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F200 PROJECTION OF FLOWS AND HYDRAULICS OF SEWERS

SECTION NO.	**SUBJECT**	**DATE**
EXAMPLE 4:	DESIGN OF NON-CIRCULAR SEWER PIPES	June-92

F 200

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F 200 INTRODUCTION

Section F 200 provides city standards, policy and procedures for the hydraulic design of sewers. It provides guidelines for the projections of residential, commercial and industrial wastewater flows. It also provides criteria for the inclusion of groundwater infiltration and extraneous inflow for sewer design.

F 210 TERMINOLOGY, DEFINITIONS AND ABBREVIATIONS

Terminology used in this Section is defined as follows:

AVERAGE DRY WEATHER FLOW (ADWF): ADWF consists of average daily sewage flows and groundwater infiltration (GWI).

CENSUS TRACT (CT): A defined area boundary developed for census purposes. The City is divided into approximately 700 CT areas. Population and employment projections are provided by CT. Each sewage drainage basin comprises CTs which are partially or wholly located within each basin boundary.

DESIGN PERIOD: The length of time a sewage facility is anticipated to provide adequate service. Actual service life of the sewage facility may differ from the design period.

DIURNAL FLOW: Fluctuation of flows over a 24 hour period.

EQUALIZATION STORAGE: The storage of peaking flows to prevent overflows from the collection and conveyance systems. The stored wastewater is discharged back to the system during low flow periods. The storage can be online or offline.

GROUNDWATER INFILTRATION (GWI): Groundwater that infiltrates pipeline and maintenance hole defects located below the ground surface. Groundwater infiltration is separate and distinguished from stormwater inflow.

INFLOW: Drainage that enters the collection system through direct illegal or permitted connections, such as, catch basins, downspouts, area drains and MH covers. Inflow is separate and distinguished from infiltration. (See Stormwater Inflow)

INFILTRATION/INFLOW (I/I): The wastewater component caused by rainfall-dependent infiltration/inflow (RDI/I) and groundwater infiltration (GWI).

PEAK DRY WEATHER FLOW (PDWF): PDWF consists of peak sewage flows plus GWI.

PEAK WET WEATHER FLOW (PWWF): PWWF consists of PDWF plus RDI/I.

PEAK FACTOR: Peak Factor is PDWF/ADWF.

RAINFALL DEPENDENT INFILTRATION (RDI): RDI consists of rainfall that enters the collection system through GWI.

RAINFALL DEPENDENT INFILTRATION/INFLOW (RDI/I): RDI/I consists of rainfall that enters the collection system through both RDI (infiltration) and SWI (inflow) sources.

SERVICE AREA: The sewer service area served by a collection system or a wastewater treatment plant. The City of Los Angeles comprises the Hyperion Service Area (HSA) and the Terminal Island Service Area (TISA).

SERVICE LIFE: The operational life of a sewage facility which should exceed the design period of the facility, provided it is designed, constructed and maintained properly.

STORMWATER INFLOW (SWI): SWI consists of rainfall runoff that enters the system through direct connections such as catch basins, downspouts and area drains.

SYSTEM ANALYSIS MODEL (SAM): SAM is a computer model used for modeling the City's interceptor system for various flow conditions.

SEWERAGE DRAINAGE BASIN: A drainage area which boundaries are determined by gravity flow. The HSA comprises 20 basins and 206 sub-basins. The TISA is one basin with 8 sub-basins.

TRIBUTARY AREA: The tributary area of a sewage system consists of all areas which contribute flow to the sewer by gravity and/or force main discharges. These include sanitary sewer as well as I/I flows.

WASTEWATER FLOW RATE UNITS: Commonly used flow rates are:

cfs	cubic feet per second
gpcd	gallons per capita per day
gpd	gallons per day
gpapd	gallons per acre per day
gped	gallons per employee per day
gpm	gallons per minute
mgd	million gallons per day

F 220 PROJECTION OF FLOWS

Each service area has its own unique characteristics. For this reason, there is no one correct approach to the projection of flows within a service area. Procedures presented in this section for the development of flows are intended as guidelines. The Engineer is encouraged to use his own initiative and judgement for the projection of flows in conjunction with these guidelines.

When possible, the Engineer should measure flows to verify parameters used to project future flows including residential, industrial, commercial and I/I flows. Key locations for monitoring flows include major interceptors, sewer outfalls, major point-source discharges and wastewater pumping plants. The Engineer may prepare a request form to WSED to measure flows. The procedure and information required to obtain flow measurements is outlined in Section F 512.14.

The following parameters shall be evaluated to project wastewater flows and are discussed in further detail in this section. Also, example problems illustrating the projection of flows and hydraulic design of pipes are shown in the appendix of this section.

a. Tributary Area
b. Design Period
c. Population Estimate
d. Land Use
e. Per Capita Flows
f. Residential Flows
g. Commercial Flows
h. Industrial Flows
i. Major Point source Discharges
j. Infiltration/Inflow

F 221 TRIBUTARY AREA

The tributary area of a sewer includes all areas which will contribute flow to the system. It includes flows from the ultimately developed service area and basin to basin flow routings. Potential service areas, such as, areas served by septic tanks and local treatment facilities should also be assessed for possible inclusion in the tributary area. The area may be limited by natural topography, natural or human-made barriers, political boundaries or economic factors. As-Built drawings and Wye and Sewer maps should be reviewed to help define the tributary area boundary. Although they may not be up-to-date, sewer maps (1" = 400' with contours) and drainage maps may be helpful in determining the tributary area.

F 222 DESIGN PERIOD

The design period is that length of time the capacity of the sewerage facility is anticipated to be adequate to service its tributary area. It must be determined before design of the facility is commenced. A standard for minimum design periods for various components of a sewer system are summarized in Table F 222. For force mains, pumping plants, and other items not documented herein, see Section F 700.

