Lecture 2

Types of Sprinkler Systems

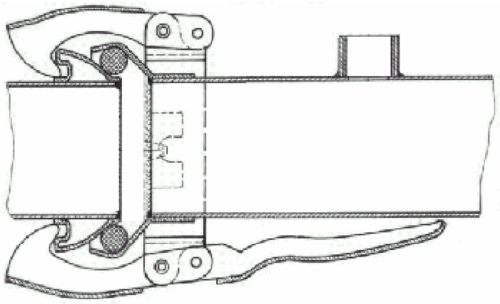
I. Sprinkler System Categories

- Two broad categories: ***set*** and ***continuous-move***
- Set systems can be further divided into: ***fixed*** and ***periodic-move***

II. Set Systems:

Hand-Move

- very common type of sprinkler system
- costs about \$30 - \$90 per acre, or \$75 - \$220 per ha
- requires relatively large amount of labor
- laterals are usually aluminum: strong enough, yet light to carry
- usually each lateral has one sprinkler (on riser), at middle or end of pipe
- to move, pull end plug and begin draining of line, then pull apart
- lateral pipe is typically 3 or 4 inches in diameter
- usually for periodic move, but can be set up for a fixed system
- sprinklers are typically spaced at 40 ft along the pipe
- laterals are typically moved at 50- or 60-ft intervals along mainline



End-Tow

- similar to hand-move, but pipes are more rigidly connected
- tractor drags the lateral from position to position, straddling a mainline
- has automatically draining values (open when pressure drops)
- pipe is protected from wear during dragging by mounting it on skid plates or small wheels
- least expensive of the mechanically-moved systems
- needs a 250-ft (75-m) “turning strip” about the mainline

Side-Roll

- very common in western U.S.
- costs about \$150 - \$300 per acre, or \$360 - \$750 per ha
- wheels are usually 65 or 76 inches in diameter

- lateral is the axle for the wheels; lateral pipe may have thicker walls adjacent to a central “mover” to help prevent collapse of the pipe during moving
- uses “movers” or motorized units to roll the lateral; these may be mounted in middle and or at ends, or may be portable unit that attaches to end of line
- self-draining when pressure drops
- must drain lines before moving, else pipe will break
- windy conditions can cause difficulties when moving the lateral, and can blow empty lateral around the field if not anchored down
- can have trail tubes (*drag lines*) with one or two sprinklers each
- need to “dead-head” back to the starting point
- mainline is often portable
- has swivels at sprinkler and trail tube locations to keep sprinklers upright
- low growing crops only (lateral is about 3 ft above ground)
- can be automated, but this is not the typical case

Side-Move

- almost the same as side-roll, but lateral pipe is not axle: it is mounted on A frames with two wheels each
- clearance is higher than for side-roll
- not as common as side-roll sprinklers

Gun

- 5/8-inch (16 mm) or larger nozzles
- rotate by rocker arm mechanism
- discharge is 100 to 600 gpm at 65 to 100 psi
- large water drops; commonly used on pastures, but also on other crops

Boom

- have big gun sprinklers mounted on rotating arms, on a trailer with wheels
- arms rotate due to jet action from nozzles
- arms supported by cables
- large water drops; commonly used on pastures, but also on other crops

Other Set Sprinklers

- Perforated Pipe
- Hose-Fed Sprinklers
- Orchard Sprinklers

Fixed (Solid-Set) Systems

- enough laterals to cover entire field at same time
- will not necessarily irrigate entire field at the same time, but if you do, a larger system capacity is needed
- only fixed systems can be used for: *frost protection, crop cooling, blossom delay*
- easier to automate that periodic-move systems

- laterals and mainline can be portable and above ground (aluminum), or permanent and buried (PVC or steel, or PE)

