Turf irrigation design in Northern Arizona

There are 4 steps to designing a sprinkler irrigation system

1. Site information (i.e., water source, ET, map, pressure, obstacles, soils, time of watering)
2. Sprinkler selection (i.e., spacing, flow rate)
3. Pipe system design (i.e., zones, laterals, mains, valves)
4. Installation (picking parts and costs, Blue Stake, contractor bids, supervision).

Site information

Design a sprinkler irrigation system for Hilltop Field at Northern Arizona University.

The water source is potable water.
The maximum ET for Kentucky Blue Grass in Flagstaff is 0.24 in/day, given in Brown (2002).
The pressure varies from 80-85 PSI.
Soils are clay loam with an infiltration rate of 0.22 in/hour.
The turf should be watered at night 9 p.m. to 5 a.m. Thus, the sprinkler system will only be used for 8 hours / day.

Sprinkler selection and layout

Sprinklers are available in a number of flow rates and diameters of throw. Hunter sprinklers will be used in this example (this is not an endorsement of Hunter sprinklers, just an example). Three Hunter sprinklers are generally used in commercial turf: I-20, I -40, I-60, and I-90. I-90's have the largest radius of throw, over 90 ft for some nozzles. They are suitable for large athletic fields or golf courses where there is very little chance of pedestrian traffic during irrigation hours. Unfortunately, the stream is strong enough to knock people off their feet or bicycles. I-40's and I-60's are suitable in most commercial settings and have a diameter of throw of approximately 60 ft, depending on the nozzle. I-20's are suitable in smaller areas and the diameter of throw is approximately 40 ft, depending on the nozzle.

In this design, select Hunter I-90 rotary sprinklers for Cardinal field. The nozzle, flow rates, operating pressures, areas, spacing, arc adjustment, and application rates for Hunter's I-90's are provided below.

The application rate refers to the depth of water that is applied by the sprinklers over a given time period. The sprinkler application rate cannot exceed the soil infiltration rate. Otherwise, runoff occurs. Assume that the maximum application rate based on soil infiltration rate is 0.22 in/hr. Note that you must divide the application rate in the Hunter tables by 2 for full circle operation. The tables are set up for half circle operation. The smaller nozzles operating under full circle conditions give an application rate in the range of 0.27 in/hr. There are no half-circle sprinklers with an application rate that even approaches the maximum application rate of 0.22 in/hr. To minimize runoff, "cycle and soak" irrigation schedules will be used. This type of approach utilizes the surface water storage capacity. The field is soaked for a short time, and then the system is turned off until the surface ponded water infiltrates into the soil. The nozzles listed in table 1 were selected.

Table 1. Sprinkler nozzles selected for design.

Brand	Sprinkler Model	Nozzle	Flow (gpm)	Pressure (PSI)	Radius (ft)	Application rate (in/hour)
Hunter	I-90-36V (full circle)	33	32	70	74	0.54 (full circle)
Hunter	I-90-ADV (adjustable arc)	38	37	70	70	1.22 (part circle)

Sprinklers were spaced one radius apart as shown in figure 1.

