Water for the World

Designing a System of Gravity Flow
Technical Note No. RWS. 4.D.1

This technical note provides information on designing a simple, gravity flow piping system from a water source to a point of use, such as a water storage tank serving an adjacent community distribution point. The design of a distribution system to multiple points or to homes throughout a village is covered in "Designing Community Distribution Systems," RWS.4.D.4.

Whenever the water source is at a higher level than the point of water use, it may be possible to avoid mechanical pumps and allow the force of gravity to deliver the water. This is the preferred method for water delivery since the cost of operating and maintaining pumps is avoided. To design a gravity system, it is first necessary to accurately determine the height of the source above the point of use. The source must be higher for a gravity system to work. The difference in elevation between the source and point of storage is called the system head. This is one of the controlling factors in determining the amount of water that can be delivered. Other factors are the pipe diameter, pipe length, pipe material and rate of flow in the pipe.

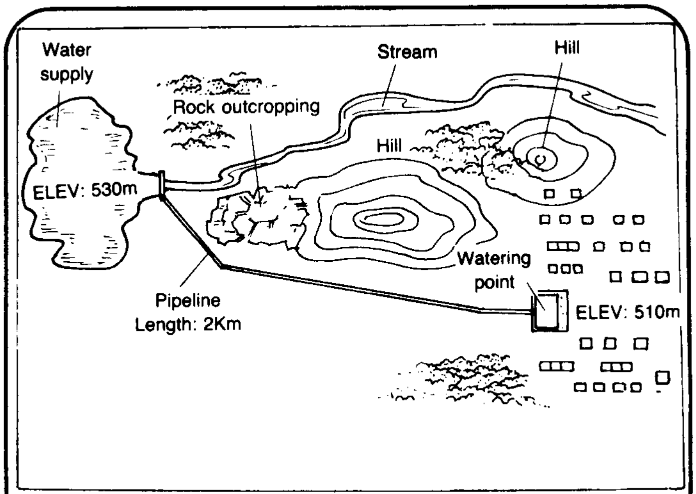

Figure 1. Location Map

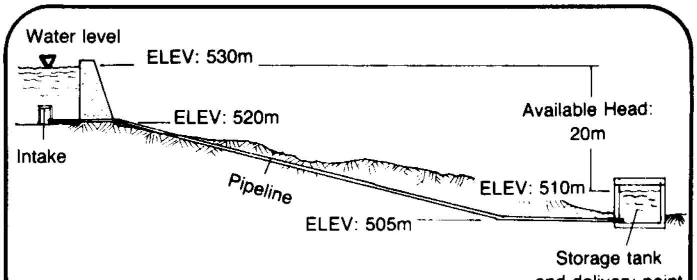

Figure 2. Profile of Pipeline

Preliminary Design Considerations

The first step in designing the system is to draw a map showing the location of the source in relation to the point of use and the distances in between. Obstacles should be shown, as should the elevations of land along the proposed conduit, particularly at the source, storage site, point of use and hills and washes in between. Figure 1 shows a map similar to that needed for a small project. Figure 2 is a profile showing elevations along the proposed conduit route.

There are two ways to conduct the water from the source to the point of use. These are open channel or piping under pressure. An open channel conduit is essentially a man-made stream. It should be carefully shaped and lined with concrete, bricks or indigenous material to make it more durable and enable the water to flow easily. This type of conduit can often be constructed using hand labor and indigenous materials. On the negative side, it must be built at a fairly uniform downhill slope. This condition may not exist due to barriers between the source and the point of use. More importantly, the water in an open conduit is open to contamination. For these reasons, a closed conduit or pressure pipeline is preferred.

A fundamental understanding of hydraulics is necessary to design a pressure pipeline. The force which pushes the water through a pipeline is known as "head" and is the height of water expressed as meters of water above any point being considered in the system. See Figure 2.

As water flows through the pipe, there is a small resistance to the flow caused by the roughness of the pipe material. This is known as "friction". Friction is also caused by sharp bends and constrictions in the pipeline. The energy required to overcome this friction is known as head loss. These losses increase as the amount of flow or the length of pipe is increased or as the diameter of pipe is decreased. This is shown in Figure 3.

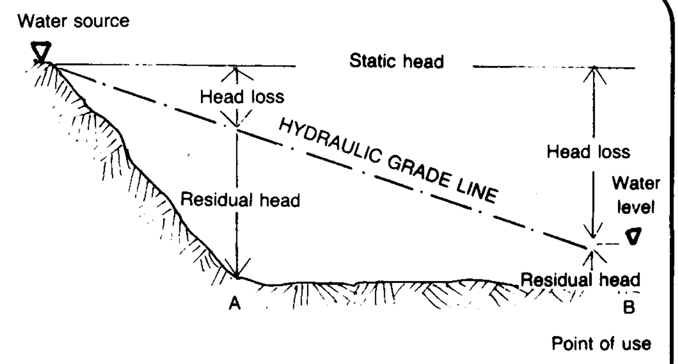

Figure 3. Available System Head

A Design Example

As an example, suppose a rural community of 500 people is located as shown on the map in Figure 1 with the profile as shown in Figure 2. The small stream shown has an available flow of 10 liters per second as measured during the lowest flow. For the present, it has been decided to provide a public distribution point in conjunction with a storage tank. As soon as the community can find the resources, it plans to expand the system to serve individual homes. There are no buildings to be served other than private homes and water for animals will not be provided by the system. Based on this, it has been decided to size the transmission line and storage as if the system were to serve the individual homes right away. Water usage of 100 liters person/day is expected.

