Drainage Design by Rational Method for Sizing Storm Sewer Pipes

Introduction

The size selection of storm sewer pipes for small systems is usually accomplished using the Rational Runoff Equation in conjunction with Manning's Equation to construct an initial design for a drainage network. The initial design that results should be checked with a hydraulic analysis to be sure the design will actually accomplish the hydraulic objectives, and to account for outfall conditions, backwater effects, and similar hydraulic situations that are beyond the initial estimated from the Rational Equation. Usually the preliminary design does indeed perform as-is in the hydraulic model, but not always.

Here we illustrate the method by an example. The method employed here is described in some detail in Wurbs (2002),Chin (2006), and Mays (2011).

Problem Statement

Consider the three drainage areas that drain to the inlets connected to the pipes as shown in Figure 1. A stormwater drainage system is being designed to carry the flow from the three areas. Table 1 lists drainage area information.

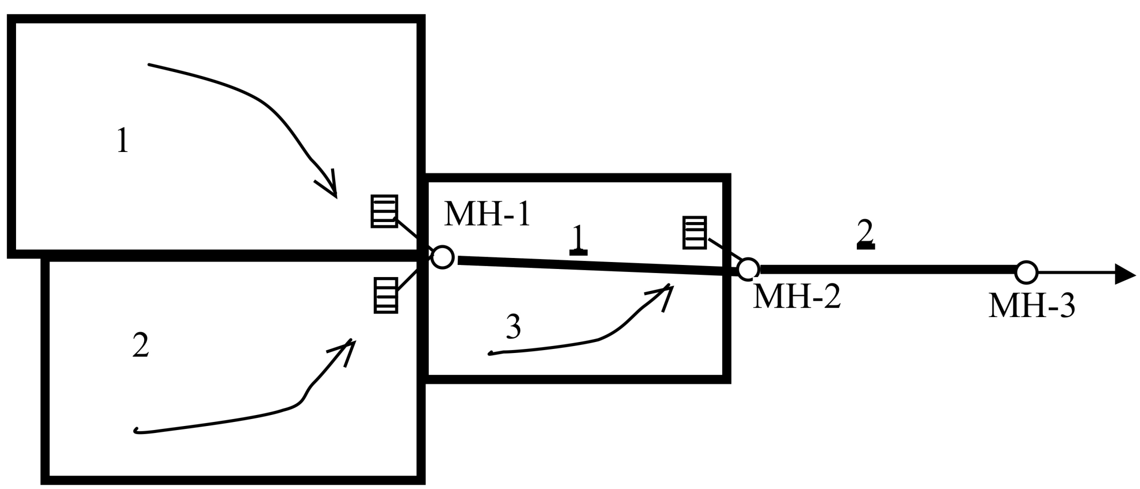

Figure 1. Drainage System Layout.

Table 2 lists pipe information.

The allowable velocity at design flow is between 2 and 10 feet-per-second.

The 10-year ARI intensity equation for the area is given in Equation 1, where I is intensity in inches-per-hour, and T_c is the averaging time, in minutes.

Table 1. Contributing Area Information.

Area ID	Area (acres)	C (runoff coefficient)	Inlet Time (minutes)
DA-1	6.0	0.65	17
DA-2	5.1	0.55	14
DA-3	3.5	0.70	12

Table 2. Pipe Information.

Pipe_ID	Upstream Junction	Downstream Junction	Length (feet)	Slope	Manning's n
P1	MH-1	MH-2	600	0.003	0.015
P2	MH-2	MH-3	600	0.003	0.015

$$I = \frac{56.6}{(T_c + 8.6)^{0.823}} \tag{1}$$

Determine the design flow rates in cfs and diameters in inches for both pipes using the Rational Method Storm Sewer Design procedure described in Mays (2011).

Solution

The solution presented here is a by-hand approach.

Build Auxiliary Equations

The method will employ the rational runoff equation, but will also use Manning's equation in several forms. Manning's equation will be used to find pipe diameters given discharge, and flow velocities in those pipes based on those diameters, so it is useful to construct these equations before beginning the actual design process.

Equation 2 is Manning's equation for a **full** circular pipe.

$$Q = \frac{1.49}{n}(\frac{\pi D^2}{4})(\frac{D}{4}^{2/3})S_o^{1/2} \tag{2}$$

If we rearrange the equation for diameter we obtain Equation 5.

$$D = [\frac{4^{5/3}\ Q\ n}{1.49\ \pi\ S_o^{1/2}}]^{3/8} \tag{3}$$

Equation 6 is Manning's equation for velocity for a **full** circular pipe.

$$V = \frac{1.49}{n}(\frac{D}{4})^{2/3}S_o^{1/2} \tag{4}$$

In the problem statement the two pipe slopes are the same as are their Manning's n values, so we can insert them into the equations directly and obtain for **this example** and obtain

$$D = (0.3958\ Q)^{3/8} \tag{5}$$

$$V = 5.44\ (\frac{D}{4})^{2/3} \tag{6}$$

Draw the Collection System

The next step is to draw the collection system topology. My rules for drawing are:

1. Draw each drainage area and label it with its area in acres and its runoff coefficient. Use a mark to indicate the inlet that it drains to. Label the local t_c as "inlet time", t_{inlet}. Figure 2 illustrates this step for the example.