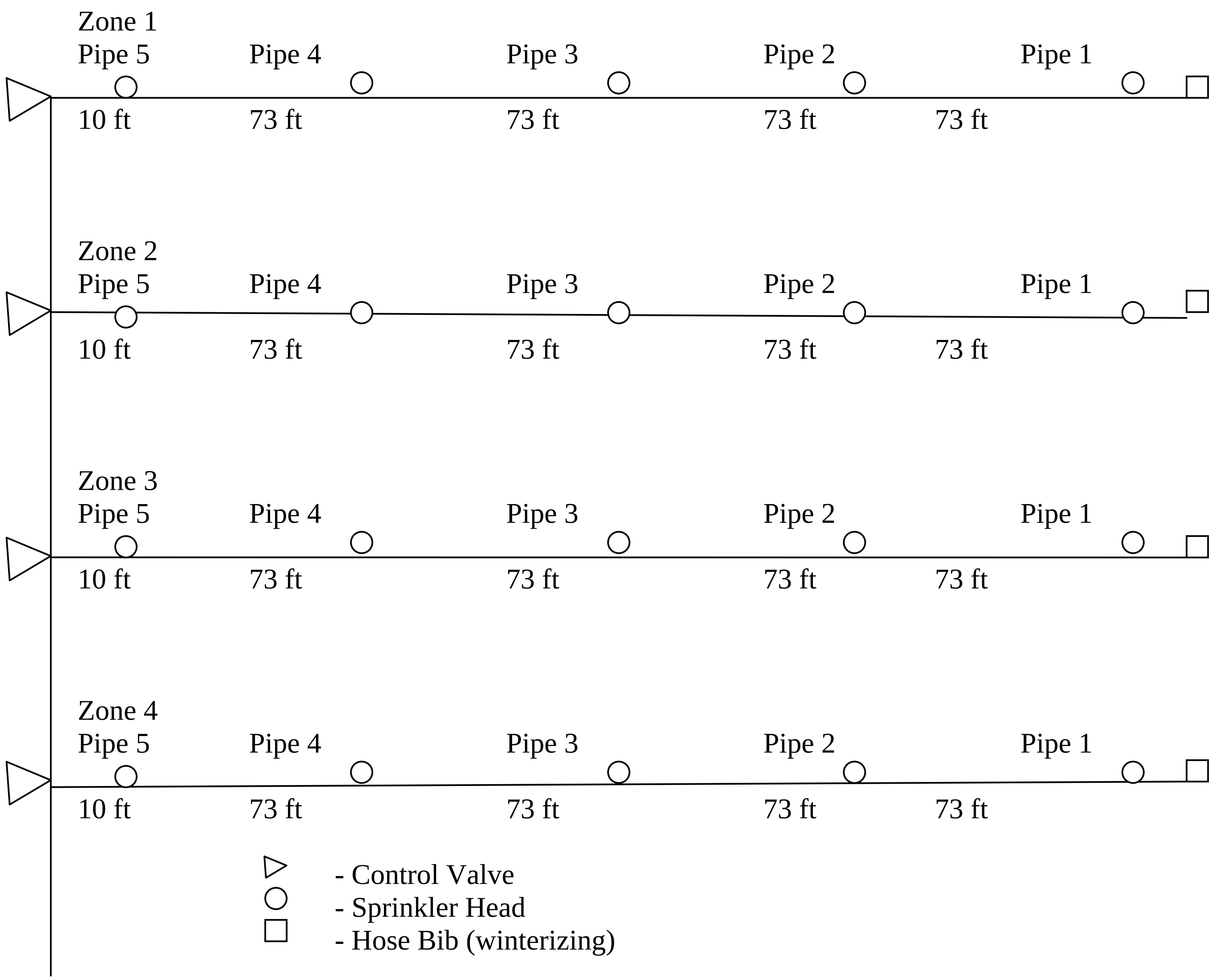

Figure 1. Sprinkler locations in Cardinal Field.

Set up the zones.

The next step is to group the sprinklers into zones. A zone includes all of the sprinklers that are operated at one time. Usually, watering the entire field at one time is not possible because the flow capacity is not large enough. In addition, larger mainlines are required to supply the laterals when the entire field is watered at one time.

