

BASIC HYDRAULICS

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INTRODUCTION

Basic hydraulics deal with moving water from location A to location B. Everyone knows that water flows downhill. Actually, to be more precise, it flows from a higher energy state to a lower energy state. A body of water higher on the hill has more potential energy than a body of water lower on the hill. Water in the delivery with the valve off has a higher energy state than water in the ditch that just came from the delivery. They are at the same elevation, but the water in the delivery is under pressure. Pressure is another type of potential energy. The two types of potential energy can be converted, back and forth, by the relationship that says that 1 psi pressure equals 2.31 feet of elevation.

Water coming out of a sprinkler nozzle moves from a place of high pressure, potential energy, to just outside of the nozzle where the elevation is the same but the pressure has fallen to zero, atmospheric. Where did the energy go? There is always a conservation of energy when dealing with water, and it has changed into the velocity of the stream of water. Velocity energy is called kinetic energy.

Bernoulli Equation

A man named Bernoulli put all of these ideas together into a formula:

$$H = V^2/2g + p/w + y$$

where:

H is the energy of the water,

V is the velocity of the water,

g is the acceleration of gravity,

w is the weight per unit volume of water, and

y is the elevation.

The first factor in the equation is kinetic energy and the second two are potential energy. The units used should be consistently in the same measuring system, English or metric.

The energy of any mass of water can be described by this equation. Two masses of water, with the same energy, can have different combinations of kinetic and potential energy, but energy will be conserved and it will be in one of these two forms.

You cannot destroy energy, but the same mass of water that is transported from one place to another can lose energy to friction. The energy at point B plus the friction loss, h_f , equals the energy at point A.

$$H_a = H_b + h_f$$

If you know the energy at point A, you can calculate the energy at point B by subtracting the friction losses. Water in a pipeline that is at rest does not have friction losses, a static system. If you installed a pressure gauge at the end of the line filled with water, the pressure would read one value.

If you start to take water from the pipeline at the end of the line, the pressure will fall, depending on the flow moving through the pipeline. Eventually the friction losses plus the kinetic energy of the water would equal the energy at the head of the pipe and the pressure gauge at the end of the line would read zero and the maximum flow rate would be achieved at the end of the pipeline.

If this terminal flow was insufficient, more energy would have to be added at the head of the pipe or the friction losses would have to be reduced to get the flow at the end that you wanted. To do this you would install a pump or you would use a larger diameter of pipe. The friction losses are related to the velocity of water in the pipe and the roughness of the pipe. The higher the velocity the higher the friction losses, and the rougher the interior of the pipe the higher the losses.

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Thus, when you choose the number of gates to open on a gated pipe system, when you choose the number of laterals to run on a handmove sprinkler system or when you choose the number of drip lines to run, you are changing the friction losses in the system. The system was designed to be run a particular way. If you choose to operate it outside of the design parameters you will most likely reduce the uniformity, increase the energy consumption or both.

Westlands' distribution system is a prime example. Each lateral was designed to supply 1 CFS to each 80 acre parcel, with everyone running. When few water users are irrigating on a lateral, the lateral is over-designed and the delivery flows can be greater. As more deliveries are tuned on, there are greater flows in the lateral and less water can be delivered at a particular delivery. When the design flow for the lateral is exceeded, irrigators at the end of the lateral will have degraded ability to deliver the desired flows. Since the left bank system is gravity flow, there are no options for increasing the deliveries.

For right bank laterals, which must deliver water uphill, capacity problems can trigger a control mechanism to shutdown the lateral, which creates a problem for all on the lateral.

ALUMINUM IRRIGATION SYSTEMS

Portable aluminum irrigation systems save water that could be lost to ditch seepage and give better control over the flows delivered to the furrow. The fact that they are portable allows them to be assembled in many layouts. The friction loss for each layout is

unique. If the system is boosted, excessive friction loss can be counteracted by increasing the boost to increase the pressure at the head end, but with energy costs rising, this additional cost may be significant.

The diameter for the mainline for sprinkler and gated-pipe systems is one of the most important decisions in setting the layout. For a single line gated-pipe system all of the water delivered must pass through the first joint, nearest the delivery. Since the head loss is related to the velocity of the water, a smaller diameter pipe will have a greater velocity for the same flow.

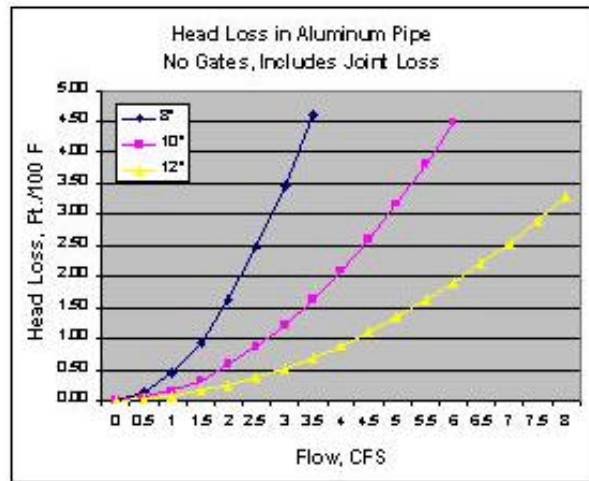
If you were using 10" pipe for the entire mainline along the head of the field and were trying to run as many furrows as possible, you would be able to run more furrows nearer to the delivery than at the end farthest from the delivery, assuming that the flow in each furrow remained constant.

