Southern Regional Aquaculture Center

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Piping Systems

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A piping system allows the controlled movement of water from one location to another. It consists of pipe to contain and direct the flow; valves to control the flow; fittings such as elbows, tees, couplings, and various other devices such as foot valves; and measurement devices such as pressure switches. It may also have water distribution devices such as spray nozzles or perforated pipe. The piping system prevents the loss of water from evaporation or seepage into the ground. Unfortunately, it also causes resistance to water movement.

General considerations

Piping systems must meet the performance criteria required of the system and do so economically. The first step in designing a piping system is determining what is required of the system. Although systems vary, these factors should always be considered.

Environmental conditions

What is the pipe exposed to, both inside and outside? Will it be exposed to the sun, freezing conditions, high internal pressures, high temperatures, abrasives or trash in the water, or chemicals or pH conditions that might react with the pipe or piping system materials? Will it be subjected to physical stresses? If so, what kinds (for example, a truck running over the pipe or long lengths of unsupported pipe)? Knowing the environmental conditions enables you to choose pipe of correct material and strength to withstand the conditions, or to solve the problem by design. If you know the exposure, your pipe supplier or manufacturer can recommend a suitable material, pipe size, and schedule. (Schedule is a measure of the thickness of the pipe wall. A larger schedule corresponds to a thicker pipe wall.) This will help you avoid incompatible materials, such as steel for a salt water exposure. Suppliers should also be able to recommend the appropriate strength pipe for your application, or offer design suggestions (such as maximum distance between supports) to avoid problems. You must also consider what the pipe may do to the water. Could chemicals harmful either to the product or to the consumer leach into the water from the piping system? Again, your pipe supplier should be able to advise you.

Required flow rates

Maximum and minimum flow rates, and their location in the piping system, should be determined. Can the piping system meet these requirements? If simultaneous flows must be maintained at different parts of the piping system, can the system be controlled to provide the needed flows? (For help in answering these questions, see the section on power requirements.) Be aware that a single-speed pump (particularly one without automatic controls) may not be suitable. For example, consider a situation in which water flow is needed in only one branch of the piping system and that flow is controlled by adjusting a valve. As the flow is restricted, the pressure in the pump increases, which can cause several problems. The pressure may become too high for the pipe or fixtures, resulting in failure. Even if the system does not fail immediately, the cycling stresses resulting from operating under varying conditions may cause connections to leak. Some pumps require a minimum flow to prevent cavitation and/or vibration, conditions that will lead to premature failure. In extreme cases, the water flow may not be sufficient to properly cool the pump. This could result in high temperatures and failure of pump seals and some types of piping.

Operating schedules and control systems

The system's operating schedule—that is, how long the system runs and how often it is turned on and off—will determine whether manual or automatic controls are needed. If changes are made infrequently, manual control

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may be feasible. Even with manual control, however, some automatic controls may be desirable, such as pressure relief valves, pressure switches with a pressure tank (commonly used with domestic well water systems), or automatically controlled multiple- or variable-speed pumps. Variable-speed pumps are expensive and usually are justifiable only for very large systems with high energy costs. Remotely monitored and controlled systems are also expensive but convenient.

Fabrication

The operating schedule also affects the choice of fabrication methods for the piping system. An operating schedule that requires periodic changes in the piping system configuration is often better served by joints that may be easily broken down, such as unions, as opposed to more permanent joints such as glued or soldered ones. If periodic changes are required, pipes should not be placed in filled trenches. Whether fabrication is permanent or reconfigurable, leaks in the piping can usually be avoided by following manufacturers' recommendations for assembly and materials. **Caution:** Two different types of pipe, even if made of the same material, may not have the same dimensional standards and thus may be prone to leaks. If the system is in an area that might experience freezing temperatures, particularly when it is not operating, the pipes should be drained. This requires drain valves or capped pipe located at low points of the piping system so that water will not have to flow uphill to drain the pipes. In addition, dead ends—parts of the piping system that experience little or no flow—should be avoided to prevent deterioration from stagnant water.

Power requirements

Aquacultural operations depend upon water flow for filling systems, aeration, and heating. To operate economically, you must minimize the work you have to do and match your pump to the requirements. Both depend upon the piping system. The piping system will resist the flow of water, and power is required to overcome the resistance.

Resistances can be divided into lift, velocity head, and friction head. Pressure requirements of devices are those necessary for the device to perform properly. An example of such a device would be a nozzle that requires 20 psi to properly aerate water and to deliver the water at a rate of 1.6 gpm (gallons per minute). Pressure is commonly expressed as feet of water or psi (pounds per square inch). One psi is equal to 2.3 feet of water. To convert from psi to feet of water, multiply by 2.3. To convert from feet of water to psi, multiply by 0.43.