One way to determine the number of zones is to divide the hours of operation by the watering time required for each zone. The calculated watering time, hr/day, is the application rate over the ET rate

$$Calculated\ watering\ time = \frac{ET\ rate\ (in/day)}{Application\ rate\ (in/hr)}$$

The application efficiency (water used/ water applied) must be included in the calculation of required watering time per day.

$$Actual\ watering\ time = \frac{Calculated\ watering\ time}{Application\ efficiency}$$

Calculate the watering time for the full circle sprinkler for the period of max ET, 0.24 in/day.

$$Calculated\ watering\ time = \frac{0.24\ (in/day)}{0.54\ (in/hr)} = 0.44\ hour/day$$

Calculate the actual watering time for the full circle sprinklers.

$$Actual\ watering\ time = \frac{0.44\ hour/day}{0.85} = 0.51\ hr/day$$

Calculate the watering time for the part circle sprinkler for the period of max ET, 0.24 in/day.

$$Calculated\ watering\ time = \frac{0.24\ (in/day)}{1.22\ (in/hr)} = 0.2\ hour/day$$

Calculate the actual watering time for the part circle sprinklers.

$$Actual\ watering\ time = \frac{0.2\ hour/day}{0.85} = 0.23\ hr/day$$

There are 10 half circle sprinklers, 4 quarter circle sprinklers, and 6 full circle sprinklers. Ideally, it is best to group all similar sprinklers together.

If each full circle sprinkler is run alone, then the watering time for all full circle sprinklers is

6 sprinklers * 0.5 hour/day = 3 hours per day.

If each half circle sprinkler is run alone, the watering time for half circle sprinklers is

10 sprinklers * 0.23 hr/day = 2.3 hours /day

If each quarter circle sprinkler is operated alone, then watering time for quarter circle sprinklers is

4 sprinklers * 0.12 hr/day = 0.5 hours/day

Total time of operation per day is approximately 6 hours. This is well within the 8 hours maximum operation time. It is best to run each of the sprinklers alone because this will lower the application rate at any one time and reduce the possibility of runoff.

The best choice for running individual sprinklers is to use a valve in head sprinkler. Most sprinkler manufacturers have a line of sprinklers with valves in heads. In this case, the solenoid valve is within the sprinkler. The Hunter I-90 sprinklers do not include a valve within the sprinkler, however, their golf line of sprinklers (G-60 through G-90) do have the valve in head. These sprinklers have the same hydraulic characteristics as the I series sprinklers.

Pipe design

Two pipe design examples are given. One includes a lateral with all of the sprinklers running at one time. The other includes a setup where each sprinkler is run individually.

First, calculate the hydraulics for a pipe lateral with 5 Hunter sprinklers with a flow rate of 37 GPM/sprinkler. Design the lateral for zones 1 and 4 (figure 1). Columns in table 2 will be discussed from left to right.

Table 2. Lateral design table for lateral with 5 sprinklers running as one zone.

Sprinkler	Arc adjustment	Flow Rate (gpm)	Cumulative Flow Rate (gpm)	Flow Rate (cfs)	Pipe Size Inside Dia (in)	Pipe Length (ft)	Friction Loss (ft)
1	0.25	36.9	37	0.082	3.07	73	0.28
2	0.5	36.9	74	0.165	3.07	73	0.99
3	0.5	36.9	111	0.247	3.07	73	2.10
4	0.5	36.9	148	0.329	4.03	73	0.95
5	0.25	36.9	185	0.411	4.03	5	0.10
				Total Friction Loss			4.42

First, specify the flow rate at each sprinkler. Note that this is not an optimal design because the quarter circle and half circle sprinklers will have the same operation time.

Second, calculate the flow rate in each pipe. Start with the flow in the last pipe and work back to the mainline. In the table, the last sprinkler on the lateral is labeled number 1. The pipe that supplies this sprinkler has a flow rate of 37 GPM. The next pipe on the lateral has to supply the last two sprinklers so its flow rate is 74 GPM, and so on.

Third, convert the flow rate of cfs (cubic feet per second) in order to use the hydraulic equation.

Fourth, specify the pipe diameter. Pipe diameters are selected based on maintaining acceptable pressure uniformity. Calculating pipe pressures is a trial and error procedure because you have to try different pipe diameters to see which pipe diameter has an acceptable pressure loss. Ultimately, pipe size selection is an economic decision because larger pipe sizes result in lower energy losses and higher water application uniformity (saves on the cost of water).

