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7. Author(s)
Shaw L. Yu and James Y. Li

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16. Abstract
A microcomputer software module was developed for the computation of hydraulic gradeline in storm sewer systems. The computer module has been attached to the program "HYDRA", which is being adopted by the FHWA organized Pooled Fund Study on Integrated Drainage System as the program for storm drain design and analysis. The module developed in this study, called HYGRD, would allow a user to check design adequacy and also to analyze the performance of a sewer system under assumed in flow conditioning.

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To Convert From	To	Multiply By
Length:		
in	cm	2.54
in	m	0.025 4
ft	m	0.304 8
yd	m	0.914 4
mi	km	1 . 609 344
Area:		
in^2	cm^2	6.451 600 E+00
ft^2	m^2	9.290 304 E-02
yd^2	m^2	8.361 274 E-01
mi^2	Hectares	2.589 988 E+02
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pt	m^3	4.731 765 E-04
qt	m^3	9.463 529 E-04
gal	m^3	3.785 412 E-03
in^3	m^3	1.638 706 E-05
ft^3	m^3	2.831 685 E-02
yd^3	m^3	7.645 549 E-01
Volume per Unit Time:	NOTE: $1m^3$ = 1,000 L	
ft^3/min	m^3/sec	4.719 474 E-04
ft^3/s	m^3/sec	2.831 685 E-02
in^3/min	m^3/sec	2.731 177 E-07
yd^3/min	m^3/sec	1.274 258 E-02
gal/min	m^3/sec	6.309 020 E-05
Mass:		
oz	kg	2.834 952 E-02
dwt	kg	1.555 174 E-03
lb	kg	4.535 924 E-01
ton (2000 lb)	kg	9.071 847 E+02
Mass per Unit Volume:		
lb/yd^2	kg/m^2	4.394 185 E+01
lb/in^3	kg/m^3	2.767 990 E+04
lb/ft^3	kg/m^3	1.601 846 E+01
lb/yd^3	kg/m^3	5.932 764 E-01
Velocity: (Includes Speed)		
ft/s	m/s	3.048 000 E-01
mi/h	m/s	4.470 400 E-01
knot	m/s	5.144 444 E-01
mi/h	km/h	1.609 344 E+00
Force Per Unit Area:		
lbf/in^2 or psi	Pa	6.894 757 E+03
lbf/ft^2	Pa	4.788 026 E+01
Viscosity:		
cS_t	m^2/s	1.000 000 E-06
P	Pa·s	1.000 000 E-01

Temperature: (°F-32)^5/9 = °C

MICROCOMPUTER SOFTWARE FOR STORM DRAIN HYDRAULIC GRADELINE COMPUTATION

by

Shaw L. Yu
Faculty Research Scientist

and

James Y. Li
Graduate Research Assistant

(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

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INTRODUCTION

An increasing use of microcomputers for planning and design analysis in transportation engineering has been witnessed in the past few years. As the use of microcomputers is being expanded, the need for high-quality software packages is being acutely felt. The Federal Highway Administration (FHWA) has organized a Pooled Fund Study to develop an integrated drainage design microcomputer system (Jones, 1987). The project is currently supported by 22 states working to evaluate and document selected software programs, to standardize the computer language and other formats, and to tie together the various microcomputer programs for highway drainage design and analysis as an integrated package. Being one of the participating agencies, the Virginia Department of Transportation is very much interested in having an hydraulic gradeline computation option added to the program PFP-HYDRA, which has been selected as the storm drain program by the Pooled Fund Study. As a result, the Virginia Transportation Research Council has conducted a study to develop a hydraulic gradeline computational module for HYDRA and will provide the program to the Virginia Department of Transportation and the Pooled Fund Study.

The hydraulic gradeline project was divided into two phases. The first phase of the project, which has been completed and is the subject of this report, involves computation of hydraulic gradeline for sewer systems under gravity flow conditions. This is useful for sewer design using PFP-HYDRA because all sewers are designed for gravity flow. The second phase of the project, which will be completed in 1988, involves computation of hydraulic gradelines for sewer systems under fully or partly pressurized flow conditions. This is useful for analyzing an existing overloaded system or checking the performance of a completed system under runoff inputs from storms other than the design storm.

PURPOSE AND TASKS

The objective of this study was to develop a hydraulic grade line procedure for storm drain design and analysis for use on a microcomputer. An eventual goal of the study is to develop a stand-alone computer program; one that could be attached to PFP-HYDRA that would improve the computational routine currently employed by the Hydraulics Section of the Virginia Department of Transportation.

Major tasks and work elements of the project were:

1. Evaluation of storm drainage models.
2. Examination of methods for computing hydraulic gradeline of sewer system.
3. Modification of PFP-HYDRA to include the hydraulic gradeline computation.
4. Implementation of the modified PFP-HYDRA in design examples.
5. Preparation of the final report.

EVALUATION OF STORM DRAINAGE MODELS

Four storm drain programs were examined: (1) PFP-HYDRA, (2) ILLUDAS, (3) PCSWMMN, and (4) EXTBAS. PFP-HYDRA performs design and analysis of storm, sanitary, or combined sewer systems. Either rational formulae or hydrologic simulation techniques can be used to generate storm runoff. Flow routing is based on a steady-state uniform flow approach. PFP-HYDRA has a data-handling algorithm especially designed to accept a sewer system of any realistically conceivable design (GKY, 1986). It is structured to allow users to change design criteria at any point in the system by overwriting old criteria with new ones. It also identifies surcharged sewer pipes in the analysis of existing overloaded sewer systems. Most of all, it provides cost estimating and financial analysis, which allows users to determine the most practical alternatives for unloading an existing overloaded system as well as for formulating a master plan for the orderly growth of the sewer system.

ILLUDAS (Terstriep & Stall, 1974) is considered an extension of the TRRL (Transportation and Road Research Laboratory) method, which utilizes the time-area method in routing runoff in sewers. Discharges are first computed from a time-area diagram and then modified by a reservoir routing equation. Although it does not actually analyze surcharged flow conditions in sewers, it points out the problem of surcharging. Data input procedures for ILLUDAS are straightforward and the computer cost is low. A microcomputer version of ILLUDAS has just been developed.

The microcomputer version of SWMM, PCSWMM, is a comprehensive model that analyses both flow quantity and quality (Computational Hydraulics, Inc., 1986). PCSWMM is a downloaded version of the widely used Storm Water Management Model (SWMM). Both single and continuous storm events can be simulated by SWMM. The program is made up of several computational blocks. The design and analysis of drainage systems are carried out by the TRANSPORT block and the EXTRAN module. The TRANSPORT block utilizes the kinematic wave approach in sewer routing, whereas the EXTRAN module employs the dynamic wave approach. EXTRAN is excellent in the analysis of pressurized flow conditions in a system with extensive interconnection loops or significant backwater effects. Both TRANSPORT and EXTRAN are capable of simulating sewers other than the common circular and rectangular shape. Besides, they can handle different appurtenances such as manhole, lift station, pump, storage unit, flow divider, weir, and gate. Because PCSWMM is so comprehensive, data preparation is quite intense. Besides, EXTRAN requires a long computation time for sewer routing using an explicit finite difference scheme because of the limitation of small time step.

EXTBAS is a BASIC downloaded version of EXTRAN (McNair, 1986). No flow control devices are modeled and only circular and trapezoidal conduits are simulated. Thus, the computation time for EXTBAS is a lot less than that of EXTRAN; also, data preparation is less intense as compared with EXTRAN. EXTBAS can handle pressurized flow conditions in sewers as well as backwater effects because the approach of flow routing is the same as that of EXTRAN.

Each sewer model discussed above has its own advantages and disadvantages. In choosing an appropriate model, it is important to identify the need for a particular application. Highway drainage systems are usually less complicated than a city sewer network in which a lot of appurtenances are involved. Cost estimation and financial analyses are important in designing a new sewer system as well as upgrading an existing sewer network. Most of all, a good sewer model should be relatively easy to use and it should be easy to prepare input data files for it. Among the sewer models discussed above, HYDRA seems to be the best choice for the design and analysis of a highway sewer system when it is not surcharged.

METHOD OF COMPUTING THE HYDRAULIC GRADELINE OF A SEWER SYSTEM

Due to the fact that PFP-HYDRA uses the steady-state uniform flow approach for flow routing in sewers, the hydraulic gradeline can be computed using the conventional approach in which computation starts from the outfall point and proceeds in the upstream direction by taking into account all the energy, or head losses, along the flow path of the sewer system.

Hydraulic Head Losses

Basically, there are two types of head losses in a sewer system: major and minor losses. Major losses are mainly due to the friction effect of the sewer wall. Since PFP-HYDRA assumes a uniform flow condition, the friction slope is equal to the conduit slope. The major loss can be computed by

$$H = S * L \qquad (1)$$

in which H = major loss due to pipe friction

S = friction slope

L = length of pipe

Minor losses include manhole loss, pipe-junction loss, and loss due to curved alignment of pipe. The manhole loss can be estimated by considering the energy balance at the manhole (FHWA, 1979). With reference to Figure 1, the energy balance at a manhole gives

Outflow energy — Inflow energy

$$Q\left(H_o + \frac{Vo}{2g}\right) = \Sigma Q_1 \left(H_1 + \frac{V_1}{2g}\right) + Q_u\left(H_u + \frac{Vu}{2g}\right) + H_d Q_d$$

Energy loss due to change of direction

$$- \Sigma H_1 Q_1 \qquad (2)$$

in which Q_o = outflow rate from the manhole
H_o = water elevation at the outflow pipe
V_o = flow velocity of the outflow
Q_l = lateral inflow into the manhole
H_l = water elevation at the lateral pipe
V_l = flow velocity of the lateral pipe
Q_u = upstream inflow rate into the manhole
H_u = water elevation at the upstream inflow pipe
V_u = flow velocity at the upstream inflow pipe
$H_l Q_l$ = energy loss due to change of direction
$H_d Q_d$ = energy into the manhole due to drop inflow
g = acceleration due to gravity

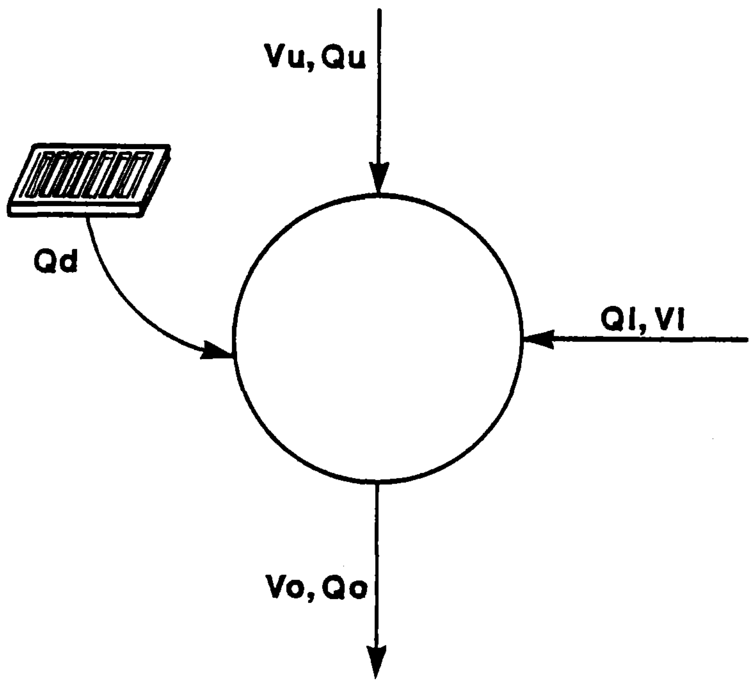


Figure 1. Flow at a manhole.