III. Continuous-Move Systems

Traveler

- could be big gun or boom on platform with wheels
- usually with a big gun (perhaps 500 gpm & 90 psi) sprinkler
- long flexible hose with high head loss
- may reel up the hose or be pulled by a cable
- large water drops; commonly used on pastures, but also on other crops
- some travelers pump from open ditch, like linear moves
- sprinkler often set to part circle so as not to wet the travel path

Center Pivot

- cost is typically $35,000 ($270/ac or $670/ha), plus $15,000 for corner system
- easily automated
- typical maximum (fastest) rotation is about 20 hrs
- don’t rotate in 24-hr increment because wind & evaporation effects will concentrate
- returns to starting point after each irrigation
- typical lateral length is 1320 ft (400 m), or ¼ mile (quarter “section” area)
- laterals are about 10 ft above the ground
- typically 120 ft per tower (range: 90 to 250 ft) with one horsepower electric motors (geared down)
- IPS 6” lateral pipe is common (about 6-5/8 inches O.D.); generally 6 to 8 inches, but can be up to 10 inches for 2640-ft laterals
- typical flow rates are 45 - 65 lps (700 to 1000 gpm)
- typical pressures are 140 - 500 kPa (20 to 70 psi)
- older center pivots can have water driven towers (spills water at towers)
- end tower sets rotation speed; micro switches & cables keep other towers aligned
- corner systems are expensive; can operate using buried cable; corner systems don’t irrigate the whole corner
- w/o corner system, $\pi/4$ = 79% of the square area is irrigated
- for 1320 ft (not considering end gun), area irrigated is 125.66 acres
- with corner system, hydraulics can be complicated due to end booster pump
- center pivots are ideal for allowing for effective precipitation
- ignore soil water holding capacity (WHC)
- requires almost no labor; but must be maintained, or it will break down
- can operate on very undulating topography
- known to run over farmers’ pickups (when they leave it out there)!
- many variations: overhead & underneath sprinklers; constant sprinkler spacing; varied sprinkler spacing; hoses in circular furrows, etc.
- sprinkler nearest the pivot point may discharge only a fine spray; constant radial velocity but variable tangential speeds (fastest at periphery)
- some center pivots can be moved from field to field

Linear Move

- costs about $40,000 for 400 m of lateral

- field must be rectangular in shape
- typically gives high application uniformity
- usually guided by cable and trip switches (could be done by laser)
- usually fed by open ditch with moving pump, requiring very small (or zero slope) in that direction
- can also be fed by dragging a flexible hose, or by automated arms that move sequentially along risers in a mainline
- need to “dead-head” back to other side of field, unless half the requirement is applied at each pass
- doesn’t have problem of variable tangential speeds as with center pivots

IV. LEPA Systems

- ***L****ow* ***E****nergy* ***P****recision* ***A****pplication* (LEPA) is a concept developed in the mid to late 1970s in the state of Texas to conserve water and energy in pressurized irrigation systems
- The principal objective of the technology was to make effective use of all available water resources, including the use of rainfall and minimization of evaporation losses, and by applying irrigation water near the soil surface
- Such applications of irrigation water led to sprinkler system designs emphasizing lower nozzle positions and lower operating pressures, thereby helping prevent drift and evaporative losses and decreasing pumping costs
- For example, many center pivot systems with above-lateral sprinklers have been refitted to position sprinkler heads under the lateral, often with lower pressure nozzle designs
- The commercialization of the LEPA technology has led to many modifications and extensions to the original concept, and is a term often heard in discussions about agricultural sprinkler systems
- The LEPA concept can be applied in general to all types of sprinkler systems, and to many other types of irrigation systems

Soil-Water-Plant Relationships

I. Irrigation Depth

$$d_x = \frac{MAD}{100} W_a Z \tag{1}$$

where d_x is the maximum net depth of water to apply per irrigation; MAD is *management allowed deficit* (usually 40% to 60%); W_a is the water holding capacity, a function of soil texture and structure, equal to FC – WP (field capacity minus wilting point); and Z is the root depth