A second criterion for pipe selection is that the maximum permissible velocity within the pipeline is 5 ft/sec according to ASAE standards.

$$\min D = \sqrt{\left(\frac{4Q}{V\pi}\right)}$$

where

V	=	velocity, 5 ft/sec.
D	=	pipe diameter (ft)
Q	=	flow rate, ft^3/sec

For example, the minimum required diameter in pipe number 5 with a flow rate of 0.072 ft^3/sec is 0.14 ft or 1.62 inches.

Thus, the minimum acceptable pipe diameter at the beginning of the pipe is 2-inch pipe. The next step is to calculate friction loss in the pipe. I increased the pipe size to 3-inch to minimize friction loss.

Pipe friction loss is calculated with the Hazen-Williams equation (Cuenca, page 397).

$$H_L = kL\left(\frac{\left(\frac{Q}{C}\right)^{1.852}}{D^{4.87}}\right)$$

where,

H_L	=	head loss in pipe, ft
k	=	constant, 10.46
Q	=	flow rate, GPM
C	=	pipe roughness coefficient, 140 for PVC pipe,
D	=	inside diameter of pipe, inches.
L	=	pipe length, ft.

For the pipe corresponding to sprinkler number 1, calculate the pipe friction loss as follows.

$$H_L = 10.46 * 73\left(\frac{\left(\frac{37}{140}\right)^{1.852}}{3.07^{4.87}}\right) = 0.28\ ft$$

Notice that friction loss is calculated in ft. 2.31 ft of friction loss is the same as 1.0 PSI friction loss.

Repeat this process for the other pipe sections in table 2. Total friction loss equals the sum of friction losses in the individual pipe sections = 4.42 ft.
A friction loss of 4.42 ft is the same as a pressure loss of approximately 2 PSI.

Add the pressure loss in the solenoid valve. Typically, the best solenoid valve size from an economic perspective is one pipe diameter smaller than the first pipe on the lateral. Because the first pipe is 4 in, then the best valve size is 3 in. Typically, the pressure loss in a properly sized irrigation valve is in the range of 3 PSI; however, you should check the chart from the manufacturer.

The pressure requirement at the City main is found by adding all of the pressure losses for the individual valves.

In order to calculate the pressure required from the city, you must add together all of the pressure losses and the required sprinkler pressure (table 3).

Table 3. Sum of pressure requirements

Total Pressure Requirements (PSI) for I-90	
Sprinkler Pressure	70
Pipe Friction Losses	2
3 inch valve	3
Total	75 PSI required from the city

Pressure provided by the City is 80-85 PSI. Thus, the design is acceptable and a booster pump is not required.

If individual valve in head sprinklers are operated independently, then the pipe system only needs to supply a flow capacity equal to the flow of one sprinkler at any time. In this case the required flow rate is 37 GPM. The distance from the City main to the last sprinkler is approximately 500 ft (figure 1). Calculate the pressure loss in 500 ft of 2 inch pipe at a flow rate of 37 GPM.

$$H_L = 10.46 * 500 \left(\frac{\left(\frac{37}{140} \right)^{1.852}}{2.07^{4.87}} \right) = 12.9 \ ft = 5.6 \ PSI$$

A pressure loss of 5.6 PSI is 5.6 / 70 100 % = 8 % pressure variation. Typically, in sprinkler irrigation design, a pressure variation less than 20 % is considered acceptable. A 20 % pressure variation leads to a 10 % flow variation. Thus, the design with 2 in pipe is acceptable based on conventional standards. However, the customer may decide to have less pressure loss and higher uniformity. The pressure loss with 3 in pipe is calculated below.

$$H_L = 10.46 * 500 \left(\frac{\left(\frac{37}{140} \right)^{1.852}}{2.07^{4.87}} \right) = 1.9 \ ft = 0.8 \ PSI$$

The customer could compare the costs of 2 in and 3 in pipe in order to make a decision.