TABLE F 222
MINIMUM DESIGN PERIODS FOR
WASTEWATER FACILITY/COMPONENTS

Wastewater Facility/Component	Minimum Design Period (Yrs)
Trunk, interceptor, outfall, and relief sewers - sewers 18-inch in diameter and greater	60 - 100
Lateral sewers - sewers less than 18-inch in diameter	100

F 223 POPULATION ESTIMATE

The population estimate for the tributary area is the basis for computing the design flow. It is customary to multiply the estimated population by the estimated per capita wastewater contribution. Because the population estimate is the basis for the computation of design flows, it is important that it be as accurate as possible. Generally, population projections prepared for land use planning have shorter projection periods than are required for the design period for sewerage facilities. However, the Advance

Planning Report (APR) projects resident and employment populations for the years 2010, 2050 and 2090. APR population projections are distributed based on Southern California Association of Governments (SCAG) population distributions and are shown by Census Tract (CT). This information is periodically updated. The Engineer may obtain this information from WPMD.

F 224 LAND USE

Land uses help define population densities and types of contributors to wastewater flows within the tributary area. Zoning maps and field review of land use can be used to verify the reasonableness of long range projections. However, because land use planning is typically done in increments for shorter time periods than the design period for a sewer, their use should be limited primarily to confirmation of shorter term flow projections.

F 225 PER CAPITA FLOWS

Per capita wastewater flows are less than per capita water consumption because of water lost to lawn irrigation, swimming pools, washing cars, etc. The unit flow rates will vary from area to area. The per capita flow rate can be estimated from flow measurement and census data. The average per capita wastewater flow in the Los Angeles area is estimated at 90 gpcd. The average employee wastewater flow is estimated at 30 gped.

F 225.1 RESIDENTIAL FLOWS

Residential flows may be estimated by multiplying the population times the per capita flow of 90 gpcd unless data is available to support a higher rate.

F 225.2 COMMERCIAL FLOWS

Commercial flows may generally be accounted for by multiplying the employment population times the estimated employee wastewater flow of 30 gped and utilizing flow rates in the Public and Commerical Facilities Average Daily Flow Table F 227 in the appendix to this section. Commercial operations which may contribute significantly greater flows, such as, car washes, laundry facilities, etc., shall be investigated by the Engineer. See F 227 for major point sources of commercial flows.

F 226 INDUSTRIAL FLOWS

Industrial wastewater flows may vary significantly depending on the industry type, size, operational techniques and whether or not the industry has onsite treatment of wastewater. Also, peak flows may be significant because of the method of operation and work shifts. If significant industries are in the project area, it shall be necessary for the Engineer to conduct a survey to determine the magnitude of contribution from the various industries. The Industrial Waste Operation Division of the Bureau of Sanitation has a list of industries within the City and information helpful in determination of industrial flows. See F 227 for major point sources of industrial flows.

F 227 MAJOR POINT SOURCE DISCHARGES

Major point source discharges include flows from institutional, commercial and industrial establishments with average daily flows greater than 40,000 gpd. Existing major point source discharges in a tributary area should be identified from available government and private documents, including industrial and institutional water use permits, pretreatment discharge permits and water conservation and flow monitoring programs. The Engineer is cautioned to confirm exact discharge locations of industrial wastewater and not rely only on the address on the permit. This is particularly true when the service area is small. Sometimes the discharge location and address location of the industry are far apart.

The Industrial Waste Operation Division can provide the Engineer with a listing of the major industries and their average daily flowrates. Such listings should be developed, updated and field verified for design of sewers and should include all the major discharges and respective flow rates in the tributary area.

Major discharges from future point sources shall also be incorporated in the design flow. Future development of major industries and institutions should be ascertained from available information, including plans of the existing establishments, industrial and institutional zoning plans and projections of past records of water and wastewater flowrates. Where uses are planned for an area and flow rates are not known, the average flow rates shown in Table F 227 in the appendix of this section can be used to estimate flows.

F 228 INFILTRATION/INFLOW

Design capacity shall include an allowance for extraneous flows which inevitably become a part of the total flow. These flows include GWI through defective pipes and maintenance holes. It also includes RDI/I flow through cross connections, faulty maintenance holes and submerged maintenance hole covers.

Studies have shown that the GWI component in the City is generally insignificant and may be accounted for by using conservative per capita flows. (Information on groundwater studies conducted within the City's drainage basins may be obtained from WPMD). If flow monitoring determines that significant GWI flows are present in the tributary area, the Engineer shall account for that additional component of flow.

RDI/I flows are accounted for by designing pipes to have a d/D ratio of 0.5 for PDWF. This is discussed further in F250.

F 230 DETERMINATION OF DESIGN FLOWS

The design of sanitary sewers must consider minimum, average, and peak flows. Normally, ADWF is determined or selected, and a factor is applied to determine PDWF. The PDWF is the design flow used to select the pipe size. Minimum flows are used to determine if specified velocities can be maintained to prevent deposition of solids.

The ratio of PDWF to ADWF will range from less than 130% for some large sanitary sewers to more that 260% for smaller sewers. Additionally, the ratio of the PDWF at the end of the design period to the minimum flow at the beginning of the design period may range from less that 3:1 to more than 20:1, depending on the rate of growth of the tributary area served.

F 231 MINIMUM VELOCITY

Gravity sewers shall be designed for a minimum velocity of three fps using the PDWF that exists at the time the pipe is placed into service. Deputy approval shall be obtained when using design velocities less than three fps. This minimum velocity is necessary to prevent deposition of solids in the sewer pipe.

F 232 AVERAGE DRY WEATHER FLOW

Average Dry Weather flow (ADWF) includes average daily sewage flows and GWI. ADWF is the basis for calculation of PDWF.

F 233 PEAK DRY WEATHER FLOW

The Peak Dry Weather Flow (PDWF) includes peak sewage flows and GWI. PDWF is the basis for selecting a pipe size. (See F 250 et. seq.)

PDWF is determined by multiplying ADWF times a peaking factor as discussed in F 235. When major point source discharges are identified in the service area as discussed in F 227, peak flows shall be determined for those discharges and added to PDWF.