Typically, no booster is used, rather the distribution system pressure is all that is needed, 5 feet of head, minimum at the delivery, which is at the high point of the field. If more water is needed for each furrow, the number of gates open must be reduced. The specific circumstance will depend on the slope of the mainline. If the loss due to friction is canceled by the gain due to loss of elevation then there is no problem, but this depends on where the field is in the District.

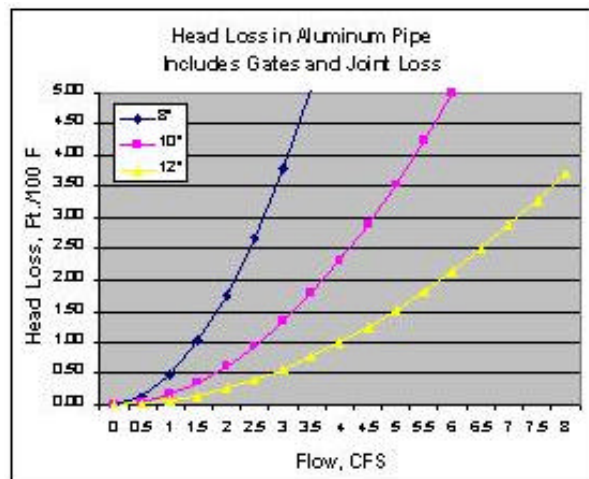
One improvement that can be made to this system configuration, if 12" diameter pipe is available, is to use 12" pipe near to the delivery and reduce to 10" at some point down the field. The figures below show that the head loss using 12" pipe is less than 1/2 the loss using 10" pipe. This configuration will reduce the friction energy loss in the first section of the mainline and allow more

furrows to be set, near and farther away from the delivery, which in turn will give more capability to adjust flows.

When mainline with no gates is used to transport water, the figure below shows the friction head loss (Ft./100 Ft.) for a particular pipe diameter at a flow (Source: After Hazen-Williams equation [11.10], ASCE Monograph 3, 1980)



Similarly, when a mainline has gates the following figure presents the same information:



The mainline without gates will apply to transport and sprinkler mainline. It is not uncommon to boost water in these situations.

For every additional 2.31 feet of head lost an additional 1 pound per square inch of pressure must be added at the booster to maintain the same flow.

When boosting water to a sprinkler system with the mainline going down the center of the field, say 1/4 mile of 10 inch mainline, 3.5 CFS will have 20.8 feet of loss from the delivery to the head of the sprinkler mainline across the field, 1.6 ft per 100 ft. for 1,300 feet, which is equivalent to 9 psi. If 12 inch pipe was used instead the loss would be 0.7 ft. per 100 ft or 9.1 feet, which is equivalent to almost 4 psi, less than half, or possibly a 10 percent energy savings if the booster pressure was dropped from 50 psi to 45 psi. See the [pumps and pumping cost](#) section.

Portable handmove sprinkler systems can be assembled and operated in many different configurations. Typically, the initial investment for a 3 inch lateral system for a quarter section will be less than a system using 4 inch laterals. A three inch system will have a transport mainline to the head of the sprinkler mainline running across the middle of the field, with 1/4 mile laterals coming off both sides. A four inch system will typically have a sprinkler mainline running along the head of the field and 1/2 mile laterals.

The reason for this is that a 1/2 mile sprinkler lateral using 3 inch pipe would have a larger pressure variation along its length, than the 4 inch line, which would give poorer uniformity. The 1/2 mile line would have twice the number of sprinklers and twice the flow in the first joint connected to the main. The pressure head loss would be greater. Assuming that the same number of laterals would be running with the same sprinkler heads, the same head loss could occur on the mainline, but the pressure distribution down the lateral would be significantly different.

Sprinkler laterals are laid out down slope, so that the gain in elevation head can offset the friction loss down the lateral. Friction loss is greater for a smaller lateral diameter because the velocity will be greater for the same number of sprinklers. The 3 inch laterals on the upslope side of the main in the middle of a field will have a greater pressure loss differential, since the friction loss and the elevation loss are additive and do not counteract each other as happens on the down slope side.

The head-loss of a sprinkler lateral can be calculated using the Hazen-Williams equation plus the Christiansen F factor, but it will not be discussed here.