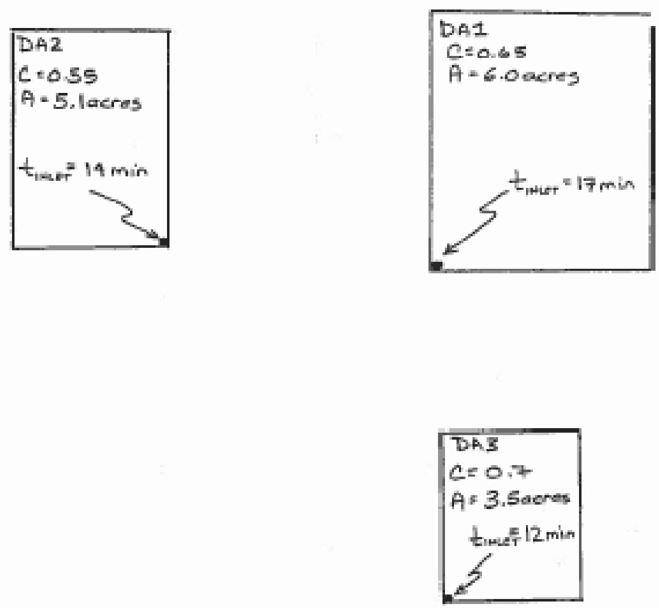

Figure 2. By-Hand Drainage System Worksheet. Drawing the Drainage Areas..

2. Draw each junction (node) as a small circle. label each junction. Leave space between the node and other objects. Figure 3 illustrates this step for the example.

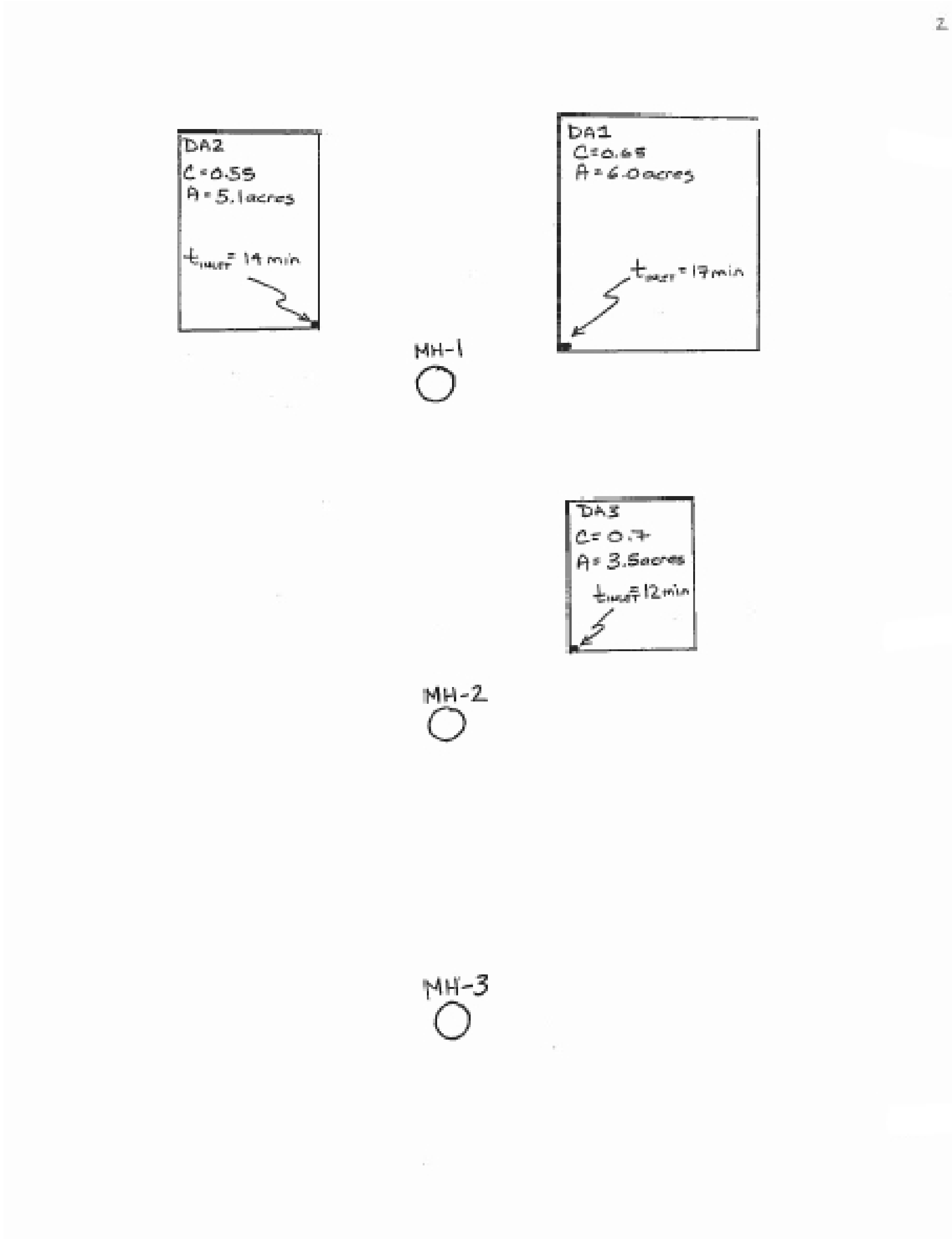

Figure 3. By-Hand Drainage System Worksheet. Adding the Junctions..

3. Draw each pipe as a small line segment. Label the segment with a pipe name, and indicate distance if known. Leave space between the pipes and other objects. Figure 4 illustrates this step for the example.