Using Worksheet A as a guide, follow these steps:

1. The estimated current daily water needed is 50000 liters/day.

2. Future use is estimated to be 200000 liters/day. This will be the volume of water used to size the tansmission line.

3. The storage reservoir is sized for future use at 200m^3. If this system were not to be expanded for a period of time, consideration would be given to providing less storage now with increased capacity to be added later.

4. The water supply has a continuous source and, because storage is being provided to meet peak demands, the transmission line can be sized to supply water over a 24-hour period. This allows for the minimum pipe size to be selected. In this case, a flow of 2.3 liters/second is needed. Since 10 liters/second is available, the source can provide the necessary flow.

5. Pipe size can now be determined based on the available head to drive the water to the point of use on the required flow and on the total length of pipe in the system.

a. The total length of pipe is determined by adding the measured length to the equivalent length including valves and fittings, shown in Table 2. The number of valves and fittings was estimated for this example. The total pipe length is 2038m.

b. The static head is the difference between the elevation of the source and the water level in the storage tank. In this case, it is 20m.

c. The head available to drive the water through the pipeline is the static head less a small amount of head held in reserve to help prevent a vacuum from occurring in the transmission line. It is recommended that at least 5m be available. This amount is used for this example so that available head is 9.8m.

d. Now use Table 1 to choose a pipe size. Read down the flow column to the flow required (2.3 liters/second). If the desired flow is listed, read across to the right as far as the first column which shows a lower head loss for that flow than is available from step 5c above. If the flow is not shown in the table, then follow the above steps for the next lower flow and the next higher flow. In this case, either flow

Table 1. Head Loss Table in Meters per 1000 Meters Pipe Diameter in mm

Flow liters/ second	30		40		50		80		100	
	GI	AC/P	GI	AC/P	GI	AC/P	GI	AC/P	GI	AC/P
0.1	3.4	2.2	1.5	0.9	.34	0.22				
0.2	5.8	3.5	2.5	1.5	.59	.36	.12			
0.3	13	5.6	4.0	2.4	.9	.55	.12			
0.3	21	8	9	3	1.25	.75	.18	.1		
0.4	23	14	14	5.7	2.2	1.4	.3	.2		
0.5	34	21	19	8.6	3.4	2.1	.45	.3	.12	
0.6	48	30	20	12.5	4.6	3	.61	.4	.15	
0.7	61	39	27	16	6	3.9	.8	.51	.2	
0.8	80	50	35	22	8	5	1.2	7.0	.26	.17
0.9	100	61	42	27	9.9	6.1	1.4	0.9	.32	.2
1.0		75	51	32	13	7.5	1.7	1.1	.39	.4
1.1		90	62	38	15	9.4	2.0	1.3	.47	.3
1.2			73	45	18	11.0	2.5	1.5	.55	.35
1.3			83	54	20	13.5	2.75	1.75	.61	.4
1.4			100	60	24	15	3.2	2.1	.75	.48
1.5				68	28	17	3.7	2.4	.88	.55
1.6				75	30	19	4	2.6	.95	.60
1.7				88	34	22	4.6	2.9	1.1	.68
1.8				95	37	25	5.0	3.2	1.25	.72
1.9					40	27	5.6	3.5	1.3	.8
2.0					46	30	6.1	4.0	1.5	.90
2.5						44	8.7	6.0	2.2	1.35
3.0						60	14	8.4	3.0	1.9
3.5						75	18	11.5	6.2	2.5
4.0						105	23	15	8.3	3.3
5.0							37	26	12	5.0
6.0							50	31	16	7
7.0							67	42	20	9.5
10							130	80	30	18.5
15									70	45
20									125	70

[Note: Based on Hazen-Williams C of 130 for asbestos cement (AC) and plastic (P) and for a C of 100 for galvanized iron (GI).]

If the desired flow rate is not shown, then use an average of the actual flow rate to the next low and next high flow rate. EXAMPLE: For a flow rate of 4.6 liters/second and a 100mm pipe:

1. $\frac{4.0 \times 3.3}{4.6} = 2.9$

2. $\frac{5.0 \times 5.0}{4.6} = 5.4$

3. $\frac{2.9 + 5.4}{2} = 4.2$m head loss

Table 2. Friction Losses in Fittings Equivalent Length of Straight Pipe Meters

Size mm	30	40	50	80	100
Gate valve-open	1.2	1.3	1.6	2.0	2.7
Elbow, 90 degree	6.7	7.5	8.6	11.1	13.1
Elbow, 45 degree	1.8	2.2	2.8	4.1	5.6
Tee, straight	4.7	5.7	7.8	12.1	17.1
Tee, through side	8.8	10.0	12.1	17.1	21.2
Check valve	13.1	15.2	19.1	27.1	38.2

requires the same pipe size, 80mm. If the next lower flow had allowed a smaller pipe size, then an interpolation would have been required, taking an average of the ratio of the actual flow to the next highest flow and the next lowest flow as shown in Table 1.

