

Lecture 13

Center Pivot Nozzling

I. Center Pivot Nozzling

- The wetted width of the application package can be reduced closer to the pivot point because the towers are moving at a slower speed at inner points; therefore, the application intensity (AR) is less ($q_r \propto r$)
- Generally, if spray booms are required near the end of the center pivot, spray drops can be used toward the center, and the spray drops nearest the pivot point will produce something like a fine mist
- At the far end of the lateral the application may be more like a torrential rain
- Generally, impact and spray sprinklers would not be mixed on a center pivot because the pressure requirements are substantially different
- The minimum wetted width at any radius r along the pivot (for an elliptical pattern) can be calculated as:

$$w_r = \frac{8rU_d}{60TAR_x DE_{pa}} \quad (274)$$

where AR_x is the maximum permissible application rate (mm/min) according to limits imposed by the soil, slope, and vegetative cover; U_d is in mm/day; T is in hrs/day; and DE_{pa} is expressed as a fraction

- Note that w_r approaches zero for $r \rightarrow 0$
- A suitable application device can then be selected for radius r such that the wetted diameter of the device, w_d , is greater or equal to w_r ($w_d \geq w_r$)
- The actual application rate (mm/min) at radius r at the ground using a device with wetted diameter w_d should be:

$$AR_r \leq \frac{rU_d R_e O_e}{7.5T w_d} \quad (275)$$

- The term " $R_e O_e$ " is included in the above equation to account for evaporation and wind drift losses, and pipe leakage
- Note that $60/8 = 7.5$ and that we are using $f = 1$ day
- Divide by R_e in the above equation to obtain AR at the nozzle
- The wetting time at any radius r (assuming an elliptical pattern) along the lateral is:

$$(t_t)_r = \frac{4D_f}{\pi AR_r} \quad (276)$$

where D_f is the total cumulative application ($d R_e O_e$)

II. Center Pivot Nozzling Example

Given:

- $U_d = 8$ mm/day
- $P_e = 0$ mm/day
- $T = 22$ hrs/day
- $Q_s = 73.6$ lps
- $R = 400$ m
- Speed = 21.6 hrs/revolution
- $AR_x = 2.3$ mm/min (allowable)
- $k_f = 1.02$
- $DE_{pa} = 0.74$
- $R_e = 0.94$
- $O_e = 0.99$

Calculations:

- Calculate U_d' :

$$U_d' = \frac{k_f (U_d - P_e)}{DE_{pa}} = \frac{1.02(8 - 0)}{0.74} = 11.0 \text{ mm/day} \quad (277)$$

- Tangential speed of the pivot at distance “r” along the lateral:

$$S_r = \frac{2\pi r}{t} \quad (278)$$

where S_r is the speed in m/min; t is the minutes per full-circle revolution; and r is the radius from the pivot point in m

- The wetting time is, then:

