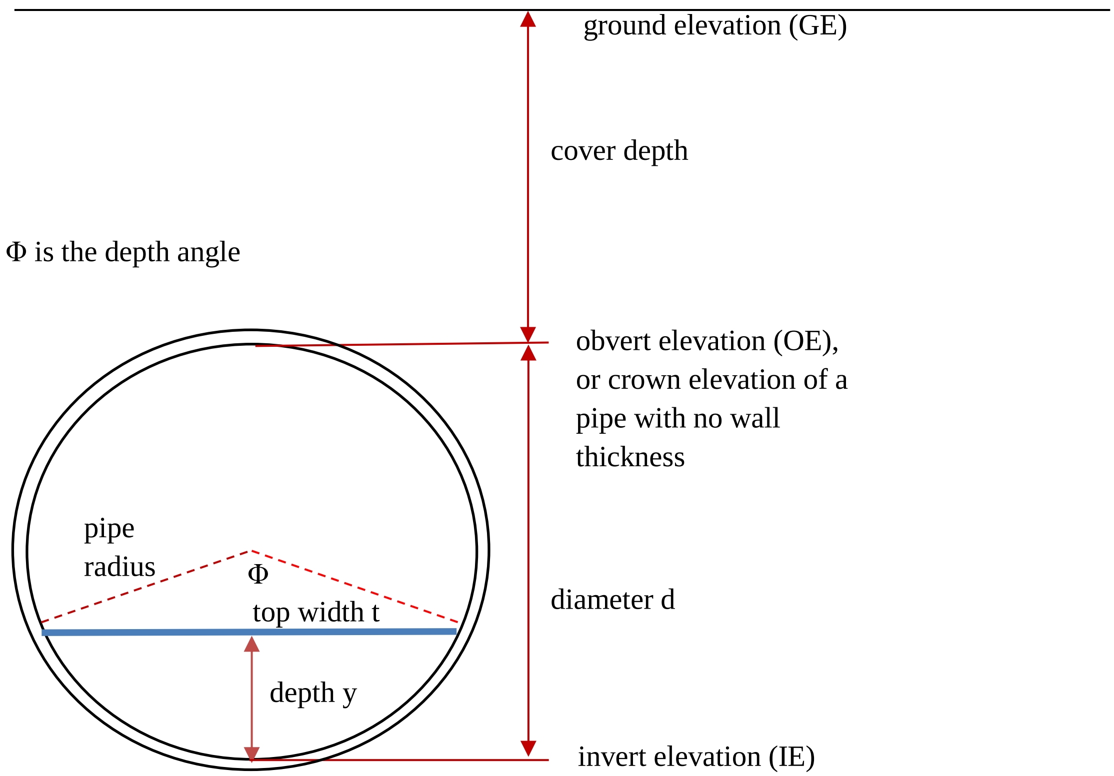
CircularPipe program for the HP Prime calculator
Uniform Flow in a Circular Pipe
7/25/2019 by ENS

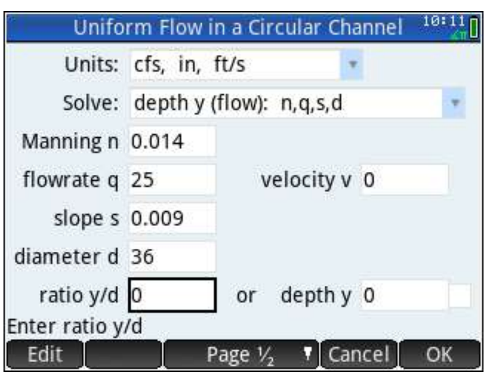
This program calculates the unknown variable for Manning's flow equation and Manning's velocity equation for a circular pipe. The program is similar to the Field's Hydraulic Slide Rule that had several scales to solve Manning's flow and velocity equations. The program can also determine the unknown variable when given (1) ground elevations and cover depths or (2) ground and invert elevations. Example problems are shown on the attachment that is enclosed with the program.

This program uses a single input screen to solve Manning's flow and velocity equations, which makes the program difficult to use, but it eliminated the need to select the program from the opening choose box that was used on the older pipeflow program. The input variables for both equations are shown on the input screen, and the user must determine which input values are to be entered to solve for the unknown. To aid the user in determining which inputs are required for the variable to be solved, the required inputs are listed next to the solved variable in the "solved" drop box. Also, when the program prints out the results, the inputs that were used and the variable that was solved are flagged with a star. When inputting the depth y, the adjacent checkbox must be checked.

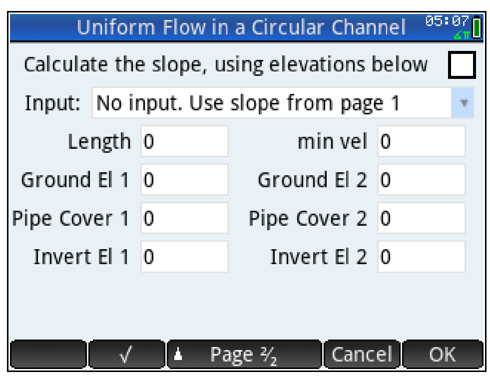
Similarly, the elevations and cover depths input variables are also included on the input screen, on page 2, which makes the program more difficult to use. The elevation and cover depths input variables are only used when the user tells the program to use the elevation data with the "Input" drop box on page 2. The input drop box on page 2 has the options to (1) ignore the elevation data and only used the inputs on page 1, (2) use ground elevations and cover depths, and (3) use ground elevations and invert elevations. When inputting the elevations, the slope s input on page 1 is ignored. When solving for the Manning formula unknown variable, if the slope is known, the slope will be calculated from the elevation data. The user must enter (1) pipe length, GE1, GE2, cover1, and cover2, or (2) pipe length GE1, GE2, IE1 and IE2. The program will then calculate the slope from the elevation data. When solving for the slope from the Manning formula, the user only enters (1) pipe length, GE1, GE2, and cover1, or (2) pipe length GE1, GE2, and IE1. The program will calculate the slope from the Manning formula, and then calculate cover2 and IE2. For this reason, cover2 and IE2 are enclosed in parenthesis. Cover2 and IE2 must be inputted when solving Manning formula where the slope is known. Cover2 and IE2 are not required when solving for the slope from the Manning formula.

To run the program, press the toolbox key. Then press the User tab. Then select CircularPipe from the menu, and then select 1 CircularPipe from the right submenu. To rerun the program, press the ↩ tab.

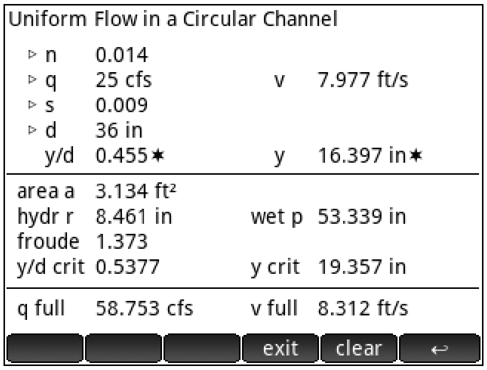




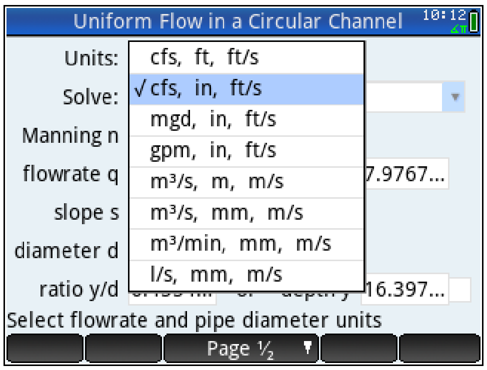
Input screen page 1



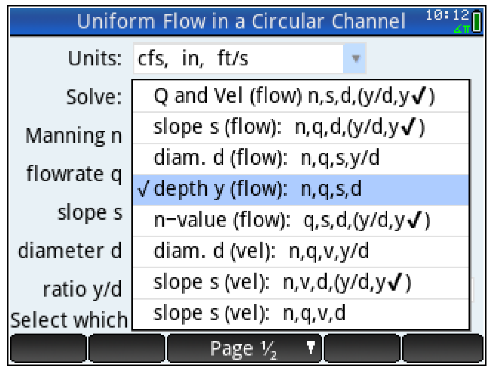
Input screen page 2 is not used for the pipe calculator output



Pipe calculator output



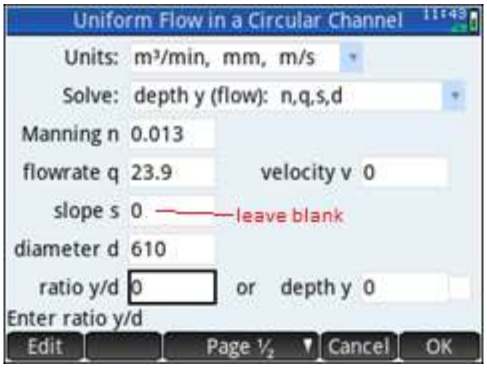
List of units that are available



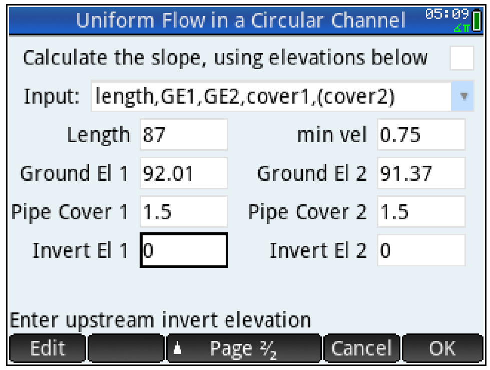
List of variables that can be solved from the Manning flow equation or Manning velocity equation. Each solved variable is followed by a list of the variables that must be inputted to solve for the unknown variable.

"(y/d, y✓)" means either "ratio y/d" or "depth y" can be inputted. If the "depth y" is to be inputted, the adjacent checkbox must be checked. If ratio y/d is to be inputted, this checkbox must not be checked.

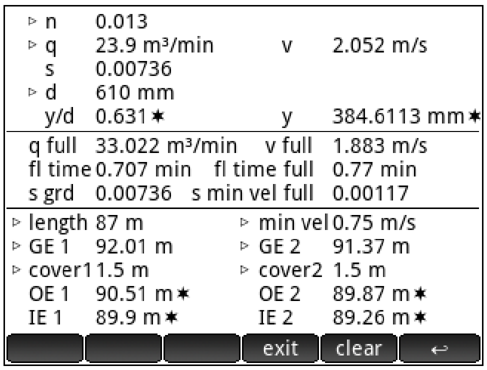
Example of using elevation data to solve for the depth of flow, where n= 0.013, flowrate = 23.9 m^3/s, minimum velocity = 0.75 m/s, diameter = 610 mm, pipe length = 87 m, upstream ground elevation 1 = 92.01, downstream ground elevation 2 = 91.37, upstream pipe cover 1 = 1.5 m, and downstream pipe cover 2 = 1.5 m. Pipe cover is measured from the ground surface to the pipe obvert or crown. When using the elevation data, the slope input on page 1 is not entered. When solving for the slope from the Manning equation, the downstream cover 2 and downstream invert elevation 2 are not entered.



