)	Y1(FT)	WS ELEV.	*	YC-IN	YN-IN	YC-OT	YN-OT	N-Y1	A-Y1	WP-Y1	V-Y1
2.00	0.22	105.72	*	0.08	0.22	0.08	0.22	0.080	4.64	22.24	0.43
4.00	0.32	105.82	*	0.12	0.32	0.12	0.32	0.080	6.91	23.26	0.58
6.00	0.41	105.91	*	0.15	0.41	0.15	0.41	0.080	9.04	24.18	0.66
8.00	0.48	105.98	*	0.19	0.48	0.19	0.48	0.080	10.75	24.90	0.74
10.00	0.55	106.05	*	0.21	0.55	0.21	0.55	0.080	12.51	25.61	0.80
12.00	0.61	106.11	*	0.24	0.61	0.24	0.61	0.080	14.06	26.22	0.85
14.00	1.02	106.52	*	0.27	0.67	0.27	0.67	0.080	25.60	30.40	0.55
16.00	2.26	107.76	*	0.29	0.72	0.29	0.72	0.080	71.08	45.62	0.23
18.00	3.81	109.31	*	0.31	0.77	0.31	0.77	0.080	165.16	76.78	0.11
********** OVERFLOW ENCOUNTERED AT 20.00 CFS DISCHARGE **********											
20.00	5.56	111.06	*	0.33	0.82	0.33	0.82	0.080	326.00	101.82	0.06
22.00	7.46	112.96	*	0.36	0.86	0.36	0.86	0.080	516.01	105.62	0.04
24.00	9.55	115.05	*	0.38	0.90	0.38	0.90	0.080	725.01	109.80	0.03
26.00	11.68	117.18	*	0.40	0.95	0.40	0.95	0.080	938.02	114.06	0.03
28.00	13.80	119.30	*	0.41	0.99	0.41	0.99	0.0801	150.02	118.30	0.02
30.00	15.93	121.43	*	0.43	1.03	0.43	1.03	0.0801	363.03	122.56	0.02

****REACH NO. 3: LENGTH= 300.00 FT AVG.GRADE= 0.50% ****

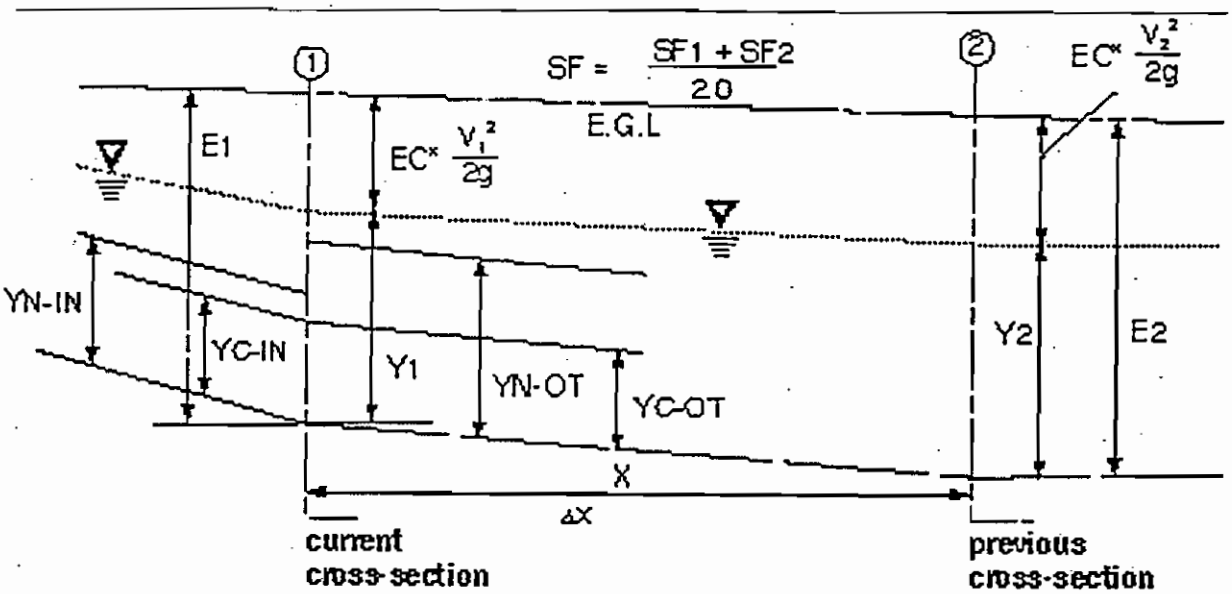
STATION 900.00: INVERT= 107.00 FT EC=1.25 Q-RATIO=0.00