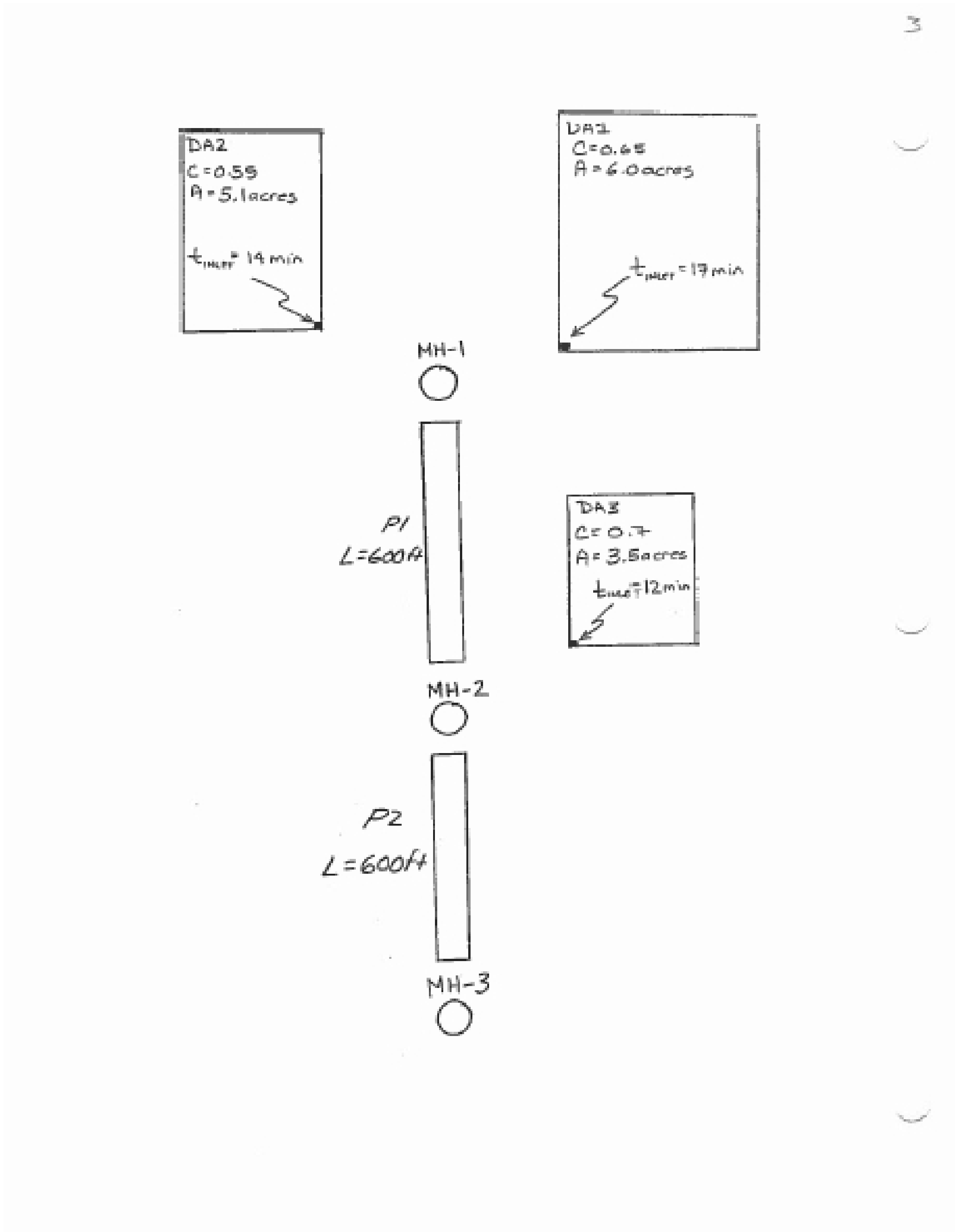

Figure 4. By-Hand Drainage System Worksheet. Adding the Pipes..

4. Use dashed lines to indicate a connection from a drainage area (inlet) to a junction. These lines indicate connectivity, but have zero "length" in a travel time sense. Figure 5 illustrates this step for the example.

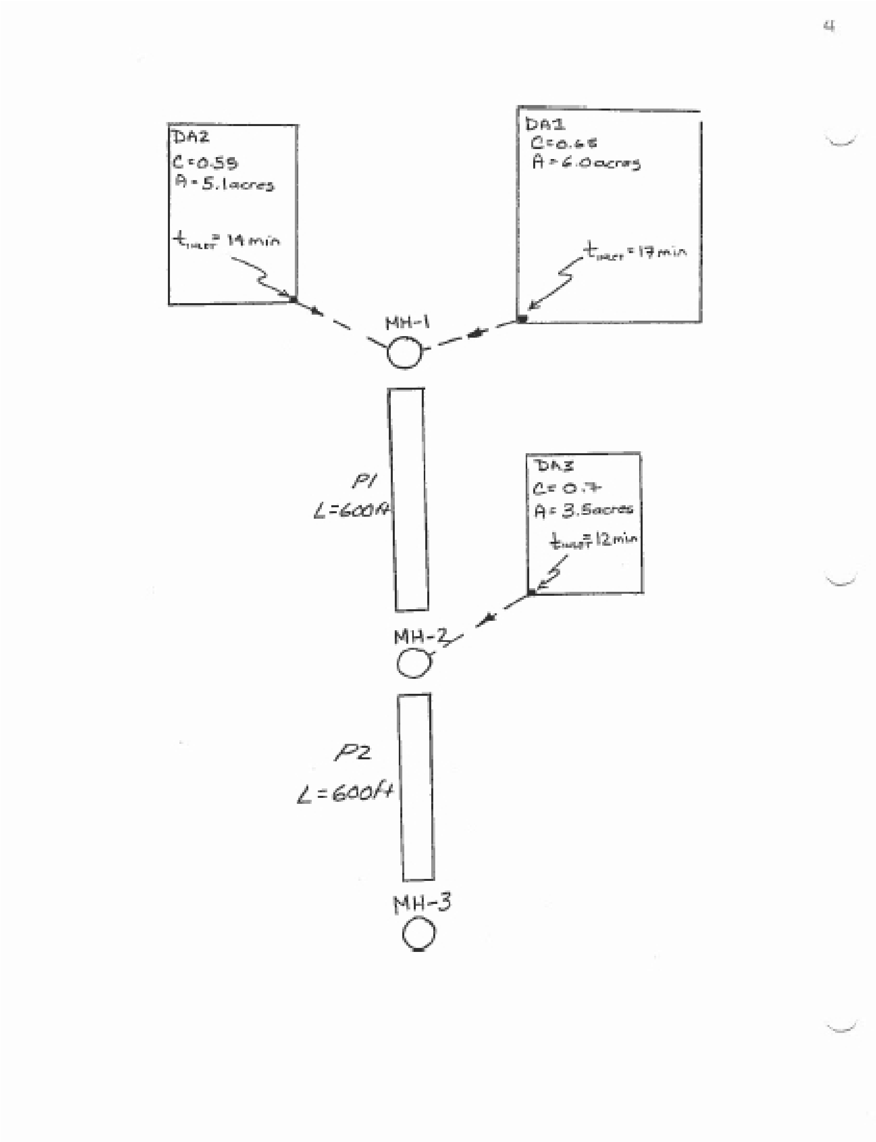

Figure 5. By-Hand Drainage System Worksheet. Connecting the Drainage Areas..