- For most agricultural soils, field capacity (FC) is attained about 1 to 3 days after a complete irrigation
- The d_x value is the same as "*allowable depletion*." Actual depth applied may be less if irrigation frequency is higher than needed during peak use period.
- MAD can also serve as a safety factor because many values (soil data, crop data, weather data, etc.) are not precisely known
- Assume that crop yield and crop ET begins to decrease below maximum potential levels when actual soil water is below MAD (for more than one day)
- Water holding capacity for agricultural soils is usually between 10% and 20% by volume
- W_a is sometimes called "TAW" (total available water), "WHC" (water holding capacity), "AWHC" (available water holding capacity)
- Note that it may be more appropriate to base net irrigation depth calculations on soil water *tension* rather than soil water content, also taking into account the crop type – this is a common criteria for scheduling irrigations through the use of tensiometers

II. Irrigation Interval

- The maximum irrigation frequency is:

$$f_x = \frac{d_x}{U_d} \tag{2}$$

where f_x is the *maximum* interval (frequency) in days; and U_d is the average daily crop water requirement during the peak-use period

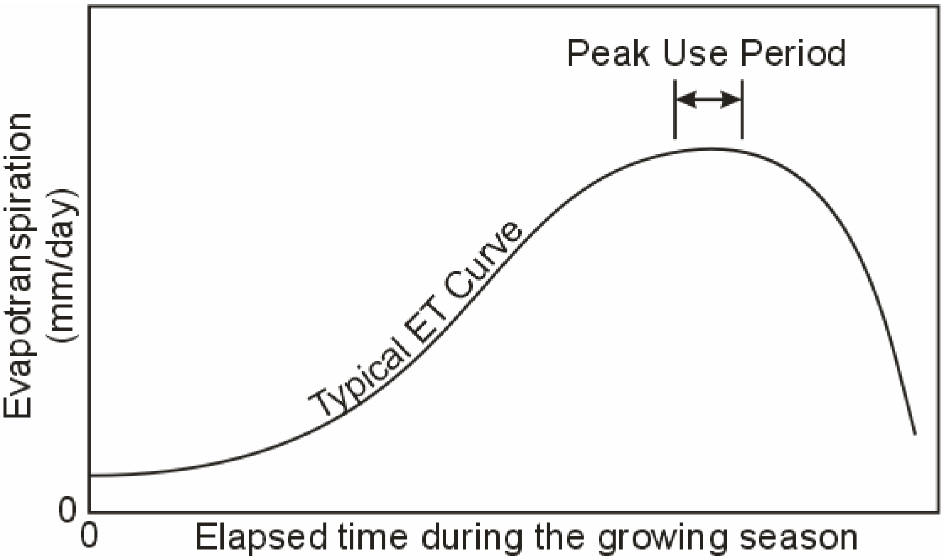
- The range of f_x values for agricultural crops is usually:

$$0.25 < f_x < 80 \text{ days} \tag{3}$$

- Then *nominal* irrigation frequency, f', is the value of f_x rounded down to the nearest whole number of days (
- But, it can be all right to round up if the values are conservative and if f_x is near the next highest integer value
- f' could be fractional if the sprinkler system is automated
- f' can be further reduced to account for nonirrigation days (e.g. Sundays), whereby $f \leq f'$
- The net application depth per irrigation during the peak use period is $d_n = f'U_d$, which will be less than or equal to d_x. Thus, $d_n <= d_x$, and when $d_n = d_x$, f' becomes f_x (the maximum allowable interval during the peak use period).
- Calculating d_n in this way, it is assumed that U_d persists for f' days, which may result in an overestimation if f' represents a period spanning many days

III. Peak Use Period

- Irrigation system design is usually for the most demanding conditions:



- The value of ET during the peak use period depends on the crop type and on the weather. Thus, the ET can be different from year to year for the same crop type.
- Some crops may have peak ET at the beginning of the season due to land preparation requirements, but these crops are normally irrigated by surface systems.
- When a system is to irrigate different crops (in the same or different seasons), the crop with the highest peak ET should be used to determine system capacity.
- Consider design probabilities for ET during the peak use period, because peak ET for the same crop and location will vary from year-to-year due to weather variations.