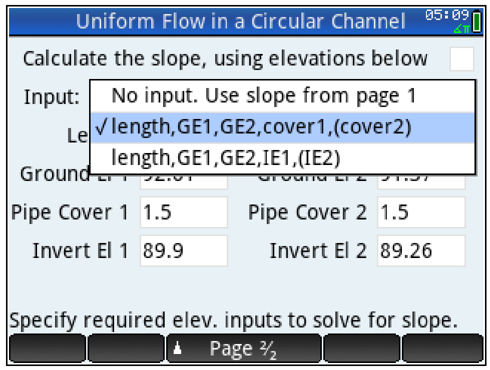
Page 1 of INPUT
Slope s is left blank when using elevation data on page 2



Page 2 of INPUT
To use the elevations, the Input must specify one of the elevation formats.



Output



List of elevation input types

Contents

A. Instructions

Starting the program.

To start the program, press the "toolbox" key. Then press the "User" tab. Select "CircularPipe" from the program list, and then select "1. CircularPIpe" from the submenu that is located to the right. Tap "1 Circularpipe" or press the "Enter" key. The program name, CircularPipe, will appear on the Home screen command line. Press "Enter" to launch the program. The Input screen will be shown.

Solving for one of the variables in Manning's equation and determining which variables needs to be inputted.

Given the problem:

> Determine the depth of flow for a 36" diameter pipe with a slope of 0.009 ft/ft and a flowrate of 25 cfs. Use Manning n value of 0.014.

For the above problem, the variable to be solved is "depth y" using the Manning flow equation. When this variable is selected from the Solve input box, "depth y (flow): n,q,s,d" is displayed in the input box. The variables that need to be inputted are "n, q, s, and d" as shown on the right side of the Solve input box.

In the problem, the flowrate units are cfs, and the pipe diameter units are inch.

The input steps to solve the above problem are:

Set Units to “cfs, in, ft/s”.
Set the variable to be solved to “depth y (flow): n,q,s,d”.
Enter 0.014 in the “Manning n” input box.
Enter 25 in the “flowrate q” input box.
Enter 0.009 in the “slope s” box.
Enter 36 in the “diameter d” box.
On page 2 of the INPUT screen, set “Input” to “No input. Use slope from page 1” (default)
Tap the “OK” tab located in the lower right corner of the screen.

The program will show the results on the G0 screen. The depth is shown to be 16.397 in. The variable that was solved has a star located on the right side. The variables that were inputted to solve the Manning equation have a triangle located on the left side.

Inputting ratio y/d (relative depth) or depth y.

In the “Solved” input box, the required input variables that must be entered to solve the “solved” variable are shown to the right of the solved variable.

There are some solved variables, where either the ratio y/d or depth y can be inputted. In the solved input box, these input variables are shown as (y/d, y✓). This means that either ratio y/d or depth y can be inputted. However, the user must tell the program which variable is to be inputted. This is done with the checkbox located adjacent to the depth y input box. To input depth y, the adjacent checkbox must be checked. When the depth y checkbox is checked, the program will use the depth y value and ignore the ratio y/d value. When the depth y checkbox is unchecked, the program will ignore the depth y value and use the ratio y/d value.

Solving for “diameter for flow” and rounding the diameter

To solve for the “diameter for flow” means to use the Manning flow equation to solve for the pipe diameter (d_{flow}). When solving the diameter, the ratio y/d (relative depth) must be inputted. One cannot solve for the diameter with the depth y inputted, because the depth angle Φ cannot be calculated. To make the program use the ratio y/d value and not the depth y value, the depth y checkbox must not be checked.

To round the calculated diameter to a common pipe size, rerun the program by pressing the ↩ tab. The input screen will be shown with the previous input values. Change “Solve” to “depth y (flow): n,q,s,d”. Change the diameter to the rounded diameter. Then, press the OK tab.

Solving for “diameter for velocity” and rounding the diameter

To solve for the “diameter for velocity” means to use the Manning velocity equation to solve for the pipe diameter (d_{vel}). When solving the diameter, the ratio y/d (relative depth) must be inputted. To make the program use the ratio y/d value and not the depth y value, the depth y checkbox must not be checked.

For a storm drains and sewer mains where the velocity flowing full must be equal to the minimum velocity, round the calculated diameter to a common size. Rerun the program by pressing the ↩ tab. The input screen will be shown with the previous input values. Change “Solve” to “slope s (vel):

n,v,d,(y/d,y✓)". This is the slope for velocity where q is <u>not</u> known. Change the diameter to the rounded diameter. Then, press the OK tab. This gives the slope flowing full. The next step is to solve for the actual depth. Rerun the program by pressing the ↩ tab. Change "Solve" to "depth y (flow): n,q,s,d". Change flowrate q to the design flowrate. Then, press the OK tab. This gives the depth of flow for the design flowrate, where V_{full} = min. vel.

<u>Solving Manning's equation with elevation data</u>

Ground elevations, cover depths and invert elevations can be entered on page 2 of the input screen. The ground elevation, cover depths, and invert elevations are only used when the user tells the program to use the elevation data with the "Input" drop box on page 2. The input drop box on page 2 of the input screen has three options: (1) ignore the elevation data and only used the inputs on page 1, (2) use ground elevations and cover depths, and (3) use ground elevations and invert elevations. When inputting the elevation and cover data, the slope input on page 1 of the input screen is ignored. When solving for the Manning formula unknown variable, if the slope is known, the slope will be calculated from the elevation data. The user must enter either (1) pipe length, GE1, GE2, cover1, and cover2, or (2) pipe length GE1, GE2, IE1 and IE2. The program will then calculate the slope from the elevation data. When solving for the slope from the Manning formula, the user need only enter (1) pipe length, GE1, GE2, and cover1, or (2) pipe length GE1, GE2, and IE1. The program will calculate the slope from the Manning formula, and then calculate cover2 and IE2. For this reason, cover2 and IE2 are enclosed in parenthesis. Cover2 and IE2 must be inputted when solving Manning formula where the slope is known. Cover2 and IE2 are not required when solving for the slope from the Manning formula.

For the two elevation input options (1) pipe length, GE1, GE2, cover1, and cover2, and (2) pipe length GE1, GE2, IE1 and IE2, the user must enter the upstream and downstream ground elevations.

The minimum velocity can also be entered on page 2 of the INPUT screen. The minimum velocity (for full flow) is used to calculate the minimum velocity slope. If the minimum velocity is not entered, the minimum velocity slope will show "na". The minimum velocity will not affect any other calculations.

<u>Rerunning and exiting the program</u>

When the results are displayed on the calculator, the user has three tab options. (1) The ↩ tab allows the user to go back to the input screen where the previous inputs are shown. This gives the user the opportunity to make changes to the previous inputs. (2) The clear tab will clear the previous inputs and go back to the input screen. (3) The exit tab will quit the program. The solved variable will be displayed on the Home screen. After 5 minutes, if the user has not pressed one of the tabs, the calculator will exit the program. After exiting the program, value of the input and calculated variables can be recalled to the Home screen by using the Vars key and User tab. However, if you run the program again, the variables will be cleared.

<u>Methods used to solve for depth</u>

Solving for the depth requires an iterative method. This program uses the calculator's fsolve function to determine the angle Φ (see the diagram) for the depth of flow, where Φ at full flow is equal to 2π. An estimate of 3 radians is used with fsolve. As a result, where there are two solution, fsolve will converge to the solution with the lower depth.

Solving for the critical depth also requires an iterative method. The bisection iterative method was used to solve the critical depth.

SI and English Units

This program can solve Manning's equation using common flowrate and pipe diameter units. Just select the flowrate and pipe diameter units from the Units input box.

When calculating the flowrate in English units, the flowrates will be about 0.2% different from programs that use a rounded k value of 1.49. When all of the inputs have been entered, program converts the user's inputs to SI units, and then calculates Manning's equation in SI units. Just before printing the results, the program will convert the SI units back to the user's units. Because of this, the program uses a Manning k value that is exact (in SI units, k=1). The k value is not rounded, such as when using a k value of 1.49 for English units. When using English units, the program will give slightly different results (more accurate) than from programs that use a rounded k value of 1.49.

If the program is halted mid-way through the code by a system error, such as a division by zero, the SI values stored in the input variables will not be converted back to the user's units. So, when the program is run after a system error interruption, the user's previous input values will be corrupted with the SI units.

To prevent a division by zero error from corrupting the previous input values, the user's inputs are checked for zero values. If the program detects a zero in the input variable, the program will first converts the SI values stored in the input variables back to the user's units, and then displays an error message. So, when the program is run a second time after an error message is displayed, the previous user's inputs are displayed, and the user can easily edit the input values to correct the error. Inputs variables that are not required for the solve variable are not checked for zero values.

For the same reasons above, the program will checks for pressure flow and will display an error message, if there is pressure flow. A pipe at full flow will not trigger the pressure flow error.

The ground elevation, pipe cover, and invert elevations are not checked for zero values, as there can be elevations of 0.

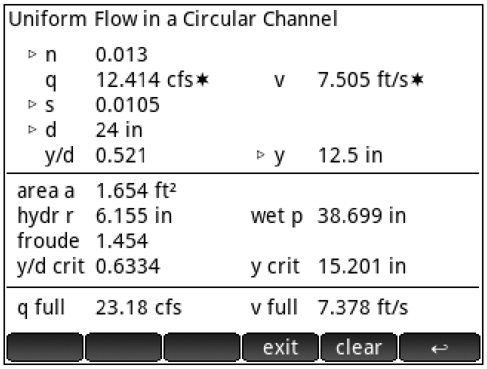
B. Example 1, Solve for flowrate q and velocity v (given depth y)

A 24 inch storm pipe is flowing at a depth of 12.5 inches. The pipe has a slope of 0.0105 ft/ft. Use a Manning n value of 0.013, and determine the flowrate q.

Run the program from the toolbox key and User tab.
Set Units to "cfs, in, ft/s".
Set Solve to "Q and vel (flow) n,s,d,(y/d.y✓)".

Input Manning n = 0.013, slope s = 0.0105, diameter d = 24, and depth y = 12.5.
<u>Check the depth y checkbox.</u>
Press the OK tab.

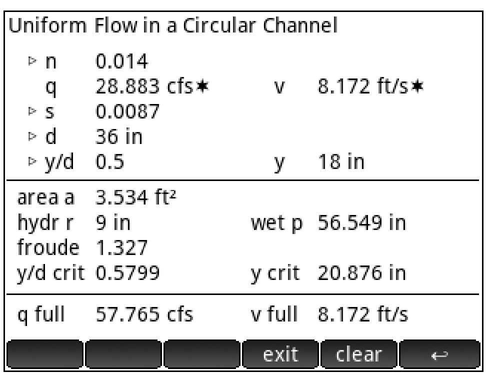
The G0 screen indicates that the flowrate q is 12.414 cfs.at a velocity of 7.505 ft/s.



C. Example 2, Solve for flowrate q and velocity v (given ratio y/d)

A 36 RCP storm line at a slope of 0.0087 is flowing half full. Determine the flowrate q. Assume n is 0.014.

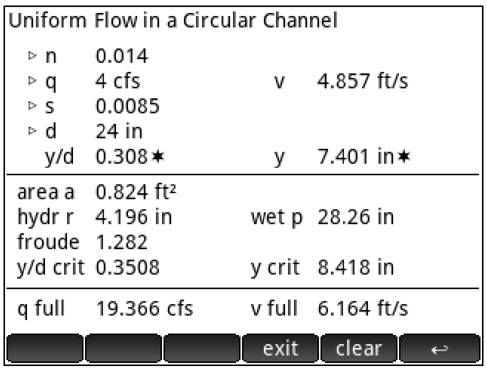
Run the program
Set Units to "ft^3/s, in, ft/s".
Set Solve to "Q and vel (flow) n,s,d,(y/y.y✓)".
Input Manning n = 0.014, slope s = 0.0087, diameter d = 36, and ratio y/d = 0.5.
Press the OK tab.
The program indicates that the flowrate q is 28.883 ft^3/s and the velocity v is 8.172 ft/s.