Rearranging Equation (2) gives the change in hydraulic gradeline at the manhole

$$H_1 = h_o - \frac{\Sigma \, Q_1 \frac{V_1^2}{2g}}{Q_o} - \frac{Q_u}{Q_o} h_u - \frac{\Sigma \, Q_1 K_1 \frac{V_1^2}{2g}}{Q_o} \tag{3}$$

in which H_1 = change of hydraulic gradeline at manhole
h_u = velocity head of upstream flow
h_o = velocity head of downstream outflow
k_1 = loss coefficient due to change of direction (see Figure 2)

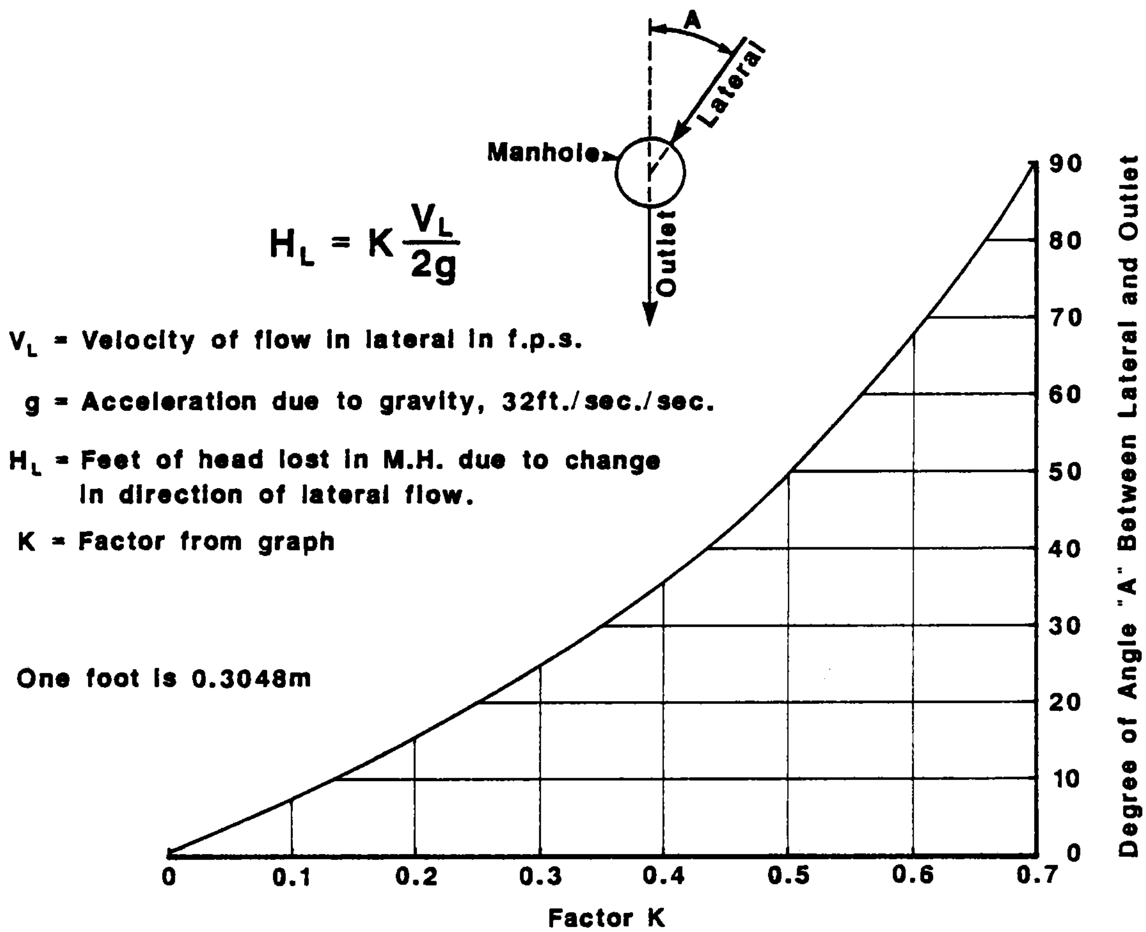


Figure 2. Loss coefficient due to change in direction of flow (after FHWA-TS-79-225).

If the direction of upstream inflow is deflected at the manhole, additional losses due to change of direction are computed by

$$H_2 = K_1 \cdot h_u \qquad (4)$$

Thus, the total head loss at the manhole is given by

$$H_T = H_1 + H_2 \qquad (5)$$

At a terminal manhole of a sewer system, the head loss due to the drop inflow from a grate inlet is estimated by the users as the loss coefficient (K2) which is the proportion of the outflow velocity head.

$$Ht = K2 * Ho \qquad (6)$$

in which Ht = head loss at terminal head loss. A value of 1.5 is suggested for the loss coefficient.

The pipe-junction loss is estimated by considering the pressure and momentum balance at the junction (FHWA, 1979). With reference to Figure 3, the junction loss is given by

$$H_j = \Delta y + hu - ho \qquad (7)$$

$$\Delta y = \frac{Q_o V_o - Q_u V_u - Q_1 V_1 \cos\Theta}{(A_u + A_o) \cdot \frac{g}{2}} \qquad (8)$$

in which H_j = junction loss
A_u = flow area of upstream inflow
A_o = flow area of downstream outflow

Head loss due to curved alignment of pipe can be computed by

$$H_b = K_b \cdot f_b \cdot \frac{V^2}{2_g} \qquad (9)$$

in which H_b = head loss due to curved alignment of pipe
K_b = bend coefficient (see Figure 4)
f_b = factor for other than 90 bend (see Figure 4)
V = flow velocity of the pipe

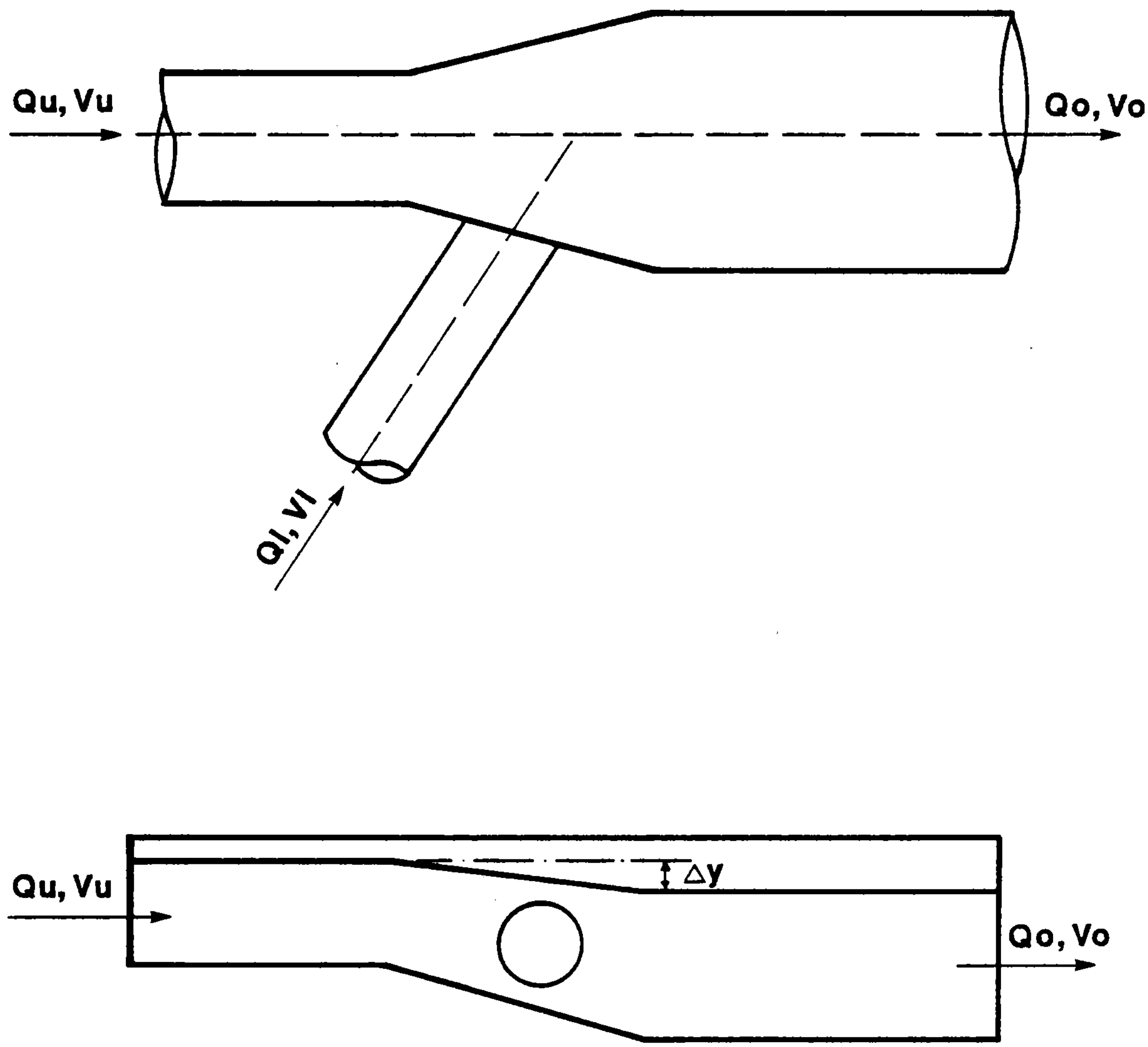
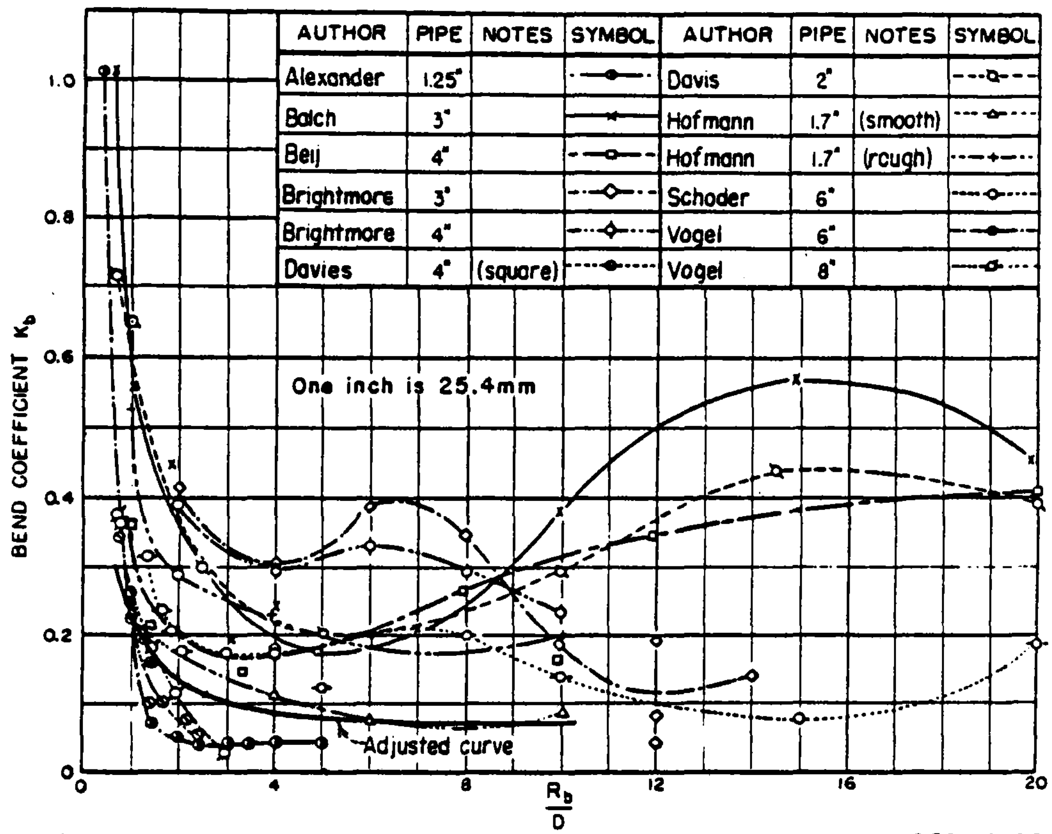
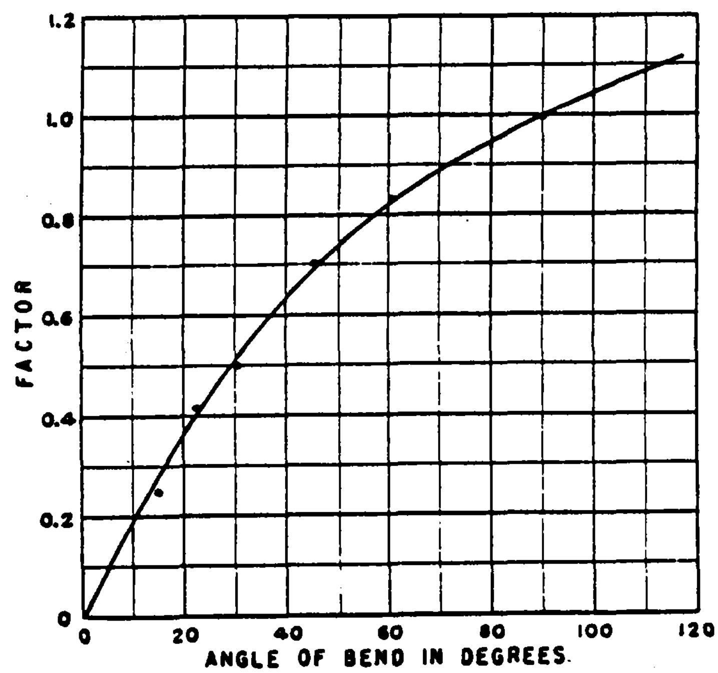


Figure 3. Flow at pipe junction.