F 234 PEAK WET WEATHER FLOW

The Peak Wet Weather Flow (PWWF) includes both PDWF as discussed in F 233 and RDI/I which occurs during storm events. RDI/I includes stormwater that enter the collection system through both infiltration and inflow sources during and shortly after a storm event. Capacity for PWWF is achieved by designing the pipe with a d/D of 0.5 for PDWF. (See F250)

F 235 USE OF THE ADWF - PDWF CHART

Figure F 235 shows the relationship between ADWF and PDWF. To determine PDWF from ADWF, project the ADWF value on the abscissa to the "flow" curve and read on the ordinate the value. To determine the peak factor, project the ADWF value on the abscissa to the "factor" curve and read the peak factor value on the ordinate. Also, the following equation shows the relationship between ADWF and PDWF:

$$Q_{PDWF} = 2.64\,(Q_{ADWF})^{0.905}$$

Example: A local sewer with an ADWF of 2.5 cfs is to discharge into an interceptor where the ADWF is 5.4 cfs.

Find: The PDWF in the interceptor sewer below the confluence point.

Average Dry Weather Flows

2.5 cfs
<u>5.4 cfs</u>
Sum = 7.9 cfs

The resulting ADWF below the confluence point is 7.9 cfs which converts to 17 cfs PDWF and peaking factor of 2.2 by use of the Chart in Figure F 235.

Examples 1 and 3 in the appendix of this section illustrate the procedure for the projection of flows.

F 240 TYPES OF FLOW

The flow of wastewater in sewers may be open channel or pressure flow. When flow fills the conduit and the Hydraulic Grade Line (HGL) rises above the sewer crown, the flow is classified as pressure flow. When the conduit is partially full and the HGL is below the sewer crown and a freewater surface develops in the sewer, the flow is classified as an open channel flow. Open channel flow will be the basis for general hydraulic design of sanitary sewers.

F 241 TYPES OF OPEN CHANNEL FLOWS

The following defines the types of open channel flows which may be found in sewers:

Steady flow occurs when the depth of flow is constant with respect to time.

Unsteady flow occurs when the depth of flow is not constant with respect to time.

Uniform flow occurs when the depth of flow does not change with respect to location.

Nonuniform flow occurs when the depth of flow changes with respect to location.

Steady uniform flow occurs when in a given stretch of a sewer pipe, having a constant shape, size, slope and interior roughness, a constant rate of flow enters the upstream end of the pipe and the same exits at the downstream end of the pipe. In this flow regime, the depth of flow is constant with respect to time and location and the HGL is parallel to the sewer invert slope.

Unsteady uniform flow occurs when the HGL remains parallel to the sewer invert and fluctuates up and down as the rate of flow fluctuates with time. This type of flow is not very common in sewer design.

Steady nonuniform flow shall be considered when different constant rates of flow enter a sewer along its length at various locations. However, a simplification of this case is used in the design of such sewers. Accordingly, the sum of all the flows for a given stretch of the sewer is assumed to enter the pipe at its upstream end, thereby reducing the flow regime to a steady-uniform case.

Unsteady nonuniform flow develops during the onset and termination of PWWFs. However, design of sewers based on this flow regime is seldom required, as it involves extensive calculations for flow routing, wave and water surface profiles. For the special projects requiring this type of approach, the consent of the City as to the specific analysis and use of special computer programs shall be obtained in advance from the Division/District Engineer.

In general, the design of sanitary sewers shall be based on steady uniform flow analysis employing the Manning equation. See F 251.

F 242 SUPERCRITICAL AND SUBCRITICAL FLOW

The Engineer should be able to identify supercritical, subcritical and critical flows. Because flows within 10 to 15 percent of critical depth are likely to be unstable they should be avoided. However, this is not always possible because of diurnal flows. The Engineer should, however, be aware of flow characteristics throughout the flow regime from minimum to PWWF.

For a given rate of flow and channel cross section, the specific energy H_o as shown in the following equation is a function of depth:

$$H_o = d + \frac{V^2}{2g} = d + \frac{Q^2}{2\,gA^2}$$

A plot of this function produces a specific energy curve like the one shown in Figure F242A. There is one depth at which H_o is a minimum. That is the "critical depth" d_c and the corresponding velocity at the depth is the "critical velocity" V_c. Each larger value of H_o can occur at either of two alternate depths. The upper depth d_u is greater than d_c while the corresponding velocity V_u is less than V_c. This flow is subcritical. The lower depth d_l is less than d_c, while the corresponding velocity V_l is greater than V_c. This flow is supercritical.

Figure F242B shows an example profile of a sanitary sewer which transitions from a steep slope to a medium slope. Upstream of the change, the steep slope produces a velocity that is greater than a certain critical value and a small depth of flow results. This flow is called "supercritical". For the same rate of flow, the medium downstream slope produces a velocity that is less than the critical value but with a greater depth. This flow is called "subcritical". Somewhere near the change in slope, the depth increases abruptly from the smaller depth to the greater depth causing a "hydraulic jump". The hydraulic jump takes place over a relatively short distance. It has an irregular surface with a high degree of turbulent motion, mixing and energy dissipation. Careful consideration should be given in the design of sewers to avoid hydraulic jumps. The rapid decrease in flow velocity across the jump may result in deposition of solids in the downstream conduit and the turbulence causes the release of sulfide gases held in solution. For this reason vertical curves are often used at significant changes in grade to avoid hydraulic jump. (See F322.2).

Computation of "critical depth" is necessary to determine whether flow may be supercritical or subcritical. Normal flow depth is compared with critical depth to determine if flow is supercritical or subcritical. If normal flow depth is above critical depth, the flow is subcritical. If normal flow depth is below critical depth, the flow is supercritical.

For circular pipes, the chart in Figure F242C can be used to compute critical depth. Critical depth can then be compared to the design depth to determine if flows will be subcritical or supercritical and whether or not a hydraulic jump may occur. Computer programs are available within the Bureau and should be used for these calculations.

F 243 FLOW AIR AND SEWER GASES

The fluid in motion in open channels drags along the air and sewer gases in contact with it creating a flow of air and sewer gases in the space above the wastewater, that follows its downstream. When the sewer pipe fills with wastewater, this free flow of air and gases in the upper portion of the pipe is inhibited and then under slight positive pressure is forced to the surface through the nearest openings such as maintenance holes, roof vents, yard drains, etc. The sewer gases forced into the atmosphere are heavier than air and have a pronounced Arotten egg@ odor. Sewer gases can include mixtures of nitrogen, oxygen, carbon dioxide, hydrogen sulfide, ammonia, and methane and may be combustible and toxic.