$$\tau = \frac{w_r}{S_r} \quad (279)$$

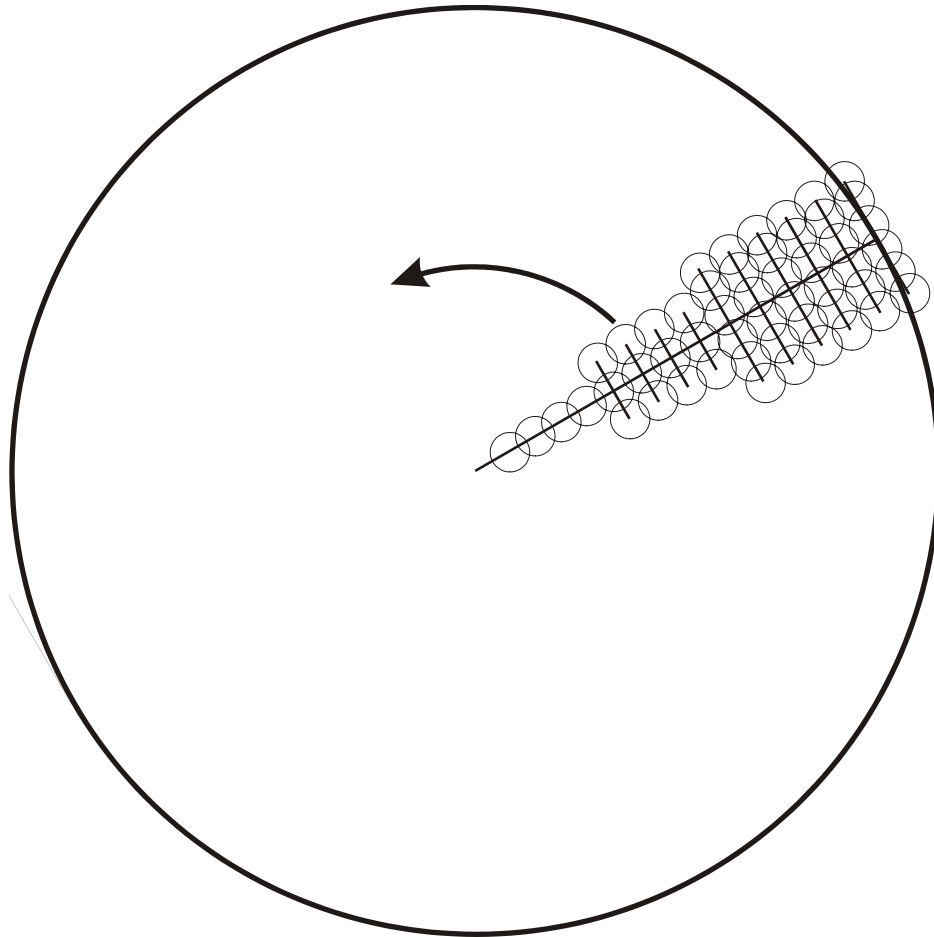
where τ is wetting time in minutes; and w_r is the minimum wetted width in m.

- The values of w_d can be selected from available boom lengths, which in this case is 6, 8, 10, and 12 m. For less than 4-m width, no boom is required. Select w_d values such that AR_x is not exceeded.

- Spreadsheet calculations:

r (m)	q (lps/m)	w _r (m)	w _d (m)	AR _r (mm/min)	tau (s)	Q _r (lps)
0	0.0000					73.6
40	0.0368	1.14	3	0.829	928	72.9
80	0.0736	2.28	3	1.658	464	70.7
120	0.1104	3.42	6	1.244	619	67.0
160	0.1472	4.56	6	1.658	464	61.8
200	0.1840	5.70	6	2.073	371	55.2
240	0.2208	6.84	8	1.866	413	47.1
280	0.2576	7.98	8	2.177	354	37.5
320	0.2944	9.12	10	1.990	387	26.5
360	0.3312	10.26	10	2.239	344	14.0
400	0.3680	11.39	12	2.073	371	0.0

- Notes about the variables:
 - “q” is the sprinkler discharge per unit length of lateral at r
 - “w_r” is the minimum wetted width at r
 - “w_d” is the actual (selected) wetted width at r
 - “AR_r” is the actual application rate at r
 - “wetting” is the wetting time at a given location
 - Q_r is the flow rate in the lateral pipe at a given location
- Most manufacturers prefer to specify the actual nozzle sizing and spacing along center pivots at the factory (rather than have the buyer specify these) for reasons of liability (they have specialized computer programs which attempt to maximize uniformity)
- Therefore, the designer will generally only specify the flow rate, pressure, and type of nozzle (spray drop, booms, impacts, etc.), and the manufacturer will specify individual nozzle sizes
- The following figure shows a center pivot with booms (the booms are greatly exaggerated in width to show the concept)

