TABLE OF CONTENTS - SECTION VIII

SECTION VIII - STORM SEWER DESIGN

8.1 GENERAL

All storm drains shall be designed by the application of the Manning equation either directly or through appropriate charts or nomographs. In the preparation of hydraulic designs, a thorough investigation shall be made of all existing waterways and drainage structures along with their performance.

The design of the storm drainage systems should be governed by the following six conditions:

1. The system must accommodate all surface runoff resulting from selected design storm without serious damage to physical facilities or substantial interruptions of normal traffic.

2. Runoff resulting from storms exceeding the design storm must be anticipated and disposed of with minimum damage to physical facilities and minimum interruption of normal traffic.

3. The storm drainage system must have a maximum reliability of operation.

4. The construction cost of the system must be reasonable with relationship to the importance of the facilities it protects.

5. The storm drainage system must require minimum maintenance and must be accessible for maintenance operations.

6. The storm drainage system must be adaptable to future expansion with minimal additional costs.

   An example of the design of the storm drainage system is outlined in Paragraphs 8.3 and 8.4. The design theory has been presented in the preceding sections with corresponding tables and graphs of information.

8.2 PRELIMINARY DESIGN CONSIDERATIONS

A. Prepare a Drainage Map of the entire area to be drained by proposed improvements. Contour maps serve as excellent area drainage maps when supplemented by field reconnaissance.

B. Make a tentative layout of the proposed storm system, locating all inlets, manholes, mains, laterals, ditches, culverts, etc.

C. Outline the drainage area for each inlet in accordance with present and future street development.

D. Indicate on each drainage area the size of the area, the direction of surface runoff by small arrows and coefficient of runoff for the area.

E. Show all existing underground utilities.

F. Establish design rainfall frequency.

G. Establish minimum inlet time of concentration.

H. Establish the typical cross section on each street.

I. Establish permissible spread of water on all streets within the drainage area.

J. All drainage improvements in the City of Bentonville shall be tied to the City of Bentonville Survey Monumentation System based upon the State Plane Coordinate System, Arkansas North Zone using the North American Datum of 1983 (NAD 83). All information for newly constructed streets and roads at the time of approval shall be delivered to the City of Bentonville Engineering Department, georeferenced, in an AutoCAD compatible digital format for review and acceptance.

All drainage construction shall use the above mentioned coordinate system and shall identify with monuments that were used for horizontal and vertical control. Elevation of controlling points shall be based on USGS NAVD 88 datum.

K. Include A. through I. with Plans submitted to the Engineering Department for review. The Drainage Map submitted shall be suitable for permanent filing in the Engineering Department and shall be a good quality reproducible.

8.3 INLET SYSTEM

Determining the size and location of inlets is largely a trial and error procedure. Using criteria outlined in earlier sections of this manual, the following steps will serve as a guide to the procedure to be used.

A. Beginning at the upstream end of the project drainage basin, outline a trial subarea and calculate the runoff from it.

B. Compare the calculated runoff to allowable street capacity. If the calculated runoff is greater than the allowable street capacity, reduce the size of the trial subarea. If the calculated runoff is less than street capacity, increase the size of the trial subarea. Repeat this procedure until the calculated runoff equals the allowable street capacity. This is the first point at which a portion of the flow must be removed from the street. The percentage of flow to be removed will depend on street capacities versus runoff entering the street downstream.

C. Record the drainage area, time of concentration, runoff coefficient, and calculated runoff for the subarea. This information shall be recorded on the Plans or in tabular form convenient for review. (Figure 7.12)

D. If an inlet is to be used to remove water from the street, size the inlet(s) and record the inlet size and amount of intercepted flow, and amount of flow carried over (bypassing the inlet).

E. Continue the above procedure for other subareas until a complete system of inlets has been established. Remember to account for carry-over from one inlet to the next.

F. After a complete system of inlets has been established, modification should be made to accommodate special situations such as point sources of large quantities of runoff, and variation of street alignments and grades.

G. Record information as in C. and D. for all inlets.

H. After the inlets have been located and sized, the inlet pipes can be designed.

I. Inlet pipes are sized to carry the volume of water intersected by the inlet and direct sources. Inlet pipe capacities may be controlled by the gradient available, or by entry condition into the pipe at the inlet. Inlet pipe sizes should be determined for both conditions and the larger size thus determined should be used.

8.4 STORM SEWER SYSTEM

After the computation of the quantity of runoff entering each inlet, the storm sewer system required to carry the runoff is designed. <u>It should be borne in mind that the quantity of flow to be carried by any particular section of the storm sewer system is not the sum of the inlet design quantities of all inlets above that section of the system, but is less than the straight total</u>. This situation is due to the fact that as the time of concentration increases the rainfall intensity decreases.

8.4.1 STORM SEWER PIPE

The ground line profile is now used in conjunction with the previous runoff calculations. **The maximum elevation of the hydraulic gradient is two feet (2') below the ground surface.** When this tentative gradient is set and the design discharge is determined, a Manning flow chart may be used to determine the pipe and velocity.