To avoid the odor problems associated with sewer gases, the sewer system under normal operating conditions should allow for the transport of the air and gases to the wastewater treatment facility where they can be collected and treated. This will require the designer to know where the hydraulic grade line is for the various stages of flow, espacially at confluence or diversion structures. Where the sewer is planned to flow full, such as for inverted siphons, separate air line(s) should be provided for conveyance of the sewer gases to a downstream portion of the system where they rejoin the flow stream.

F 250 DESIGN CRITERIA

The criteria for design of sewer pipe includes type/size sewer line, design period, design depth of flow and PDWF. Table F250 summarizes the design criteria for sewer pipe.

TABLE 250
DESIGN CRITERIA FOR SEWER PIPE

TYPE/SIZE SEWER LINE	DESIGN PERIOD (years)	DESIGN DEPTH OF FLOW* (d/D)
Trunk, interceptor, outfall and relief sewers - sewers 18-inch diameter and greater.	60 - 100	0.5
Lateral sewers - sewers 18-inch diameter and smaller.	100	0.5

*Depth of flow in the pipeline is based on (PDWF)
d = depth of flow
D = Pipe diameter

Sewers shall be sized so the depth of the PDWF, projected for the design period, shall be no more than one half the pipe diameter (d/D = 0.5). Where upstream treatment and/or storage reservoirs are planned or available, their effect on reducing peak flows shall be considered in sizing downstream sewers.

F 251 CALCULATION OF PIPE SIZE

After the design criteria have been determined the required pipe size may be calculated using Manning's formula.

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

where,
Q = Flow, cfs
A = Area of flow, ft^2
R = Hydraulic radius (A/P), ft
n = Roughness factor

S = Slope, ft/ft

Calculation of the required pipe size may be accomplished by using Manning's equation or by use of the charts shown in Figures F251A through F251M in the appendix of this section. Also, reference may be made to Storm Drain Office Standards No. 116 and 117. Minimum pipe size shall be 8-inch. These charts apply to circular pipes 8-inch to 42-inch in diameter. Flow is shown on the abscissa in cfs, and the slope is indicated on the ordinate in feet per foot. Any given point on these charts corresponds to a flow, slope, depth of flow, and velocity for the pipe diameter chosen. A "Minimum Energy" line is also shown on these charts. The points located above the "Minimum Energy" line correspond to supercritical flow, and the points below the line depict subcritical flow. Figure F 251N in the appendix of this section is an alignment chart which allows the calculation of pipes flowing full using the Manning Formula. This chart applies to circular pipes 8-inch through 96-inch.

Examples 2 and 3 in the appendix of this section illustrate the use of these Flow charts. Example 4 in the appendix of this section illustrates the design of non-circular sewer pipes.

F 252 MANNINGS ROUGHNESS COEFFICIENT "n"

A Manning's roughness coefficient of "n" = 0.014 shall be used for sizing gravity sewers. This Manning's roughness coefficient shall be used regardless of the type of pipe specified.

F 253 MINIMUM SLOPE

Gravity sewers shall be designed for a minimum velocity of three fps using the PDWF that exists at the time the pipe is placed into service.

Deputy City Engineer approval must be obtained to use lower design velocities, except in the extreme upper reaches of the system with few connections. In these cases, 8-inch diameter minimum pipe size and 0.0044 ft/ft minimum slope will govern except for the last upstream reach to a terminal maintenance hole where 0.0060 ft/ft minimum slope will govern. See F 232.

F 254 INVERT DROPS ACROSS MAINTENANCE HOLES (ALL PIPES THE SAME SIZE)

For straight through flow the invert drop shall be computed by multiplying the diameter of the MH times the average slope of the inlet and outlet sewers. When possible to attain, the minimum invert drop across a MH should be 0.10 foot.

For side inlet flow into the MH the invert drop across the MH shall be computed by multiplying the diameter of the MH times the average slope of the side inlet and outlet sewers and adding 0.10 foot.

F 255 INVERT DROPS ACROSS MAINTENANCE HOLES (OUTLET PIPE IS LARGER THAN THE INLET PIPE)

For straight through flow the drop across the invert of the MH shall be computed by multiplying the diameter of the MH times the average slope of the inlet and outlet sewers and adding the additional drop as shown in Table F255.

TABLE F255

ADDITIONAL INVERT DROPS ACROSS MAINTENANCE HOLE WHEN THE OUTLET SEWER IS LARGER THAN THE INLET SEWER PIPE SIZES 8-INCH THRU 15-INCH

Diameter Outlet Sewer Inches	Diameter Inlet Sewer (inches)			
	6	8	10	12
8	0.08	-	-	-
10	0.17	0.08	-	-
12	0.25	0.17	0.08	-
15	0.38	0.29	0.13	0.13

In the above table the sewers are assumed to be flowing with the d/D = 0.50 and water surfaces at the same level. For pipes 18-inch and larger the 0.50 depth point of both pipelines shall be at the same level as shown in Figure F255. This approximates maintaining the same hydraulic energy gradient from the inlet to the outlet pipe. The maximum invert drop across MHs for sewers 15-inch and smaller shall be 0.60 foot for straight through flow and 1.00 foot for side inlet flow.

F 256 SEWER DESIGN COMPUTATION SHEET

Figure F256 shows a typical "Gravity Sewer Design Computation Sheet". All Engineers should use this computation sheet for the design of gravity sewers. It includes identification of MHs by number and station. It summarizes design flows including ADWF and PDWF and resulting velocities. It also shows sewer characteristics including length, slope, pipe size and fall.

F 257 TRIGGER FLOW

The trigger flow in a sanitary sewer is the quantity of flow that, once reached, would initiate the planning for a relief or replacement sewer. The initiate of the trigger flow is to allow sufficient time, ahead of when additional capacity is needed, for planning,design, and construction of the new relief or replacement sewer. Trigger flow is determined by subracting a buffer capacity from the capacity of the exsisting sewer at the flow depth when additional capacity is needed. The buffer capacity is defined as the product of the estimated years to complete the new sewer project and the rate of recent flow increases in the sewer being evaluated. Figure F257 shows a 15-inch-diameter sewer with annual depth of flow gauging to illustrate the trigger flow and buffer capacity concept.