- Consider *deficit irrigation*, which may be feasible when water is very scarce and or expensive (relative to the crop value). However, in many cases farmers are not interested in practicing deficit irrigation.

IV. Leaching Requirement

- Leaching may be necessary if annual rains are not enough to flush the root zone, or if deep percolation from irrigation is small (i.e. good application uniformity and or efficiency).
- If EC_w is low, it may not be necessary to consider leaching in the design (system capacity).
- Design equation for leaching:

$$LR = \frac{EC_w}{5EC_e - EC_w} \tag{4}$$

where LR is the leaching requirement; EC_w is the EC of the irrigation water (dS/m or mmho/cm); and EC_e is the estimated saturation extract EC of the soil root zone for a given yield reduction value

- Equation 4 is taken from FAO Irrigation and Drainage Paper 29
- When LR > 0.1, the leaching ratio increases the depth to apply by 1/(1-LR); otherwise, LR does not need to be considered in calculating the gross depth to apply per irrigation, nor in calculating system capacity:

$$LR \le 0.1: \quad d = \frac{d_n}{E_a} \tag{5}$$

$$LR > 0.1 \qquad d = \frac{0.9\,d_n}{(1-LR)E_a} \tag{6}$$

- When LR < 0.0 (a negative value) the irrigation water is too salty, and the crop would either die or suffer severely
- Standard salinity vs. crop yield relationships (e.g. FAO) are given for electrical conductivity as saturation extract
- Obtain saturation extract by adding pure water in lab until the soil is saturated, then measure the electrical conductivity
- Here are some useful conversions: 1 mmho/cm = 1 dS/m = 550 to 800 mg/l (depending on chemical makeup, but typically taken as 640 to 690). And, it can usually be assumed that 1 mg/l ≈ 1 ppm, where ppm is by weight (or mass).

V. Leaching Requirement Example

Suppose EC_w = 2.1 mmhos/cm (2.1 dS/m) and EC_e for 10% reduction in crop yield is 2.5 dS/m. Then,

$$LR = \frac{EC_w}{5EC_e - EC_w} = \frac{2.1}{5(2.5) - 2.1} = 0.20 \tag{7}$$

Thus, LR > 0.1. And, assuming no loss of water due to application nonuniformity, the gross application depth is related to the net depth as follows:

$$d = d_n + (LR)d = \frac{d_n}{1 - LR} \tag{8}$$

and,

$$d = \frac{d_n}{1 - 0.20} = 1.25\, d_n \tag{9}$$

See Eq. 5.3 from the textbook regarding nonuniformity losses.

Sprinkle Irrigation Planning Factors

I. Farm Systems vs. Field Systems

- The authors of the textbook only devote a few paragraphs to this topic, but it is one of great importance
- A complete understanding of the distinctions between farm and field systems comes only through years of experience
- Variability in design, operation and management conditions is limitless

> *“A poorly designed system that is well managed can often perform better than a well designed system that is poorly managed”*

- Farm systems may have many field systems
- Planning considerations should include the possibility of future expansions and extra capacity
- Permanent buried mainlines should generally be oversized to allow for future needs -- it is much cheaper to put a larger pipe in at the beginning than to install a secondary or larger line later
- Consider the possibility of future automation
- Consider the needs for land leveling before burying pipes
- How will the system be coordinated over many fields?

- What if the cropping patterns change? (tolerance to salinity, tolerance to foliar wetting, peak ET rate, root depth, need for crop cooling or frost protection, temporal shifting of peak ET period)
- What if energy costs change?
- What if labor availability and or cost change?
- What if the water supply is changed (e.g. from river to groundwater, or from old well to new well)?
- What if new areas will be brought into production?