It is probable that the tentative gradient will have to be adjusted at this point since the intersection of the discharge in the slope on the chart will likely occur between standard pipe sizes. The smaller pipe should be used if the design discharge and corresponding slope does not result in an encroachment on the two-foot (2') criteria below the ground surface. If there is an encroachment, use the larger pipe which will establish a capacity somewhat in excess of the design discharge. Velocities can be read directly from a Manning flow chart based on a given discharge, pipe size, and gradient slope.

8.4.2 JUNCTIONS, INLETS, AND MANHOLES

A. Determine the hydraulic gradient elevation at the upstream end and downstream end of the pipe section in question. The elevation of the hydraulic gradient of the upstream end of the pipe is equal to the elevation of the downstream (hydraulic gradient) plus the product of the length of the pipe and the friction slope.

B. Determine the velocity of flow for incoming pipe (main line) at junction, inlet or manhole at design point.

C. Determine the velocity of flow for outgoing pipe (main line) at junction, inlet or manhole at design point.

D. Compute velocity head for outgoing velocity (main line) at junction, inlet, or manhole at design point.

E. Compute velocity head for incoming velocity (main line) at junction, inlet or manhole at design point.

F. Determine head loss coefficient "K" at junction, inlet, or manhole at design point from Tables 3.5, 3.6, 3.7, or Figures 3.10 or 3.11.

G. Compute head loss at junction, inlet, or manhole.

$$h_j = K_j \, (v_2^2 - v_1^2)/2_g$$

H. Compute hydraulic gradient at upstream end of junction as if junction were not there.

I. Add head loss to hydraulic gradient elevation determined to obtain hydraulic gradient elevation at upstream end of junction.

All information shall be recorded on the Plans or in tabular form convenient for review.

8.4.3 PROPORTIONING STORM SEWER PIPES.

The computations involved in proportioning various runs of sewer pipe are summarized in the tabulation sheet titled "Storm Sewer Computations", Figure 8.1.

Computer generated computations and output are accepted and subject to review by City Engineer.

Column 1: Inlet Number - Enter the inlet number.

Column 2: Inlet Location - Enter the station and location of the inlet.

Column 3: Inlet CA from the Inlet Flow Calculation Table, Figure 7.12, the quotient of Column 25 ÷ Column 6 or Column 27 is used to obtain the CA product to be entered in Column 3. Only structures contributing flow to the system should have values in Column 3.

Column 4: Other CA - Enter the CA product of flow from any contributing upstream structure.

Column 5: Structure No. - Number the inflowing structure.

Column 6: Total CA - Enter the sum of Columns 3 and 4.

Column 7, 8, & 9: The time of concentration is the time required for water to flow from the most remote part of the drainage area or areas involved to the upper end of the pipe run under consideration. The first run time of concentration is the inlet time for the first inlet. For all succeeding runs, time of concentration may be either the time as computed along the sewer line or the inlet time of the inlet at the beginning of the run under consideration, depending upon which of these two periods is longer. Accordingly, the larger of the two is used in determining "I" and "Q", unless this larger value is less than 10 minutes, in which case the established minimum time of 10 minutes is used.

The time of concentration shown in Column 7 is computed by taking the time of concentration for the preceding run and adding it to the time required for water to flow through the preceding run to the beginning of the run under consideration.

At junctions of lines, the larger value of the time of concentration is used.

Column 10: i - Rainfall intensity in inches per hour for the design storm. Base on T_c. See Figure 2.5.

Column 11: Q_t - Total flow in pipe in CFS. Equal to the product of Column 6 times Column 10.

Columns 12: 13, 14, & 15: Pipe Characteristics - The size and gradient of pipe as shown in Columns 12 and 14 must be chosen in such manner that the pipe when flowing full, but not under head, will carry an amount of water approximately equal or greater than the computed discharge, "Q". In other words,the "Capacity" shown in Column 15 must be approximately equal to or greater than the value "Q" shown in Column 11.

The capacity may be calculated by Manning's formula:

$$Q = \frac{1.486}{n} AR^{2/3}S^{1/2}$$

or capacity can be taken directly from the appropriate nomographs in Sections III and IV.

Whenever a pipe run is designed in such a manner that the capacity of a pipe as shown in Column 15 is less than the computed discharge shown in Column 11, a check of the hydraulic gradient above this run should be made to make such that the backwater head created by such a design is not large enough to cause blowouts at inlets or junctions above the run.

Column 16: The velocities shown in this column can be calculated by Manning's formula:

$$V = \frac{1.486}{n} R^{2/3}S^{1/2}$$

or the velocities can be taken directly from the appropriate graphs or figures in Sections III and IV.

Column 17: L - The length of each run as shown in this column is the length center to center of inlets or junctions in feet. This length is used in determining the time of flow from one inlet or junction to another.

Column 18: Pipe T_c - The time of concentration in the pipe under consideration is actual flow time, in minutes from the present inlet to the next junction point. Run time is calculated by dividing the length of run (Column 17) by velocity of flow (Column 16) and converting the answer to minutes by dividing by 60.