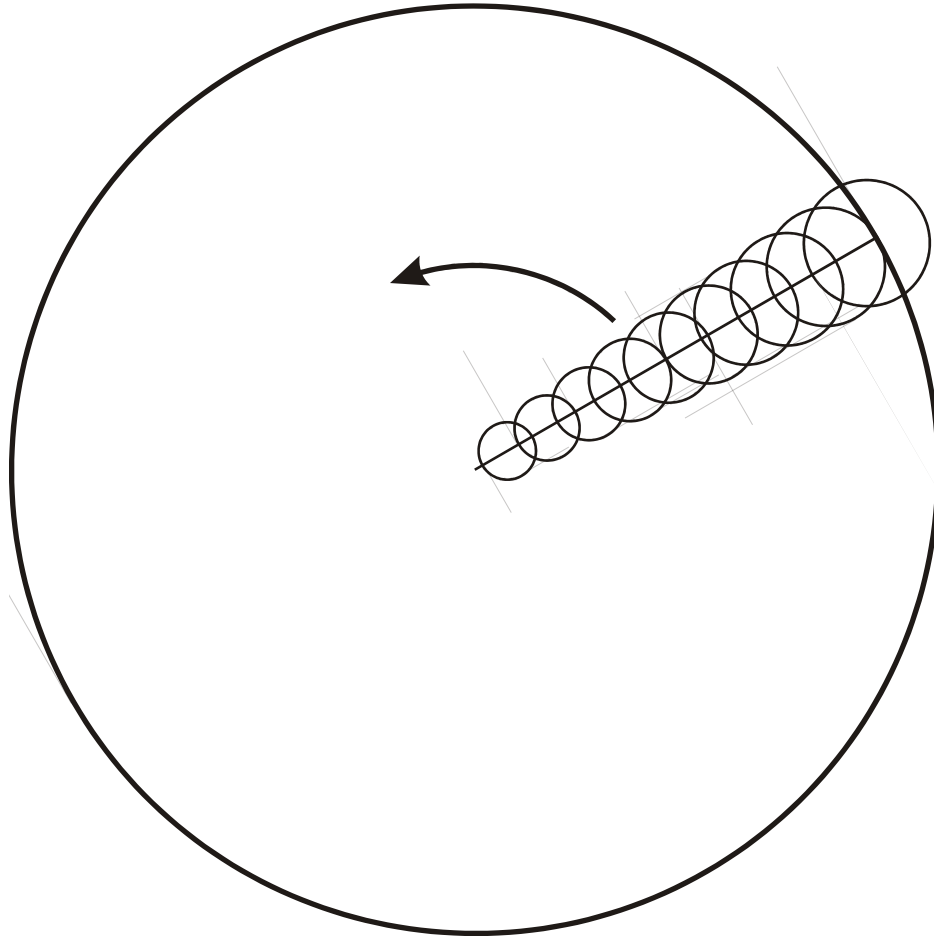


III. Sprinkler/Nozzle Configurations

- Because the required discharge per unit of lateral is linearly proportional to the distance along the lateral, discharge rates of sprinklers (or the sprinkler spacing) need to be varied to match this linear variation in flow rate
- Various configurations of locating sprinklers along a center pivot lateral are used

1. Uniform Sprinkler Spacing

- q_a of nozzles increases with r
- Large heads are required near the end of the lateral
- A large w (due to large heads) results near the end which is good, but large drop sizes may cause soil surface sealing and infiltration reduction
- The next figure shows a center pivot lateral with uniform sprinkler spacing and increasing w values toward the downstream end of the lateral