(A) VARIATION OF BEND COEFFICIENT WITH RELATIVE RADIUS FOR 90° BENDS OF CIRCULAR CROSS SECTION, AS MEASURED BY VARIOUS INVESTIGATORS



(B) FACTORS FOR OTHER THAN 90° BENDS

Figure 4. Bend loss coefficient (after Bureau of Reclamation).

DEVELOPMENT OF A HYDRAULIC GRADELINE MODULE FOR PFP-HYDRA

In running PFP-HYDRA, users are required to formulate a sewer system in a logical sequence using a series of predefined command statements. A sewer system is modeled by describing the characteristics of inflow and pipes. However, hydraulic gradeline computation concerns mostly the potential water level at manholes and junctions. As a result, a sewer system can be modeled as a link-node connection network in which a link is defined as a sewer pipe and a node is defined as a manhole or junction.

In PFP-HYDRA, a command statement called PIP is used to represent a link, and a link number is automatically assigned to each pipe specified by each PIP statement during execution of the program. A new command statement called PNC (see Figure 7) was created to describe the connection of links and nodes. Each PIP statement is followed by a PNC statement describing the upstream and downstream connecting nodes and the change of flow direction. Another command statement called BEN (see Figure 5) was also created to input data for computing head loss due to curved alignment of pipe. Finally, a command statement called HGL (see Figure 6) was created to allow users to abandon the gradeline computation capability of PFP-HYDRA.

In order to compute the head losses using the equations discussed above, flow data and the characteristics of pipes are needed. These data are stored in any array during the normal computation of the original PFP-HYDRA for the later computation of hydraulic gradeline.

Hydraulic gradeline computation starts soon after the normal termination of the original PFP-HYDRA. As shown in Figure 9, hydraulic gradeline computation is carried out mainly by the subroutine GRADE. The algorithm of the hydraulic gradeline computation module is summarized as follows (see Figure 10).

1. Compute the gradeline at the outfall point by adding the invert elevation and flow depth.

2. Compute the major friction loss of the upstream connecting pipe A.

3. Check whether the invert of mainline(M) and lateral(L) inflow pipes are higher than the upstream crown elevation of pipe A.

4. Change the mainline or lateral inflow to drop inflow if step 3 is confirmed (see Figure 11).

5. Compute the minor losses at the upstream node B of pipe A according to either Equation (5) or (7).

COMMAND BEN - Pipe BENd data

Purpose: This is to specify the bend angle and radius for the computation of losses due to curved alignment of pipe as shown in the following figure. This is usually placed after the PNC statement to indicate that a bend occurs at the link specified by the previous PIP statement.

Structure:

BEN F1, F2

1) F1 - Bend angle of the link specified by the previous PIP statement (degree).
2) F2 - Bend radius of the link specified by the previous PIP statement (ft).

Notes:

1) Bend angle is usually between 0 to 120 degree.

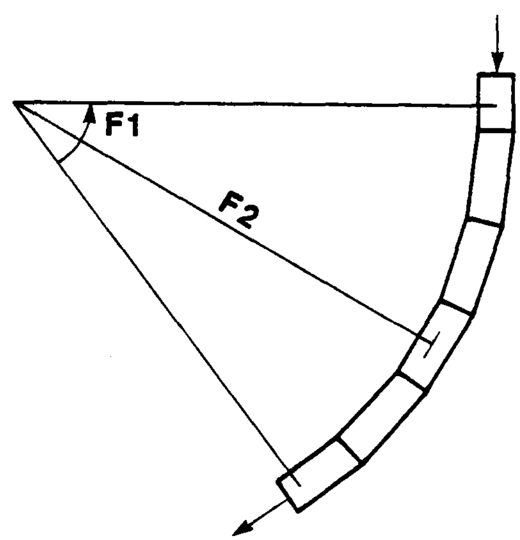


Figure 5. Description of BEN command statement.

COMMAND HGL - Hydraulic Gradeline Computation control

Purpose: This is to stop the computation of the hydraulic gradeline in HYDRA. When this command is present in the input data file, HYDRA will not compute the gradeline after the design or analyse of the system. Otherwise, HYDRA will assume that the user wants to compute the hydraulic gradeline. This command has no parameters following it. As well, it can be placed anywhere in the data file.

Figure 6. Description of HGL command statement.

COMMAND PNC - Pipe-Node Connection

Purpose: This is to specify the connection of links and nodes for the computation of hydraulisc gradeline. Each PNC statement must immediately follows the PIP statement.

Structure:

PNC I1, I2, I3, I4, I5, F6, I7, F8, (F9)

1) I1 - Node No. connecting the upstream end of the link specified by the previous PIP statement.
2) I2 - Type of node I1 (1 for manhole; 2 for pipe junction; 3 for pump; 5 for terminal manhole; any other numbers are invalid).
3) I3 - Node No. connecting the downstream end of the link specified by the previous PIP statement.
4) I4 - Type of node I3 (1 for manhole; 2 for pipe junction; 3 for pump; 4 for outfall point; any other numbers are invalid).
5) I5 - Identification of the link specified by the previous PIP statement as mainline link (1 for yes; 0 for No).
6) F6 - Deflection angle of the mainline link (degree).
7) I7 - Identification of the link specified by the previous PIP statement as sideline link (1 for Yes; 0 for No).
8) F8 - Skew angle of the sideline link (degree).
9) (F9) - Loss coefficient for terminal nodes. (e.g. terminal manhole loss coefficient; entrance loss coefficient)

Notes:

1) For a pictorial representation of the defection and skew angle, please see the appendix.
2) The previous eight input parameters are required.
3) F9 is only required for terminal nodes. For terminal manhole, a value of 1.5 is suggested for the loss coefficient.

Figure 7. Description of PNC command statement.

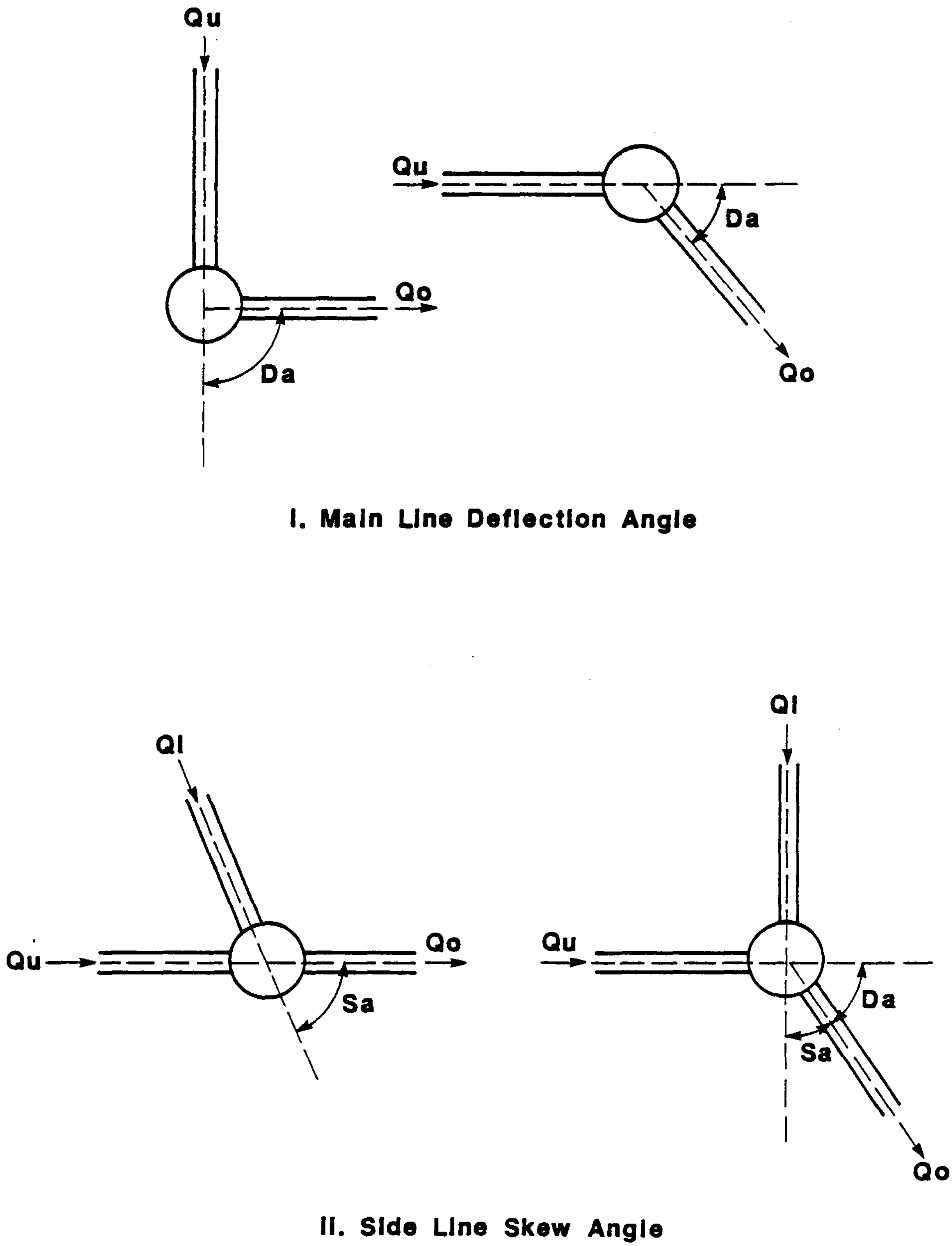


Figure 8. Definition of mainline deflection angle and sideline skew angle.