D. Example 3, Solve for the depth y or ratio y/d

A 24 inch storm pipe is flowing at 4 cubic feet per second. The pipe has a slope of 0.0085 ft/ft. Use a Manning n value of 0.014, and determine the depth of flow.

Set Units to "cfs, in, ft/s".
Set Solve to "depth y (flow): n,q,s,d".
Input Manning n = 0.014, flowrate q = 4, slope s = 0.0085, diameter d = 24.
Press the OK tab.
The print terminal indicates that the depth y is 7.401 inch at a velocity v of 4.857 fps.



E. Example 4a, Solve for diameter for full flow (size storm drain for full flow, y/d=1 and round up to a standard pipe size) revised 7/24/19

Design a storm line to handle a design flow of 23.9 m^3/min, where the ground slope is 0.0074. Assume N = 0.013. V_{min} = 0.75 m/s flowing full. The minimum diameter is 305 mm. The soft metric storm diameters that were used in 1979 were 305, 380, 460, 530, 610, 685, 760, 840, 915, and 1220 mm.

If the pipe is 87 m long, calculate the flow time.

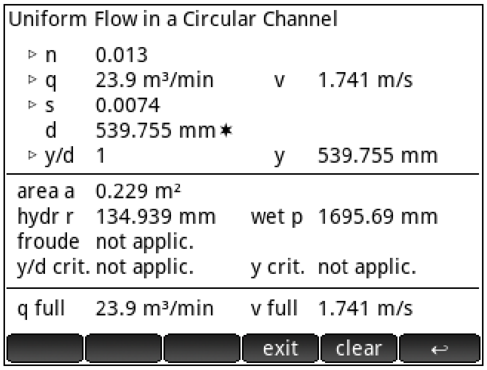
This problem is from the example problem shown on table 17-3 "Design of a storm sewer system" in the book Water Supply and Sewerage, 5th Ed., McGraw-Hill, 1979, by EW Steel and TJ McGhee, pages 400-403. This is line 3 on 15th St from from Beach to Spruce street. In this example, the ground slope is used for the slope of the pipe. The relative depth of flow is not adjusted by changing the slope. The relative depths of the 16 pipes in the book example are between 0.444 and 0.812. Using this method, the relative depth would never exceed 0.819, which is the relative depth at a flowrate equal to full flow. The variations in the relative depth from 0.444 and 0.812 are caused from rounding the diameter upwards to the next standard size. The 0.444 relative depth was caused by rounding the 218 mm calculated diameter in line 13 up to the minimum required diameter of 305 mm.

Step 1. Determine the calculated diameter for flow.

Run the program
Set Units to "m^3/min, mm, m/s".

Set Solve to “diam. d (flow): n, q, s, y/d ”.
On page 1 of the input screen:
Enter Manning n = 0.013, flowrate q = 23.9, slope s = 0.0074, and ratio y/d = 1.
Press the OK tab.

The program indicates that a diameter of 539.755 mm is required for the design flow rate

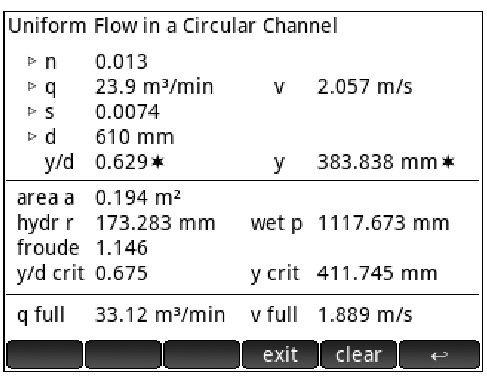


<u>Step 2. Round the diameter and determine the actual depth of flow</u>

Round the 539.755 mm upward to 610 mm.

Rerun the program by pressing the ↩ tab.
The input screen will show the values that were last used.
On page 1 of the input screen:
Change Solve to “depth y (flow): n,q,s,d”
Change diameter d to 610 mm.
Press the OK tab.

For a 610 mm pipe, the relative depth is y/d = 0.629, and the depth is 383.838 mm. Q full is 33.12 m^3/min, and V full is 1.889 m/s.



<u>Calculate the flow time</u>

In general, there are two ways to determine the pipe flow time. The old method is to use the velocity of the 610 mm pipe flowing full when calculating the flow time.

$$flow\ time = \frac{length}{v\_full{*}60\frac{s}{min}} = \frac{87\ m}{1.889\frac{m}{s}{*}60\frac{s}{min}} = 0.768\ min \text{ (old method)}$$

The newer method, which is shown in the Federal Highway Administration, Urban Drainage Design Manual, Section 7.6, "Storm Drain Design Example", Example 7-3 Preliminary Storm Drain Design, page 7.72, Sept. 2009, is to use the actual velocity of 2.057 ft/s when calculating the flow time for preliminary storm designs.

$$flow\ time = \frac{length}{v\_full{*}60\frac{s}{min}} = \frac{87\ m}{2.057\frac{m}{s}{*}60\frac{s}{min}} = 0.705\ min \text{ (new method)}$$

There was a third method, where the average velocity was approximated by the full flow velocity of the calculated diameter, but this method is not used anymore, as the actual velocity is easily determined by computer software programs.

F. Example 4b, Solve for diameter for full flow using ground elevations (size storm main for full flow, y/d=1 and round up to a standard pipe size)

This problem is the same problem used in example 4a above form table 17-2 in the book Water Supply and Sewerage, 5th Ed., McGraw-Hill, 1979 by WE Steel and TJ McGhee, pages 395-399. This is line 3. N = 0.013. $V_{min.}$ = 0.75 m/s. Minimum cover = 1.5 m. Minimum pipe diameter is 200 mm. The soft metric storm diameters that were used in 1979 were 200, 305, 380, 460, 530, 610, 760 840, 915, and 1200 mm. Line 2 drains into line 3.

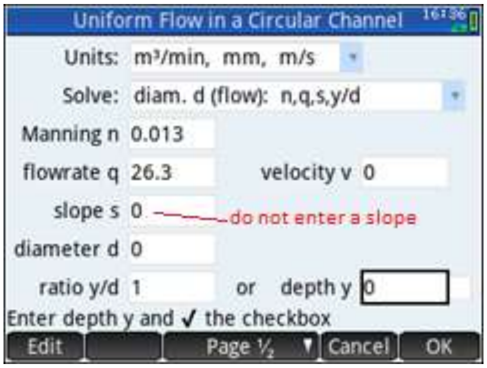
Line	From MH	To MH	Pipe Length m	Q m^3/s	Upper Cover m	Upper Ground Elev m	Lower Ground Elev m	Grade	Calc Dia mm	Pipe Dia mm	Q (full) m^3/s	Vel (full) m/s	Vel m/s	Flow Time full min	Upper Invert Elev m	Lower Invert Elev m	Lower Cover m
1	1	2	87	5.8		93.29	92.62	0.0070		380	9.3	1.4		1.0	91.41	90.74	
2	2	3	87	16.4		92.62	92.01	0.0070		530	22.6	1.7		0.9	90.59	89.98	1.5
3 book	3	4	87	23.9		92.01	91.37	0.0074		610	32.3	1.9		0.8	89.90	89.26	
3 calc	3	4	87	23.9	1.5	92.01	91.37										1.5

Step 1. Determine the calculated diameter for flow.

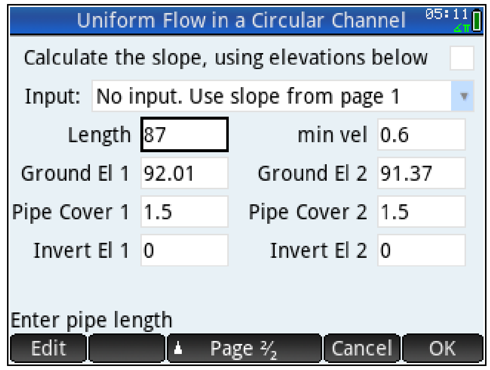
Run the program
Set Units to "m^3/min, mm, m/s".
Set Solve to "diam. d (flow): n, q, s, y/d ".
On page 1 of the input screen:
  Enter Manning n = 0.013, flowrate q = 26.3, and ratio y/d = 1.
On page 2 of the input screen enter:
  Set Input to "length, GE1, GE2, cover1, (cover2)"
  Enter pipe length = 87, min vel = 0.6, GE1 = 91.37, GE2 = 91.22, cover 1 = 1.5, cover 2 = 1.5
  (The minimum velocity does not need to be entered. It is used to calculate the minimum velocity

slope.)
Press the OK tab.

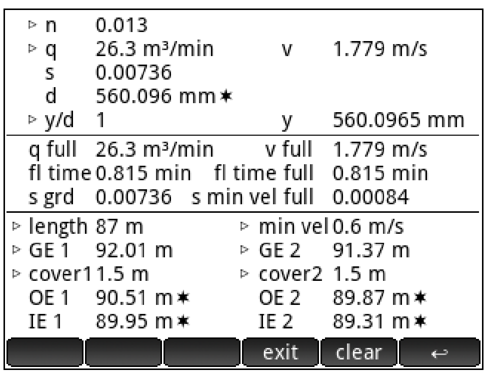
The calculate shows the calculated diameter to be 560.096 mm and v full to be 1.779 m/s.



Input Page 1
When entering elevations, do not input the slope on page 1. In this case, the slope is calculated from the elevation data.



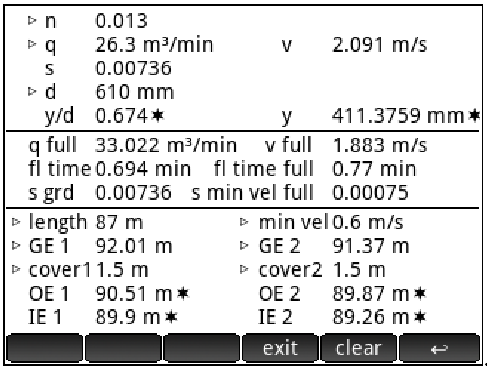
Input Page 2
Because the slope is necessary to calculate the diameter, cover 2 must be entered.



Calculated diameter = 560.096

Step 2. Round the diameter and determine the actual depth of flow

Rerun the program by pressing the ↩ tab.
The input screen will show the values that were last used.
On page 1 of the input screen:
  Change Solve to “depth y (flow): n,q,s,d”
  Change diameter d to 610 mm.
No changes are made to page 2 of the input screen.
Press the OK tab.



For a 610 mm pipe, the flow depth is 411.3759 mm at a velocity of 2.091 m/s. The upstream and downstream invert elevations are 89.90 and 89.26 m. The program calculated the flowrate flowing full to be 33.02 m^3/min, while the book calculated it to be 32.2. This seems to be a typo in the book.