CROSS-SECTION DATA:
DIST/STAGE IS MEASURED FROM INVERT; N-FAC IS MEASURED BETWEEN STAGES

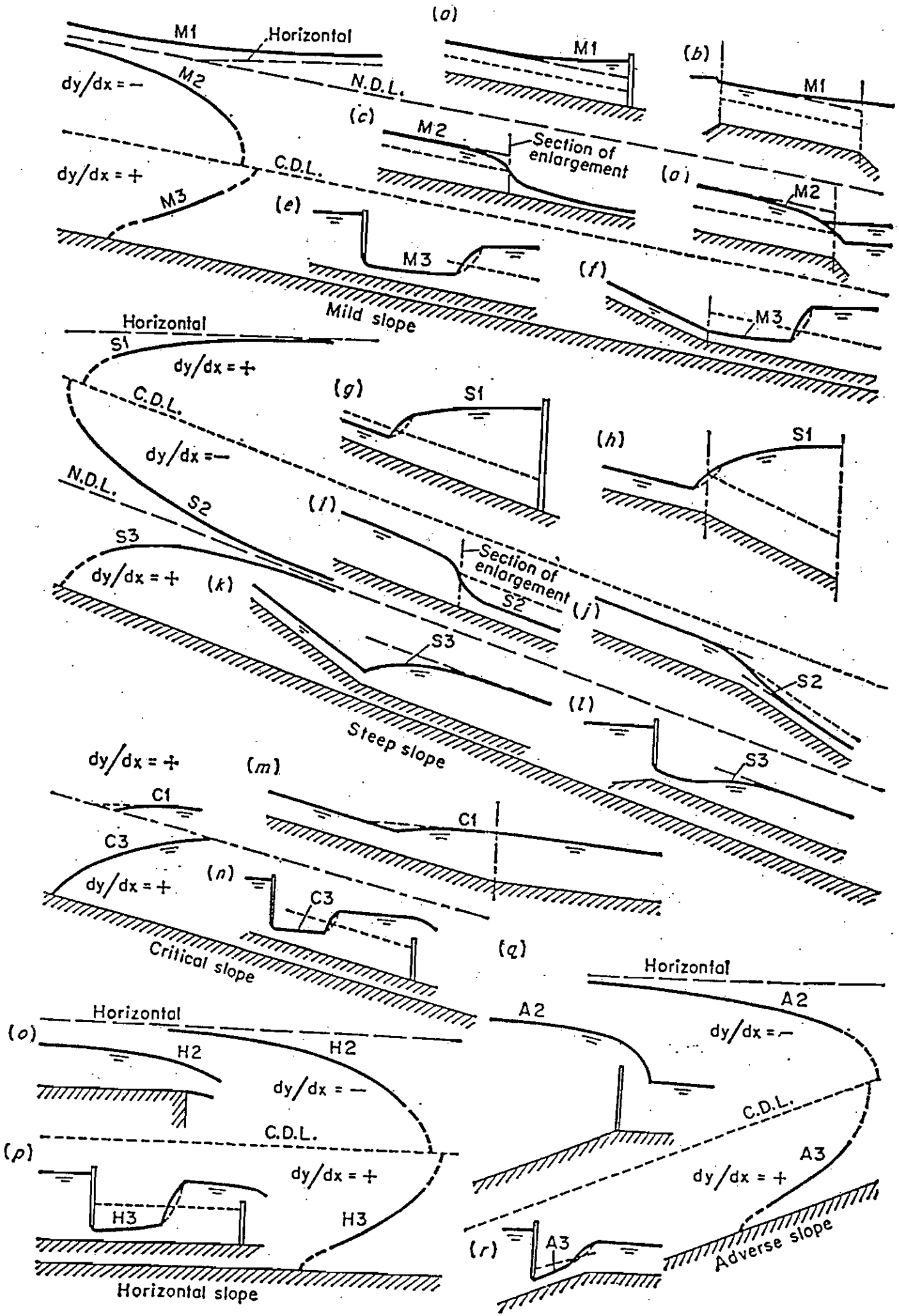
LEFT(FT)	STAGE(FT)	N-FACTOR	*	RIGHT(FT)	STAGE(FT)	N-FACTOR
10.00	0.00	0.080	*	10.00	0.00	0.080
20.00	2.00	0.080	*	20.00	2.00	0.080
50.00	5.00	0.080	*	50.00	5.00	0.080