Lift

Lift is the vertical distance between two points in the water stream. The total lift is the vertical distance between the surface of the supply water and the point of discharge from the piping system. It is the only component of resistance that is not directly affected by the piping system or the velocity of the water. A typical unit for lift is feet of water.

Velocity head

Velocity head refers to the energy generated by the water's velocity. As water falls through a distance, it reaches a velocity dependent on the distance. In the process of falling, potential energy due to position is transformed into kinetic energy. This kinetic energy (due to velocity) is often measured in feet of water and is termed "velocity head." In equation form, the velocity head (in feet of water) is:

$$\text{Velocity head} = V^2 \div 64$$

(V = velocity as feet per second)

Table 1 lists velocity and velocity head as a function of inside pipe diameter. **Note: Actual pipe sizes are nominal. The inside diameter generally will not equal the nominal pipe size. Use the actual values for the pipe you are using.**

Table 1. Velocity (feet per second) and velocity head (feet) as a function of inside diameter and flow rate.

Flow gpm → Diameter (inches) ↓	10		20		50		100		200		500	
	V	VH	V	VH	V	VH	V	VH	V	VH	V	VH
1	4.1	0.3	8.2	1.0	20.4	6.5	40.9	26.1	81.7	104.3	204.3	651.9
1.5	1.8	0.1	3.6	0.2	9.1	1.3	18.2	5.2	36.3	20.6	90.8	128.8
2	1.0	0.0	2.0	0.1	5.1	0.4	10.2	1.6	20.4	6.5	51.1	40.7
4	0.3	0.0	0.5	0.0	1.3	0.0	2.6	0.1	5.1	0.4	12.8	2.5
6	0.1	0.0	0.2	0.0	0.6	0.0	1.1	0.0	2.3	0.1	5.7	0.5
12	0.0	0.0	0.1	0.0	0.1	0.0	0.3	0.0	0.6	0.0	1.4	0.0

Friction head

Friction head is the pressure loss caused by frictional resistance as water flows through pipe and fittings (valves, couplings, elbows, etc.). This loss is directly dependent on the length of the pipe and on the number and types of fittings. For example, if the length of a pipe is doubled and the same water flow maintained, the friction loss would also double and twice the power would be required to overcome the friction loss. Friction losses vary approximately as the velocity squared. Thus, friction losses are very dependent on pipe diameter— the smaller the pipe, the greater the pressure drop and the more pumping power is required to move the same amount of water. Friction losses for pipe are quite often given as the pressure drop in feet of water at a given flow rate for a 100-foot length of pipe. Table 2 lists representative head losses for various flow rates of water for 100 feet of several diameters of pipe. **Again, this table lists data for illustrative purposes. Actual pipe would be expected to have different values. Your pipe supplier should have actual values for friction losses.**

Friction losses caused by fittings such as elbows and couplings are often expressed in terms of equivalent lengths of a pipe of the same diameter as the fitting. That is, if a fitting has an equivalent length of 20 feet, it would have the same friction loss as 20 feet of pipe of the same diameter as the fitting. Table 3 lists representative equivalent lengths of some common fittings in the form of equivalent length (L) divided by the diameter (D).

Device operating requirements

Be sure to include the pressure characteristics of devices fed/operated by the water flow. For example, a nozzle may require a minimum pressure to supply properly aerated water. The pressure characteristics should include information on water flow rate as a function of pressure.

Table 2. Friction loss in feet of water for 100 feet of pipe as a function of inside diameter and flow rate.

Flow gpm → Diameter (inches) ↓	10	20	50	100	200	500
0.5	216.45	785.71	4319.49	15680.06	56919.83	312919.04
1	7.45	27.06	148.74	539.94	1960.01	10775.22
1.5	1.04	3.77	20.73	75.26	273.18	1501.84
2	0.26	0.93	5.12	18.59	67.49	371.04
4	0.01	0.03	0.18	0.64	2.32	12.78
6	0.00	0.00	0.02	0.09	0.32	1.78
12	0.00	0.00	0.00	0.00	0.01	0.06

Table 3. Equivalent lengths of selected fittings.