Compute CA values

The next step is to determine the CA values for each drainage area and the accumulating $\sum(CA)_i$ as one traverses downstream in the drainage network.

A suggested procedure is to:

1. Compute the product of C and A for each drainage area. List the value at the drainage area outlet (which will be a sewer inlet). Figure 6 illustrates this step for the example.

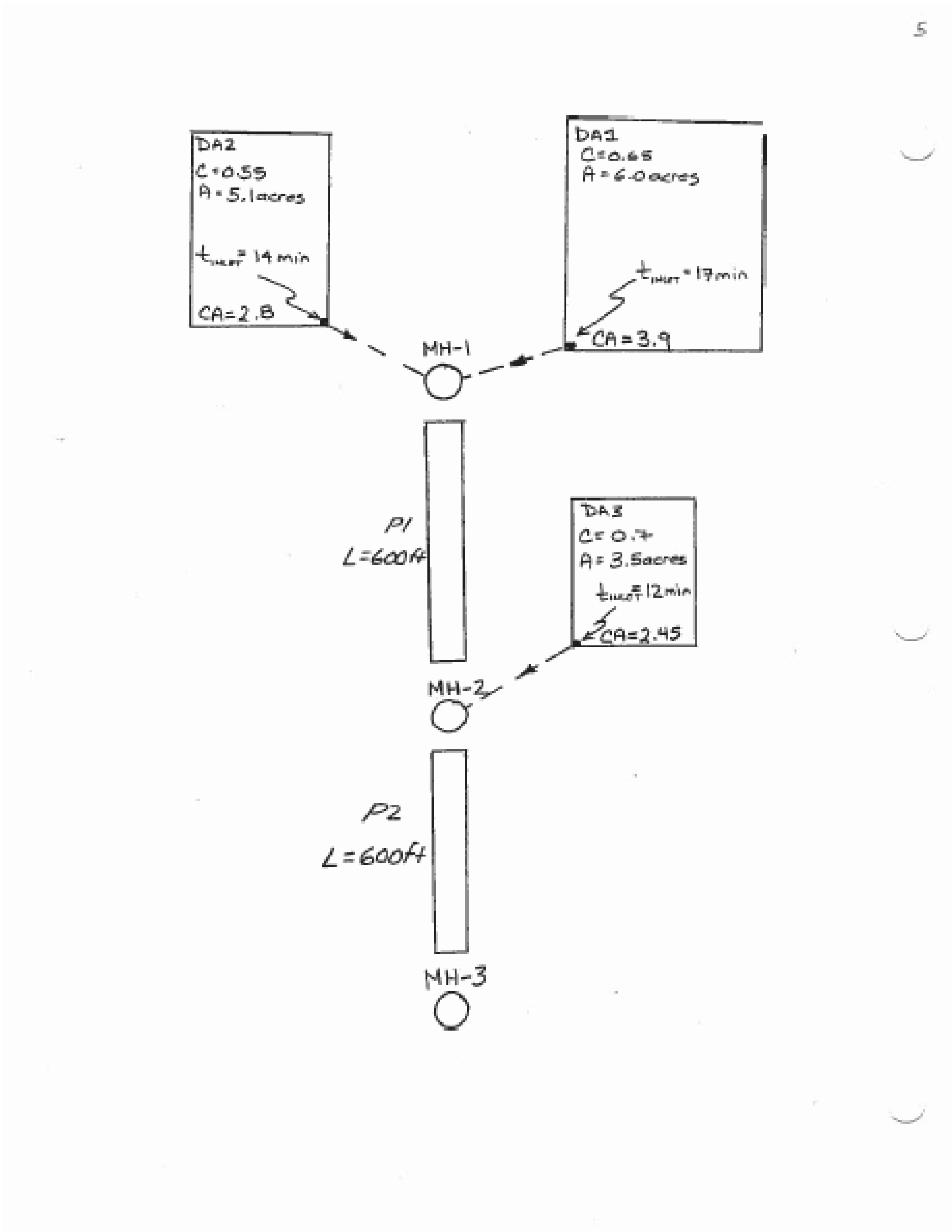

Figure 6. By-Hand Drainage System Worksheet. Computing the CA values..

2. When all the drainage areas are labeled, starting at the most upstream drainage area, find the junction the drainage area connects to and accumulate the sum of all CA values to that junction, including any area that is connected by an upstream pipe. List the $\sum(CA)_i$ next to the junction so you can refer to the value later on in the procedure. Figure 7 illustrates this step for the example.