The time required to complete a new sewer relief or replacement project is at least five years.

The depth of flow at which hydraulic relief or replacement is needed can vary from time to time according to policy changes reflecting economic conditions and resources available for collection system improvements. Currently, hydraulic relief is needed when the dept of flow reaches three-fourths of the pipe diameter.

The trigger flow may vary for different service areas, different time periods, and special circumstances. For example, during a given time period, the anticipated rate of population increase may vary for different service areas. Special circumstances such as the rehabilitation of a structurally deficient sewer may alter the capacity of the exsisting sewer and accelerate the need for hydraulic relief of the sewer. The anticipated sewage discharge from a proposed subdivision or property redevelopment could trigger the need for initiating a sewer or replacement project.

An appropriate level of service area analysis, including depth of flow monitoring in existing sewers as well as other information and data should be considered to substantiate the trigger flow before commencement of sewer relief efforts. A concept report should be used to determine the scope of needed relief and address local problems within the service.

F 258 MINIMUM VELOCITY IN EXISTING SEWERS

When and existing sewer is to be relieved, and also retained as part of the system, the relief method should maintain a velocity of three feet per second of possible, but not less tha the minimum velocity for which the sewer was originally designed. Sufficient flow should remain in the existing sewer to maintain that original designed velocity. Overflow relief may be one way to satisfy the minimum velocity requirement. The total combined capacity of the new sewer and the existing sewer, (whether rehabilitated or not), when both are flowing full, (d/D = 1.0), shall equal twice the estimated PDWF as projected to the end of the designed period as shown in Table 250.

F 259 FLOW ROUTING

Complexity to system operation should be minimized. However, sometimes it is necessary to route wastewater flow between existing and new sewers. Ideally, when practically possible, a passive system that utilizes system capacity to convey wastewater flows to the treatment facility with fixed diversion settings should be as provided. Flow diversion providing system flexibility should be as simple and passive as possible. Datailed operating procedures and instructions will be prepared during design when when needed to facilitate optimum operation of the conpleted system. These procedures and instructions should cover the full range of operating conditions and startup procedures.

F 260 HYDRAULIC ANALYSIS OF JUNCTIONS

The general instructions and sample problems shown in Figures F260A to F260O in the appendix of this section illustrate the analytical method of determining the hydraulic characteristics at junctions where open channel flow conditions exist. The method shown utilizes the pressure-momentum formula.

The minimum length of a transition shall be the greater of the following:

1. A length computed with an 11^{o} 30' maximum interior angle between the opposite sides of the transition.

$$\text{Tan}\,\frac{11^{o}\,30'}{2} = 0.10$$

2. A length equal to the diameter or width of the larger pipe or conduit but not to exceed 6 feet.

In the design of an expanding transition (decreasing velocity), the loss in energy across the structure shall be calculated by the following formula:

$$h = 0.20\,\frac{(V_1 - V_2)^2}{2g}$$

In the design of a contracting transition (increasing velocity), the loss in energy across the structure shall be calculated by the following formula:

$$h = 0.10\,\frac{(V_2 - V_1)^2}{2g}$$

F 270 INVERTED SIPHONS

Within the sanitary sewerage system there are numerous special structures serving particular needs. These special structures include inverted siphons crossing rivers, creeks, depressed highways and other obstructions. Inverted siphons and airlines (sometimes called an "air jumper") are constructed to convey sewage flows (liquid and gas) across obstructions where such crossings cannot be attained by a sewer placed on a continuous grade. Inverted siphons and airlines are designed to criteria to ensure proper functioning during the design period of the system to be fail-safe and to minimize maintenance and odors. This section discusses those criteria and is intended to serve as a guide for Engineers.

F 271 LOCATION DESIGN

Inverted siphons and airlines should be located completely within a public right-of-way. Preference should always be for a dedicated right-of-way, such as a highway or street. If this is unavailable, an easement or other limited right-of-entry location may suffice. In all cases, the right-of-way should be of sufficient size to not only contain the physical structures, but also allow vehicles, workers and equipment to enter and perform any construction, repair, maintenance and operational activity.

When located within a public highway or street, it is usually necessary and advisable to place all parts of the inverted siphon underground. Airlines may be constructed either underground or above the ground surface. Elsewhere, the inverted siphon is placed underground, but the airline is usually located above the ground surface. The inverted siphon should also be located so that it will not impact on other facilities, nor be impacted upon by other facilities. Adequate clearances from other facilities should be maintained. Normally, this should not be less than three feet horizontally and two feet vertically. Airlines should, whenever possible, be located within or adjacent to another structure, such as a bridge. When crossing another facility below the ground surface, the airline may be constructed integral with the other facility. An example would be to place it inside or integral with the top, bottom or side slab of a large box or arch structure or laid on top of it, properly backfilled or encased. This will allow the other structure to structurally support the airline and thereby minimize the size of the airline structure as well as its cost. Additionally, it will be less obvious and less objectionable environmentally and aesthetically. It will also preclude, or at least minimize complaints as to visual conception, safety and noxious odors. Finally, operation and maintenance, and their attendant costs, are minimized due to ease of accessibility. Where it is not possible or feasible to place the airline within or adjacent to another structure, a separate structure will be required. This may result in a large structure spanning a major highway, river or similar facility. In those cases, economics mandate the shortest structure possible, precluding obstruction of the airline or the other facility, and permitting operation, maintenance and repair.

F 272 SINGLE VS. MULTIPLE BARREL DESIGN

The design of both inverted siphons and airlines may involve either single or multiple barrels. In general, a single unit is hydraulically and structurally more efficient, and will be cheaper to construct and maintain, than a multiple system. However, it is inadvisable for inverted siphons, and it may not be possible for airlines due to hydraulic constraints or due to geometric limitations to size or shape. Airlines may be amenable to single barrel design. This is especially true when the airline is located immediately beneath or adjacent to a bridge, as well as, when the airline is a separate structure spanning another facility. When placed inside a bridge deck, a multiple design may be necessary due to geometric constraints or structural requirements. When an airline is located so that it crosses another subsurface facility, and the airline cannot be constructed integral with the other subsurface facility, the airline may have to be a multiple barrel located adjacent to, usually above, the other facility.