Q(CFS)	Y1(FT)	WS ELEV.	*	YC-IN	YN-IN	YC-OT	YN-OT	N-Y1	A-Y1	WP-Y1	V-Y1
2.00	0.22	107.22	*	0.08	0.22	0.08	0.22	0.080	4.64	22.24	0.43
4.00	0.32	107.32	*	0.12	0.32	0.12	0.32	0.080	6.91	23.26	0.58
6.00	0.41	107.41	*	0.15	0.41	0.15	0.41	0.080	9.04	24.18	0.66
8.00	0.48	107.48	*	0.19	0.48	0.19	0.48	0.080	10.75	24.90	0.74
10.00	0.55	107.55	*	0.21	0.55	0.21	0.55	0.080	12.51	25.61	0.80
12.00	0.61	107.61	*	0.24	0.61	0.24	0.61	0.080	14.06	26.22	0.85
14.00	0.67	107.67	*	0.27	0.67	0.27	0.67	0.080	15.64	26.83	0.89
16.00	1.00	108.00	*	0.29	0.72	0.29	0.72	0.080	25.00	30.20	0.64
18.00	2.33	109.33	*	0.31	0.77	0.31	0.77	0.080	74.29	47.03	0.24
20.00	4.07	111.07	*	0.33	0.82	0.33	0.82	0.080	185.65	82.00	0.11
********** OVERFLOW ENCOUNTERED AT 22.00 CFS DISCHARGE **********											
22.00	5.97	112.97	*	0.36	0.86	0.36	0.86	0.080	367.00	102.64	0.06
24.00	8.06	115.06	*	0.38	0.90	0.38	0.90	0.080	576.01	106.82	0.04
26.00	10.19	117.19	*	0.40	0.95	0.40	0.95	0.080	789.01	111.08	0.03
28.00	12.31	119.31	*	0.41	0.99	0.41	0.99	0.0801	001.02	115.32	0.03
30.00	14.44	121.44	*	0.43	1.03	0.43	1.03	0.0801	214.02	119.58	0.02

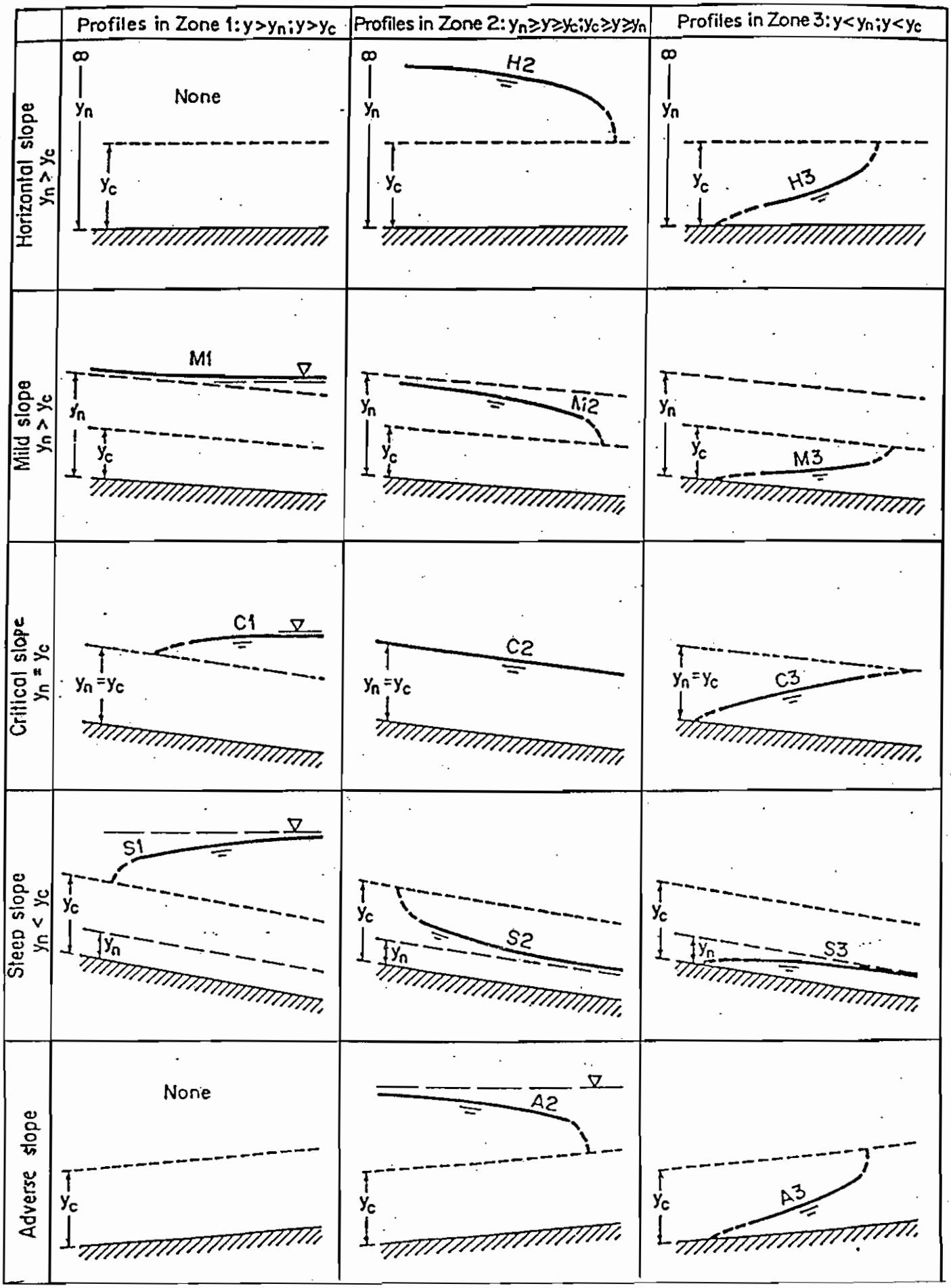
```
****REACH NO. 4:     LENGTH= 600.00 FT     AVG.GRADE=  0.50% ****

STATION 1500.00:     INVERT= 110.00 FT     EC=1.25     Q-RATIO=0.00

CROSS-SECTION DATA:
  DIST/STAGE IS MEASURED FROM INVERT; N-FAC IS MEASURED BETWEEN STAGES

  LEFT(FT)   STAGE(FT)   N-FACTOR   *   RIGHT(FT)   STAGE(FT)   N-FACTOR
   10.00       0.00       0.080     *     10.00       0.00       0.080
   20.00       2.00       0.080     *     20.00       2.00       0.080