Results for Line 3 (brown color) from the program

Line	From MH	To MH	Pipe Length m	Q m^3/s	Upper Cover m	Upper Ground Elev m	Lower Ground Elev m	Grade	Calc Dia mm	Pipe Dia mm	Q (full) m^3/min	Vel (full) m/s	Vel m/s	Flow Time full min	Upper Invert Elev m	Lower Invert Elev m	Lower Cover m
1	1	2	87	5.8		93.29	92.62	0.0070		380	9.3	1.4		1.0	91.41	90.74	
2	2	3	87	16.4		92.62	92.01	0.0070		530	22.6	1.7		0.9	90.59	89.98	1.5
3 book	3	4	87	23.9		92.01	91.37	0.0074		610	32.3	1.9		0.8	89.90	89.26	
3 calc	3	4	87	23.9	1.5	92.01	91.37	0.00736	560	610	33.02	1.9	2.09	0.8	89.90	89.26	1.5

G. Example 5, Solve for diameter for peak flow (size storm drain for peak flow, y/d=0.93 and round up to a standard pipe size) revised 7/24/19

Problem. A storm drain is to be installed in street with a ground slope of 0.0085 ft/ft. Size the pipe for peak flow using a design flow of 5.8 cfs and a Manning n value of 0.014.

In the previous example 4a, the pipe diameter was calculated based on full flow y/d=1, and was always rounded upward to the next standard size. Some engineers would compare the calculated diameter to the rounded down diameter. If the calculated diameter was close to the round down diameter, those engineers would round the calculated diameter downward. For example, if the calculated diameter was 15.2 inches, and the round down diameter was 15 inches, these engineers would round the diameter downward to 15 inches. This takes advantage of the fact that peak flow in a circular pipe is greater than full flow. Peak flow occurs when the relative depth is approximately equals 0.929619 and where q/q_full approximately equals 1.075706, and where n is constant with depth. So, the rounded down diameter can handle the extra flow as long as q/q_full does not exceed 1.075706.

Comparing the calculated diameter to the rounded down diameter is tedious. An easier way to round downward if the calculated diameter is close to the round down diameter is to calculate the diameter using a relative depth equal to 0.93, and then to round the diameter upward to the next standard size. This has the same effect of rounding the diameter downward if the rounded pipe has the capacity to handle the flow, and it does not affect pipes that would not have been rounded downward.

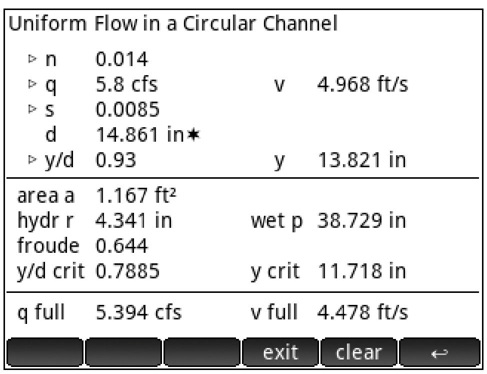
This peak flow procedure only affects how the pipes are rounded. It does not flatten the slope as in the next example. If this procedure was applied to the previously referenced problem (table 17-3 “Design of a storm sewer system” in the book Water Supply and Sewerage, 5th Ed., McGraw-Hill, 1979, by EW Steel and TJ McGhee, pages 400-403), the 16 pipes would have a relative depth from 0.444 to 0.874. Most of the pipes would be rounded the same as with the example in Steel’s book. The few pipes that are rounded down will have a relative depth between 0.819 and 0.9296. Using this method, the relative depth would never exceed 0.929619, which is the relative depth at a flowrate equal to peak flow, where q/q_full equals 1.075706.

This method of rounding the pipe downward to a nominal pipe size is old and is probably not used much.

Step 1. Determine the calculated diameter

Set Units to “cfs, in, ft/s”.
Set Solve to “diam. d (flow): n, q, s, y/d ”.
Input Manning n = 0.014, flowrate q = 5.8, slope s = 0.0085, and ratio y/d = 0.93.
Press the OK tab.

The output indicates that 15 diameter pipe is required when flowing at peak flow where y/d=0.93.

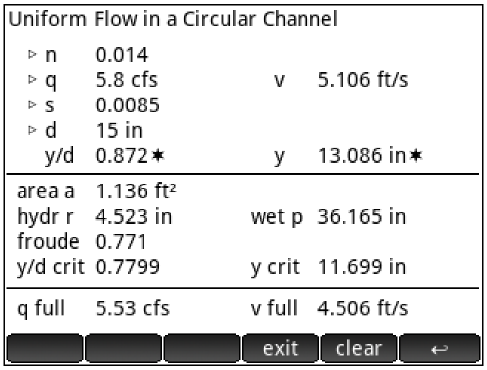


Step 2. Round the calculated diameter upwards and determine the depth of flow

Storm pipes are not available in a diameter of 14.8611 inches. Because the pipe diameter was sized for peak flow, the pipe diameter must always be rounded upward. So, the pipe diameter is rounded to 15 inch.

Rerun the program by pressing the ↩ tab.
The input screen will show the values that were last used.
Change Solve to “depth y (flow): n,q,s,d”.
Change the diameter d = 15.
(The inputs used are n=0.014, q=5.8, s=0.0085, d=15)
Press the OK tab.

The print terminal shows that for a 15 diameter pipe, the depth is 13.0858 inches at a velocity of 5.1059 ft/s. q_full = 5.5299 cfs and v_full = 4.5062 ft/s.



H. Example 6. Solve for diameter for full flow and flatten slope (size storm drain for full flow, y/d=1 and round up to a standard pipe size and flatten the slope, if feasible) revised 7/24/19.

Problem from example 4a. Design a storm line to handle a design flow of 23.9 m^3/min, where the ground slope is 0.0074. Assume N = 0.013. V_{min} = 0.75 m/s flowing full. The minimum diameter is 305 mm. The soft metric storm diameters that were used in 1979 were 305 (12), 380 (15), 460 (18), 530 (21), 610 (24), 685 (27), 760 (30), 840 (33), 915 (36), and 1220 (48) in mm and (inch).

The procedure to flatten slope when sizing pipes is stated in the Oregon Dept. of Transportation, Hydraulics Manual, April 2014, page 13-F-14, which says

> Step 15 … determine the design discharge …
>
> Step 16 … Enter … a trail slope … Usually, the slope of the roadway can be used.
>
> Step 17 … When the appropriate nomograph is available, determine the size of pipe by laying a straight edge between the discharge and slope scales … The appropriate size pipe will be read directly above the straight edge on the pipe diameter scale.
>
> Step 18 Adjust the straight edge on the nomograph such that it lies on the slope and the pipe diameter. *(It sounds like one always uses the rounded up diameter.)*
>
> Step 19 Read the pipe capacity at full flow on the discharge scale. If this value is 10 percent larger than the design flow … then the pipe slope should be flattened if feasible. The slope at which the pipe will flow full can be found by lying the straight edge between the design discharge and culvert diameter scales, and reading the new slope on the slope scale.

ODOT Hydraulics Manual does not list any reference or states why the pipe slope is flattened if the full flow value is 10% larger than the design flow. However, in the 1969 ASCE Design and Construction of Sanitary and Storm Sewers, on page 130, in the section on the design depth of flow, it states:

"For storm sewers, the most common design practice is to have the line [depth of flow] just full or slightly surcharged at the design flow, but some engineers go further and allow the energy grade line to rise to within approximately 1 ft (0.3m) of the gutter invert."

Having the depth of flow at just full was done presumably to provide a more economical (smaller pipe size) and hydraulically efficient flow (close to full flow). In the 1969 ASCE manual, the storm sewer design example on page 55, shows the lower portion of the storm line with a depth of flow close to the pipe crown (similar to the ODOT method), while the upper portion of the line is surcharged.

In contrast, in the 1979 Water Supply and Sewerage book by Steel and McGhee, in storm sewer system design example on page 402, the storm system has relative depths (y/D) from 0.444 to 0.812 without any surcharging.

The design criteria from the Oregon Dept. of Transportation, Hydraulics Design Manual, April 2014, Appendix F "Storm Drains", Page 13-F-29 also shows the different design criterial used for open channel flow and pressure flow. In Section 2, Design Guidelines, page 13-F-3, roughly says:

> Storm drainage systems operation under open channel flow need only to account for major losses (pipe friction loss). Minor losses can be ignored, but the Manning n-value must be increased to account for the minor losses by using the Maximum n-value.
>
> Storm drainage systems operating under pressure flow shall evaluate the hydraulic grade line and shall determine the minor losses for manhole losses, bends in pipes, expansion and contraction losses, etc. Because minor losses are determined, the Normal n-value is used. The HGL must be 0.5 below the rim elevation of structures, and the EGL must be at or below the rim elevation of structures. For pressure flow, a preliminary storm drain is performed to size the pipes in the drainage system. Then, a hydraulic grade line analysis is preformed using the invert elevations, slopes, and pipe diameters calculated in the preliminary design.
>
> Examples of a preliminary storm design with a hydraulic grade line analysis are in the FHWA Urban Drainage Design Manual, Sept. 2009.
>
> The two n-values used for open channel flow and for pressure flow are listed in the ODOT Hydraulics Design Manual. The use of two n-values is not used in the FHWA Urban Drainage Design Manual.

<u>Solve the problem using ODOT flatten slope method and using a nomograph</u>

Problem from example 4a. Design a storm line to handle a design flow of 23.9 m^3/min, where the ground slope is 0.0074. Assume N = 0.013. V_{min} = 0.75 m/s flowing full. The minimum diameter is 305 mm. The soft metric storm diameters that were used in 1979 were 305 (12), 380 (15), 460 (18), 530 (21), 610 (24), 685 (27), 760 (30), 840 (33), 915 (36), and 1220 (48) in mm and (inch).

Using nomograph on page 360, with s = 0.0074 and q = 23.9 m^3/min, we find d = 532 mm which is between a 530 and 610 mm pipes or 21 and 24 inch pipes.

Round the diameter upward to 610 mm (24 inch).

Using the round up diameter d = 610 mm and the slope = 0.0074, we find q full = 32.0 m^3/min.

$\frac{q\ full - q\ design}{q\ design} = \frac{32-23.9}{23.9} = 0.338\ or\ 33.8\%$, which exceeds 10% so flatten slope

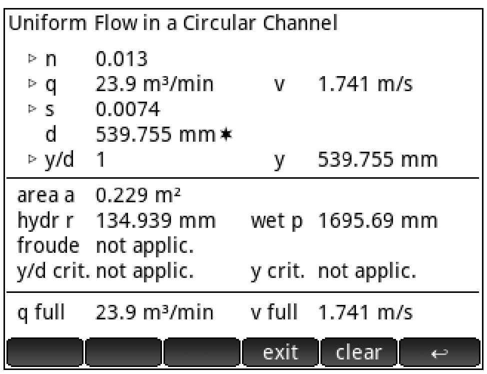
Using the round up diameter d = 610 and q design = 23.9 m^3/min, we get a slope of s = 0.004, where q full = 23.9.

<u>Solve the problem using ODOT flatten slope method and using the CircularPipe program</u>

<u>Step 1. Determine the calculated diameter.</u>

Run the program
Set Units to "m^3/min, mm, m/s".
Set Solve to "diam. d (flow): n, q, s, y/d,".
On page 1 of the input screen:
  Enter Manning n = 0.013, flowrate q = 23.9, slope s = 0.0074, and ratio y/d = 1.
Press the OK tab.

The program indicates that a diameter of 539.755 mm is required for the design flow rate

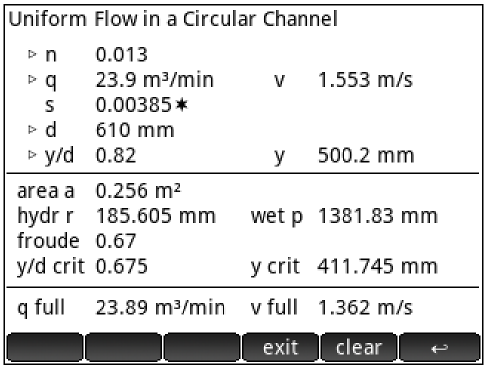


<u>Step 2. Round the calculated diameter upwards, and determine new slope at y/d = 0.82 (approx. depth at full flow)</u>

Rounding the 539.755 mm calculated diameter upwards to the next standard size, give 610 mm.