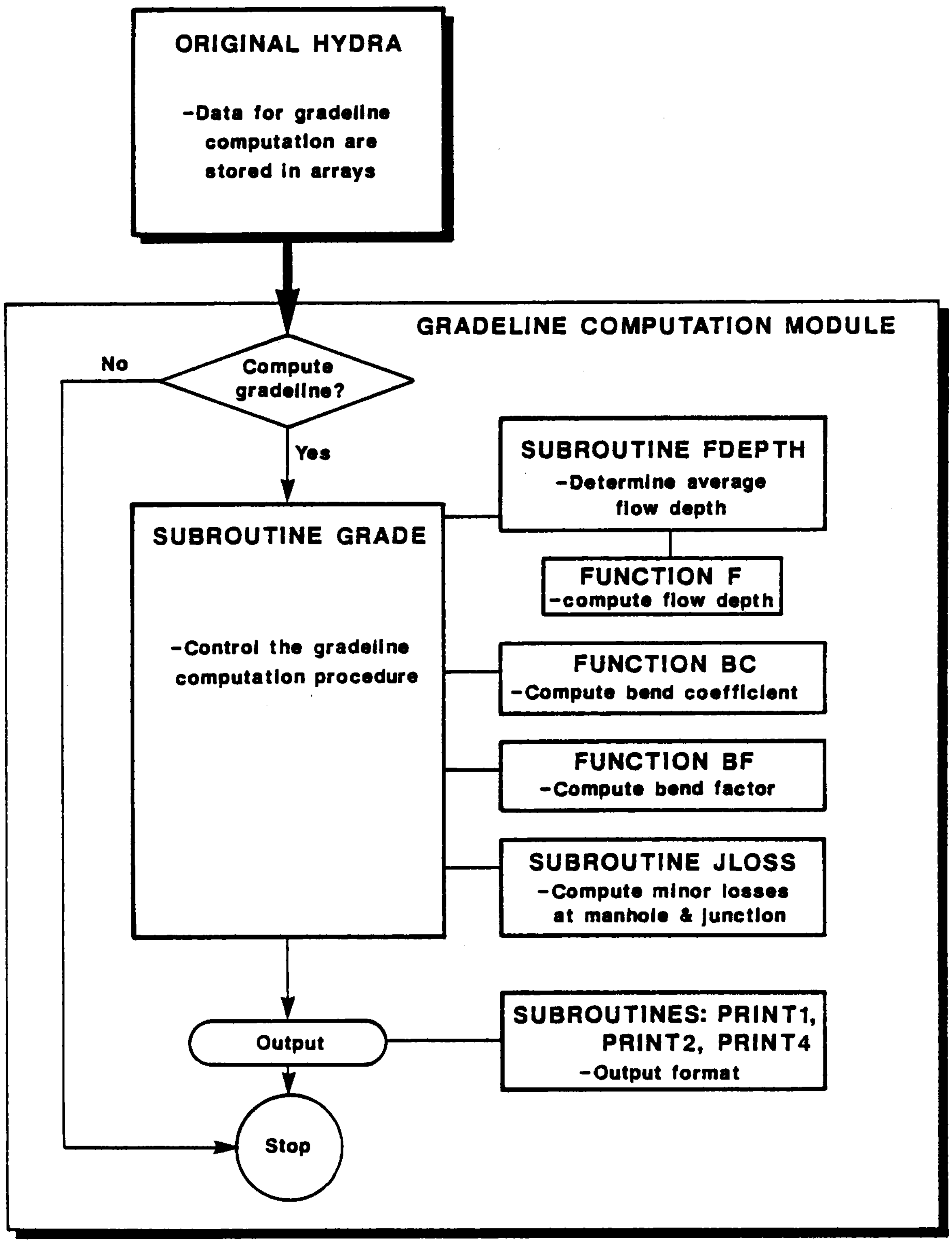


Figure 9. Flow chart of the modified HYDRA.

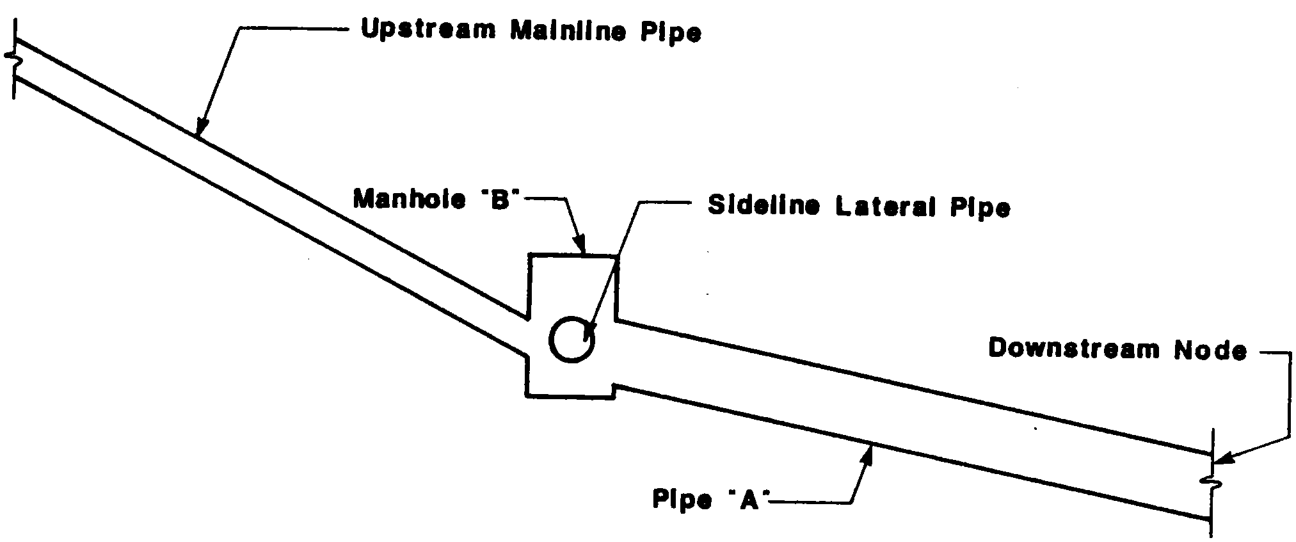


Figure 10. Schematic of computational pipe-node element in hydraulic gradeline computation.

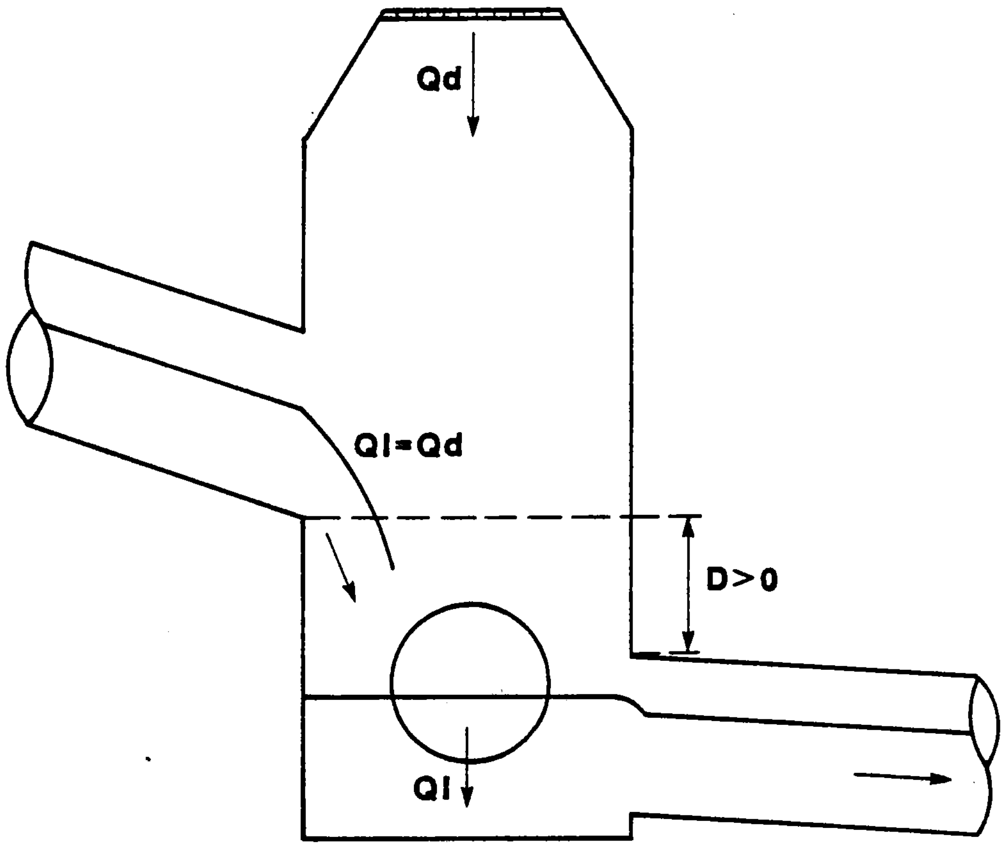


Figure 11. Drop inflows at manhole.

6. Compute head loss due to curved alignment according to Equation (9) if a bend is present in the pipe.

7. Compute the hydraulic gradeline at upstream node B by adding the major and minor losses to the hydraulic gradeline at outfall point.

8. Proceed to the upstream direction and compute the hydraulic gradeline by repeating steps 2 through 7.

9. Add head loss due to drop inflow at terminal manhole.

10. Check whether any pipes are surcharged at the nodes.

11. Printout the hydraulic gradeline at each node.

IMPLEMENTATION OF THE MODIFIED PFP-HYDRA

Three examples, which are based on design examples in the PFP-HYDRA manual, are used here to illustrate the computation of hydraulic gradeline for common design applications. The application of the two new commands are introduced here. The PNC command describes the connection of link-node systems such as node number, type of node, and change in flow direction. The BEN command allows the user to simulate curved alignment of pipe by providing angle and radius of curving. Since PFP-HYDRA assigns a link number to the pipe specified by the PIP command statement, the PNC command statement must be placed immediately after the PIP command so that the program will remember the pipe-node connection for that particular link. Also, the curved alignment of a pipe can be specified by placing a BEN command statement after the PIP command statement that describes that particular pipe. The total number of links that can be analyzed by the hydraulic gradeline module is limited to 300. The numbering of the nodes must be consecutive from 1 to 300. The gravity flow gradeline computation is suitable for pipe design problems because all pipes are designed for gravity flow conditions. For the analysis of existing overloaded systems, the gravity flow gradeline computation may not be adequate. Thus, it is suggested that gravity gradeline computations be employed for pipe design problems.

Example of Sanitary Sewer Design

A sanitary sewer system (shown in Figure 12) is planned for which the amount of per capita sanitary flow is 100 gallons per day. The area serviced by Kenyon Street lateral has an infiltration rate of 2,000 gallons/day/acre into the system, whereas all the other areas have an infiltration rate of 1,000 gallons/day/acre.