   50.00       5.00       0.080     *     50.00       5.00       0.080

 Q(CFS)   Y1(FT)   WS ELEV. * YC-IN YN-IN YC-OT YN-OT  N-Y1   A-Y1  WP-Y1  V-Y1
*****************************************************************************
   2.00     0.22     110.22  *  0.08  0.00  0.08  0.22 0.080   4.64  22.24  0.43
   4.00     0.32     110.32  *  0.12  0.00  0.12  0.32 0.080   6.91  23.26  0.58
   6.00     0.41     110.41  *  0.15  0.00  0.15  0.41 0.080   9.04  24.18  0.66
   8.00     0.48     110.48  *  0.19  0.00  0.19  0.48 0.080  10.75  24.90  0.74
  10.00     0.55     110.55  *  0.21  0.00  0.21  0.55 0.080  12.51  25.61  0.80
  12.00     0.61     110.61  *  0.24  0.00  0.24  0.61 0.080  14.06  26.22  0.85
  14.00     0.67     110.67  *  0.27  0.00  0.27  0.67 0.080  15.64  26.83  0.89
  16.00     0.72     110.72  *  0.29  0.00  0.29  0.72 0.080  16.99  27.34  0.94
  18.00     0.78     110.78  *  0.31  0.00  0.31  0.77 0.080  18.64  27.95  0.97
  20.00     1.33     111.33  *  0.33  0.00  0.33  0.82 0.080  35.44  33.56  0.56
  22.00     2.99     112.99  *  0.36  0.00  0.36  0.86 0.080 109.40  60.29  0.20
**************** OVERFLOW ENCOUNTERED AT  24.00 CFS DISCHARGE ****************
  24.00     5.07     115.07  *  0.38  0.00  0.38  0.90 0.080 277.00 100.84  0.09
  26.00     7.20     117.20  *  0.40  0.00  0.40  0.95 0.080 490.01 105.10  0.05
  28.00     9.32     119.32  *  0.41  0.00  0.41  0.99 0.080 702.01 109.34  0.04
  30.00    11.45     121.45  *  0.43  0.00  0.43  1.03 0.080 915.02 113.60  0.03

Save results to HW/TW file:chanex.bwt
Save results to Routing file:chanex.RS1
```