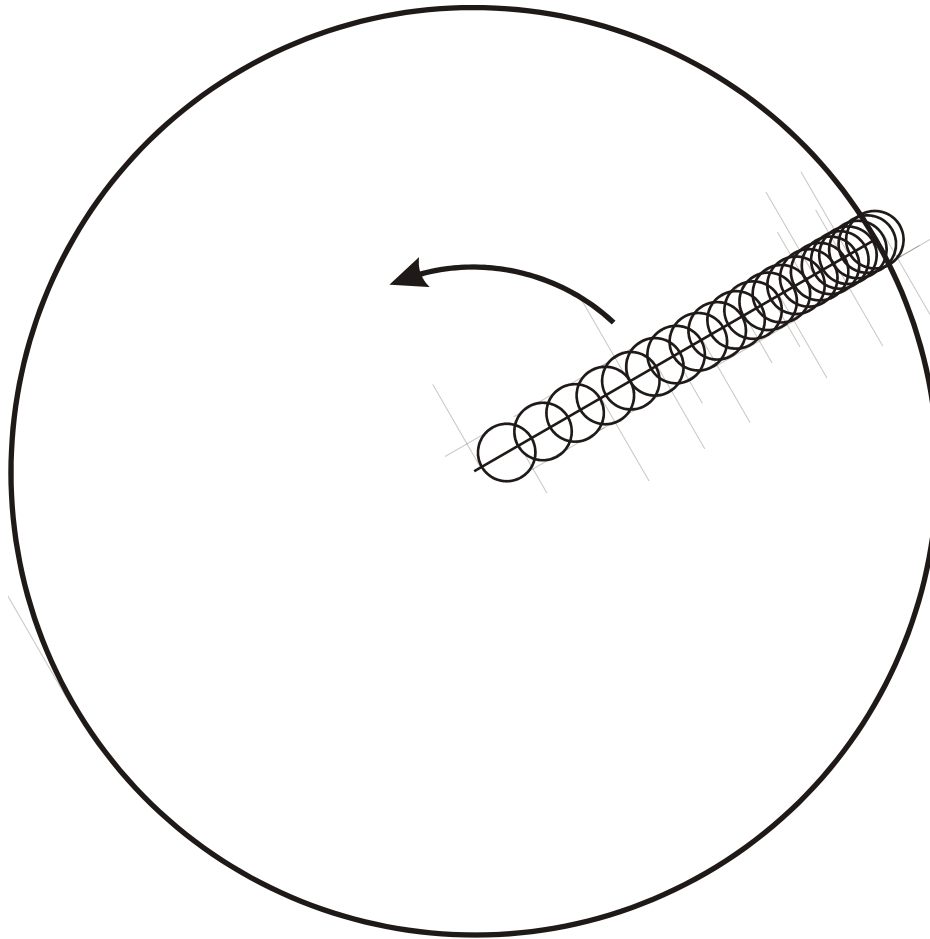


2. **Uniform Sprinkler Size** where the distance between sprinklers decreases with r

- Sprinkler density is higher near the downstream end of the lateral
- May allow the use of small nozzles with lower pressures and less soil sealing
- The value of w is smaller, so the soil must support a higher application rate
- See the following figure

3. **Combination of 1 and 2**

- This is the most common configuration because it is easier to match the required q/m of the lateral
- Smaller drop size
- Intermediate wetted width, w
- May have uniform spacing of outlets on lateral spans, but unused outlets are plugged (w/o any sprinkler), so pipes in each span are identical and interchangeable



Sizing Individual Nozzles:

1. Determine q for each spacing along the lateral (see Eq. 14.20a):

$$q_r = r S_r \frac{2Q_s}{R^2} \quad (280)$$

where R is the maximum effective radius of the center pivot (approximately equal to $L + 0.4w$); S_r is the sprinkler spacing at a distance r from the pivot point; and r , S_r and R have the same units (m or ft)

2. Beginning at the design pressure at the end of the lateral, L (where q is known), determine P_r :

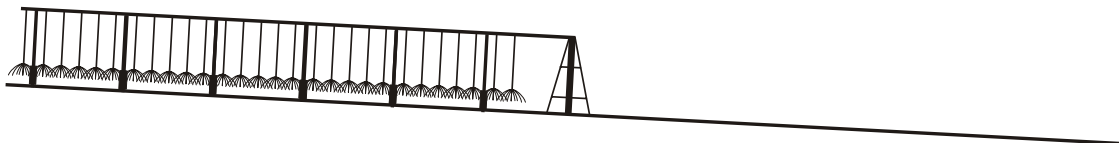
$$P_r = (P_a)_{\text{end}} + (h_{fr})_{\text{end}} + (\Delta H_e)_{\text{end-r}} \quad (281)$$

where $(h_{fr})_{\text{end}}$ is the friction loss from point r to the far (downstream) end of the lateral. Note that $(\Delta H_e)_{\text{end-r}}$ often averages out to zero as the pivot makes its way around the circle, if the field slope is uniform (see the next figure).

3. Select the best nozzle size to provide q_r at a pressure of P_r
4. Return to Step 1 and repeat for the next r - S_r location
5. The required pressure at the pivot point is $P_r = 0$



no slope



uniform slope



centered on a hill



centered on a depression

IV. Trajectory Angles of Impact Sprinklers

- For center pivots, sprinklers with 6° to 18° trajectory angles (low angle) are preferred because drift losses are minimized (see Table 14.3 in the textbook)
- Other things being the same, wind drift and evaporation losses can be higher with center pivots than with other types of sprinkler systems because of the relative height of the sprinklers above the ground
- But, you can use drop-down sprayers on a “goose-neck” pipe – some of these may be only a few centimeters from the mature crop canopy

V. End Guns

- The discharge for an end gun can be computed as (see Eq. 14.21):

$$Q_g = \frac{\left(\frac{2S_r Q \left(L + \frac{S_r}{2} \right)}{R^2} \right)}{0.93} \quad (282)$$

where L is the lateral length; R is the effective length of the pivot ($R = L + S_r$); Q_g is the end gun discharge; Q is the total center pivot flow rate (includes Q_g); S_r is $R - L$, which equals the effective wetted radius (or 75% of the gun radius)