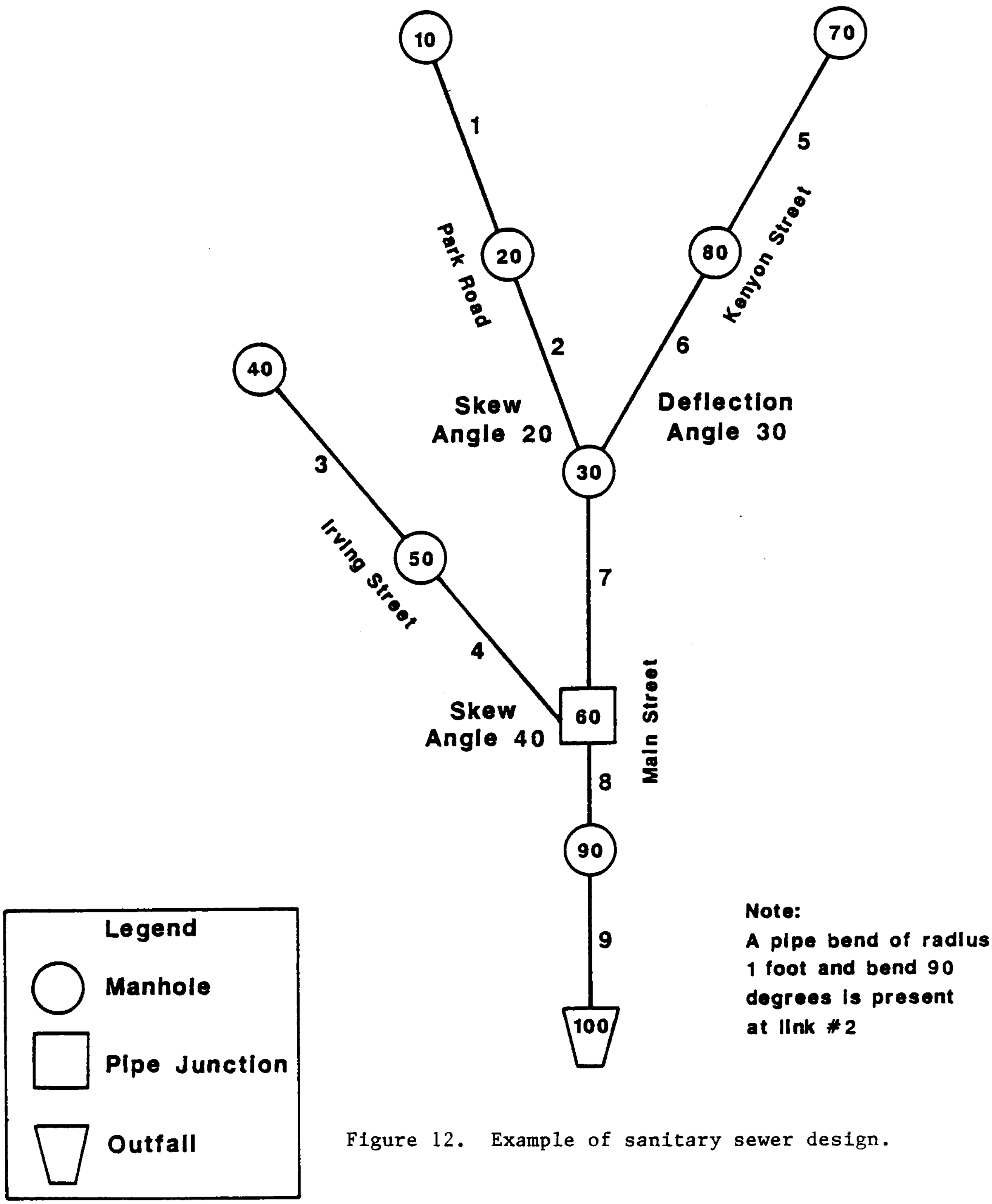


Figure 12. Example of sanitary sewer design.

```
0010 JOB EXAMPLE ONE
0020 REM
0030 GPC 100
0040 PEA .01 4.46 .05 3.78 .1 3.3 1 2.6 10 2.1 100 1.7+
0050     1000 1.4 10000 1.13
0060 INF 0 1000
0070 CST 1.5 1.5 0 0 .5 0 2.5 .5 0 4 1.15 .4 2.5 3.5 .25
0080 EXC 0 .75 10 .75
0090 PCO 8 2.5 10 3.5
0100 PDA .013 6 7 4 2.5 .001
0110 TSL 0 .2 10 .2
0120 REM
0130 NEW PARK ROAD
0140 SAN 35.6 10
0150 PIP 290.5 100.8 93.6
0151 PNC 10 5 20 1 1 0. 0 0. 1.5
0160 SAN 17.5 18
0170 SAN 18.2 20
0180 PIP 308.8 93.6 84.7
0181 PNC 20 1 30 1 0 0. 1 20.
0182 BEN 1. 90.
0190 HOL 1
0200 REM
0210 NEW IRVING STREET
0220 SAN 40.3 8.5
0230 PIP 330 95 81.2
0231 PNC 40 5 50 1 1 0.0 0 0. 1.5
0240 SAN 15.2 12
0250 SAN 17.3 15
0260 PIP 320 81.2 74.3
0261 PNC 50 1 60 2 0 0. 1 40.
0270 HOL 2
0280 REM
0290 NEW KENYON STREET
0300 INF 0 2000
0310 SAN 46.3 5.6
0320 PIP 390 97.5 89
0321 PNC 70 5 80 1 1 0. 0 0.
0330 SAN 18.3 12
0340 SAN 25.3 12
0350 PIP 420 89 84.7
0351 PNC 80 1 30 1 1 30. 0 0.
0360 HOL 3
0370 REM
0380 NEW MAIN STREET
0390 INF 0 1000
0400 REC 1
0410 REC 3
0420 SAN 16.5 20
0430 SAN 13.1 35
0440 SAN 14.7 20
0450 PIP 400 84.7 74.3 -.8
0451 PNC 30 1 60 2 1 0. 0 0.
0460 REC 2
0470 SAN 24.8 20
0480 PIP 410 74.3 67
0481 PNC 60 2 90 1 1 0. 0 0.
0490 SAN 22.6 15
0500 SAN 18.0 40
0510 SAN 22.8 15
0520 PIP 450 67 65.1
0521 PNC 90 1 100 4 1 0. 0 0.
0530 END
```

Figure 13. Input file of sanitary sewer design.

```
*** PFP-HYDRA (Version of Oct. 2, 1986) ***               DATE 07-14-87
                                                          PAGE NO    1

        EXAMPLE ONE

Commands Read From File example.hda
   10 JOB
   20 REM
   30 GPC 100
   40 PEA .01 4.46 .05 3.78 .1 3.3 1 2.6 10 2.1 100 1.7+
        1000 1.4 10000 1.13
   60 INF 0 1000
   70 CST 1.5 1.5 0 0 .5 0 2.5 .5 0 4 1.15 .4 2.5 3.5 .25
   80 EXC 0 .75 10 .75
   90 PCO 8 2.5 10 3.5
  100 PDA .013 6 7 4 2.5 .001
  110 TSL 0 .2 10 .2
  120 REM
  130 NEW PARK ROAD
  140 SAN 35.6 10
  150 PIP 290.5 100.8 93.6
  151 PNC 10 5 20 1 1 0. 0 0. 1.5
  160 SAN 17.5 18
  170 SAN 18.2 20
  180 PIP 308.8 93.6 84.7
  181 PNC 20 1 30 1 0 0. 1 20.
  182 BEN 1. 90.
  190 HOL 1
  200 REM
  210 NEW IRVING STREET
  220 SAN 40.3 8.5
  230 PIP 330 95 81.2
  231 PNC 40 5 50 1 1 0.0 0 0. 1.5
  240 SAN 15.2 12
  250 SAN 17.3 15
  260 PIP 320 81.2 74.3
  261 PNC 50 1 60 2 0 0. 1 40.
  270 HOL 2
  280 REM
  290 NEW KENYON STREET
  300 INF 0 2000
  310 SAN 46.3 5.6
  320 PIP 390 97.5 89
  321 PNC 70 5 80 1 1 0. 0 0.
  330 SAN 18.3 12
  340 SAN 25.3 12
  350 PIP 420 89 84.7
  351 PNC 80 1 30 1 1 30. 0 0.
  360 HOL 3
  370 REM
  380 NEW MAIN STREET
  390 INF 0 1000
  400 REC 1
```

Figure 14. Output file of sanitary sewer design.

```
*** PFP-HYDRA (Version of Oct. 2, 1986) ***                DATE 07-14-87
                                                           PAGE NO    2

       EXAMPLE ONE
 410 REC 3
 420 SAN 16.5 20
 430 SAN 13.1 35
 440 SAN 14.7 20
 450 PIP 400 84.7 74.3 -.8
 451 PNC 30 1 60 2 1 0. 0 0.
 460 REC 2
 470 SAN 24.8 20
 480 PIP 410 74.3 67
 481 PNC 60 2 90 1 1 0. 0 0.
 490 SAN 22.6 15
 500 SAN 18.0 40
 510 SAN 22.8 15
 520 PIP 450 67 65.1
 521 PNC 90 1 100 4 1 0. 0 0.
 530 END
END OF RUN.
```

Figure 14 cont.

*** PFP-HYDRA (Version of Oct. 2, 1986) ***

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EXAMPLE ONE

*** PARK ROAD — Pipe Design

Link	Length (ft)	Diam (in)	Invert Up/Dn (ft)	Slope (ft/ft)	Depth Up/Dn (ft)	Min. Cover (ft)	Velocity Act/Full (ft/sec)	--Flow-- Act/Full (cfs)	Estimated Cost ($)
1	291	6	93.8	.02478	7.0	6.5	3.9	.26	1213.
			86.6		7.0		4.5	.89	
2	309	6	86.6	.02882	7.0	6.5	5.2	.63	1289.
			77.7		7.0		4.9	.96	

LENGTH = 599. COST = 2502.
TOTAL LENGTH = 599. TOTAL COST = 2502.

*** IRVING STREET — Pipe Design

Link	Length (ft)	Diam (in)	Invert Up/Dn (ft)	Slope (ft/ft)	Depth Up/Dn (ft)	Min. Cover (ft)	Velocity Act/Full (ft/sec)	--Flow-- Act/Full (cfs)	Estimated Cost ($)
3	330	6	88.0	.04182	7.0	6.5	4.7	.26	1378.
			74.2		7.0		5.9	1.15	
4	320	6	74.2	.02156	7.0	6.5	4.4	.51	1336.
			67.3		7.0		4.2	.83	

LENGTH = 650. COST = 2714.
TOTAL LENGTH = 650. TOTAL COST = 2714.

Figure 14 cont.

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EXAMPLE ONE

*** KENYON STREET

Pipe Design

Link	Length (ft)	Diam (in)	Invert Up/Dn (ft)	Slope (ft/ft)	Depth Up/Dn (ft)	Min. Cover (ft)	Velocity Act/Full (ft/sec)	--Flow-- Act/Full (cfs)	Estimated Cost ($)
5	390	6	90.5	.02179	7.0	6.5	3.9	.30	1628.
			82.0		7.0		4.2	.83	
6	420	12	82.0	.01024	7.0	5.9	3.5	.68	3126.
			77.7		7.0		4.6	3.61	

LENGTH = 810. COST = 4754.
TOTAL LENGTH = 810. TOTAL COST = 4754.

*** MAIN STREET

Pipe Design

Link	Length (ft)	Diam (in)	Invert Up/Dn (ft)	Slope (ft/ft)	Depth Up/Dn (ft)	Min. Cover (ft)	Velocity Act/Full (ft/sec)	--Flow-- Act/Full (cfs)	Estimated Cost ($)
7	400	12	77.7	.02600	7.0	5.9	6.5	1.82	2977.
			67.3		7.0		7.3	5.76	
8	410	12	67.3	.01780	7.0	5.9	6.1	2.47	3051.
			60.0		7.0		6.1	4.77	
9	450	18	60.0	.00422	7.0	5.4	3.8	3.04	4990.
			58.1		7.0		3.9	6.84	

LENGTH = 1260. COST = 11018.
TOTAL LENGTH = 3319. TOTAL COST = 20987.

Figure 14 cont.

*** PFP-HYDRA (Version of Oct.2, 1986) ***

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	Node									Bend	
	Number		Type		Main	Deflected	Side	Skew		Radius	Angle
Link	U/S	D/S	U/S	D/S	Line	Angle	Line	Angle		[Ft]	
1	10	20	5	1	1	.0	0	.0		.00	.0
2	20	30	1	1	0	.0	1	20.0		1.00	90.0
3	40	50	5	1	1	.0	0	.0		.00	.0
4	50	60	1	2	0	.0	1	40.0		.00	.0
5	70	80	5	1	1	.0	0	.0		.00	.0
6	80	30	1	1	1	30.0	0	.0		.00	.0
7	30	60	1	2	1	.0	0	.0		.00	.0
8	60	90	2	1	1	.0	0	.0		.00	.0
9	90	100	1	4	1	.0	0	.0		.00	.0

Figure 14 cont.

*** PFP-HYDRA (Version of Oct.2, 1986) ***

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Node#	Potential Water Level (Ft)	Ground Level (Ft)	Lowest Crown Elevation of Links Connecting Node Link#	Elevation (Ft)	Location	Possible Surcharging to the Link
10	95.9	100.8	1	94.3	Upstream	Yes
20	88.3	93.6	1	87.1	Downstream	Yes
30	79.0	84.7	2	78.2	Downstream	Yes
40	89.3	95.0	3	88.5	Upstream	Yes
50	75.0	81.2	3	74.7	Downstream	Yes
60	67.9	74.3	4	67.8	Downstream	Yes
70	91.9	97.5	5	91.0	Upstream	Yes
80	83.4	89.0	5	82.5	Downstream	Yes
90	60.5	67.0	8	61.0	Downstream	No
100	58.8	65.1	9	59.6	Downstream	No

Figure 14 cont.