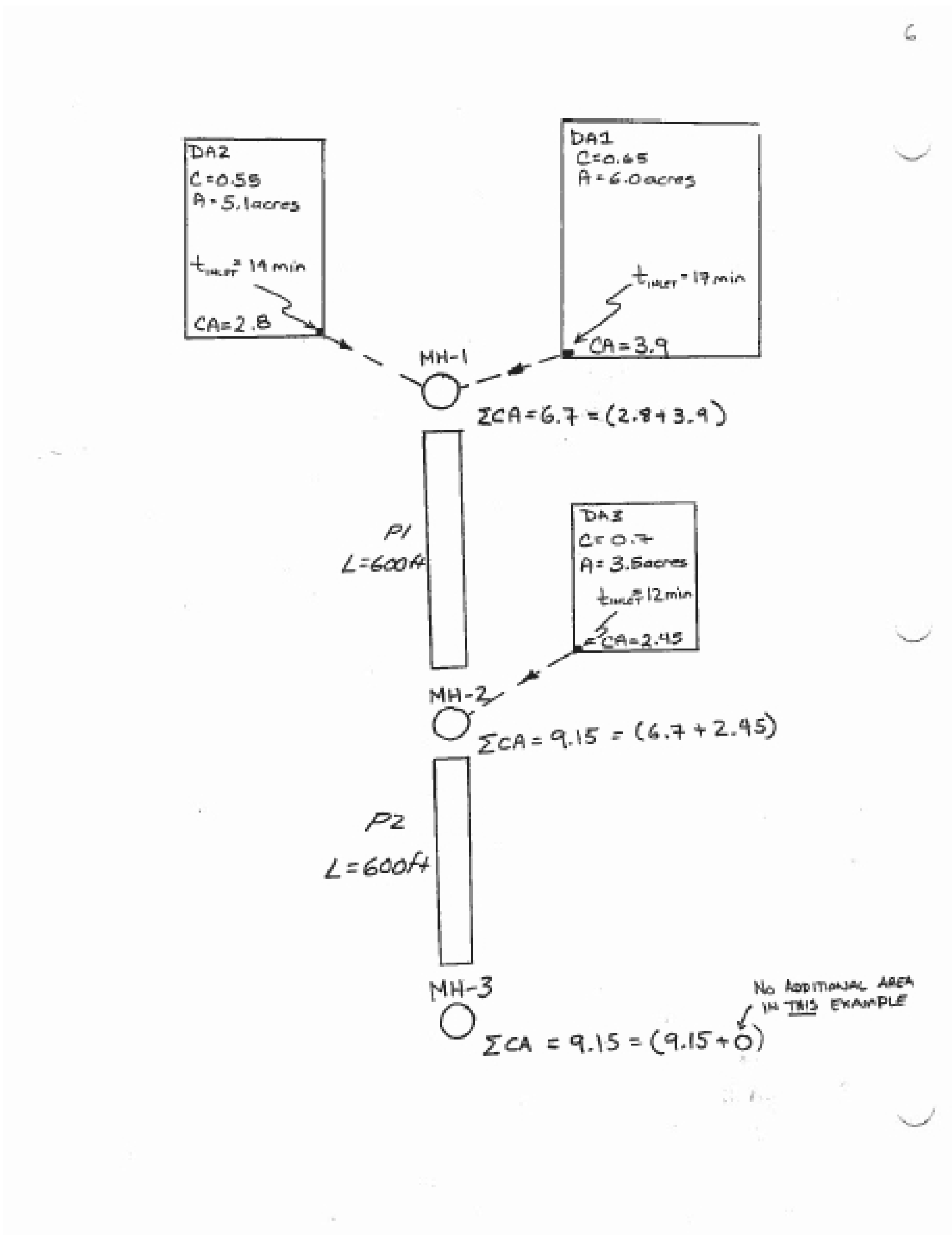

Figure 7. By-Hand Drainage System Worksheet. Computing the $\sum(CA)_i$ values..

Compute $Q_{junction}$, D_{pipe},V_{pipe}, and t_{pipe}

The next step is to compute the discharge leaving each junction and the various pipe parameters of the pipe connected **downstream** of the junction. Observe how the topology was drawn; flow leaves a junction and enters a sewer conduit, so the flow leaving a junction will be the flow that enters the pipe downstream of that junction. We will use that flow value to determine the pipe travel time as we proceed downstream.

1. Starting at the most upstream junction, determine the t_c to use for the rational method as the longer of local inlet times (time associated with any directly connected drainage area) or the total accumulated travel time to the junction.

$$t_c = max(t_{i,local}, t_{up}) \tag{7}$$

2. Apply that t_c in the rational equation and use the $\sum(CA)_i$ value at the junction to determine the discharge leaving the junction.
3. Write that discharge as the discharge in pipe immediately downstream of the junction.
4. Use that discharge to compute the full pipe diameter. Write the value next to the pipe.
5. Use the diameter to compute the full pipe velocity. Write the value next to the pipe.
6. Compute the pipe travel time $t_{pipe} = \frac{L_{pipe}}{V_{pipe}}$; express the result in minutes.
7. Move to the next junction. If you reach a junction which has un-calculated upstream contribution, complete the upstream contribution calculations before proceeding to the next junction.
8. Repeat steps 1 through 6 to find the pipe time (and flows) to the next junction.

The designer repeats the steps above, iteratively as needed until the entire network has been traversed from upstream to the outfall. The resulting values constitute an initial guess for a design.

The next several pages show these steps for the example problem.

Figure 8 illustrates Step 1 for $MH-1$, the longest time in this instance is the inlet time for $DA-1$. Because $DA-1$ and $DA-2$ both connect to the junction, we will use the $\sum(CA)_i$ value we have already computed for the junction.