For inverted siphons, a minimum of two barrels shall be provided. Figure F 272 shows a typical two barrel siphon. One redundant barrel shall always be provided for bypass capacity, for emergencies, and for use when another barrel is taken off-line for maintenance or repairs. When two barrels are installed, they should be the same size, each one capable of conveying the full design flow rate. When three or more barrels are installed, they should, if possible, be of the same size, provided minimum velocities can be attained. If this is not possible, the redundant barrel should be of the same size as the largest of the other barrels so as to ensure bypass capacity.

F 273 HYDRAULICS

The hydraulic capacity of an inverted siphon shall never be less than the capacity of the sewer system upstream of the inverted siphon. Hydraulically, inverted siphons shall be designed so that for the ADWF, the preferable minimum velocity is not less than 4 fps, and the absolute minimum velocity is 3 fps. Velocities less than these are non-self-cleaning velocities which may allow material to deposit in the conduit, which in turn will result in blockages, higher maintenance costs and a shorter life. The daily PDWF shall always provide a minimum velocity of 4 fps at least once a day. Hydrographs indicating a wide range of values of flow rates and/or velocities usually indicate the need for multiple barrels. Inflows to and outflows from a multiple barrel can be controlled by manual or automatic gates and/or weirs. The minimum size of any inverted siphon conduit shall be 8-inch. A conduit less than 8 inches will be difficult to maintain, clean and operate, and this in turn will result in clogging, higher maintenance costs and failure.

F 274 HORIZONTAL ALIGNMENT

Inverted siphon and airline systems should always be constructed in a public right-of-way. Economically, the most cost effective system is usually the shortest in length. The shortest system would be one that is normal to, or radial to, in the case of a curved facility, the facility that is being crossed. This may not always be attainable for various reasons, such as the presence of other existing or planned facilities, existing topography, right-of-way alignments, and political or economic constraints. The alignment should be a single, straight alignment. A curved alignment or one with an angle point should be avoided. Of the latter two, the curved alignment is less objectionable. If a curved alignment is necessary, an access structure for maintenance purposes shall be constructed at both ends of the curve. If an angle point is necessary, an access structure for maintenance purposes shall be constructed at the angle point.

F 275 VERTICAL ALIGNMENT

The vertical alignment of an inverted siphon should also be a straight alignment with bends and angle points minimized. Obviously, an inverted siphon cannot be constructed without either or both. An inverted siphon with a vertical curve is preferable to one with an abrupt change of grade, but this is often difficult to construct with straight sections of pipe. If possible, an access structure for maintenance should be constructed at any change in grade. A sag point in the middle of an inverted siphon should be avoided if possible. The sag point will be a point of blockage, frequent maintenance and possibly failure. An inverted siphon with a high point in the middle, while not desirable, may be permitted. The best design is for a uniform grade from one end of the inverted siphon to the other end. The gradient may, if necessary, be varied along the entire length of the inverted siphon, provided a sag point is avoided. The maximum slope of the downstream (rising) leg approaching the outlet structure shall be 15% to allow solids to be conveyed upwards from the conduit into the outlet structure. For an inverted siphon crossing a stream or waterway, the top of the inverted siphon shall be not less than 3 feet below the level of possible scour in the stream or waterway, nor shall the inverted siphon be located in close proximity to an outlet of a lateral or a drop structure that could cause adverse effects.

An airline may be constructed either elevated above the ground surface or below ground surface. Site conditions will dictate, together with environmental, aesthetic and economic considerations. Usually, external controls dictate the vertical alignment of an airline more so than an inverted siphon. This is especially true when the airline is appurtenant to another structure, such as a bridge. A sag point in an airline shall not be allowed because condensate will eventually block the airline, thereby causing a system failure.

F 276 HYDRAULIC DESIGN OF INVERTED SIPHONS

Hydraulically, inverted siphons are designed like any other pipeline or conduit by using the Mannings equation where:

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

but which is usually transposed so that for circular, undeflected conduits flowing full, the equation becomes:

$$D = 1.3346 \quad \frac{Q^{0.375}\ n^{0.375}}{S^{0.1875}}$$

Where:

D= Conduit inside diameter, ft
Q= Volumetric flow rate, cfs
n= Mannings roughness coefficient
S= Friction slope, ft/ft

For circular sewers flowing full, a recommended value for "n" is 0.014 for any pipe material, be it clay, concrete, iron, steel, or any plastic. When using the Manning's equation, losses due to bends, angle points, junctions and diversions, and other hydraulic losses need to be considered.

F 277 HYDRAULIC DESIGN OF AIRLINES

As with inverted siphons, airlines must be properly designed hydraulically. There are two methods that can be utilized for design, the theoretical method and the empirical method. Of the two, the empirical method is the method of choice and shall be used absent unusual conditions and only when approved by the District/ Division Engineer.

The empirical method requires the determination of the cross sectional area of the conduit allocated for gas flow approaching the inverted siphon. The cross-sectional area of the airline is then assumed to be twice that of the cross-sectional area allocated for gas flow of the approach conduit, or:

$$A_A = 2A_s$$

Where:

A_A = Cross sectional area of airline
A_S = Flow cross sectional area allocated for gas flow of the approach conduit

Thus, for a circular sewer designed for a depth of flow (d) equal to 1/2 of the inside diameter (D), the upper 1/2 of the inside diameter is allocated for gas flow. As the area of a circular conduit equals $3.14D^2/4$ or $0.785D^2$ and the area of sewage flow, when d/D = 0.5, is $0.39D^2$, the difference, $0.39D^2$ is the area of the circular conduit allocated for gas flow in the approach conduit. Therefore, the airline cross-sectional area should be $.785D^2$ where D is the diameter of the upstream conduit approaching the siphon system, or

$$A_A = 0.785\ D^2$$

Where:

A_A = Cross sectional area of airline
D = Diameter of the approach conduit

F 278 STRUCTURAL DESIGN

Both inverted siphons and airlines must be designed structurally to withstand all loads anticipated during their design period. For the inverted siphon, which is invariably buried, the design should conform to American Association of State Highway and Transportation Officials (AASHTO) criteria, except for Section 18 therein. Soil loads for plastic (flexible) conduits should conform to the German Standard ATV A127.(5). As the siphon may, at various times, be either full and under pressure, or empty,the conduit should be designed for both conditions. All dead and live loads, internal pressures as well as all other design criteria, including allowable stresses, for conduit materials and soil loading shall also comply with AASHTO criteria, except as noted above for Section 18. For highway crossings, loading shall conform to AASHTO H20-S16. For railroad crossings, loadings shall conform to American Railway Engineering Association's (AREA) Copper's E-80. For waterway crossings, the maximum 100 year flood water surface elevation shall be utilized for any structural calculations. Highway, railroad and other crossings may require the inverted siphon to be installed within another casing or carrier conduit. Investigation of this possibility shall be conducted at the earliest possible time.