Rerun the program by pressing the ↩ tab.
The input screen will show the values that were last used.
Change Solve to "slope s (flow): n,q,d,(y/d,y✓)".
Change diameter d = 610
Change ratio y/d = 0.82 (relative depth close to full flow)
(The inputs used are n=0.015, q=23.9, d=610, and y/d=0.82)
Press the OK tab.

The output screen indicates that for the 610 mm pipe flowing at a relative depth of 0.82, the slope is 0.00385. V = 1.553 m/s. V full = 1.364 m/s, and Q full = 23.917 m^3/s. Notice that the slope was flattened from 0.0074 to 0.00385. The depth of flow is close to the crown of the pipe, as mentioned in the ASCE manual, at a relative depth y/d = 0.82, while in the previous example 4a, the same pipe was flowing at a relative depth of 0.629.



I. Example 7. Solve for diameter for peak flow and flatten slope for peak flow (size storm drain for peak flow, y/d=0.93 and round up to a standard pipe size and flatten the slope to y/d=0.93, if feasible) revised 7/24/19.

In the Federal Highway Administration, Urban Drainage Design Manual, Section 7.1.2, "Open Channel vs Pressure Flow", page 7.2, Sept. 2009, it is noted that for less conservative storm drain designs or if the storm drain can easily handle pressure flow, the pipe can be sized for peak flow, where a ratio y/d = 0.93 is used instead of a ratio y/d of 1. Sizing a pipe for peak flow takes advantage of the pipe's ability to handle flows greater than full flow. Peak flow occurs in a pipe when the ratio y/d is approximately equals 0.929619 and where q/q_full approximately equals 1.075706. However, when sizing a pipe for peak flow, a ratio y/d of 0.93 is used.

As previously mentioned in 1969 ASCE Design and Construction of Sanitary and Storm Sewers, on page 130, it was a common design practice is to have the depth of flow in a pipe to be just full or slightly surcharged at the design flow. Some agencies today, will not accept this method for open channel flow designs, because the pipe flow exceed full flow. These agencies would only allow this method for pressure flow.

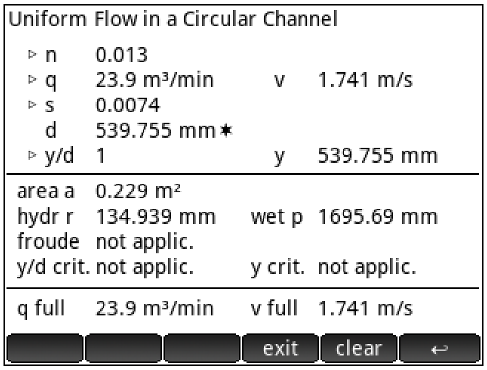
Problem from example 4a. Design a storm line to handle a design flow of 23.9 m^3/min, where the ground slope is 0.0074. Assume N = 0.013. V_{min} = 0.75 m/s flowing full. The minimum diameter is 305 mm. The soft metric storm diameters that were used in 1979 were 305 (12), 380 (15), 460 (18), 530 (21), 610 (24), 685 (27), 760 (30), 840 (33), 915 (36), and 1220 (48) in mm and (inch).

Step 1. Determine the calculated diameter.

Run the program
Set Units to "m^3/min, mm, m/s".
Set Solve to "diam. d (flow): n, q, s, y/d,".
On page 1 of the input screen:

Enter Manning n = 0.013, flowrate q = 23.9, slope s = 0.0074, and ratio y/d = 0.93.
Press the OK tab.

The program indicates that a diameter of 539.755 mm is required for the design flow rate

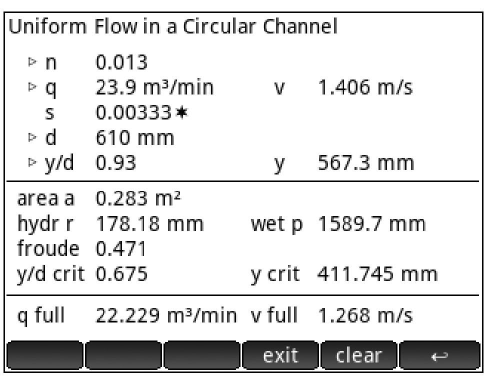


<u>Step 2. Round the calculated diameter upwards, and determine new slope at y/d = 0.93 (approx. depth at peak flow)</u>

Rounding the 539.755 mm calculated diameter upwards to the next standard size, gives a 610 mm diameter pipe.

Rerun the program by pressing the ↩ tab.
The input screen will show the values that were last used.
Change Solve to "slope s (flow): n,q,d,(y/d,y✓)".
Change diameter d = 610
Change ratio y/d = 0.93 (relative depth close to peak flow)
(The inputs used are n=0.015, q=23.9, d=610, and y/d=0.93)
Press the OK tab.

The output screen indicates that for the 610 mm pipe flowing at a relative depth of 0.93, the slope is 0.00333. V = 1.406. V full = 1.268 m/s, and Q full = 22.229 m^3/s. Notice that the slope was flattened from 0.0074 to 0.00333. The depth of flow is close to the crown of the pipe, as mentioned in the ASCE manual, at a relative depth y/d = 0.93, while in the previous example 4a, the same pipe was flowing at a relative depth of 0.629.



J. Example 8, Decrease the diameter of large storm drains by steepening the slope using elevation data

This problem is from the example problem shown on table 17-3 "Design of a storm sewer system" in the book Water Supply and Sewerage, 5th Ed., McGraw-Hill, 1979, by EW Steel and TJ McGhee, Pages 400-403. This is line 8 on Spruce St from 14th Ave to 13th Ave. Line 4 and 7 drain into line 8.

Line	Q m^3/min	Grade	*Calc Dia mm*	Pipe Dia mm	Vel (full) m/s	Pipe Length m	Flow Time minutes	Upper Ground Elev m	Lower Ground Elev m	Upper Invert Elev m	Lower Invert Elev m	*Lower Cover m*
4	26.3	0.0011		840	0.9	140	2.8	91.37	91.22	89.03	88.88	*1.50*
7	24.0	0.0126		530	2.2	87	0.6	92.32	91.22	90.29	89.19	*1.50*
8	48.5					140		91.22	91.10			

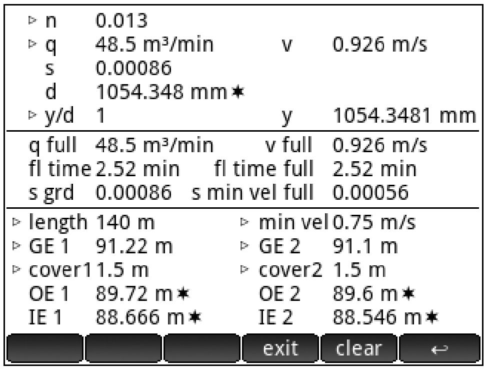
Size the pipe given Q = 48.5 m^3/min, upstream ground elevation = 91.22 m, downstream ground elevation = 91.10 m, pipe length = 140 m. The minimum velocity is 0.75 m/s, and the minimum pipe cover is 1.5 m, where the pipe thickness is ignored. N = 0.013. First, size the pipe using the ground slope information. Second, steepen the slope to reduce the pipe size by two standard diameters. In 1979, soft metric storm diameters were 305, 380, 460, 530, 610, 840, 915, 1050, 1220, 1370, 1520 mm.

In the book example, large diameter pipes had their diameters reduced by one or two pipe diameters to reduce construction costs.

Part 1. Size the pipe using the ground slope.

Step 1. Solve diameter for flow

Run the program.
Set Units to "m^3/min, mm, m/s".
Set Solve to "diam. d (flow): n, q, s, y/d ".
Input Manning n = 0.013, flowrate q = 48.5 m^3/min, and ratio y/d = 1.
Scroll to page 2 of the INPUT screen
Set Input to "length, GE1, GE2, cover1, cover2".
Input: Length = 140 m, Ground El 1 = 91.22 m, Ground El 2 = 91.10 m, Pipe Cover 1 = 1.5 m, Pipe Cover 2 = 1.5 m.
Input minimum velocity = 0.75 m/s
Press the OK tab.
The G0 screen indicates that the calculated diameter is 1054.3481 mm when flowing full at 48.5 m^3/min at the ground slope of 0.000857.

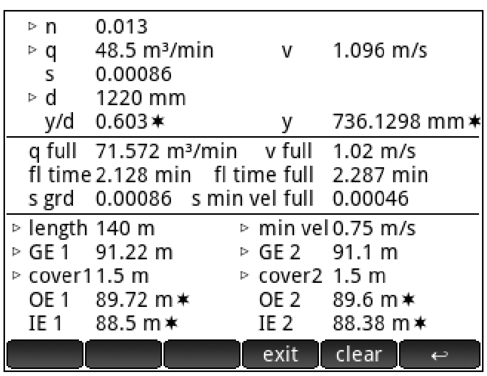


Step 2. Round the diameter to 1220 mm and solve for the actual depth

Go back to the INPUT screen by pressing the ↩. The previous input values will be shown.
Change Solve to "depth y (flow): n,q,s,d".
Change diameter d to 1220 mm.
Press the OK tab.
The calculator indicates that a 1220 mm pipe at a 0.000857 slope is flowing at a relative depth of 0.6034 with a V_{full} = 1.0204 m/s.

Part 1 Size line 8 using the ground slope

Line	Q m^3/min	Grade	*Calc Dia mm*	Pipe Dia mm	Vel (full) m/s	Pipe Length m	Flow Time minutes	Upper Ground Elev m	Lower Ground Elev m	Upper Invert Elev m	Lower Invert Elev m	*Lower Cover m*
4	26.3	0.0011		840	0.9	140	2.8	91.37	91.22	89.03	88.88	*1.50*
7	24.0	0.0126		530	2.2	87	0.6	92.32	91.22	90.29	89.19	*1.50*
8	48.5	0.00086	*1054*	1220	0.9	140		91.22	91.10	88.50	88.38	*1.50*

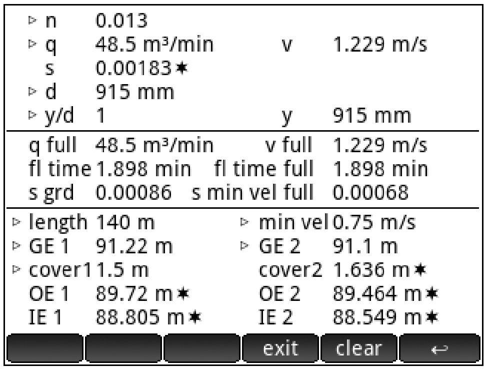


Part 2. Increase the pipe slope to reduce the pipe diameter by two standard pipe sizes and determine the slope for velocity at full flow.

Step 1. Determine the nominal pipe size, and then determine the slope for flow, flowing full

From part 1, the pipe size for line 8 was determined to be 1220 mm where the slope is equal to the slope of the street (ground slope). Reducing the 1220 mm pipe by two nominal pipe sizes gives a nominal pipe size of 915 mm. The next step is to determine slope for flow for a 915 mm pipe flowing full at the design flow rate.