	BWCHAN – VARIABLE DEFINITIONS
YC-IN	Critical Depth (ft) at current section based on ***incoming*** flow rate.
YC-OUT	Critical Depth (ft) at current section based on ***outgoing*** flow rate.
YN-IN	Normal Depth (ft) at current section based on ***incoming*** flow rate/channel grade.
YN-OUT	Normal Depth (ft) at current section based on ***outgoing*** flow rate/channel grade.
Y1	Final Water Depth (ft) at current cross section
N-Y1	Composite n-factor of current section for final depth, Y1.
A-Y1	Cross-sectional Area of current section for final depth, Y1.
WP-Y1	Wetted Perimeter (ft) of current section for final depth, Y1.
V-Y1	Average Velocity (fps) of current section for final depth, Y1.
E1	Total Energy Head (ft) at current section $(Y1 + EC * V_1^2 / 2g)$
E2	Total Energy Head (ft) at pervious or downstream section.
SF1	Friction Slope of current section.
SF2	Friction Slope of previous or downstream section.
DXY	Distance (expressed as a fraction of the current reach length) from the previous or downstream section to where the flow profile would intersect the final water depth, Y1, assuming Y1 were to remain constant
EC	Energy Coefficient "α"
Q-TW	The flow rate used to determine Tailwater Height from an inputted HW/TW Data File.
TW-HT	Tailwater Height.
Q-Y1	Flow rate (cfs) in channel at current section, for depth, Y1
VU-Y1	Upstream Velocity (fps) at current section for depth, Y1 ("Adjust" option).
V1-HD	Channel Velocity Head (ft) at current section.
VU-HD	Upstream Velocity Head (ft) at current section.