For the airline, again AASHTO criteria, except as noted above for Section 18, shall be followed. Both dead and live loads shall be considered. The dead load would normally consist of the weight of the airline itself and any loads due to backfill. Live loads that must be considered include:

a. The weight of water filling the entire airline in the event sewage could, in some manner, fill and/or flow through the airline. (The specific gravity of sewage may be assumed to be unity absent unusual conditions);

b. A live load on top of the airline resulting from workers and/or equipment that may be located on the airline during construction, maintenance and operations. See AASHTO;

c. Wind loads. See AASHTO.

d. Seismic loads. See AASHTO and/or applicable Building Codes;

e. Impact loads. See AASHTO.

f. Any other live load that may be unique to the site on the system itself.

g. Additionally, for waterway crossings, any possible effect of buoyancy on the system shall be determined and evaluated.

F 279 CORROSION RESISTANCE AND PREVENTION

In general, a surface exposed to sewer gases is always subject to corrosion. Similarly, any surface that is intermittently wet or dry from liquid sewage is also subject to corrosion. Conduits that normally flow full but may be evacuated intermittently (i.e., during maintenance operations) are also subject to corrosion.

Inverted siphons and airlines are subject to corrosive environments. Failure to protect the system will result in premature failure. Therefore, all components of the system which may, in any manner, be exposed to sewage flows or gases shall be designed to preclude corrosion. This can be accomplished either by specifying materials for the inverted siphon and the airline that are inherently corrosion resistant, or are treated in some manner (i.e., coated) by material that is corrosion resistant.

F 280 MATERIAL SELECTION

Materials used for inverted siphons and airlines are many and varied. They can be rigid or flexible. They can be preformed, precast or prefabricated, or cast or formed in place. They shall be selected with extreme care to ensure structural integrity, ability to function during the required design period and be either corrosion resistant or amenable to some treatment to properly resist corrosion.

Portland cement concrete, utilizing either Type I, II, III or V Portland cement, is commonly used. The type is dependent on the corrosion anticipated during the life of the system, including reactive soils, and availability. Invariably, the concrete is steel reinforced, as opposed to unreinforced. When properly designed, it will provide the necessary structural strength and meet the design period requirements. Its primary drawback is that concrete is not corrosion resistant to sewage atmospheres. When used, surfaces exposed to sewer gases or intermittent liquid sewage flows must be provided with some form of protection against corrosion, such as PVC plastic liner. It usually does not need protection against normal atmospheric conditions. Standards and specifications for concrete are many and varied. For a viable and objective standard, see Section 201 of the "Green Book." (4) for appropriate specifications.

Steel is a material that is commonly used for both inverted siphons and airlines. Its primary advantage is its high strength. Its primary weakness is, except for certain stainless steels, (Series 300), and even when exposed to the atmosphere, it is subject to severe corrosion and must be provided with some form of corrosion protection. See Section 206 of the Green Book (4) for appropriate specifications.

Cast iron and ductile iron can also be utilized for inverted siphons and airlines. While not always having the strength of steel and usually more brittle than steel, they are stronger than many other materials. They must be provided with some form of corrosion protection. They are usually resistant to normal atmospheric conditions but not resistant to most sewage atmospheres. They must be provided with some form of corrosion protection. See section 206-3 of the Green Book (4) for appropriate specifications.

Reinforced concrete pipe (RCP) and reinforced concrete box (RCB) is commonly and effectively used for inverted siphons, especially in large diameters, and sometimes for airlines when sufficient support is available. Its advantages are its high strength, economy, abrasion resistance and resistance to atmospheric corrosion. Its only disadvantage is that it is subject to corrosion in the presence of sewage atmospheres or gases. This can occur whenever the inverted siphon barrel is emptied of liquid and air is allowed to enter. This disadvantage is easily overcome by lining the interior with polyvinyl chloride (PVC) sheets. While RCP or RCB usually has 270+/- degrees of PVC liner plate coverage when used as a gravity sewer, for either inverted siphons or airlines 360 degrees coverage is required. RCP and RCB for any sanitary sewer or inverted siphon or airline should always have joints that are airtight. For RCP, it shall be a reinforced concrete pressure pipe (RCPP). Sealing rings such as "O-Ring" gaskets or similar sealing systems shall always be utilized. In the Green Book, (4) see section 207-2 for specifications for RCP, 207-3 for lined RCP, 207-4 for concrete cylinder pipe and 207-5 for RCPP.

Cast iron and ductile iron pipe (CIP & DIP) are also utilized in inverted siphons and airlines. Their advantages are their high strength, longer precast lengths and their ability to resist atmospheric corrosion. In most cases, especially for smaller to medium sizes, CIP and DIP are the material of choice. They should also be fitted with sealing rings at joints and provided with some form of corrosion protection internally. See section 207-9 of the Green Book, (4).

Vitrified clay pipe (VCP) can be used for both inverted siphons and airlines under some circumstances. Their advantage is that they have relatively high strength, are completely corrosion resistant, and depending on the joint utilized, are not only water and air tight, but can sustain a degree of pressure. Their disadvantage is short laying lengths (4 feet to 10 feet), and inability to sustain high internal pressures. For inverted siphons, they can be readily utilized provided the internal pressure can be sustained by the pipe and its joints. For airlines, they are very satisfactory when the pipe has adequate support, as when they can be placed inside a bridge deck. In these circumstances, they are highly recommended.