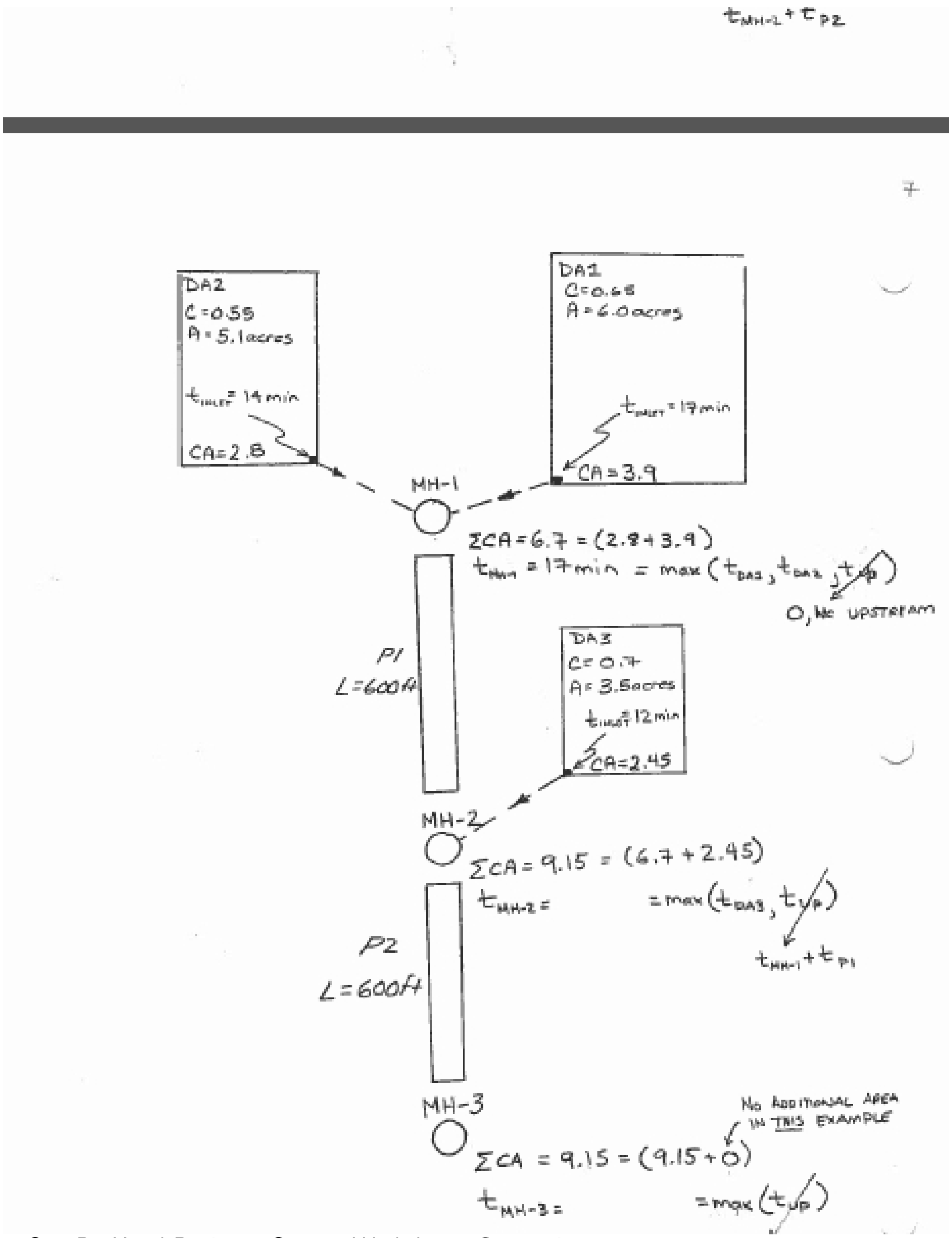

Figure 8. By-Hand Drainage System Worksheet. Computing t_{MH-1}.

Figure 9 illustrates Steps 2-6 for $MH-1$ and $P-1$. The computed pipe travel time is 2.57 minutes, and this time is added to t_{MH-1} to become the t_{UP} for the next node time of concentration determination.