(a)
M1
Horizontal
dy/dx = −
M2
N.D.L.
(b)
M1
(c)
M2
Section of enlargement
C.D.L.
dy/dx = +
M3
(d)
M2
(e)
M3
(f)
M3
Mild slope
Horizontal
S1
dy/dx = +
C.D.L.
(g)
S1
(h)
S1
dy/dx = −
N.D.L.
S2
(i)
S3
Section of enlargement
S2
dy/dx = +
(k)
(j)
S3
S2
(l)
Steep slope
S3
dy/dx = +
(m)
C1
C1
C3
dy/dx = +
(n)
C3
Critical slope
(q)
Horizontal
A2
A2
dy/dx = −
Horizontal
(o)
H2
H2
dy/dx = −
C.D.L.
(p)
dy/dx = +
H3
H3
Horizontal slope
C.D.L.
A3
dy/dx = +
(r)
A3
Adverse slope

GRADUALLY VARIED FLOW



```
BACKWATER PROGRAM FOR ROUND/ARCH CULVERTS
Tailwater from HW/TW File:chanex.bwt
          Discharge Range:2. to 30. Step of 2. [cfs]
       Overflow Elevation:112.75  feet
       Broad Crested Weir: Length:50. feet, Height:0.6 feet
        Upstream Velocity:1. feet/sec


CULV NO. 1:   30 LF - 24"CMP  @  0.83%  OUTLET: 110.00  INLET: 110.25  INTYP: 1

            TW DATA ADJUSTED BASED ON CROSS-SECTIONAL AREA
     Q-TOT(CFS)   TW(FT)   TW-ELEV(FT)  Q-ADJ(CFS)   AREA(SQ-FT)
*****************************************************************
        0.00       0.00      110.00        0.00         0.00
        2.00       0.15      110.15        2.00         0.11
        4.00       0.23      110.23        4.00         0.20
        6.00       0.30      110.30        6.00         0.30
        8.00       0.36      110.36        8.00         0.38
       10.00       0.41      110.41       10.00         0.46
       12.00       0.46      110.46       12.00         0.55
       14.00       0.50      110.50       14.00         0.61
       16.00       0.55      110.55       16.00         0.70
       18.00       0.62      110.62       18.00         0.83
       20.00       1.24      111.24       20.00         2.05
       22.00       2.99      112.99       22.00         3.14
       24.00       5.07      115.07       24.00         3.14
       26.00       7.20      117.20       26.00         3.14
       28.00       9.32      119.32       28.00         3.14
       30.00      11.45      121.45       30.00         3.14

 Q(CFS)   HW(FT)   HW ELEV. * N-FAC   DC    DN    TW    DO    DE    HWO    HWI
*******************************************************************************
   2.00     0.77     111.02  * 0.024  0.50  0.58  0.15  0.50  0.58   0.77   0.66
   4.00     1.13     111.38  * 0.024  0.71  0.83  0.23  0.71  0.83   1.13   0.99
   6.00     1.42     111.67  * 0.024  0.87  1.05  0.30  0.87  1.05   1.42   1.28
   8.00     1.68     111.93  * 0.024  1.01  1.26  0.36  1.01  1.26   1.68   1.54
  10.00     1.94     112.19  * 0.024  1.14  1.48  0.41  1.14  1.47   1.94   1.80
  12.00     2.19     112.44  * 0.024  1.25  1.84  0.46  1.25  1.65   2.19   2.05
  14.00     2.46     112.71  * 0.024  1.35  2.00  0.50  1.35  1.84   2.46   2.31
**************** OVERFLOW ENCOUNTERED AT  16.00 CFS DISCHARGE *****************
  16.00     2.50     112.75  * 0.024  1.45  2.00  0.55  1.45  2.06   2.81   2.53


                    TOTAL "HW" VS."Q" DATA PRINT-OUT

                      Q(CFS)   HW(FT)   HW-ELEV(FT)
   ********************************************************************
                       2.00     0.77      111.02
                       4.00     1.13      111.38
                       6.00     1.42      111.67
                       8.00     1.68      111.93
                      10.00     1.94      112.19
                      12.00     2.19      112.44
                      14.00     2.45      112.70
**************** OVERFLOW ENCOUNTERED AT  16.00 CFS DISCHARGE *****************
********** THE FOLLOWING DATA INCLUDES CULVERT FLOW PLUS WEIR FLOW ***********
                      16.00     2.50      112.75
                      18.00     2.63      112.88
                      20.00     2.68      112.93
                      22.00     2.72      112.97
                      24.00     3.18      113.43
```

```
26.00      3.18      113.43
28.00      3.18      113.43
30.00      3.18      113.43
```

```
BACKWATER PROGRAM FOR ROUND/ARCH CULVERTS
Tailwater from HW/TW File:chanex.bwt
          Discharge Range:2. to 30. Step of 2. [cfs]
       Overflow Elevation:112.75  feet
       Broad Crested Weir: Length:50. feet, Height:0.6 feet
        Upstream Velocity:1. feet/sec

CULV NO. 1:   30 LF - 24"CP   @  0.83%  OUTLET: 110.00  INLET: 110.25  INTYP: 6
```