II. Outline of Sprinkler Design Procedure

1. Make an inventory of resources

   - visit the field site personally if at all possible, and talk with the farmer
   - get data on soil, topography, water supply, crops, farm schedules, climate, energy, etc.
   - be suspicious of parameter values and check whether they are within reasonable ranges

2. Calculate a preliminary value for the maximum net irrigation depth, d_x
3. Obtain values for peak ET rate, U_d, and cumulative seasonal ET, U (Table 3.3)
4. Calculate maximum irrigation frequency, f_x, and nominal frequency, f'

   - this step is unnecessary for automated fixed systems and center pivots

5. Calculate the required system capacity, Q_s

   - first, calculate gross application depth, d
   - for center pivots use $d/f = U_d$, and $T \approx 90\%$ of 24 hrs/day = 21.6

6. Determine the "optimum" (or maximum) water application rate

   - a function of soil type and ground slope (Table 5.4)

7. Consider different types of feasible sprinkle systems
8. For periodic-move and fixed (solid-set) systems:

   (a) determine S_e, q_a, nozzle size, and P for optimum application rate (Tables 6.4 to 6.7)
   (b) determine number of sprinklers to operate simultaneously to meet Q_s ($N_n = Q_s/q_a$) (Chapter 7)
   (c) decide upon the best layout of laterals and mainline (Chapter 7)
   (d) Adjust f, d, and/or Q_s to meet layout conditions
   (e) Size the lateral pipes (Chapter 9)
   (f) Calculate the maximum pressure required for individual laterals
9. Calculate the mainline pipe size(s), then select from available sizes
10. Adjust mainline pipe sizes according to the "economic pipe selection method" (Chapter 10)

11. Determine extreme operating pressure and discharge conditions (Chapter 11)
12. Select the pump and power unit (Chapter 12)
13. Draw up system plans and make a list of items with suggestions for operation

III. Summary

- Note that MAD is not a precise value; actual precision is less than two significant digits; this justifies some imprecision in other values (don't try to obtain very precise values for some parameters when others are only rough estimates)
- Why use **f** to determine Q_s but **f'** to determine net application depth? (because Q_s must be based on gross requirements; not irrigating 24 hrs/day and 7 days/week does not mean that the crop will not transpire water 7 days/week)
- When determining the seasonal water requirements we subtract P_e from U. However, to be safe, the value of P_e must be reliable and consistent from year to year, otherwise a smaller (or zero) value should be used.
- Note that lateral and sprinkler spacings are not infinitely adjustable: they come in standard dimensions from which designers must choose. The same goes for pipe diameters and lengths.
- Note that design for peak U_d may not be appropriate if sprinklers are used only to germinate seeds (when later irrigation is by a surface method).

IV. Example Calculations for a Periodic-Move System

Given:

Crop is alfalfa. Top soil is 1.0 m of silt loam, and subsoil is 1.8 m of clay loam. Field area is 35 ha. MAD is 50% and EC_w is 2.0 dS/m. Application efficiency is estimated at 80%, and the soil intake rate is 15 mm/hr. Lateral spacing is 15 m and lateral length is 400 m. Assume it takes ½ hour to change sets. Seasonal effective rainfall is 190 mm; climate is hot. Assume one day off per week (irrigate only 6 days/week).