Columns 19 to 24: These columns are believed to be self-explanatory.

8.4.4 HYDRAULIC GRADE LINE

The final step in designing a storm sewer is to check the Hydraulic Grade Line (HGL). Computing the HGL will determine the elevation under design conditions to which water will rise in various inlets, manholes, junctions, and etc.

The HGL should be computed for all storm sewer systems. Computations are summarized in tabulation sheet entitled "Hydraulic Grade Line", Figure 8.2.

Computer generated computations and output are accepted and subject to review by City Engineer.

Column 1: Inlet Station - Enter the station for the junction immediately upstream of the outflow pipe. HGL computations begin at the outfall and are worked upstream taking each junction into consideration.

Column 2: Outlet Water Surface Elevation - Enter tailwater elevation in feet if the outlet will be submerged during the design storm or 0.8 diameter of pipe plus invert out elevation of the outflow pipe, whichever is greater.

Column 3: D_o - Enter diameter of outflow pipe in inches.

Column 4: Q_o - Enter design discharge for outflow pipe in CFS.

Column 5: L_o - Enter length of outflow pipe in feet.

Column 6: S_{fo} - Enter friction slope in feet/foot of the outflow pipe using the Manning's formula:

$$S_f = \left(\frac{Qn}{1.486\ AR^{2/3}}\right)^2$$

Column 7: H_f - Enter friction loss by multiplying Column 5 by Column 6.

Column 8: V_o - Enter velocity of the outflow pipe in feet per second.

Column 9: Q_i - Enter design discharge (Q_1, Q_2, Q_3...) in CFS for each pipe flowing into the junction.

Column 10: V_i - Enter velocity (V_1, V_2, V_3...) in feet per second for each pipe flowing into the junction.

Column 11: H_{tm} - Enter terminal junction losses in feet for the upper reach of each storm sewer run using the formula:

$$H_{tm} = \frac{V^2}{2g}$$

Column 12: H_e - Enter pipe entrance losses in feet for the upper reach of each storm sewer run using the formula:

$$H_e = \frac{K\,V^2}{2g}$$

where: K = 0.5 for square-edge

Column 13: Enter junction losses H_{jl} or H_{j2} in feet for each junction using the formula:

$$H_{jl} = \frac{V^2\ \text{outflow}}{2g}$$

or:

$$H_{j2} = \frac{Q_4V_4^2 - Q_1V_1^2 - Q_2V_2^2 + KQ_1V_1^2}{2gQ_4}$$

Column 14: H_b - Enter bend losses (changes in direction of flow) in feet for each inflowing pipe to the outflow pipe using the formula:

$$H_b = \frac{K V^2}{2g}$$

Refer to Section III for "K" values.

Column 15: H_t - Enter total head losses in feet using the formula:

$$H_t = H_f + H_{tm} + H_e + H_{jl} \text{ or } H_{j2} + H_b$$

Column 16: HGL - Enter the new Hydraulic Grade in feet by summing elevations in column 2 and column 15. This elevation is the potential water surface elevation for the junction under design conditions.

Column 17: Enter the top of junction cover or the gutter flow line, whichever is lowest and compare it with the HG in Column 16.

PROJECT ____________________

PLAN SHT. NO. __________ DATE __________

COMPUTED BY __________ CKD. __________

CITY OF BENTONVILLE, ARKANSAS
STORM SEWER COMPUTATIONS

											PIPE DESIGN							PIPE INVERTS			DROP INLET		
(1) Inlet No.	(2) Location	(3) Inlet CA	(4) Other CA	(5) From Struct. No.	(6) Total CA	(7) Inlet Tc (Min)	(8) Pipe Tc (Min)	(9) Design Tc (Min)	(10) I (IN/HR)	(11) Pipe Qt (CFS)	(12) Pipe Size (IN)	(13) Pipe n	(14) Pipe Slope (FT/FT)	(15) Pipe Cap. (CFS)	(16) Pipe Vp (FPS)	(17) Pipe L (FT)	(18) Pipe Tc (Min)	(19) Inlet Elev. (FT)	(20) Total Fall (FT)	(21) Outlet Elev. (FT)	(22) Flow Line (FT)	(23) Top Elev. (FT)	(24) HT (FT)

STORM SEWER COMPUTATIONS

Figure 8.1

CITY OF BENTONVILLE, ARKANSAS
HYDRAULIC GRADE LINE

PROJECT ____________________

PLAN SHT. NO. ____________ DATE ____________

COMPUTED BY ____________ CKD. ____________

(1) Inlet Station	(2) Outlet WSE	(3) Do	(4) Qo	(5) Lo	(6) Sfo	(7) Hf	VELOCITY HEAD LOSSES								(16) Total HGL	(17) Top Ring or Gutter
							(8) Vo	(9) Qi	(10) Vi	(11) Htm	(12) He	(13) Hj	(14) Hb	(15) HL		

HYDRAULIC GRADE LINE

Figure 8.2