Entrances		
Rounded L ÷ D = 2.2	Sharp-edged L ÷ D = 22	Re-entrant L ÷ D = 45

Fittings	Standard ELL	Coupling	Wide-open gate valve	Branch flow in tee L ÷ D for branch
L ÷ D	30	1.5	6.7	70

Sudden enlargements						
Diameter ratio	1.25	1.33	1.50	2.00	3.00	4.00
Equivalent length of smaller pipe L ÷ D	5.8	8.6	13.9	25.3	35.6	39.6

Sudden contraction						
Diameter ratio	1.25	1.33	1.50	2.00	3.00	4.00
Equivalent length of smaller pipe L ÷ D	8.0	11.0	12.5	16.2	18.9	20.3

Determining pressure drop

A piping system or segments of a piping system may be arranged in series or parallel. A serial arrangement means that all the water will have to flow through each section of pipe. A parallel arrangement means that the water may flow in two or more paths. In a parallel arrangement, the water will divide the total flow so that the total pressure drop in each path will be the same. The total pressure drop in series is determined by adding the pressure drops for all sections of pipe. The total pressure drop in a parallel arrangement is determined by following one path and adding up all the pressure drops in that path.

Determining the pressure drop in a parallel path may require a trial and error approach. An assumption (or guess) is made and calculations based on that guess conducted. If the result obtained is feasible, then the guess was good. If not, a new guess is made and the process repeated. Of course, the results of one guess can guide the choice of the next guess. For example, suppose we know the total pressure available (say 30 psi) for a piping system in which 200 feet of pipe feeds two branches, one of which is 100 feet long and the other 200 feet long, and we want to know the flow rate in each path. We could begin by guessing the pressure available immediately after the first 200 feet of pipe. Perhaps we guess 20 psi. We would then determine the flow rate in each branch, keeping in mind that each branch has 20 psi available and thus the flow rate should result in a pressure drop of 20 psi in each branch. Suppose we end up with 23 gpm and 17 gpm for the flow in the two branches. We add the two flows and determine the pressure drop in the feeder pipe. If the pressure drop is 10 psi it results in a pressure before the branches of 20 psi and we are finished with the calculation. If not, we guess a new value for the pressure available at the branch and repeat the process until we obtain a "close enough" agreement.

Analyzing a piping system

The following procedure is often useful in analyzing a piping system.

1. Determine the required flow rate in gallons per minute (gpm). You may want to add a safety factor, say 10 percent, to compensate for pipe wear and pipe aging.
2. Determine the lift in feet.
3. Choose the diameter of the pipe.
4. Determine the total equivalent length of the pipe plus the equivalent length of all fittings.
5. If the pipe discharge is not accounted for by pressure requirements of a device, determine the velocity head. (It is usually not helpful to suddenly enlarge the pipe because of losses a sudden enlargement will cause.)
6. Determine the friction loss. Your pipe supplier should be a source of the table or graphs you need.
7. If the diameter of the pipe changes, treat each section of pipe of different diameter separately, and then add friction losses for sections in series.
8. Add the lift, friction losses, velocity head, and device requirements as appropriate. The result is the total head that the pump must supply.
9. The power a perfect pump and motor (100 percent efficient) would require is the water horsepower. The water horsepower may be calculated as:

   Water horsepower = flow rate in gpm × pressure required in feet of water ÷ 3,960

10. Examine the pressure and power requirements of the piping system. If the performance is not suitable, try a different design and repeat these steps.
11. Determine the suction required of the pump. The suction required is the sum of the lift to the pump, the friction head loss from the water source to the pump, and the velocity head in the suction pipe. With the information on required water flow rate, needed pressure at that flow rate, and suction requirements, choose a suitable pump. If no suitable pump can be found, redesign the piping system.

Example: A piping system is needed to supply both a spray aeration system and a tank. The tank requires 2 gpm, and the spray aeration system requires at least 10 psi. There are ten nozzles. It is anticipated that both the tank and aeration system will be operated continuously, but that either should be capable of being turned off independently of the other. Water is supplied from a pressure tank. The initial pressure range is 20 to 40 psi (pump on at 20 psi, off at 40 psi). The pipe from the pressure tank will run 200 feet before teeing off into the two circuits, each of which is 50 feet long. The relationship between pressure and flow rate for each nozzle is listed in Table 4.

Table 4. Nozzle performance.

Pressure (psi)	Flow rate (gpm)
10	1
15	1.2
20	1.4
25	1.6
30	1.7
35	1.9
40	2.0

Determine the performance of piping systems of 1.5- and 2-inch-diameter pipe. Assume the electrical cost is 10 cents per water horsepower hour.

Solution: The minimum flow rate is 12 gpm (2 gpm for the tank, 10 gpm for the ten nozzles). Since no lift is mentioned, none will be assumed. Both 1.5-inch and 2-inch pipe will be considered. The piping system will be considered in three sections: the main pipe, the branch to and including the nozzles, and the branch to the tank.