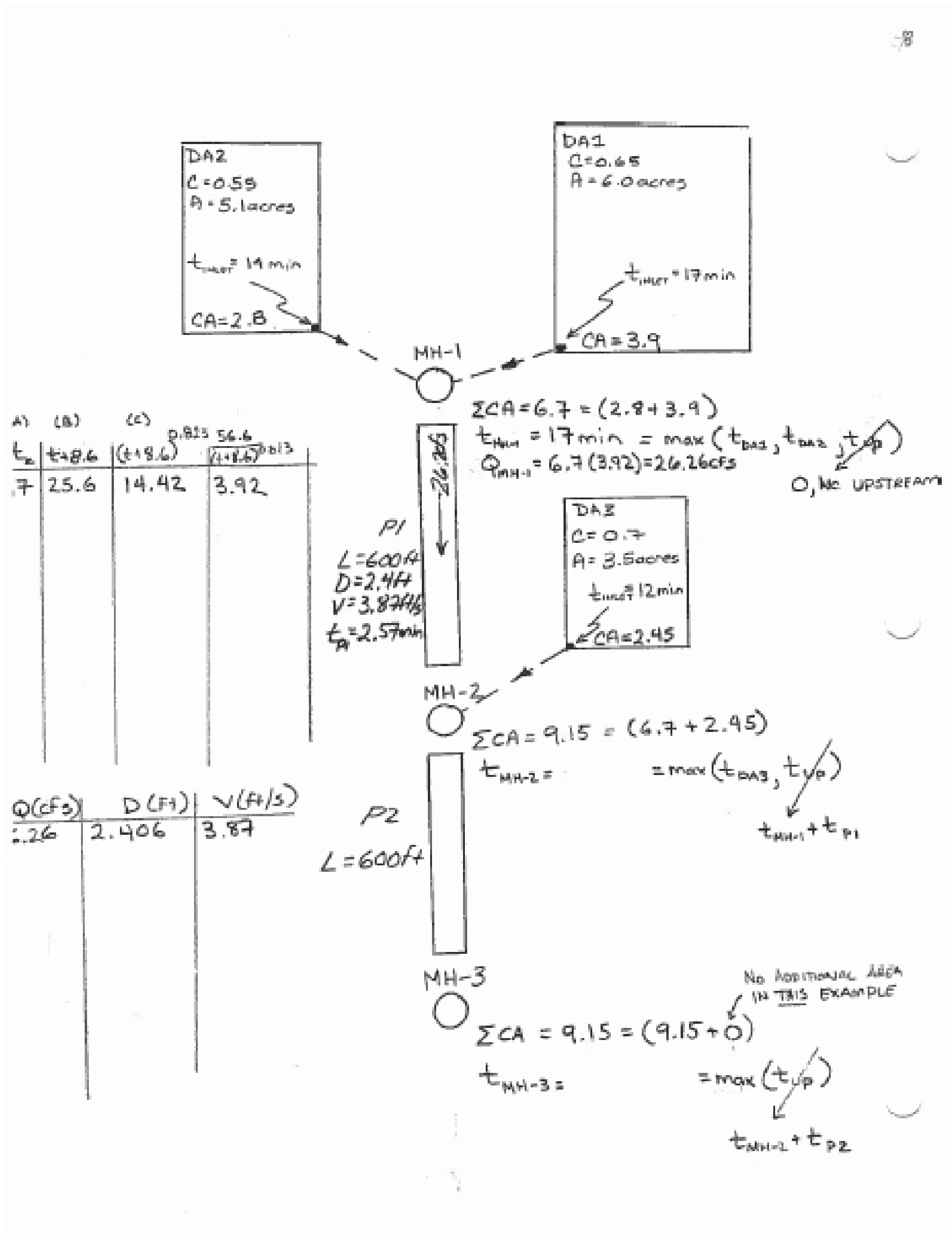

Figure 9. By-Hand Drainage System Worksheet. Computing Q_{MH-1}, D_{P1}, V_{P1}, and t_{P1}.

Figure 10 illustrates Steps 1-6 for $MH-2$ and $P-2$. The longest time to $MH-2$ is the larger of the local time from $DA-3$ or the upstream travel time t_{UP}. In this case the longer time is the upstream time, which has a value of 19.57 minutes. This time is then used in the rational equation, with the $\sum(CA)_i$ for $MH-2$.

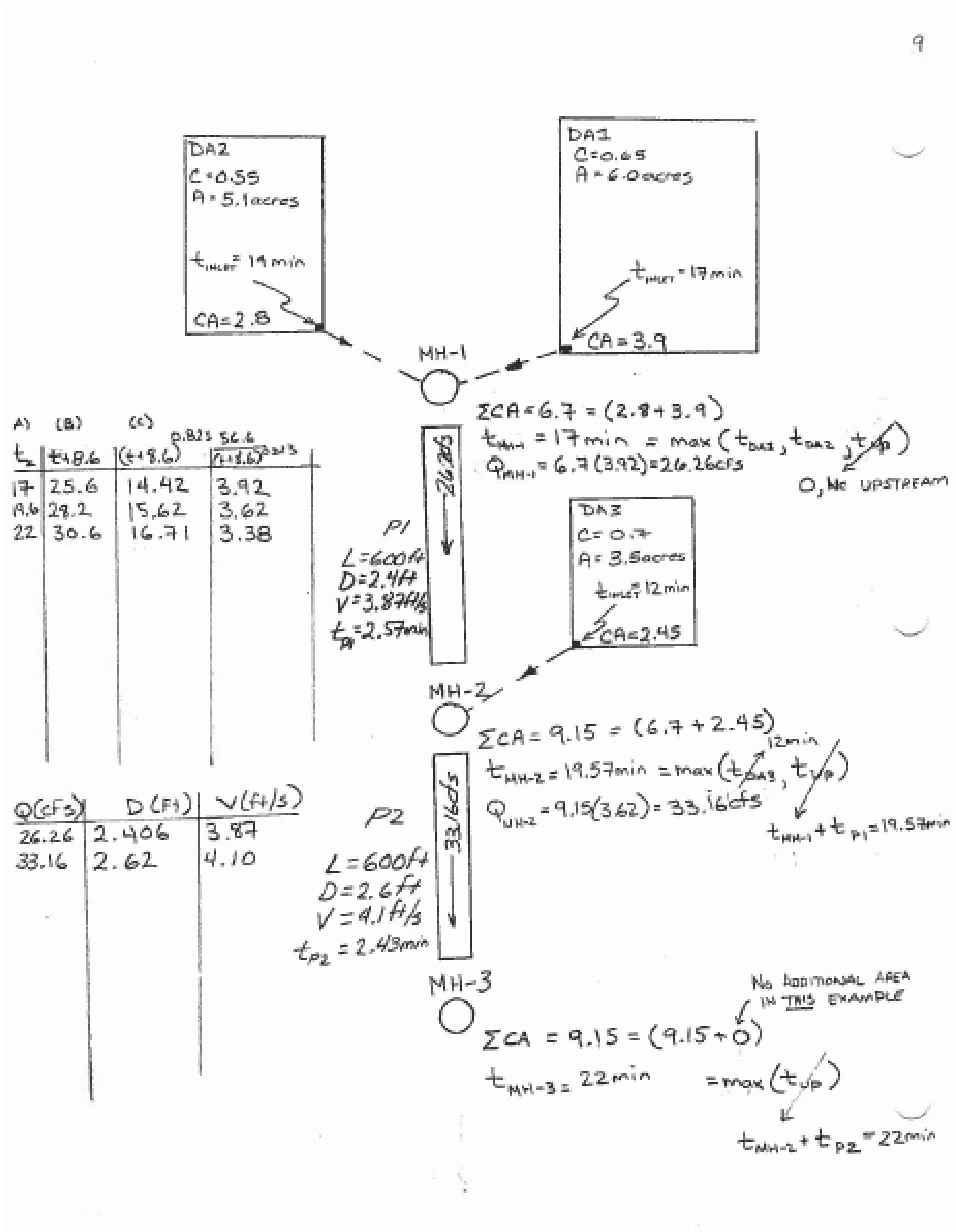

Figure 10. By-Hand Drainage System Worksheet. Computing t_{MH-2}, Q_{MH-2}, D_{P2}, V_{P2}, and t_{P2}.

Once the discharge is computed, the pipe properties are found using Manning's equation to find the pipe diameter and travel time. The computed pipe travel time is 2.43 minutes which is added to the t_{MH-2} to become the next t_{UP} if we needed to continue the computations further downstream.