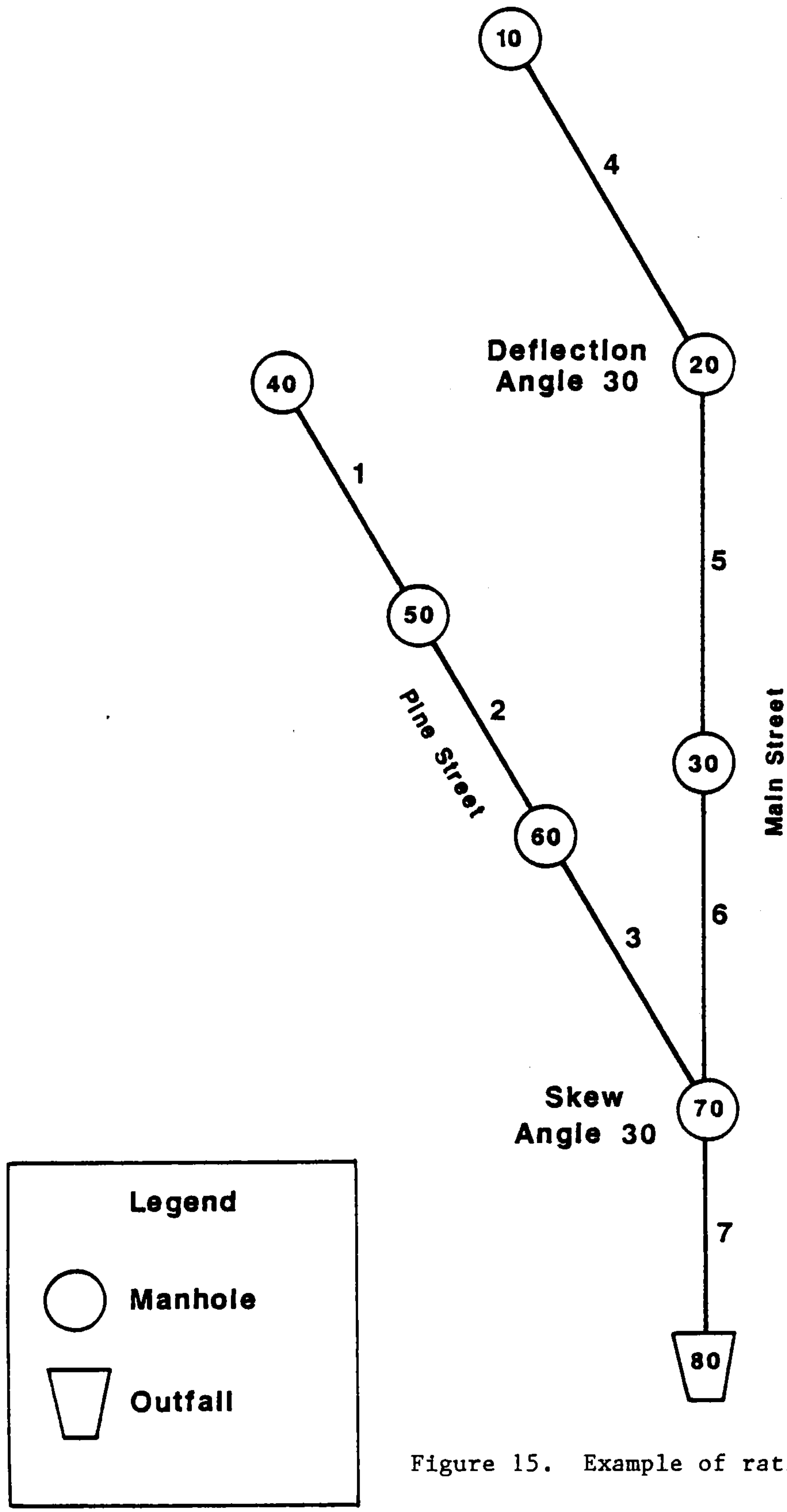

Figure 15. Example of rational method design.

```
0010 JOB EXAMPLE 3 RATIONAL METHOD DESIGN
0020 SWI 2
0030 PDA .013 12 4 3 2 .001
0040 RAI 0 1.55 5 1.55 8 1.2 10 1.1 15 .9 18 .8 24 .7 32 .6 44 .5 +
0050     50 .46 65 .4 80 .36 180 .22 300 .22
0060 EXC 5 .72 25 1.13
0070 TSL 0 .25 10 .25
0080 PCO 12 4.58 36 24.84
0090 CST 1.5 1.5 0 0 0 .5 6.21 1 0 1.52 1.05 .6 1.56 1.52 0
0100 NEW PINE STREET
0110 STO 3.3 .6 15
0120 PIP 350 200 185
0125 PNC 40 5 50 1 1 0. 0 0. 1.5
0130 STO 3.5 .6 15
0140 STO 3.9 .6 15
0150 PIP 550 185 184.4
0155 PNC 50 1 60 1 1 0. 0 0.
0160 STO 3.6 .6 15
0170 STO 3.5 .6 15
0180 PIP 350 184.3 184.4
0185 PNC 60 1 70 1 0 0. 1 30.
0190 HOL 1
0200 NEW MAIN STREET
0210 STO 5.2 .2 21
0220 PIP 450 193.5 192
0225 PNC 10 5 20 1 1 30. 0 0. 1.5
0230 STO 4.0 .5 28
0240 STO 5.8 .6 15
0250 STO 2.6 .6 15
0260 PIP 750 192 184.3
0265 PNC 20 1 30 1 1 0. 0 0.
0270 STO 5.6 .5 15
0280 STO 3.2 .7 15
0290 PIP 500 184.3 184.4
0295 PNC 30 1 70 1 1 0. 0 0.
0300 STO 4.5 .8 15
0310 REC 1
0320 PIP 400 184.4 184.
0325 PNC 70 1 80 4 1 0. 0 0.
0330 END
```

Figure 16. Input file of rational method design.

```
          *** PFP-HYDRA (Version of Oct. 2, 1986) ***          DATE 07-14-87
                                                               PAGE NO    1

          EXAMPLE 3 RATIONAL METHOD DESIGN

 Commands Read From File example.hda
    10 JOB
    20 SWI 2
    30 PDA .013 12 4 3 2 .001
    40 RAI 0 1.55 5 1.55 8 1.2 10 1.1 15 .9 18 .8 24 .7 32 .6 44 .5 +
         50 .46 65 .4 80 .36 180 .22 300 .22
```

```
                              IDF CURVE

.15E+01**.....................................................................
       .                                                                     .
       .                                                                     .
       .                                                                     .
.12E+01. *                                                                   .
       .                                                                     .
       . *                                                                   .
       .                                                                     .
       .   *                                                                 .
.77E+00.   *                                                                 .
       .     *                                                               .
       .                                                                     .
       .      *                                                              .
       .         * *                                                         .
.39E+00.              *                                                      .
       .                  *                                                  .
       .                                         *                           *
       .                                                                     .
       .                                                                     .
.00E+00*......................................................................
       .00       .71      1.43      2.14      2.86      3.57      4.29      5.00
```

PLOT-DATA (VALUE Vs.TIME)

.000	1.550	1.083	.400	.000	.000	.000	.000	.000	.000
.083	1.550	1.333	.360	.000	.000	.000	.000	.000	.000
.133	1.200	3.000	.220	.000	.000	.000	.000	.000	.000
.167	1.100	5.000	.220	.000	.000	.000	.000	.000	.000
.250	.900	.000	.000	.000	.000	.000	.000	.000	.000
.300	.800	.000	.000	.000	.000	.000	.000	.000	.000
.400	.700	.000	.000	.000	.000	.000	.000	.000	.000
.533	.600	.000	.000	.000	.000	.000	.000	.000	.000
.733	.500	.000	.000	.000	-99.000	.000	.000	.000	.000
.833	.460	.000	.000	.000	.000	.000	.000	.000	.000

```
    60 EXC 5 .72 25 1.13
    70 TSL 0 .25 10 .25
    80 PCO 12 4.58 36 24.84
    90 CST 1.5 1.5 0 0 0 .5 6.21 1 0 1.52 1.05 .6 1.56 1.52 0
```

Figure 17. Output file of rational method design.

```
*** PFP-HYDRA (Version of Oct. 2, 1986) ***                DATE 07-14-87
                                                           PAGE NO    2

       EXAMPLE 3 RATIONAL METHOD DESIGN
 100 NEW PINE STREET
 110 STO 3.3 .6 15
 120 PIP 350 200 185
 125 PNC 40 5 50 1 1 0. 0 0. 1.5
 130 STO 3.5 .6 15
 140 STO 3.9 .6 15
 150 PIP 550 185 184.4
 155 PNC 50 1 60 1 1 0. 0 0.
 160 STO 3.6 .6 15
 170 STO 3.5 .6 15
 180 PIP 350 184.3 184.4
 185 PNC 60 1 70 1 0 0. 1 30.
 190 HOL 1
 200 NEW MAIN STREET
 210 STO 5.2 .2 21
 220 PIP 450 193.5 192
 225 PNC 10 5 20 1 1 30. 0 0. 1.5
 230 STO 4.0 .5 28
 240 STO 5.8 .6 15
 250 STO 2.6 .6 15
 260 PIP 750 192 184.3
 265 PNC 20 1 30 1 1 0. 0 0.
 270 STO 5.6 .5 15
 280 STO 3.2 .7 15
 290 PIP 500 184.3 184.4
 295 PNC 30 1 70 1 1 0. 0 0.
 300 STO 4.5 .8 15
 310 REC 1
 320 PIP 400 184.4 184.
 325 PNC 70 1 80 4 1 0. 0 0.
 330 END
END OF RUN.
```

Figure 17 cont.

*** PFP-HYDRA (Version of Oct. 2, 1986) ***

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PAGE NO 3

EXAMPLE 3 RATIONAL METHOD DESIGN

*** PINE STREET

Pipe Design

Link	Length (ft)	Diam (in)	Invert Up/Dn (ft)	Slope (ft/ft)	Depth Up/Dn (ft)	Min. Cover (ft)	Velocity Act/Full (ft/sec)	--Flow-- Act/Full (cfs)	Estimated Cost ($)
1	350	12	195.9	.04286	4.1	3.0	7.7	1.78	2093.
			180.9		4.1		9.4	7.40	
2	550	24	179.8	.00100	5.2	3.0	2.5	5.62	9545.
			179.2		5.2		2.3	7.17	
3	350	30	178.6	.00100	5.7	3.0	2.8	8.30	8137.
			178.2		6.2		2.6	13.01	

LENGTH = 1250. COST = 19775.
TOTAL LENGTH = 1250. TOTAL COST = 19775.

*** MAIN STREET

Pipe Design

Link	Length (ft)	Diam (in)	Invert Up/Dn (ft)	Slope (ft/ft)	Depth Up/Dn (ft)	Min. Cover (ft)	Velocity Act/Full (ft/sec)	--Flow-- Act/Full (cfs)	Estimated Cost ($)
4	450	12	189.4	.00333	4.1	3.0	2.4	.78	2691.
			187.9		4.1		2.6	2.06	
5	750	18	187.3	.01016	4.7	3.0	6.0	5.25	8720.
			179.7		4.6		6.0	10.61	
6	500	30	178.6	.00100	5.7	3.0	2.8	8.19	11637.
			178.1		6.3		2.6	13.01	
7	400	36	178.1	.00100	6.3	3.1	3.3	16.20	11647.
			177.7		6.3		3.0	21.15	

LENGTH = 2100. COST = 34694.
TOTAL LENGTH = 3350. TOTAL COST = 54469.

Figure 17 cont

*** PFP-HYDRA (Version of Oct.2, 1986) *** DATE 07-14-87
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Link	Node Number U/S	Node Number D/S	Node Type U/S	Node Type D/S	Main Line	Deflected Angle	Side Line	Skew Angle	Bend Radius [Ft]	Bend Angle
1	40	50	5	1	1	.0	0	.0	.00	.0
2	50	60	1	1	1	.0	0	.0	.00	.0
3	60	70	1	1	0	.0	1	30.0	.00	.0
4	10	20	5	1	1	30.0	0	.0	.00	.0
5	20	30	1	1	1	.0	0	.0	.00	.0
6	30	70	1	1	1	.0	0	.0	.00	.0
7	70	80	1	4	1	.0	0	.0	.00	.0

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Node#	Potential Water Level (Ft)	Ground Level (Ft)	Lowest Crown Elevation of Links Connecting Node: Link#	Elevation (Ft)	Location	Possible Surcharging to the Link
40	197.3	200.0	1	196.9	Upstream	Yes
50	180.9	185.0	2	181.8	Upstream	No
60	180.5	184.3	3	181.1	Upstream	No
70	180.1	184.4	6	180.6	Downstream	No
10	190.3	193.5	4	190.4	Upstream	No
20	188.6	192.0	5	188.8	Upstream	No
30	180.4	184.3	6	181.1	Upstream	No
80	179.7	184.0	7	180.7	Downstream	No

Figure 17 cont.