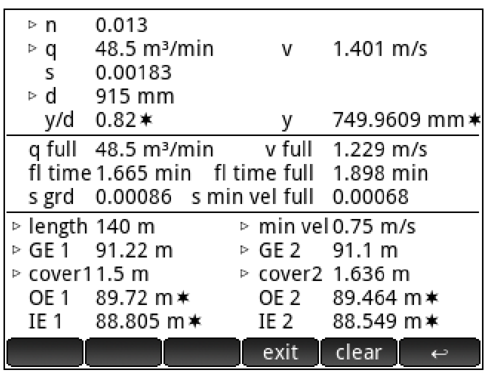
Go back to the INPUT screen by pressing the ↩. The previous input values will be shown.
Change Solve to "slope s (flow) n,q,d,(y/d,y)"
Change diameter to 915
Change ratio y/d to 1



Slope at full flow is 0.00183

<u>Step 2. Determine the actual depth of flow</u>

Go back to the INPUT screen by pressing the ↩. The previous input values will be shown.
Change Solve to "depth y (flow) n,q,s,d"
Change diameter to 915
Change ratio y/d to 1



ratio y/d = 0.82
flow time (full) = 1.898 min.

The book used a slope of 0.0020 instead of the 0.00183 calculated above.

Part 2 Summary. Line 8 pipe size was reduced from 1220 to 915 mm

Line	Q m^3/min	Grade	Calc Dia mm	Pipe Dia mm	Vel (full) m/s	Pipe Length m	Flow Time minutes	Q full	Upper Cover m	Upper Ground Elev m	Lower Ground Elev m	Upper Invert Elev m	Lower Invert Elev m	Lower Cover m
4	26.3	0.0011		840	0.9	140	2.8	28.9	1.50	91.37	91.22	89.03	88.88	1.50
7	24.0	0.0126		530	2.2	87	0.6	28.9	1.50	92.32	91.22	90.29	89.19	1.50
8 book	48.5	0.0020		915	1.3	140	1.8	51.0	1.495	91.22	91.10	88.81	88.53	1.655
~~8 calc~~	~~48.5~~	~~0.00086~~	~~1054~~	~~1220~~	~~0.9~~	~~140~~	~~2.287~~	~~71.57~~	~~1.50~~	~~91.22~~	~~91.10~~	~~88.50~~	~~88.38~~	~~1.50~~
8 calc	48.5	0.00183		915	1.401	140	1.898	48.5	1.50	91.22	91.10	88.809	88.549	1.636

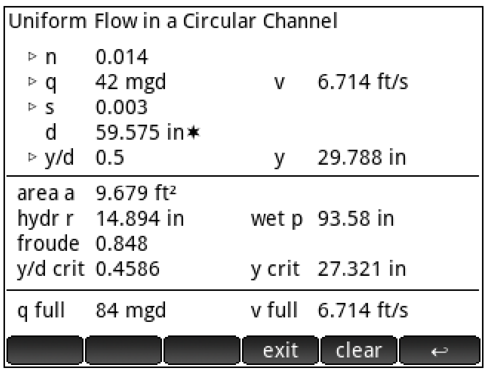
K. Example 9a, Solve for diameter for flow, d_{flow} (size interceptor sewer main for half flow)

A sewer pipe is to be installed in street with a ground slope of 0.003 ft/ft. Design the pipe for a PDWF flow of 42 mgd flowing one-half full, and ADWF flow of 23 mgd. Use a Manning n value of 0.014. The minimum velocity at full and ½ full is 3 fps.

This problem is from the City of Los Angeles, Bureau of Engineering, Sewer Design Manual Part F, Appendix F200, Example 3, Projection of flows and design of interceptor sewer pipe, June 1992. PDWF is the Peak Dry-Weather Flow and ADWF is the Average Dry-Weather Flow.

Step 1. Determine the diameter at one half full flow.

Set Units to "mgd, in, ft/s".
Set Solve to "diam. d (flow): n,q,s,y/d".
Input Manning n = 0.014, flowrate q = 42, slope s = 0.003, and ratio y/d = 0.5.
Press the OK tab.
The output indicates that 59.5751 inch diameter pipe is required when at one-half full.

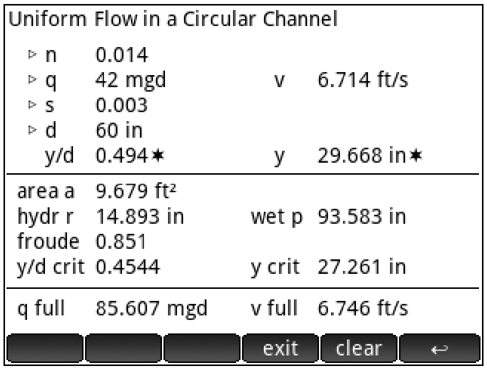


Step 2. Round the diameter to a standard size and recalculate the depth of flow and velocity.

Sewer pipes are not available in a diameter 59.5751 inches. So, the diameter is rounded upwards to 60 inches. The depth is recalculated for a diameter of 60 inches using the same slope of 0.003.

Rerun the program by pressing the ↩.
The input screen will show the values that were last used.
Change Solve to "depth y (flow): n,q,s,d".
Change the diameter d = 60.
(The inputs used are n=0.014, q=42, s=0.003, d=60)
Press the OK tab.
The program shows that for a 60 diameter pipe, the depth is 29.668 inches at a velocity is 6.714 fps.

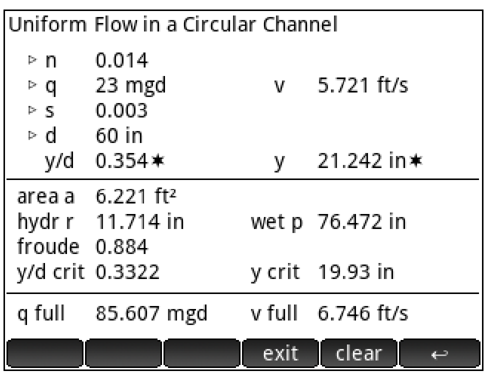
The key to understanding this problem is that for any calculation, the slope was chosen to be fixed at 0.003. This is similar to sizing a storm line for a specific ground slope, except that there are additional requirements for the depth of flow. When the diameter is rounded upwards, the ratio y/d decrease by a small amount. We want the ratio y/d to be equal to or slightly less than 0.5. If the diameter was rounded downward, the ratio y/d would be greater than 0.5, and would not meet the design requirements for the flow to be designed for one half full. So, for a fixed slope, the diameter is rounded upwards.



Step 3. For the rounded pipe diameter, calculate the depth and velocity for the average flow

For the 60 inch diameter pipe, recalculate the depth and velocity for the ADWF flow of 23 mgd (average dry weather flow)

Rerun the program by pressing the ↩.
The input screen will show the values that were last used.
Change the flowrate q = 23.
(The inputs used are n=0.014, q=23, s=0.003, d=60)
Press the OK tab.
The print terminal shows that the depth for a 60 diameter pipe is 21.242 inches at a velocity of 5.721 fps.



L. Example 9b, Solve for diameter for flow, d_{flow} using elevation data (size sewer main for full flow)

The following example is from Water Supply and Pollution Control, 5th Ed. By W Viessman, Jr and MJ Hammer, 1993, Example 7.5, pp 212-217. N = 0.013. The data for lines 2, 4, and 5 are shown below. The minimum velocity is 2 ft/s. The min. diameter is 8 in. A manhole drop of 0.10 ft is required at bends which is an old method for estimating the head loss at bends. The desired cover is 6 ft. Available sewer diameters are 8, 10, 12, 15 and 18 in. Lines 2 and 4 drain into line 5. Design line 5 for full flow.

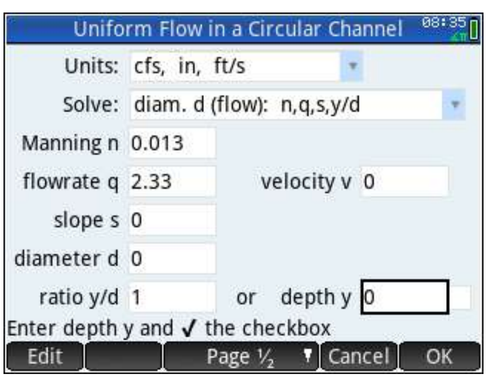
Line	From MH	To MH	Pipe Length ft	Q ft^3/s	*Upper Cover ft*	Upper Ground Elev ft	Lower Ground Elev ft	Grade	Calc Dia in	Pipe Dia in	Q (full) ft^3/s	Vel (full) ft/s	Vel ft/s	Depth in	Upper Invert Elev ft	Lower Invert Elev ft	*Lower Cover ft*
2	6	5	470	1.97	*6.00*	112.19	109.23	0.0063	10.26	12	2.83	3.60	3.89	7.44	105.19	102.23	*6.00*
4	8	5	385	0.26	*6.00*	112.04	109.23	0.0073		8	1.03	2.96	2.42	2.8	*105.37*	*102.56*	*6.00*
5 book	5	4	330	2.33	*6.10*	109.23	107.25	0.006	10.93	12	2.76	3.52	3.94	8.4	102.13	100.15	*6.10*
5 calc	5	4	330	2.33	*6.10*	109.23	107.25	0.0057	11.37	12	2.69	3.42	3.85	8.63	102.13	100.25	*6.00*

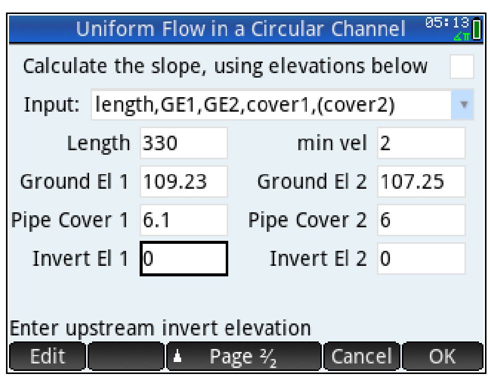
<u>Determine the upstream and downstream cover for line 5.</u>

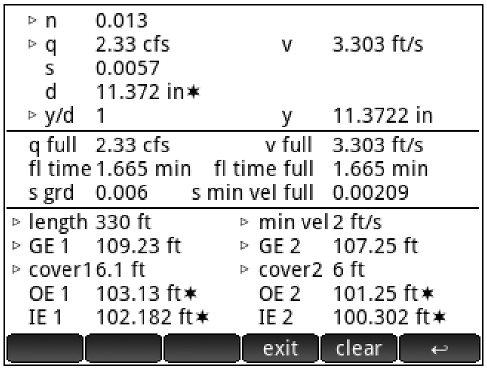
Lines 2 and 4 have a downstream cover of 6 ft, and both lines drain into line 5. A 0.1 ft drop is required at MH 5 because of the change in direction. So, the cover for the upstream end of line 5 is increased by 0.1 ft to 6.1 ft. To maintain the desired cover of 6 ft, the cover for the downstream end of line 5 should be 6 ft; this avoids cover creep. (The example in the book used 6.1 ft.)

<u>Solve diameter for flow (calculated diameter)</u>

Run the program.
Set Units to "ft^3/s, in, ft/s".
Set Solve to "diam. d (flow): n, q, s, y/d ".
On page 1 of the INPUT screen:
  input Manning n = 0.013, flowrate q = 2.33, and ratio y/d = 1.
On page 2 of the INPUT screen:
  set Input to "length, GE1, GE2, cover1, cover2".
  input Length=330, Ground El 1 = 109.23, Ground El 2 = 107.25, Pipe Cover 1 = 6.1, Pipe Cover 2 = 6.0
Press the OK tab.
The G0 screen indicates that the calculated diameter is 11.372 in when flowing full at a velocity of 3.303 ft/s. The velocity exceeds the minimum velocity of 2 ft/s, so the calculated diameter is OK. The pipe slope is 0.0057 and was calculate based on the ground elevations and cover depths. In this case, because the upstream and downstream cover depths were different, the pipe slope shown is not the same as the ground slope (0.006).