See section 207-8 of the Green Book. (4)

Steel pipe has been utilized for both inverted siphons and airlines. It is particularly useful for airlines which are designed for long spans due to its strength. However, it is subject to corrosion and must be protected from corrosion and failure by an appropriate lining or coating. See section 207-10 of the Green Book. (4)

PVC, ABS, and polyethylene (PE) solid wall plastic pipes can be used for inverted siphons. Typically they shall not be used for airlines unless protected from sunlight and ultraviolet (UV) rays. These materials shall be obtained in pressure rated classes, fabricated from resins that are pressure rated and are corrosion resistant. In the Green Book (4) see Sections 207-17 for PVC plastic pipe, section 207-15 for solid wall ABS pipe and section 207-19 for PE plastic pipe except that American Waterworks Association (AWWA) C900 should be specified for PVC pipe, ASTM D2282 for ABS pipe and ASTM F714 for PE pipe. PVC, ABS, and PE shall not be used for exposed airlines unless protected from sunlight and UV for reason that, like all thermoplastic and thermosetting plastic materials, they are, in time, subject to UV degradation, hardening, brittleness, crazing and cracking, and thereby can and will fail when exposed for long periods to the environment.

Weirs, stoplogs and similar devices can be fabricated of stainless steel, corrosion resistant plastics or wood. For wood, Redwood is preferred, although treated Douglass Fir is acceptable.

Steps, ladders, maintenance hole frames and covers, gratings and other appurtenances may be fabricated of stainless steel, cast or ductile iron or carbon steel. Except for stainless steel, these items shall be coated with a corrosion resistant epoxy, PVC, PE, polypropylene or a non-solvenated (100% solids) polyurethane.

Materials that should not be used for inverted siphons or airlines are follows:

a. Non-reinforced concrete pipe. It is usually of lower strength than RCP, is not an economically available alternative, is rarely pressure rated, and can develop numerous cracks and is therefore neither watertight nor airtight.

b. Asbestos cement sewer pipe (Pressure and non-pressure types). It is not corrosion resistant, contains non-friable asbestos, and will be phased out of production by order of the U.S. Environmental Protection Agency by 1997.

c. Corrugated (profile) pipes (steel, aluminum, plastic). These pipes are usually not pressure rated, can resist little if any internal pressure, are neither watertight nor airtight, and in the case of plastics, are typically inadequate structurally, having a very low pipe stiffness (less than 46 psi, oftentimes less than 20 psi, and sometimes less than 10 psi).

d. Fiberglass or polyester pipes and materials including RPM, FRP, RTR and GRP. Prior failures of these materials and pipes in both sewage and domestic water applications have been extensive. Failure modes have been delamination, stain corrosion, joint leakage and other modes. Recent developments claim to have solved these earlier problems, and investigations continue, but proof is not yet conclusive.

F 281 APPURTENANT STRUCTURES FOR INVERTED SIPHONS

Appurtenant structures in an inverted siphon and airline system include inlet structures, outlet structures, access structures and cleanouts.

Inlet structures typically require inlet control systems which convey liquid sewage from the approach pipeline to a single or multiple barrel inverted siphon. If a single inverted siphon conduit is selected, an access maintenance hole may be all that is required. The maintenance hole shall be sized sufficiently to allow for any maintenance and operation procedure. Typically, depending on the approach conduit size, this shall be not less than four feet in diameter to allow adequate work room, and usually not more than six feet in diameter. A rectangular maintenance hole may be selected as this could simplify connection of the inlet to the airline. Typically, for a circular inlet structure, precast concrete pipe is used. The interior surface shall be lined, coated or otherwise protected with a suitable corrosion resistant material. For a rectangular inlet, cast-in-place concrete is most common, but precast concrete box sections may be utilized. The interior surfaces shall be provided with suitable corrosion resistant material above constantly submerged surfaces. Access to these inlets shall be provided by means of round maintenance hole frames and covers. The material of choice for these is cast iron. The minimum size cover should be 27-inch diameter, but a larger cover is preferable, oftentimes 30 or 36-inch diameter. Larger covers may be required, and if so, these larger covers shall not be a single cover because of the weight. Foundries have two piece circular covers a 12+/- to 24+/- inch cover fitting into the larger cover. Rectangular covers shall not be used.

For inlets to a multiple inverted siphon, precast round or rectangular concrete maintenance holes may suffice, however a cast-in-place concrete structure is recommended, again protected against corrosion above submerged surfaces. Access to these multiple inverted siphon inlets shall be by means of maintenance hole covers. preferably round, but more often multiple rectangular covers, or when located above ground surface, by some kind of doorway or other large above ground entry. Large systems may sometimes include the construction of a building above grade to house the inlet system.

Inside the inlets, there may be located any type of structure, equipment or material. This is especially true in the case of a large facility serving multiple inverted siphons. These could include gates, either manually, mechanically or automatically operated to control flows into the siphons. Similarly, control weirs may be located in these structures. Gauging stations and instruments, either manually or automatically operated, are also oftentimes installed at these inlet structures. Depending on needs, special circumstances and conditions, equipment and material may also be stored in these locations. Although not frequently utilized for flow measurements, this structure may also house within or adjacent to it, facilities for workers. Any inlet structure, other than a simple maintenance hole designed for workers to enter, must have a positive air purification system and other protective measures to prevent hazardous conditions.

Typically, inlet structures are not utilized for screening or treatment of the sewage. However, some provision shall be provided to prevent the clogging of an inverted siphon by material flowing into the system. The size of an inverted siphon is usually smaller than the inflowing sewer. Failure to protect against clogging will invariably lead to a failure at the inlet to the inverted siphon. Concurrent with this protection, a means of removal of large debris shall be provided for.

Inverted siphon outlet structures are similar to inlet structures except that they are less complex and usually will not have all of the features of inlet structures. Size and complexity will determine its configuration and design.

Cleanouts shall be provided whenever the length of the inverted siphon exceeds 400 feet. The location of a cleanout is usually site specific. The size of the cleanout shall be sufficient to handle the debris that may accumulate, and at least as large as the inverted siphon itself. A cleanout/blowoff is mandatory at any sag point.

Access structures shall be provided whenever access for maintenance or repairs may be necessary. The size shall be sufficient to allow workers to enter with materials, tools and equipment and perform their tasks.