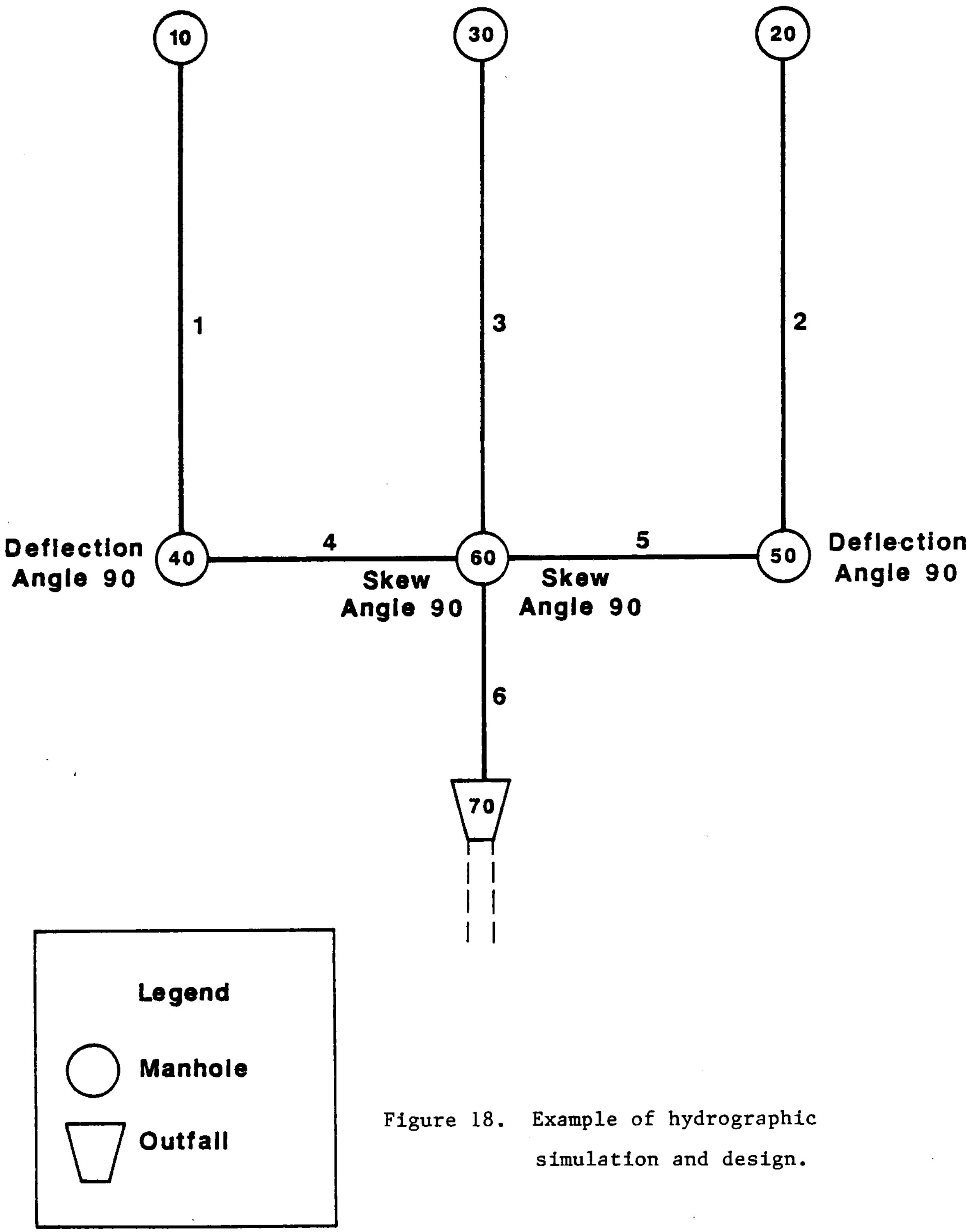

Figure 18. Example of hydrographic simulation and design.

```
0010 JOB EXAMPLE FIVE: HYDROGRAPHIC SIMULATION AND DESIGN
0020 SWI 3
0030 PDA .013 12 5 4 2.5 .001
0040 PCO 12 46 15 51 18 57 21 63 24 69 27 74 30 M80 33 86 36 97 +
0050     42 109 48 126 54 143 60 160 66 177 72 206 84 297
0060 CST 1.5 1.5 0 0 0 .5 6.21 1 0 1.52 1.05 .6 1.56 1.52 0
0070 EXC 5 .72 25 1.13
0080 TSL 0 .25 10 .25
0090 STE 2
0100 HYE 0.0 3.51 7.03 10.54 9.03 7.53 6.02 4.52 3.01 1.51
0110 UNP .15 .5 .1 .1 4.0 1.5 .07 45 .03 24 48
0120 PAV .013 .1 .05 .2 .5 30 .4
0130 NEW FEEDER 1
0140 HYD .5 49 .025 .77 2.2
0150 INL 1 2.5 26 0 0 0 1
0160 PIP 88 940 931.62
0165 PNC 10 5 40 1 1 90. 0 0. 1.5
0170 HOL 1
0180 NEW FEEDER 2
0190 HYD .5 49 .025 .77 2.2
0200 INL 2 2.5 27
0210 PIP 88 940 931.62
0215 PNC 20 5 50 1 1 90. 0 0. 1.5
0220 HOL 2
0230 NEW FEEDER 3
0240 GET 26
0250 GUT 500 940 932.5 .013 0 0 50
0260 HYD 0.5 49 0.025 0.77 2.2
0270 PUT 28
0280 GET 27
0290 GUT 500 940 932.5 .013 0 0 50
0300 HYD 0.5 49 .025 .77 2.2
0310 GET 28
0320 INL 3 20.0
0330 PIP 88 932.5 924.1
0335 PNC 30 5 60 1 1 0. 0 0. 1.5
0340 HOL 4
0350 NEW LEFT-SIDE MAIN
0360 REC 1
0370 HYD .5 49 .025 .77 2.2
0380 INL 4 2.5 29
0390 PIP 500 931.6 924.1
0395 PNC 40 1 60 1 0 0. 1 90.
0400 HOL 5
0410 NEW RIGHT-SIDE MAIN
0420 REC 2
0430 HYD .5 49 .025 .77 2.2
0440 INL 5 2.5 30
0450 PIP 500 931.6 924.1
0455 PNC 50 1 60 1 0 0. 1 90.
0460 HOL 6
0470 NEW OUTFALL PIPE
0480 REC 4
0490 REC 5
0500 REC 6
0510 GET 29
0520 GUT 500 931.6 924.1 .013 0 0 50
0530 HYD 0.5 49 0.025 0.77 2.2
0540 PUT 31
0550 GET 30
0560 GUT 500 931.6 924.1 .013 0 0 50
0570 HYD 0.5 49 0.025 0.77 2.2
0580 GET 31
0590 INL 6 6.5
0600 PIP 50 924.1 920 0 0 0 0 1 1
0605 PNC 60 1 70 4 1 0. 0 0.
0610 HOL 7
0620 NEW OUTFALL CHANNEL
0630 REC 7
0640 CHA 1000 914.0 912.0 .034 1 4 1
0650 END
```

Figure 19. Input file of hydrographic simulation and design.

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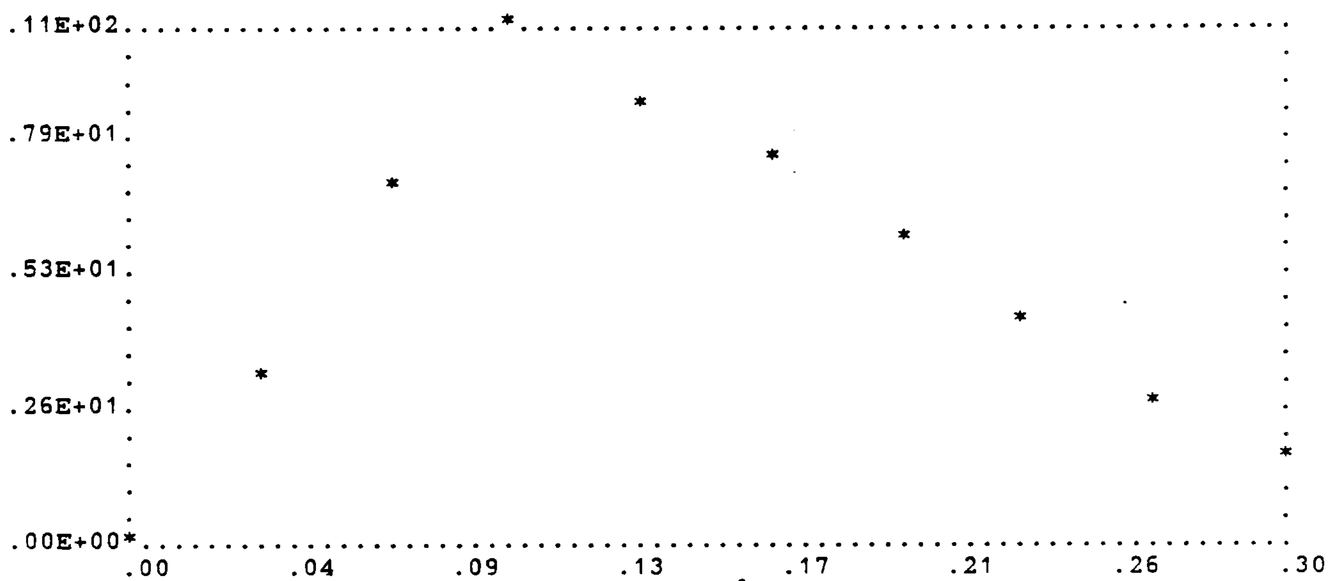
EXAMPLE FIVE: HYDROGRAPHIC SIMULATION AND DESIGN

```
Commands Read From File example.hda
   10 JOB
   20 SWI 3
   30 PDA .013 12 5 4 2.5 .001
   40 PCO 12 46 15 51 18 57 21 63 24 69 27 74 30 M80 33 86 36 97 +
        42 109 48 126 54 143 60 160 66 177 72 206 84 297
   60 CST 1.5 1.5 0 0 0 .5 6.21 1 0 1.52 1.05 .6 1.56 1.52 0
   70 EXC 5 .72 25 1.13
   80 TSL 0 .25 10 .25
   90 STE 2
*** STEP RESET FROM 15.0 MINUTES
  100 HYE 0.0 3.51 7.03 10.54 9.03 7.53 6.02 4.52 3.01 1.51
```

HYETOGRAPH (IN/HR)



PLOT-DATA (VALUE Vs.TIME)

.000	.000	.333	.000	.667	.000	1.000	.000	1.333	.000
.033	3.510	.367	.000	.700	.000	1.033	.000	1.367	.000
.067	7.030	.400	.000	.733	.000	1.067	.000	1.400	.000
.100	10.540	.433	.000	.767	.000	1.100	.000	1.433	.000
.133	9.030	.467	.000	.800	.000	1.133	.000	1.467	.000
.167	7.530	.500	.000	.833	.000	1.167	.000	1.500	.000
.200	6.020	.533	.000	.867	.000	1.200	.000	1.533	.000
.233	4.520	.567	.000	.900	.000	1.233	.000	1.567	.000
.267	3.010	.600	.000	.933	.000	1.267	.000	1.600	.000
.300	1.510	.633	.000	.967	.000	1.300	.000	1.633	.000

```
  110 UNP .15 .5 .1 .1 4.0 1.5 .07 45 .03 24 48
```

Figure 20. Output file of hydrographic simulation and design.