The size of the nozzle will determine the discharge from the sprinkler head. Typically, 7/64" and 1/8" nozzles are used in Westlands. The 7/64" nozzle will discharge about 77% of the discharge of a 1/8" nozzle, assuming other conditions being equal. Thus, 7/64" nozzles will typically be used on 3 inch laterals, but this will mean that more irrigations will be needed to apply the same amount of water as with the larger nozzles, and labor requirements for handmove sprinkler laterals would be higher.

Laterals are typically evenly spread along the mainline. There is a head-loss reason for this. The head-loss relationship to flow is not linear, so it does matter how the laterals are distributed along the mainline. The situation where all of the laterals are blocked together as far down the mainline as possible is the case where the pressure change due to head-loss will be greatest. The opposite extreme is where the block is nearest to the head of the mainline. The booster pressure, ideally, would be adjusted differently for each set. Where the laterals are evenly spread out, the pressure requirement is similar, from the first set to the last, and the difference between the

maximum and the minimum is less than when using blocks.

This situation also occurs when using a solid set system. A solid set system is used on high value crops that need to have frequent, light irrigations. The investment in equipment is very high when a single lateral is not moved to the next position, but the current lateral is turned off and the next lateral is turned on, both remain in place. The hydraulics are the same. With frequent, light irrigations, small variations in sprinkler discharge due to pressure variation result in a larger variation in the distribution uniformity, on a percentage basis.

In conclusion, there are many tradeoffs between fixed and variable costs in the economic analysis of portable aluminum irrigation systems. Fixed capital costs will be higher for 4 inch sprinkler lateral systems, but but variable costs such as energy and labor can be less. Similarly, fixed capital costs for 12 inch gated pipe would be higher, but variable labor costs can be less if the irrigation can be completed in a shorter period of time and water can be saved if uniformity is higher.

PVC PIPELINE

Thermoplastic pipes are commonly divided into low and high pressure categories. It is typically used for buried pipelines, but it is also used for portable surface pipelines such as gated pipe.

Head loss calculations, such as with the Hazen-Williams equation, are very similar to those for aluminum pipe, and so, the head loss graphs presented for the aluminum are useable. Head loss calculations depend on the condition of the pipe. New pipe has less loss and older or corroded pipe will have greater

loss. Aluminum and PVC pipe have similar hydraulic characteristics.

Buried systems are generally designed with one management scheme in mind. If it is operated differently, the uniformity can suffer, due to head-loss considerations. For example if the distribution system for a grape vineyard was designed to irrigate 6 rows of vines, evenly spaced across the field. was operated as a block of 6 adjacent rows, there probably would be uniformity problems. Typically, the cost of the distribution system for an evenly spaced configuration is less expensive than a one that was designed for more flexibility to be operated as an adjacent block. Flexibility must be designed into the system. Such a system is not necessarily the least expensive. Again, head loss considerations cause the problems with uniformity.

Any buried system must be designed with hydraulic consideration for water hammer, thrust blocking, air release, trench width and trench depth.

DITCHES AND CANALS

Ditches and canals are used to distribute water to fields and within fields as part of irrigations systems. All water delivered by the District is delivered from a pipeline distribution system. Water moved on the surface is typically associated with tailwater reuse systems. Siphon tubes are used to deliver water from a head-ditch into a furrow in places where the soil intake rates are conducive to this practice. Typically, the lands that are suited to this type of system are on the east side of the district are near the valley trough, and as such have fine textured soils and flatter slopes.

Water that flows on the surface responds to gravity and flows downhill. Furrow and border strip systems fall into this category.

[Border strip irrigation systems](#) are covered in another section.

Siphon tube, furrow irrigation systems deliver water into the furrow from a head-ditch cut into the head, or mid-field, the furrow that is lower than the level of water in the ditch. The head-ditch is generally checked with tarps to divide the head ditch into shorter segments. The irrigator begins near the head end of the head-ditch and works away. As the irrigator gets to a head-ditch check, the check is removed and the water flows down to the next check. The irrigator will set the required number of siphon tubes to match the total flow going into the furrows to maintain the level of water in the ditch in an equilibrium so it does not overflow and wash out the ditch. The ditch generally has a large cross sectional area, so that the velocity will be small and erosion minimized.

Flow of water in ditches can be categorized into two types, laminar or turbulent. In the laminar state, viscous forces predominate over internal forces and flow is smooth. Turbulent flow is the opposite. Bernoulli's equation still holds, but there is no pressure head, since the system is open to the atmosphere. When water flows there are friction losses. Water will flow in the laminar state where the level of the water surface will be parallel with the bottom of the ditch and the friction losses will equilibrate with the energy gain from the slope of the bottom. For a particular laminar flow, the depth of flow will be less with a steeper slope. As the depth gets to a critical height and the velocity is faster the state of the flow will change to turbulent. The turbulent flow state is much more complicated and will not be discussed here, since it is not desirable to occur except in a lined canal where erosion can be minimized. The shape and roughness of a canal will also influence the flow characteristics.

Erosion is minimized in head-ditches, but the slope of tailwater collection and transport ditches must be considered to minimize erosion in this case.