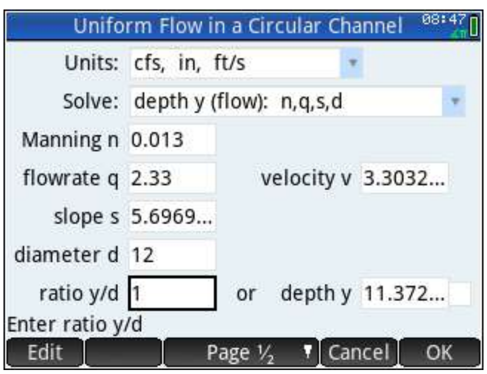


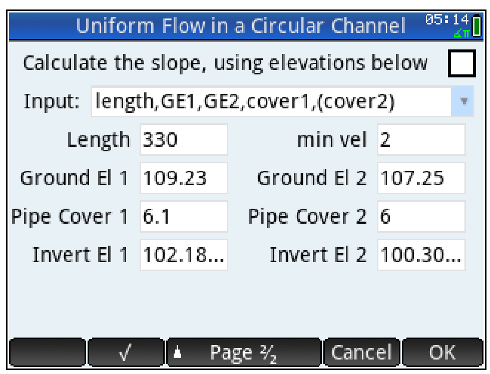


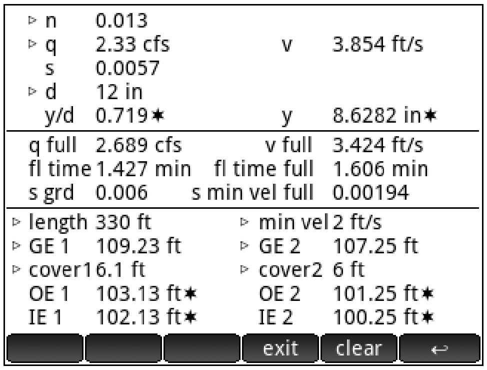
Round the diameter and solve for the actual depth

Rerun the program by pressing the ↩ tab. The previous input values will be shown.
On page 1 of the INPUT screen:
Change Solve to "depth y (flow): n, q, s, d ".
Change diameter d to 12.
(the inputs used are n = 0.013, q = 2.33, and d=12).
Make no change to page 2 of the INPUT screen:
(the inputs used are length=330, GE1=330, GE2=109.23, cover1=6.1, cover2 = 6.0)
Press the OK tab.

The program indicates that the actual depth and velocity are 11.372 in and 3.303 ft/s. The upstream and downstream inverts are 102.182 and 100.302 ft. The values are slightly different from the book, because the downstream cover for line 5 was 6.0 ft and not 6.1 ft. If a cover of 6.0 was used, you would get the same results as the book.

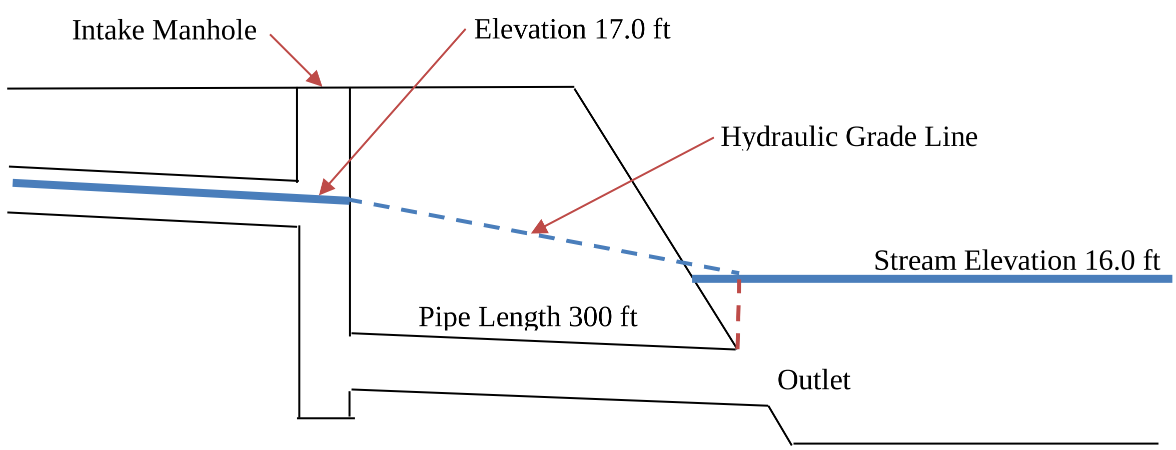






M. Example 10, Solve for diameter for flow of a submerged storm outlet

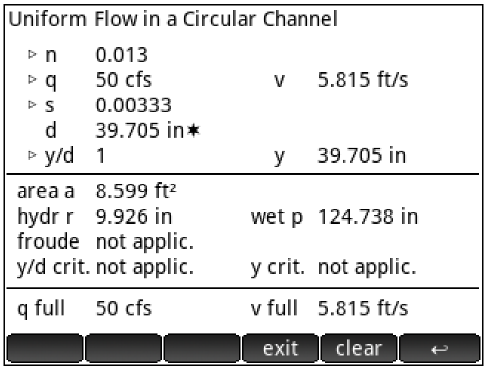
Determine the diameter of a pipe needed to prevent water from backing up during a major storm event for a design discharge of 50 cfs, pipe length of 300 ft, water surface elevation of upstream pipe = 17 ft, and water surface elevation (high water) of stream = 16 ft. Assume n = 0.013.



The problem is from the Iowa Department of Transportation, Design Manual, Chapter 4, “Drainage”, Example 4A-10_5: Pressure Flow Problem 2, 2011. It uses Manning’s Flow equation for pressure flow, and is a quick and dirty way to size a submerged outlet pipe. (This problem ignores the entrance and exit losses.)

The slope of the hydraulic grade line is (Elev. 17 – Elev. 16)/300 ft = 0.003333.

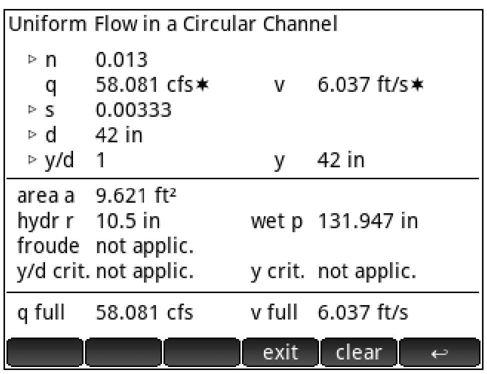
Run the program.
Set Units to “cfs, in, ft/s”.
Set Solve to “diam. (flow): n,q,s,y/d”.
Input Manning n = 0.014, flowrate q = 50, slope s = 0.003333, and ratio y/d = 1.
Press the OK tab.
The print terminal indicates that 39.7055 inch diameter pipe is required.



The 39.7055 inch diameter is rounded upward to 42 inch. Check the velocity for the 42 inch pipe.

Rerun the program by pressing the ↩ tab.
The input screen will show the values that were last used.
Change Solve to “Q and vel (flow) n,s,d,(y/d, y✓)” to solve for the velocity
Change diameter d to 42.
(The inputs used are n=0.013, s=0.003333, d=42, and y/d=1)
Press the OK tab.

The output screen indicates that the velocity v is 6.0368 ft/s and the flowrate q is 58.0810. Notice that the rounding of the diameter to a larger pipe has increase the flowrate q. The actual flowrate q is still 50 cfs. So, the velocity shown here is only approximate and is used to just see if the designed pipe diameter has sufficient velocity between 3 and 15 fps.



This example from the Iowa Department of Transportation stops here. If one wanted to find the actual velocity, one would need to recalculate the slope of the hydraulic grade line using the Manning flow equation, which for a larger pipe should be something less than 0.003333. The outlet water level is fixed by the creek, so there would be a minor drop in the water surface elevation at the upstream manhole. But, since this method is a quick and dirty method, the approximate velocity of 6.0368 fps is used with the flowrate of 50 cfs and the HGL slope of 0.003333.

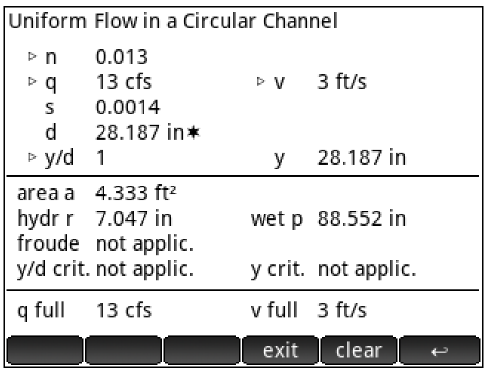
Today, one would need to analyze this problem as pressure flow, as shown in the Federal Highway Administration, Urban Drainage Design Manual.

N. Example 11, Solve for diameter for velocity, d_{vel} (size storm drain for full flow using the slope for minimum velocity)

Design a storm drain to handle a design flow of 13 cfs, where the minimum velocity when flowing full is 3 fps. Use n equal to 0.013.

Step 1. Determine the diameter at full flow.

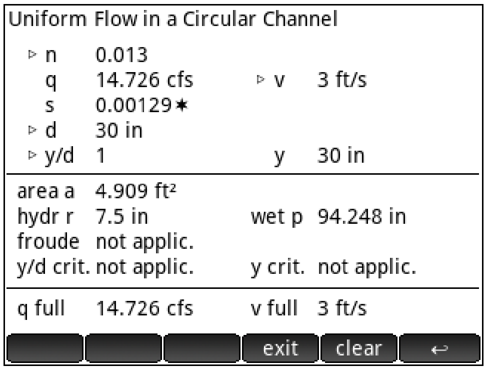
Set Units to "cfs, in, ft/s".
Set Solve to "diam. d (vel): n,q,v,y/d".
Input Manning n = 0.013, flowrate q = 13, velocity v = 3, and ratio y/d = 1
Press the OK tab.
The print terminal indicates that 28.1869 inch diameter pipe is required when flowing full.



Step 2. Round the diameter to a common size and determine the slope for velocity where q is not known

The 28.1869 inch diameter is rounded to a diameter of 30 inches. Solve for the slope for velocity where q is unknown.

Rerun the program by pressing the ↩ tab.
The input screen will show the values that were last used.
Change Solve to "slope s (vel): n,v,d(y/d,y✓)", where q is not known
Change the diameter d = 30.
(The inputs used are n=0.013, v=3, d=30, y/d=1)
Press the OK tab.



The output above shows that the 30 inch pipe has a slope of 0.00129. v_full is 3 ft/s, but q was calculated to be 14.726 cfs. The actual flowrate q is 13 cfs.