- The above equation is essentially Eq. 14.20a with $r = L + S_r/2$
- The 0.93 factor (taken as O_e) is to account for ineffective discharge beyond 75% of the gun's wetted width, w (see page 349 of the textbook)
- Also, Q_g can be approximated as:

$$Q_g \approx Q \left(1 - \frac{L^2}{R^2} \right) \quad (283)$$

where Q includes Q_g and $R = L + S_r$

- Note that you can derive this last equation by substituting $R - L$ for S_r in the previous equation as follows:

$$\begin{aligned} \frac{2(R-L)Q[L + 0.5(R-L)]}{0.93R^2} &= \\ \frac{2QL(R-L) + Q(R-L)^2}{0.93R^2} & \quad (284) \\ &= \frac{Q}{0.93} \left(1 - \frac{L^2}{R^2} \right) \end{aligned}$$

where the only difference is the 0.93 in the denominator

- A *part circle* rotation (typically about 150°) is generally used to achieve best uniformity under the area covered by the gun sprinkler, which is beyond the end of the lateral pipe
- If the rotation of the end gun covered 180° or more, it might make it too muddy for the wheels of the end tower – so with 150° (or so) the path in front of the end tower stays relatively dry

Booster Pump

- If an end gun is used primarily on corners, and if $Q_g > 0.2Q$, then a booster pump in parallel or series may be necessary
- Without a booster, when the gun is turned on (at the corner), the pressure along the lateral will drop, and individual sprinkler flow rates will be approximately $q[Q/(Q+Q_g)]$
- An alternative to a booster pump is to automatically decrease the center pivot speed at the corners: $S_{\text{corner}} = S[Q/(Q+Q_g)]$, where S is the speed in all places except the corners. That is, turn the gun on in the corners without any booster pump. This can help provide for equivalent, more nearly uniform application in all parts of the field (friction losses will be greater when the gun is operating; therefore, uniformity will not be perfect)
- If the end gun requires higher pressure than the nozzles along the center pivot lateral, then an electric-motor-driven booster pump may be mounted on the last tower, upstream of the end gun. This pump will increase the pressure to the end gun only. All other nozzles will be operated at lower pressure.



Center Pivot Hydraulic Analysis

I. Center Pivot Hydraulics

- The total discharge in the lateral pipe (not the flow rate from sprinklers at r) at any point r is approximately:

$$Q_r = Q_s \left(1 - \frac{r^2}{R^2} \right) \quad (285)$$

where Q_s is total system capacity (possibly including an end gun); r is measured radially from the pivot point; and R includes S_r

Friction Loss

- (1) For a center pivot without an end gun:

$$h_f = k_h F_p L \left(\frac{Q}{C} \right)^{1.852} D^{-4.87} \quad (286)$$

where k_h is 10.50 for h_f and L in ft, Q in gpm, and D in inches; k_h is $16.42(10)^4$ for h_f and L in m, Q in lps, and D in cm

- F_p is the multiple outlet friction factor for a center pivot (see Fig. 14.12)
- $F_p = 0.555$ for a center pivot with a “large” number of outlets and no end gun when using the Hazen-Williams equation.
- Other sources suggest using $F_p = 0.543$
- The value of C is about 130 for galvanized steel, or 145 for epoxy-coated steel

(2) For a center pivot with an end gun:

Compute friction loss as though the center pivot were R m long rather than L , and then subtract the non-existent friction past the point L , where R is the effective (wetted) radius and L is the physical length of the lateral pipe.

A traditional way to consider the effects of an end gun on friction loss is:

$$h_f = k_h F_p R \left(\frac{Q}{C} \right)^{1.852} D^{-4.87} - k_h F_g (R - L) \left(\frac{Q_g}{C} \right)^{1.852} D^{-4.87} \quad (287)$$

where Q is the total flow rate of the pivot plus the end gun; and Q_g is the flow rate of the end gun

- F_g should represent F_p for the distance $R - L$
- Base this on the bottom of page 355 of the textbook, where the number of outlets is $(R - L)/S_e$, where S_e is the sprinkler spacing on the last (downstream) span
- This F_g value will be conservative (it will underestimate the imaginary friction loss, therefore, will overestimate the total friction in the pivot lateral), because F_g will be greater than that stated
- Note that, near the end gun, the change in Q with distance is small; therefore, the value of F_g will usually be near unity
- A different method for calculating friction loss is suggested in the textbook (Eq. 14.26a)
- This may be a better method than that given above