Figure 11 illustrates the initial design of the system including specification of commercial pipe sizes.

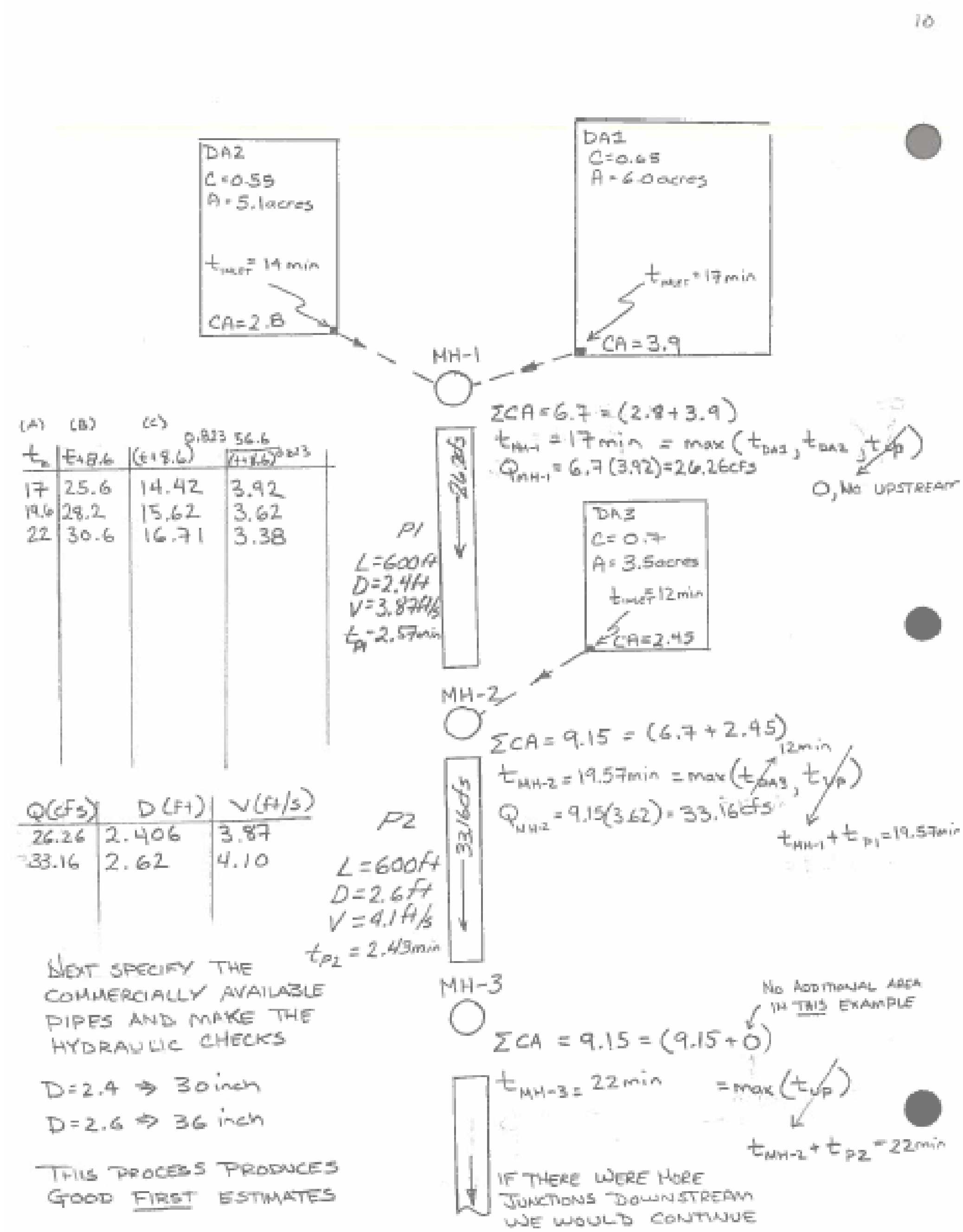

Figure 11. By-Hand Drainage System Worksheet. Specification of commercial pipe dimensions. This represents the initial design. If behavior at $MH-3$ and beyond were important, then continue the process..

Table 3 summarizes the results of the process applied to the example problem.

This initial design would be subjected to further refinements and checks. The next step would be to check the hydraulics (and hydrology) using the commercial pipes

– this check will impact the pipe times a little bit, but otherwise the process is unchanged.[1]

The next step would be to specify invert elevations for the junctions so that the pipes will be underground and buried deep enough to carry any overburden loads that are anticipated. These invert elevations are dictated by the outfall elevation, so the step is not trivial.

Once these elevations are specified, then one will move to a hydraulic model to check effects of downstream boundary conditions, verify that the system will not surcharge, and make adjustments to diameters and elevations to accommodate a design storm.[2]

Table 3. Drainage Preliminary Design.

Pipe_ID	Length (ft)	Area (ac.)	$\sum CA$	T_C (min)	I (in/hr)	Q (cfs)	$D_{calc.}$ (ft)	D_{used} (in)	V_{pipe} (ft/s)	T_{pipe} (min)
P-1	600	11.1	6.7	17	3.92	26.26	2.4	30	3.87	2.57
P-2	600	14.6	9.15	19.57	3.62	33.16	2.6	36	4.1	2.43

References

Chin, D. (2006). *Water Resources Engineering, 2 ed.* Prentice Hall, Inc.

Mays, L. W. (2011). *Water-Resources Engineering.* Wiley.

Wurbs, R.A., and James, W. P. (2002). *Water Resources Engineering* Prentice Hall; pp.130-156; and 156-198.

[1] The partial-full pipe equations are used in this check with the known diameters and discharges to compute the average velocities and pipe times. Then as one moves downstream the t_c change a little bit. Mostly one should discover that the times don't change very much, neither do the discharges.

[2] This check is what SWMM or HEC-RAS is used for (SWMM is usually the better choice for sewer systems).