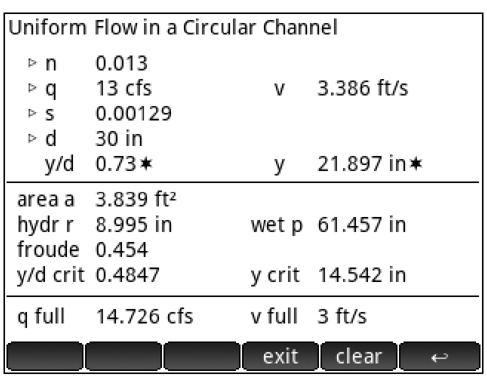
Instead of calculating the minimum slope as shown above, the minimum slope can also be obtained from Table 7-7, Minimum Pipe Slopes to Ensure 0.9 m/s (3.0 ft/s) Velocity in Storm Drains Flowing Full on page 7-29 in the Federal Highway Admin., Urban Drainage Design Manual, Hydraulic Engineering Circular No. 22, Third Edition, Sept. 2009, which shows that for a 30 in pipe with n=0.013, the slope at full flow = 3 fps is 0.0013.

<u>Step 3. Use the design flowrate and solve for the actual depth</u>

The last step is to determine the depth of flow in the 30 in pipe with a slope of 0.0013 using the actual flowrate of 13 cfs.

Rerun the program by pressing the ↩ tab.
The input screen will show the values that were last used.
Change Solve to "depth y (flow): n,q,s,d".
Change the flowrate q = 13.
(The inputs used are n=0.013, q=13, s=0.0013, d=30)
Press the OK tab.

The print terminal shows that depth y = 21.8968 inch, velocity = 3.386 ft/s, and v_full = 3 ft/s.



O. Example 12, Solve for diameter for velocity, d_{vel} (size local sewer main for half flow at minimum velocity flowing full)

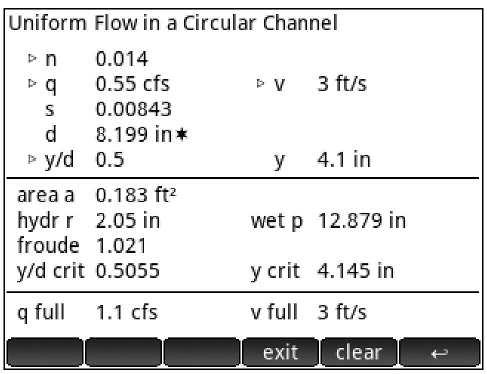
Design a local sewer to handle a design flow of 0.55 cfs flowing at half full. The minimum velocity required at full and half full is 3 fps.

This problem is from the City of Los Angeles, Bureau of Engineering, Sewer Design Manual Part F, Appendix F200, Example 2, Calculation of Pipe Size by Use of Flow Charts, June 1992.

This is a two-step process. (1) Determine the diameter for velocity at 1/2 full flow, and (2) Round the diameter to a common size and determine the slope s for flow for the rounded diameter at ½ full flow.

Step 1 Solve for diameter for velocity

Set Units to "cfs, in, ft/s".
Set Solve to "diam. d (vel): n,q,v,y/d".
Input Manning n = 0.014, flowrate q = 0.55, velocity v = 3, and ratio y/d = 0.5
Press the OK tab.
The print terminal indicates that 8.1992 inch diameter pipe at a slope of 0.0084 is required when flowing half full.

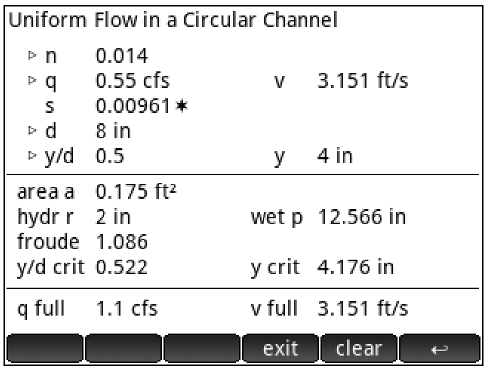


Step 2. Round diameter downward and solve for slope for flow.

In this case, the diameter is rounded downward to 8 inches, and the slope is recalculated. Rounding downwards will increase the slope and velocity provided the pipe is still flowing one half full.

The answer from step 1 for a 8.1992 inch diameter pipe is unique for the given flowrate, velocity, and ratio y/d. If the diameter is changed by rounding to 8 inches, you cannot solve for a slope with a ratio y/d = 0.5 and velocity v = 3.0. For the rounded diameter flowing at one-half full, one can only solve for (1) a ratio y/d = 0.5 and a and a velocity close to 3.0, or (2) a velocity = 3.0 and a ratio y/d close to 0.5. For a sewer pipe, it is more important to keep the ratio y/d equal to one-half full than it is to keep the velocity equal to 3 fps. So, when solving for the slope, the ratio y/d is set equal to 0.5, and the velocity is allowed to change. Rounding the diameter downwards will result in an increase in the velocity. If the pipe diameter was rounded upwards, the velocity would decrease below 3 fps flowing at one-half full, which is unacceptable. Lastly, the slope is determined using the Manning's flow equation, and not the Manning velocity equation.

Rerun the program by pressing the ↩ tab.
The input screen will show the values that were last used.
Change Solve to "slope s (flow): n,q,d,(y/d,y✓)", where the slope is calc'ed from the flow equation
Change the diameter d = 8.
(The inputs used are n=0.014, q=0.55, d=8, and y/d=0.5)
Press the OK tab.
The output screen indicates that the slope of the 8 inch pipe flowing half full is 0.0096, and the velocity is 3.1513 fps.



Special case of calculating the slope for the rounded diameter using Manning's velocity equation.

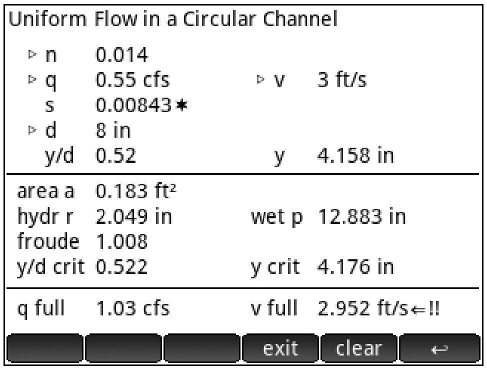
In the previous example above, the 0.0096 slope for the rounded diameter was calculated using Manning's Flow Equation. What would happen if the calculated slope of 0.0096 from Step 2 above cannot be accommodated by the available slope?

The City of Los Angeles pipe sizing example briefly discusses possible alternatives if the slope 0.0096 cannot be accommodated by the available slope. These alternatives involve option (2) previously mentioned above, where the slope is recalculated by holding the velocity = 3 and allowing the ratio y/d to something other than 0.5.

Alternative 1, Round the calculated 8.1992 inch diameter downwards, and determine the slope for velocity where q is given

The first alternative is to use an 8 inch diameter pipe flowing at a velocity of 3 fps. The slope is recalculated using the "slope for velocity where q is given". This would give a slope of 0.00843 and a ratio y/d of 0.52.

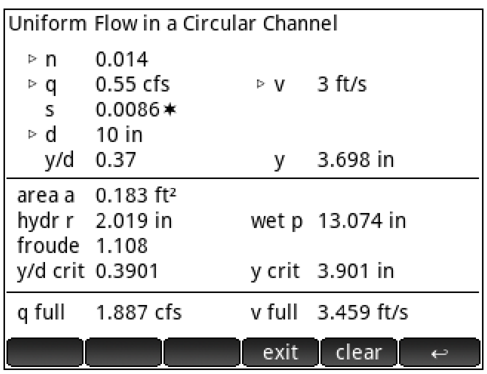
Rerun the program by pressing the ↩ tab.
The input screen will show the values that were last used.
Change Solve to "slope s (vel): n,q,v,d", where q is known
Change diameter to 8 in
(The inputs used are n=0.014, q=0.55, v=3, and d=8)



Alternative 2, Round the calculated 8.1992 inch diameter upwards, and determine the slope for velocity where q is given

The second alternative is to use a larger 10 diameter pipe flowing at a velocity of 3 fps. The slope is recalculated using the "slope for velocity". This would give a slope of 0.0086 and a ratio y/d of 0.37.

Rerun the program by pressing the ↩ tab.
The input screen will show the values that were last used.
Change diameter to 10 in
(The inputs used are n=0.014, q=0.55, v=3, and d=10)



These two alternatives do not meet the requirement that the flow be at one-half full during the design flow. These alternatives would only be considered, if the design slope of 0.0096 cannot be accommodated by the available field conditions.

P. Example 13. Solve for diameter for velocity, d_{vel} (special case to size pipeline, where y/d = 0.3 and actual velocity equals minimum velocity)

Size a pipeline to carry 0.05 m^3/s flowing at a relative depth of 0.3 on a grade of 0.009, where the actual velocity is equal to 0.75 m/s. Assume n = 0.014. Available hard metric diameters are 300, 350, 400, 450, 500, 550, 600, 700, 800, 900, 1000 mm.

Step 1. Determine the calculated diameter for velocity

Run the program
Set Units to "m^3/s, mm, m/s".
Set Solve to "diam. d (vel): n,q,v,y/d".
Input Manning n = 0.014, flowrate q = 0.05, velocity v = 0.75, and ratio y/d = 0.3
Press the OK tab.

The program shows that the calculated diameter is 580.012 mm.

As stated in the previous example, this problem can't be solved, because there are too many restrictions. N = 0.014, q = 0.05, v = 0.75, diameter = 600 mm, and y/d = 0.3, where q and v do not correspond to a y/d of 0.3. Either s, q, v or y/d restriction has to be relaxed.

Q. Example 14. Solve for minimum slope of a storm pipe flowing full, where Q is unknown

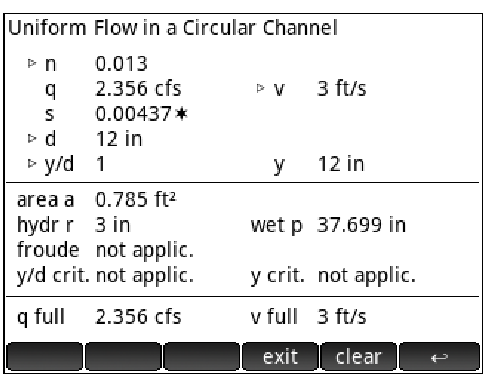
An agency requires storm pipes to have a minimum diameter of 12 inches. The agency also requires storm drains to maintain full-flow pipe velocities of 3 ft/s or greater to maintain a self-cleaning velocity. Determine the minimum slope for (1) a 12 inch RCP pipe with an n-value of 0.013, and (2) a 12 inch CMP pipe with an n-value of 0.024.

See Oregon Department of Transportation 2013 Hydraulics Manual, Appendix F, Storm Drains, Section 7, Minimum Velocity and Grades, page 13-F-7, or FHWA Urban Drainage Design Manual, Sept. 2009, Table 7.7 Minimum Pipe Slopes to Ensure 0.9 m/s (3 ft/s) Velocity in Storm Drains Flowing Full, page 7-29.

(1) a 12 inch RCP pipe with an n-value of 0.013

Run the program
Set Units to "cfs, in, ft/s".
Set Solve to "slope s (vel): n,v, d, (y, y/d✓)".
Input Manning n = 0.013, velocity v = 3, diameter d = 12, and ratio y/d = 1
Press the OK tab.

The print terminal shows that the minimum slope is 0.00437 at a q_full = 2.356 cfs flowing full and v_full = 3 ft/s.



(2) a 12 inch CMP pipe with an n-value of 0.024

Run the program
Set Units to “cfs, in, ft/s”.
Set Solve to “slope s (vel): n,v, d, (y, y/d✓)”
Input Manning n = 0.024, velocity v = 3, diameter d = 12, and ratio y/d = 1
Press the OK tab.

The print terminal shows that the minimum slope is 0.01491 at q_full = 2.356 cfs and v_full = 3 ft/s.