Dual Pipe Sizes

- A center pivot may be assembled with dual pipe sizes (8- and 6-inch pipe, or 8- and 6 5/8-inch, for example)

- One requirement to note is that the tower spacing must be closer for the 8-inch pipe due to the added weight of water in the 8-inch pipe, and traction problems from towers which are too heavy and sink into the soil
- Therefore, balance the savings in h_f with added cost for the system
- Tower spacing is often 100 ft (30 m) for 8-inch pipe, and 150 ft (45 m) for 6-inch pipe
- Weight per tower = Wt of tower + Wt of 1 span (steel) + Wt of water in the span

Pressure Balance Equation

$$H_l = H_a + h_f + \Delta H_e + H_r + H_{\text{minor}} \quad (288)$$

where H_l is the pressure head required at ground level, at the pivot point; H_a is the pressure head requirement of the last nozzle (or end gun); h_f is the total friction loss along the pivot lateral; ΔH_e is the elevation increase between the pivot point and lateral end; H_r is the height of the lateral pipe less the vertical length of any drop tubes; and H_{minor} is the sum of all minor losses along the lateral

- H_a is, then, the pressure head requirement of the last nozzle
- If end guns require higher pressure than the nozzles along the lateral, then an electric booster pump can be installed at the last tower on the pivot
- See Chapter 14 of the textbook for the hydraulic effect of turning end guns or corner systems on and off, and for additional elevation effects

II. An Alternative Method for Determining H_f and H_l

- An alternative method to compute the exact value of H_l is to start at the pivot end and progress toward the pivot, adding friction losses
- This is a "stepwise" computational procedure, and is generally more accurate than using the $JF_p L$ equations
- Friction loss, h_f , in pipe segments between nozzles on the pivot can be computed using the Hazen-Williams or Darcy-Weisbach equations with $F_p = 1$
- In this case, include ΔH_e if H_{end} is the minimum pressure head at the highest elevation position of the lateral

$$H_l = H_{\text{end}} + \sum_{i=0}^n \left[(h_{f_i} + \Delta H_{e_i}) + H_r + H_{\text{minor}} \right] \quad (289)$$

where H_{end} is the desired nozzle pressure head at the pivot end; i is the outlet number along the lateral ($i = 0$ at the end, and $i = n$ at the pivot point); n is the number of outlets (sprinklers) on the lateral; ΔH_{e_i} is the elevation

difference between two adjacent points (i and i+1) along the lateral; and h_{fi} is the friction loss between outlet i and i+1, where i+1 is upstream of i. This last term is defined as:

$$h_{fi} = \frac{J_i \Delta L_i}{100} \quad (290)$$

where,

$$J_i = 1.21(10)^{12} \left(\frac{Q_i}{C} \right)^{1.852} D_i^{-4.87} \quad (291)$$

with Q_i in lps and D_i in mm

and,

$$Q_i = \sum_{j=0}^i q_j \quad (292)$$

in which j is the outlet number (j = 0 at the downstream end of the lateral); and q_j is a function of h_j and K_d

- H_{minor} includes short hose connections between pipe segments (at towers)
- Therefore, actual computed h_j values should be used with the selected nominal nozzle size (or FCN size), where h_j is the pressure head at outlet j
- The desired q_j is:

$$q_j = r_j S_{r_j} \left(\frac{2Q}{R^2} \right) = r_j \Delta L_i \left(\frac{2Q}{R^2} \right) \quad (293)$$

where ΔL_i is the distance between outlet i and outlet i+1.

- ΔL_i is constant for constant spacing, variable nozzle size
- ΔL_i is variable for variable spacing, constant nozzle size

Point of "Average" Elevation

The point of "average" elevation along a lateral may be determined by weighting elevations according to areas as (Allen 1991):

$$H_{\text{ew}} = \int_{r=0}^L \int_{\alpha}^{2\pi} \frac{r(H_e)_{r,\alpha}}{2\pi L^2} dr d\alpha \quad (294)$$

where r is a weighting term; and $(H_e)_{r,\alpha}$ is the elevation at radius r and pivot rotation angle α .

- Use $\alpha = 0$ for the whole irrigated area
- Note that on uniform slopes, the weighted elevation, H_{ew} , equals $(H_e)_{pivot}$
- Note also that you probably won't have data for elevations in polar coordinates, so this equation may be rather "academic"
- See the textbook for additional equations which consider elevation effects