- Main pipe: This section consists of 200 feet of pipe. I will assume ten couplings with an equivalent pipe length of 200 feet. The equivalent length of each fitting is L ÷ D = 1.5 (Table 3).

  1.5-inch diameter
  L ÷ D = 1.5 for ten couplings, or 15. Equivalent length of fittings (L) = 15 × 1.5 inches × 1 inch = 1.9 feet. Total equivalent length of pipe and fittings = 201.9 feet.

  2-inch diameter
  Coupling equivalent length (L) = 2.5 feet. Total equivalent length of pipe and fittings = 202.5 feet.

- Tank branch: This section has 50 feet of pipe. From Table 1, the velocity head at 20 gpm in a 1.5-inch pipe is 0.2 feet. Comparatively, this is very small and will be neglected.

  1.5-inch pipe
  Assume one gate valve, three couplings, and one tee (branch flow). L ÷ D for fittings = (3 × 1.5 + 1 × 6.7 + 70) × (1.5 ÷ 12) = 10.2 feet. Total equivalent length of pipe = 60.2 feet.

  2-inch pipe
  L ÷ D for fittings = (3 × 1.5 + 6.7 + 70) × (2 inches) = 13.5 feet. Total equivalent length = 63.5 feet.

- Nozzle branch: This is the same as the tank branch except for the nozzles. Assume 10 psi and thus 10 gpm flow rate. 10 psi = 23 feet of water.

Note: In this example, the friction loss of the valves can be adjusted. Thus, the assumption is made that the flow rate is 10 gpm in the nozzle branch and 2 gpm in the tank branch when 20 psi (46 feet) is available.

Pressure drops

20 psi

- Main pipe:

  1.5-inch pipe
  Total equivalent length = 201.9 feet, flow rate = 12 gpm. Extrapolating from Table 2, friction loss per 100 feet of pipe is estimated as about 1.5 feet. Therefore, a pressure loss of 1.5 × 201.9 ÷ 100 = 3.0 feet would be expected. The low pressure at the pressure tank is 20 psi = 46 feet of water. Thus 46 – 3 = 43 feet of pressure is available at the entrance to each branch.

  2-inch pipe
  Total equivalent length = 202.5 feet, flow rate = 12 gpm. From Table 2, friction loss per 100 feet of pipe is estimated as about 0.4 feet. A pressure loss of 0.4 × (202.5 ÷ 100) = 0.8 feet would be expected. Thus 46 – 0.8 = 45.2 feet of pressure is available at each branch.

- Nozzle branch:

  1.5-inch pipe
  The equivalent length of pipe and fittings = 60.2 feet. From Table 2, friction loss at a flow rate of 10 gpm for 1.5-inch pipe is 1.04 feet per 100 feet of pipe (about 0.6 feet for 60.2 feet of pipe). This means that there would be more than enough pressure. Assuming that the valve will be adjusted to produce 10 psi at the nozzle, the branch with partially closed valve will have a pressure drop of 43 – 23 = 20 feet of water. Since each 100 feet of equivalent length results in a friction loss of 1.04 feet, the valve will be adjusted to produce a total (pipe and fittings) equivalent length of (20 ÷ 1.04) × 100 = 1,923 feet total equivalent length.

  2-inch pipe
  The equivalent length of pipe and fittings is 63.5 feet. From Table 2, friction loss at a flow rate of 10 gpm is 0.26 per 100 feet of pipe. The valve will be adjusted to provide 45.2 – 23 = 22.2 feet of friction loss. This requires an equivalent length of (22.2 ÷ 0.26) × 100 = 11,100 feet.

- Tank branch:

  1.5-inch pipe
  The equivalent length of pipe and fittings will be adjusted with the valve to obtain a friction loss of 43 feet of water at a flow of 2 gpm. From Table 2, the friction loss for 100 feet of 1.5-inch pipe is estimated as 0.05 feet. Thus, the valve will be adjusted so that the total equivalent length is (43 ÷ 0.05) × 100 = 86,000 feet.

  2-inch pipe
  The equivalent length of pipe and fittings will be adjusted with the valve to obtain a friction loss of 45.2 feet of water at a flow of 2 gpm. From Table 2, the friction loss for 100 feet of 2-inch pipe is estimated as 0.01 feet. Thus, the valve will be adjusted so that the total equivalent length is (45.2 ÷ 0.01) × 100 = 452,000 feet.