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```
        EXAMPLE FIVE: HYDROGRAPHIC SIMULATION AND DESIGN
 120 PAV .013 .1 .05 .2 .5 30 .4
 130 NEW FEEDER 1
 140 HYD .5 49 .025 .77 2.2
 150 INL 1 2.5 26 0 0 0 1
```

```
                          INLET   1 HYDROGRAPH IN CFS

.25E+01..***.......................................................................
       .                                                                          .
       .    *                                                                     .
       .                                                                          .
.19E+01.                                                                          .
       .                                                                          .
       .*    *                                                                    .
       .                                                                          .
       .                                                                          .
.13E+01.                                                                          .
       .      *                                                                   .
       .                                                                          .
       .                                                                          .
       .                                                                          .
.63E+00.      *                                                                   .
       .       *                                                                  .
       .        *                                                                 .
       .         *                                                                .
       .*         ****                                                            .
.00E+00*..............*************************************************************
      .00       .45       .90      1.36      1.81      2.26      2.71      3.17
```

PLOT-DATA (VALUE Vs.TIME)

.000	.000	.333	.684	.667	.059	1.000	.009	1.333	.003
.033	.111	.367	.519	.700	.048	1.033	.008	1.367	.002
.067	1.771	.400	.347	.733	.039	1.067	.007	1.400	.002
.100	2.500	.433	.299	.767	.032	1.100	.006	1.433	.002
.133	2.500	.467	.226	.800	.026	1.133	.005	1.467	.002
.167	2.500	.500	.181	.833	.022	1.167	.005	1.500	.002
.200	2.500	.533	.143	.867	.018	1.200	.004	1.533	.002
.233	2.227	.567	.114	.900	.015	1.233	.004	1.567	.001
.267	1.709	.600	.091	.933	.013	1.267	.003	1.600	.001
.300	1.196	.633	.073	.967	.011	1.300	.003	1.633	.001

```
*** MAXIMUM STORAGE              .0 C.F.
*** PONDING TIME                1.0 MINUTES
 160 PIP 88 940 931.62
 165 PNC 10 5 40 1 1 90. 0 0. 1.5
 170 HOL 1
 180 NEW FEEDER 2
 190 HYD .5 49 .025 .77 2.2
```

Figure 20 cont.

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```
         EXAMPLE FIVE: HYDROGRAPHIC SIMULATION AND DESIGN
  200 INL 2 2.5 27
  210 PIP 88 940 931.62
  215 PNC 20 5 50 1 1 90. 0 0. 1.5
  220 HOL 2
  230 NEW FEEDER 3
  240 GET 26
  250 GUT 500 940 932.5 .013 0 0 50
*** DEPTH=  .11  VEL= 2.38  WIDTH= 5.39
   DISCHARGE =      .70  SLOPE =   .01500 FT/FT
  260 HYD 0.5 49 0.025 0.77 2.2
  270 PUT 28
  280 GET 27
  290 GUT 500 940 932.5 .013 0 0 50
*** DEPTH=  .11  VEL= 2.38  WIDTH= 5.39
   DISCHARGE =      .70  SLOPE =   .01500 FT/FT
  300 HYD 0.5 49 .025 .77 2.2
  310 GET 28
  320 INL 3 20.0
  330 PIP 88 932.5 924.1
  335 PNC 30 5 60 1 1 0. 0 0. 1.5
  340 HOL 4
  350 NEW LEFT-SIDE MAIN
  360 REC 1
  370 HYD .5 49 .025 .77 2.2
  380 INL 4 2.5 29
  390 PIP 500 931.6 924.1
  395 PNC 40 1 60 1 0 0. 1 90.
  400 HOL 5
  410 NEW RIGHT-SIDE MAIN
  420 REC 2
  430 HYD .5 49 .025 .77 2.2
  440 INL 5 2.5 30
  450 PIP 500 931.6 924.1
  455 PNC 50 1 60 1 0 0. 1 90.
  460 HOL 6
  470 NEW OUTFALL PIPE
  480 REC 4
  490 REC 5
  500 REC 6
  510 GET 29
  520 GUT 500 931.6 924.1 .013 0 0 50
*** DEPTH=  .11  VEL= 2.38  WIDTH= 5.39
   DISCHARGE =      .70  SLOPE =   .01500 FT/FT
  530 HYD 0.5 49 0.025 0.77 2.2
  540 PUT 31
  550 GET 30
  560 GUT 500 931.6 924.1 .013 0 0 50
*** DEPTH=  .11  VEL= 2.38  WIDTH= 5.39
   DISCHARGE =      .70  SLOPE =   .01500 FT/FT
  570 HYD 0.5 49 0.025 0.77 2.2
```

Figure 20 cont.

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       EXAMPLE FIVE: HYDROGRAPHIC SIMULATION AND DESIGN
  580 GET 31
  590 INL 6 6.5
*** MAXIMUM STORAGE              125.3 C.F.
*** PONDING TIME                   6.0 MINUTES
  600 PIP 50 924.1 920 0 0 0 0 1 1
```

SYSTEM HYDROGRAPH IN CFS

PLOT-DATA (VALUE Vs.TIME)

.000	.000	.333	6.841	.667	.509	1.000	.079	1.333	.021
.033	.598	.367	4.620	.700	.412	1.033	.068	1.367	.019
.067	9.857	.400	3.234	.733	.335	1.067	.058	1.400	.017
.100	20.011	.433	2.531	.767	.274	1.100	.051	1.433	.016
.133	23.065	.467	1.999	.800	.225	1.133	.044	1.467	.015
.167	23.684	.500	1.567	.833	.186	1.167	.039	1.500	.013
.200	23.206	.533	1.244	.867	.155	1.200	.035	1.533	.012
.233	21.407	.567	.989	.900	.129	1.233	.030	1.567	.012
.267	15.616	.600	.789	.933	.109	1.267	.026	1.600	.011
.300	10.953	.633	.633	.967	.092	1.300	.023	1.633	.010

```
  605 PNC 60 1 70 4 1 0. 0 0.
  610 HOL 7
  620 NEW OUTFALL CHANNEL
  630 REC 7
  640 CHA 1000 914.0 912.0 .034 1 4 1
  650 END
```

Figure 20 cont.

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EXAMPLE FIVE: HYDROGRAPHIC SIMULATION AND DESIGN

*** FEEDER 1   Pipe Design

Link	Length (ft)	Diam (in)	Invert Up/Dn (ft)	Slope (ft/ft)	Depth Up/Dn (ft)	Min. Cover (ft)	Velocity Act/Full (ft/sec)	--Flow-- Act/Full (cfs)	Estimated Cost ($)
1	88	12	934.9	.09523	5.1	4.0	11.3	2.50	4190.
			926.5		5.1		14.0	11.02	

LENGTH = 88. COST = 4190.
TOTAL LENGTH = 88. TOTAL COST = 4190.

*** FEEDER 2   Pipe Design

Link	Length (ft)	Diam (in)	Invert Up/Dn (ft)	Slope (ft/ft)	Depth Up/Dn (ft)	Min. Cover (ft)	Velocity Act/Full (ft/sec)	--Flow-- Act/Full (cfs)	Estimated Cost ($)
2	88	12	934.9	.09523	5.1	4.0	11.3	2.50	4190.
			926.5		5.1		14.0	11.02	

LENGTH = 88. COST = 4190.
TOTAL LENGTH = 88. TOTAL COST = 4190.

*** FEEDER 3   Pipe Design

Link	Length (ft)	Diam (in)	Invert Up/Dn (ft)	Slope (ft/ft)	Depth Up/Dn (ft)	Min. Cover (ft)	Velocity Act/Full (ft/sec)	--Flow-- Act/Full (cfs)	Estimated Cost ($)
3	88	12	927.4	.09545	5.1	4.0	15.0	7.21	4190.
			919.0		5.1		14.1	11.04	

LENGTH = 88. COST = 4190.
TOTAL LENGTH = 88. TOTAL COST = 4190.

Figure 20 cont.

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EXAMPLE FIVE: HYDROGRAPHIC SIMULATION AND DESIGN

*** LEFT-SIDE MAIN — Pipe Design

Link	Length (ft)	Diam (in)	Invert Up/Dn (ft)	Slope (ft/ft)	Depth Up/Dn (ft)	Min. Cover (ft)	Velocity Act/Full (ft/sec)	--Flow-- Act/Full (cfs)	Estimated Cost ($)
4	500	18	925.9	.01487	5.7	4.0	6.8	5.00	29619.
			918.5		5.6		7.3	12.85	

LENGTH = 500. COST = 29619.
TOTAL LENGTH = 588. TOTAL COST = 33809.

*** RIGHT-SIDE MAIN — Pipe Design

Link	Length (ft)	Diam (in)	Invert Up/Dn (ft)	Slope (ft/ft)	Depth Up/Dn (ft)	Min. Cover (ft)	Velocity Act/Full (ft/sec)	--Flow-- Act/Full (cfs)	Estimated Cost ($)
5	500	18	925.9	.01487	5.7	4.0	6.8	5.00	29619.
			918.5		5.6		7.3	12.85	

LENGTH = 500. COST = 29619.
TOTAL LENGTH = 588. TOTAL COST = 33809.

*** OUTFALL PIPE — Pipe Design

Link	Length (ft)	Diam (in)	Invert Up/Dn (ft)	Slope (ft/ft)	Depth Up/Dn (ft)	Min. Cover (ft)	Velocity Act/Full (ft/sec)	--Flow-- Act/Full (cfs)	Estimated Cost ($)
6	50	18	917.8	.06950	6.3	4.0	17.7	23.68	2966.
			914.4		5.6		15.7	27.77	

LENGTH = 50. COST = 2966.
TOTAL LENGTH = 1314. TOTAL COST = 74774.

Figure 20 cont.

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EXAMPLE FIVE: HYDROGRAPHIC SIMULATION AND DESIGN

*** OUTFALL CHANNEL Channel

Link	Length (ft)	-Channel Shape-- Left (ft)	Ctr (ft)	Right (ft)	Slope (ft/ft)	Invert Up/Dn (ft)	Surface Up/Dn (ft)	Depth (ft)	Surf Width (ft)	Flow (cfs)	Vel (fps)
7	1000	1.0	4.0	1.0	.00200	914.00 912.00	915.86 913.86	1.9	7.7	23.6	2.2

LENGTH = 1000. COST = 0.
TOTAL LENGTH = 2314. TOTAL COST = 74774.

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Link	Node Number U/S	Node Number D/S	Node Type U/S	Node Type D/S	Main Line	Deflected Angle	Side Line	Skew Angle	Bend Radius [Ft]	Bend Angle
1	10	40	5	1	1	90.0	0	.0	.00	.0
2	20	50	5	1	1	90.0	0	.0	.00	.0
3	30	60	5	1	1	.0	0	.0	.00	.0
4	40	60	1	1	0	.0	1	90.0	.00	.0
5	50	60	1	1	0	.0	1	90.0	.00	.0
6	60	70	1	4	1	.0	0	.0	.00	.0

Figure 20 cont.

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Node#	Potential Water Level (Ft)	Ground Level (Ft)	Lowest Crown Elevation of Links Connecting Node			Possible Surcharging to the Link
			Link#	Elevation (Ft)	Location	
10	942.6	940.0	1	935.9	Upstream	Yes
40	931.2	931.6	4	927.4	Upstream	Yes
20	942.6	940.0	2	935.9	Upstream	Yes
50	931.2	931.6	5	927.4	Upstream	Yes
30	936.2	932.5	3	928.4	Upstream	Yes
60	922.6	924.1	6	919.3	Upstream	Yes
70	915.4	920.0	6	915.9	Downstream	No

Figure 2[illegible] cont.

CONCLUSIONS

1. Several storm sewer computer programs were reviewed and compared. PFP-HYDRA, a component program of the FHWA Pooled Fund Integrated Drainage Design Package, was found to be a good program for systems not under surcharge conditions. PFP-HYDRA is noted for the following capabilities: (1) generating storm runoff using either Rational Formula or hydrological simulation techniques, (2) changing design criteria at any point in the system, (3) analyzing any kind of system using the programming-like command statements; and (4) providing cost estimates and financial analysis.

2. The capability of PFP-HYDRA in the design of sewer systems has been enhanced by the addition of a hydraulic gradeline computation module so that engineers can determine the possibility of surface flooding during storms event by computing the hydraulic gradeline of a sewer system.

3. A sewer system designed for gravity flow conditions may experience a locally surcharged condition when major and minor head losses are considered in the hydraulic gradeline computation. This is illustrated in the report.

4. The gradeline computation module was structured so that an improved method of estimating head losses could be incorporated in the module easily.

RECOMMENDATIONS

1. It is recommended that the enhanced PFP-HYDRA be used as an initial step for the determination of the hydraulic gradeline of a sewer system. Although PFP-HYDRA does not give an explicit account of the pressurized flow situation, it gives an indication of the possibility of surcharging at particular pipes.

2. As part of the sewer system pressurizes, the analysis of flow in the system becomes more complicated. Since pressurized flow conditions are unsteady, the steady-state uniform approach for flow routing used by the original PFP-HYDRA is inadequate. A new flow routing method should be used. As mentioned in the report, the second phase of the gradeline study is to analyze the pressurized flow condition in sewer system. With both the gravity and pressurized flow gradeline computation module, PFP-HYDRA will become one of the most versatile computer models in sewer design and analysis.

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