TW DATA ADJUSTED BASED ON CROSS-SECTIONAL AREA

Q-TOT (CFS)	TW(FT)	TW-ELEV(FT)	Q-ADJ(CFS)	AREA(SQ-FT)
0.00	0.00	110.00	0.00	0.00
2.00	0.15	110.15	2.00	0.11
4.00	0.23	110.23	4.00	0.20
6.00	0.30	110.30	6.00	0.30
8.00	0.36	110.36	8.00	0.38
10.00	0.41	110.41	10.00	0.46
12.00	0.46	110.46	12.00	0.55
14.00	0.50	110.50	14.00	0.61
16.00	0.55	110.55	16.00	0.70
18.00	0.62	110.62	18.00	0.83
20.00	1.24	111.24	20.00	2.05
22.00	2.99	112.99	22.00	3.14
24.00	5.07	115.07	24.00	3.14
26.00	7.20	117.20	26.00	3.14
28.00	9.32	119.32	28.00	3.14
30.00	11.45	121.45	30.00	3.14

Q(CFS)	HW(FT)	HW ELEV.	* N-FAC	DC	DN	TW	DO	DE	HWO	HWI
2.00	0.64	110.89	* 0.012	0.50	0.41	0.15	0.41	0.50	*****	0.64
4.00	0.95	111.20	* 0.012	0.71	0.58	0.23	0.58	0.71	*****	0.95
6.00	1.20	111.45	* 0.012	0.87	0.71	0.30	0.71	0.87	*****	1.20
8.00	1.43	111.68	* 0.012	1.01	0.83	0.36	0.83	1.01	*****	1.43
10.00	1.65	111.90	* 0.012	1.14	0.94	0.41	0.94	1.14	*****	1.65
12.00	1.86	112.11	* 0.012	1.25	1.05	0.46	1.05	1.25	*****	1.86
14.00	2.08	112.33	* 0.012	1.35	1.15	0.50	1.15	1.35	*****	2.08
16.00	2.26	112.51	* 0.012	1.45	1.26	0.55	1.26	1.45	*****	2.26
18.00	2.41	112.66	* 0.012	1.53	1.36	0.62	1.36	1.53	*****	2.41
********** OVERFLOW ENCOUNTERED AT 20.00 CFS DISCHARGE **********										
20.00	2.50	112.75	* 0.012	1.61	1.48	1.24	1.48	1.61	*****	2.64

TOTAL "HW" VS."Q" DATA PRINT-OUT

Q(CFS)	HW(FT)	HW-ELEV(FT)
2.00	0.64	110.89
4.00	0.95	111.20
6.00	1.20	111.45
8.00	1.43	111.68
10.00	1.65	111.90
12.00	1.86	112.11
14.00	2.08	112.33
16.00	2.26	112.51
18.00	2.41	112.66

********** OVERFLOW ENCOUNTERED AT 20.00 CFS DISCHARGE **********

********** THE FOLLOWING DATA INCLUDES CULVERT FLOW PLUS WEIR FLOW **********

20.00	2.50	112.75

22.00	2.64	112.89
24.00	3.88	114.13
26.00	3.88	114.13
28.00	3.88	114.13
30.00	3.88	114.13

```
BACKWATER PROGRAM FOR ROUND/ARCH CULVERTS
Tailwater from HW/TW File:chanex.bwt
          Discharge Range:2. to 30. Step of 2. [cfs]
       Overflow Elevation:113.  feet
       Broad Crested Weir: Length:50. feet, Height:0.6 feet
        Upstream Velocity:1. feet/sec

CULV NO. 1:   30 LF - 24"CP   @  0.83%  OUTLET: 110.00  INLET: 110.25  INTYP: 6

            TW DATA ADJUSTED BASED ON CROSS-SECTIONAL AREA
     Q-TOT(CFS)   TW(FT)   TW-ELEV(FT)   Q-ADJ(CFS)   AREA(SQ-FT)
*****************************************************************
        0.00       0.00      110.00        0.00         0.00
        2.00       0.15      110.15        2.00         0.11
        4.00       0.23      110.23        4.00         0.20
        6.00       0.30      110.30        6.00         0.30
        8.00       0.36      110.36        8.00         0.38
       10.00       0.41      110.41       10.00         0.46
       12.00       0.46      110.46       12.00         0.55
       14.00       0.50      110.50       14.00         0.61
       16.00       0.55      110.55       16.00         0.70
       18.00       0.62      110.62       18.00         0.83
       20.00       1.24      111.24       20.00         2.05
       22.00       2.99      112.99       22.00         3.14
       24.00       5.07      115.07       24.00         3.14
       26.00       7.20      117.20       26.00         3.14
       28.00       9.32      119.32       28.00         3.14
       30.00      11.45      121.45       30.00         3.14

 Q(CFS)   HW(FT)   HW ELEV. * N-FAC   DC    DN    TW    DO    DE    HWO    HWI
*******************************************************************************
   2.00    0.64     110.89  * 0.012  0.50  0.41  0.15  0.41  0.50  *****  0.64
   4.00    0.95     111.20  * 0.012  0.71  0.58  0.23  0.58  0.71  *****  0.95
   6.00    1.20     111.45  * 0.012  0.87  0.71  0.30  0.71  0.87  *****  1.20
   8.00    1.43     111.68  * 0.012  1.01  0.83  0.36  0.83  1.01  *****  1.43
  10.00    1.65     111.90  * 0.012  1.14  0.94  0.41  0.94  1.14  *****  1.65
  12.00    1.86     112.11  * 0.012  1.25  1.05  0.46  1.05  1.25  *****  1.86
  14.00    2.08     112.33  * 0.012  1.35  1.15  0.50  1.15  1.35  *****  2.08
  16.00    2.26     112.51  * 0.012  1.45  1.26  0.55  1.26  1.45  *****  2.26
  18.00    2.41     112.66  * 0.012  1.53  1.36  0.62  1.36  1.53  *****  2.41
  20.00    2.64     112.89  * 0.012  1.61  1.48  1.24  1.48  1.61  *****  2.64
**************** OVERFLOW ENCOUNTERED AT  22.00 CFS DISCHARGE ****************
  22.00    2.75     113.00  * 0.012  1.68  1.61  2.99  2.99  2.99   3.89   2.89


                    TOTAL "HW" VS."Q" DATA PRINT-OUT

                      Q(CFS)   HW(FT)   HW-ELEV(FT)
*******************************************************************
                       2.00     0.64      110.89
                       4.00     0.95      111.20
                       6.00     1.20      111.45
                       8.00     1.43      111.68
                      10.00     1.65      111.90
                      12.00     1.86      112.11
                      14.00     2.08      112.33
                      16.00     2.26      112.51
                      18.00     2.42      112.67
                      20.00     2.64      112.89
```

```
**************** OVERFLOW ENCOUNTERED AT  22.00 CFS DISCHARGE ****************
********** THE FOLLOWING DATA INCLUDES CULVERT FLOW PLUS WEIR FLOW ***********
                    22.00     2.75      113.00
                    24.00     2.90      113.15
                    26.00     6.18      116.43
                    28.00     6.18      116.43
                    30.00     6.18      116.43
```