Other Factors in Designs

Factors other than pipe size must be considered when designing a transmission line. These include high and low points along the line and valving to facilitate operation and maintenance.

Even when a positive pressure is maintained by providing for a residual head, it is possible for air to collect at high points in a line. An air release valve should therefore be installed at the top of each rise as shown in Figure 4. Low points in the line should be equipped with a drain valve so that any sediment that collects can be flushed out. This is very important if the source contains sand or fine sediment.

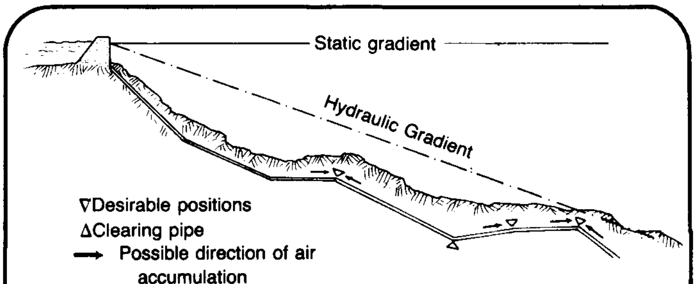

Figure 4. Desirable Positions for Air Valves on Pipeline

Gate valves should be placed in the line to permit system operation and repair. In a piped distribution network, valves are located so portions of the lines can be isolated for repair while the rest of the system is still in operation. With a simple gravity system, a failure anywhere in the line will put the entire system out of operation so a large number of valves are not needed. One valve should be placed at the source and a second near the storage tank or point of use. Additional valves located at intervals of 1000m may be desirable for quicker access to turn the system off should a break occur or to isolate portions of the line for testing purposes.

Worksheet A. Designing a System of Gravity Flow

1. Estimated present water needs in liters:

	Number of:			Unit Use		Total
Population	Persons	500	x	100	=	50,000
School	Students	______	x	______	=	______
Church	Attendees	______	x	______	=	______
Commercial		______	x	______	=	______
Large animals (cows)		______	x	______	=	______
Small animals (sheep)		______	x	______	=	______
Public watering fountains		______	x	______	=	______

Total present water needs = 50000

2. Estimated future water use:

Use a 20-year design life. If no better information is available, use a population growth of 2 times the present population and an increase in animals of 1.25 times the present number. In addition, assume an increase in the rate of use of 2 times.

Population	Present use 50,000	x 4 =	200,000 liters
Institutions and public fountains	Present use ______	x 2 =	______ liters
Animals	Present use ______	x 1.25 =	______ liters

Total future water use = 200,000 liters/day

3. Storage tank:

Take the future water use and convert it to cubic meters:

Reservoir = $\frac{200{,}000}{1000}$ liters = 200 m^3

Worksheet A. Designing a System of Gravity Flow Continued

4. Source production requirements:

Determine the required production rate in liters/second

$$\text{Total daily demand} = \frac{200{,}000 \text{ liters}}{86400 \text{ second}} = \underline{2.3} \text{ liters/second}$$

Assume water production over 24 hours or 86400 seconds

5. Pipe sizing:

a. To calculate the pipe size, first find the total equivalent length of pipe.

Total length = measured length + equivalent length of fittings

Equivalent length of pipe due to fittings (Table 2):

Fitting	Number	x	Equivalent length	=		
Gate valve	1	x	2.7m	=	2.7	m
Elbow, 90 degree	2	x	13.2	=	26.4	m
Elbow, 45 degree	____	x	____	=	____	m
Tee (straight)	____	x	____	=	____	m
Tee (through side)	____	x	____	=	____	m
Swing check valve	1	x	38.2	=	38.2	m

Total equivalent length = 67.3 m

Length of pipe from source to storage = 1971.0 m

Total pipe length = 2038 m

b. Determine static head:

Static head = elevation at source - elevation at top of storage

= 530 m - 510 m = 20 m

c. Find head available per 1000m to overcome friction:

$$\text{Head available} = \frac{\text{static head} - 5\text{m residual head}}{\text{Total pipe length in km}}$$

$$= \frac{20 \text{ m} - 5\text{m}}{2.038 \text{ km}} = \underline{9.8} \text{ m/1000m}$$

d. Select a pipe size from Table 1 using the 24-hour flow in liters/second and the available head loss found in c. above.

	Flow liters per second	Head loss per 1000m	Pipe size	Type material	Select yes/no
Required	2.3	Available 9.8	____ mm		
Next low	2.0	6.1, 4.0	80 mm	GI P/AC	____
Next high	2.5	8.7, 6.0	80 mm	CI P/AC	____

From d. a pipe size of 80 mm is recommended for the transmission line as the head loss is too great for the next smaller pipe size.