40 psi

The valve settings and equivalent lengths remain the same as for 20 psi, since the valves are adjusted manually. We know the overall pressure drop (40 psi), but not the flow rates or pressure drops in each section. However, if we knew the pressure drop or flow rate in one of the sections, we could determine the rest. We don't know, so we guess a value and check to see if the guess is "good enough" for our use. If it is, we have our answer; if not, we guess again.

- Main pipe:

  1.5-inch pipe

  Assuming the same flow rate as for 20 psi: 201.9 feet equivalent length results in a friction loss of about 3 feet of pressure, thus (40 × 2.3) – 3 = 89 feet of pressure would be available at the entrance to each branch.

  - Nozzle branch: 1,923 feet total equivalent length or 19.23 100-foot lengths. Assume pressure available is 89 – 23 = 66 feet of pressure. From Table 2, 66 feet of pressure loss is estimated to require a flow of about 40 gpm without any increase in the pressure demand of the nozzle. However, a total flow of 40 gpm means there is 4 gpm per nozzle, which from Table 4 requires more than 40 psi. Assuming a pressure drop less than 40 psi for the nozzles, say 30 psi (69 feet), results in a flow of 1.7 gpm per nozzle or 17 gpm in the branch with an allowable friction loss of less than 89 – 69 = 20. This is not enough to overcome the pipe and valve resistances (53.6 feet at 17 gpm), so I continue the trial and error process until I get satisfactory results.

    Guess nozzle pressure = 21 psi. Flow rate per nozzle = 1.45 gpm. Pressure drop in branch pipe and valve = 89 – (21 × 2.3) = 40.7 feet. Flow rate = 10 × 1.45 = 14.5 gpm. Pressure drop in pipe and valve is about 39.9 feet. These assumptions yield a pressure drop for the nozzles, pipe, and valve of 88.2 feet compared to the assumed value of about 89 feet—close enough.

  - Tank branch: Equivalent length of pipe and valve = 86,000 feet. Assume pressure available is 89 feet. A flow rate of about 2.9 gpm is estimated to have a friction head of about 89 feet.

- Main pipe:

  1.5-inch pipe

  Total flow = 14.5 (nozzle branch) + 2.9 (tank branch) = 17.4 gpm. Friction loss for the main pipe at a flow of 17.4 gpm is estimated as 2.9 feet per 100 feet of pipe. This results in a pressure drop of (2.9 × 201.9) ÷ 100 = 5.9 feet. This means that the actual pressure available to the tank and nozzle branches is 86.1 rather than 89 feet. This is close enough. This yields a total flow at 40 psi of 17.4 gpm.

- Main pipe:

  2-inch pipe

  Following the same procedure as for the 1.5-inch pipe, I obtained an estimated flow of 16 gpm at 40 psi.

Summary: At 20 psi the total flow was 12 gpm for either the 1.5-inch pipe or for the 2-inch pipe. At 40 psi the total flow was 17.4 gpm for the 1.5-inch pipe and 16 gpm for the 2-inch pipe. Assuming that the system operates at 20 psi half the time and at 40 psi the other half, electrical costs are estimated as:

Estimated Annual Operating Costs

Operating pressure (psi)	20		40		total	
Pipe diameter (inch)	1.5	2.0	1.5	2.0	1.5	2.0
Flow rate (gpm)	12	12	17.4	16		
Water horsepower (flow rate – gpm) x (head – feet) ÷ 3,960	0.14	0.14	0.40	0.37		
Water horsepower hour	610.5	611	1771	1628		
Electric cost ($)	61.05	61.1	177	163	238.1	223.9

Although the costs of electricity for the two pipe sizes are close, 1.5-inch pipe would probably be the choice because it would cost less. From the analysis we also learn that the cost of operating at the higher pressure is almost four times that of operating at the lower pressure. The higher cost results from both higher pressures (more head) and greater flow. This gives rise to the possibility of

- Reducing the minimum and maximum pressure. The operating pressure range could be 12 to 24 psi. Minimum flow could be maintained by not closing the valves as much. This should allow about the same run time as the 20 to 40 psi range.
- Installing a pressure-reducing valve so that the piping system is exposed to essentially the minimum pressure all of the time.

Estimated Annual Operating Costs (with modifications)

Operating pressure (psi)	**12**		**24**		**total**	
Pipe diameter (inch)	1.5	2.0	1.5	2.0	1.5	2.0
Flow rate (gpm)	12	12	12	12		
Water horsepower (flow rate - gpm) x (head - feet) ÷ 3,960	0.08	0.08	0.17	0.17		
Water horsepower hour	366.3	366	733	733		
Electric cost ($)	36.63	36.6	73.3	73.3	109.9	109.9

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