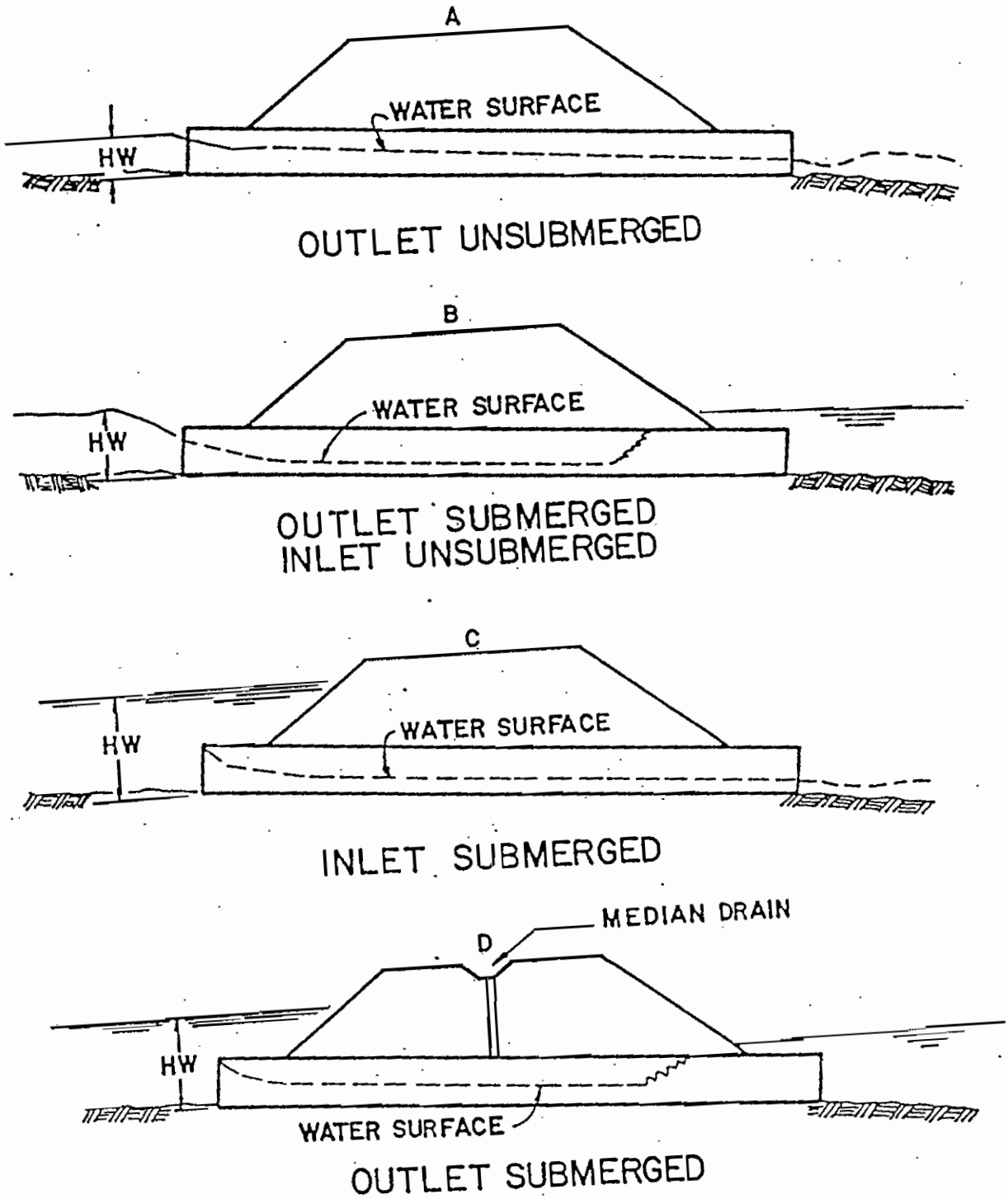


Figure III-1--Types of inlet control.

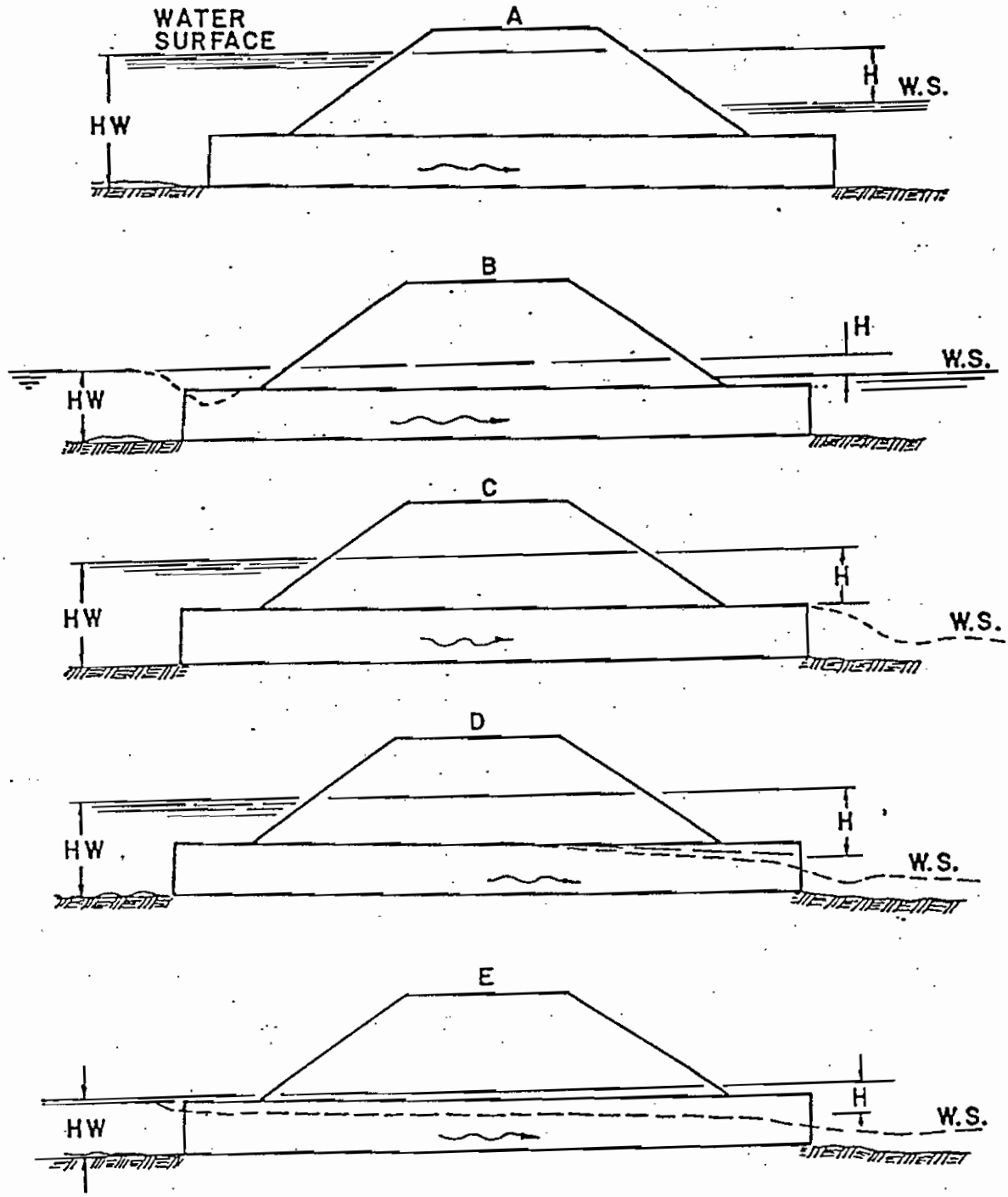


Figure III-7-- Types of outlet control.