From tables in the textbook:

Hot climate, table 3.3 gives............U_d = 7.6 mm/day, and U = 914 mm/season
Top soil, table 3.1 gives ....W_a = 167 mm/m
Sub soil, table 3.1 gives ....W_a = 183 mm/m
Root depth, table 3.2 gives ....Z = (1.2 + 1.8)/2 = 1.5 m
Salinity for 10% yield reduction, table 3.5 gives........................EC_e = 3.4 dS/m

1. Average water holding capacity in root zone:

top soil is 1.0 m deep; root zone is 1.5 m deep...

$$W_a = \frac{1.0(167) + (1.5 - 1.0)(183)}{1.5} = 172.3 \text{ mm/m} \tag{10}$$

2. Max net application depth (Eq. 3.1):

$$d_x = \frac{MAD}{100} W_a Z = \left(\frac{50}{100}\right)(172.3)(1.5) = 129.2 \text{ mm} \tag{11}$$

3. Maximum irrigation interval (Eq. 3.2):

$$f_x = \frac{d_x}{U_d} = \frac{129.2 \text{ mm}}{7.6 \text{ mm/day}} = 17.0 \text{ days} \tag{12}$$

4. Nominal irrigation interval (round down, or truncate):

$$f' = \text{trunc}(f_x) = 17 \text{ days} \tag{13}$$

5. Net application depth:

$$d_n = f' U_d = (17 \text{ days})(7.6 \text{ mm/day}) = 129.2 \text{ mm} \tag{14}$$

6. Operating time for an irrigation:

> 17 days is just over two weeks, and depending on which day is off, there could be 3 off days in this period. So, with one day off per week, we will design the system capacity to finish in 17 - 3 = 14 days. Thus, f = 14 days. But, remember that we still have to apply 17 days worth of water in these 14 days (we irrigate 6 days/week but crop transpires 7 days/week)

7. Leaching requirement (Eq. 3.3):

$$LR = \frac{EC_w}{5EC_e - EC_w} = \frac{2.0}{5(3.4) - 2.0} = 0.13 \tag{15}$$

> LR > 0.1; therefore, use Eq. 5.3 b...

8. Gross application depth (Eq. 5.3b):

$$d = \frac{0.9 d_n}{(1 - LR)(E_a / 100)} = \frac{0.9(129.2)}{(1 - 0.13)(0.8)} = 167.1 \text{ mm} \tag{16}$$

9. Nominal set operating time:

With 167.1 mm to apply and a soil intake rate of 15 mm/hr, this gives 11.14 hrs minimum set time (so as not to exceed soil intake rate). Then, we can make the nominal set time equal to 11.5 hours for convenience. With 0.5 hrs to move each set, there are a total of 12.0 hrs/set, and the farmer can change at 0600 and 1800 (for example).

At this point we could take the lateral spacing, S_l, sprinkler spacing, S_e, and actual application rate to determine the flow rate required per sprinkler.

10. Sets per day:

From the above, we can see that there would be two sets/day.

11. Number of sets per irrigation:

(14 days/irrigation)(2 sets/day) = 28 sets

12. Area per lateral per irrigation:

Lateral spacing on mainline is S_l = 15 m. Lateral length is 400 m. Then, the area per lateral is:

(15 m/set)(28 sets)(400 m/lateral) = 16.8 ha/lateral

13. Number of laterals needed:

$$\frac{35\text{ ha}}{16.8\text{ ha/lateral}} = 2.08\text{ laterals} \tag{17}$$

Normally we would round up to the nearest integer, but because this is so close to 2.0 we will use two laterals in this design.

14. Number of irrigations per season:

$$\frac{U - P_e}{d_n} = \frac{914\text{ mm - }190\text{ mm}}{129.2\text{ mm/irrig}} = 5.6\text{ irrigations} \tag{18}$$

Thus, it seems there would be approximately six irrigations in a season. But, the initial R_z value is less than 1.5 m, so there may actually be more than six irrigations.

15. System flow capacity (Eq. 5.4):

with 11.5 hours operating time per set and two sets per day, the system runs 23 hrs/day...

$$Q_s = 2.78\frac{Ad}{fT} = 2.78\frac{(35\text{ ha})(167.1\text{ mm})}{(14\text{ days})(23\text{ hrs/day})} = 50.5\text{ lps (800 gpm)} \tag{19}$$

This is assuming no effective precipitation during the peak ET period.