B.C. SPRINKLER IRRIGATION MANUAL

Chapter 7

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LIMITATION OF LIABILITY AND USER'S RESPONSIBILITY

The primary purpose of this manual is to provide irrigation professionals and consultants with a methodology to properly design an agricultural irrigation system. This manual is also used as the reference material for the Irrigation Industry Association's agriculture sprinkler irrigation certification program.

While every effort has been made to ensure the accuracy and completeness of these materials, additional materials may be required to complete more advanced design for some systems. Advice of appropriate professionals and experts may assist in completing designs that are not adequately convered in this manual.

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7 CENTRE PIVOT SYSTEM DESIGN

Centre pivot systems have become more popular as a replacement for existing irrigation systems or for a new installation due to the lower operating costs and reduced labour. In the Province of British Columbia, it is more common to see part circle pivots than full circle units. This is due to the topography of the land and field shapes. Pivot systems travel while irrigating and therefore must apply sufficient water during a short application time, resulting in higher application rates. See section 3.3 for more information on centre pivot systems.

7.1 Application Rate

During each successive pass, a centre pivot system must apply an equal amount of water to the soil along the length of the pivot. To accomplish this, the outside radius of the pivot must apply as much water as is applied near the pivot point, but in a much shorter time period. Application rates at the end of the pivot are therefore much higher than near the pivot point.

For example, a centre pivot with a wetted radius of 1,320 ft is often used to irrigate a quarter section or 160 acres. The pivot will irrigate only 125 acres out of the 160 acre quarter section unless a corner system is used. Starting from the pivot point,

- The first 660 ft irrigates 31.4 acres
- The next 273 ft irrigates 31.4 acres
- The next 210 ft irrigates 31.4 acres
- The next 177 ft irrigates 31.4 acres

The last 177 ft of the pivot's wetted radius, which is only 13.4% of the total radius, must irrigate 25% of the area.

Figure 7.1 compares the application rate for two locations along the pivot lateral to the intake rate of the soil.

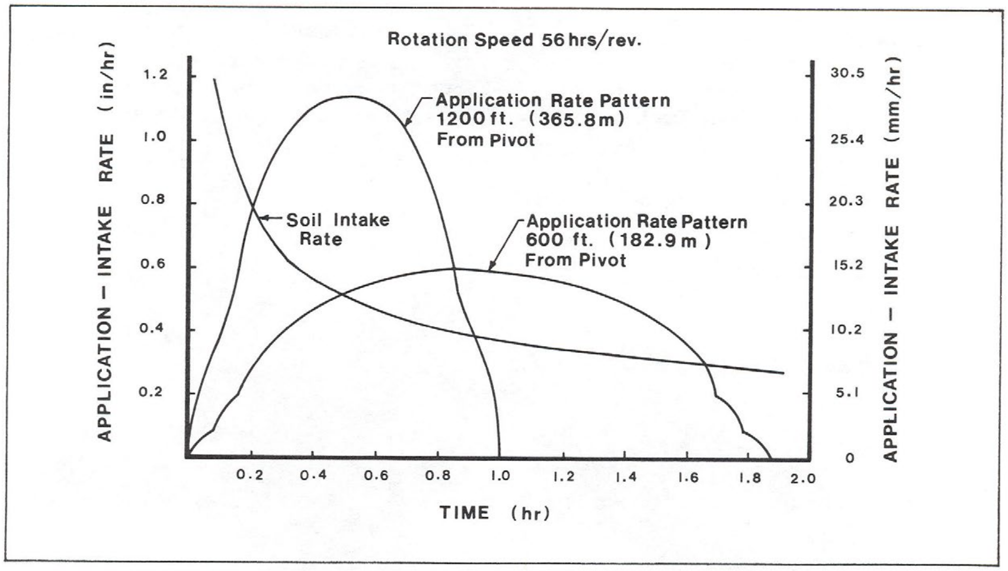

Figure 7.1 Centre Pivot Application and Soil Intake Rate Patterns

Source: Design and Operation of Irrigation Farm Systems. ASABE 2007

Where the system application rate exceeds the soil intake rate, puddling and runoff can occur. System design and sprinkler selection must take into account soil, crop, climate and application rate to achieve the best performance. The maximum application rate applied by a centre pivot system can be determined from Equation 7.1.

Equation 7. 1 Maximum Application Rate

$$PAR = \frac{122.5 \times Q}{R \times r}$$

where $R = L + r \times 0.75$

where	PAR =	Maximum application rate of centre pivot (in/hr)
	Q =	Centre pivot flow rate (US gpm)
	R =	Effective wetted radius of pivot (ft)
	r =	Wetted radius of the large sprinklers near the end of the pivot (ft)
	L =	Physical length of the pivot (ft)

The effective wetted radius of the centre pivot, R, is the nominal radius of the field that is to be irrigated. It is calculated using the distance from the centre point to the terminal sprinkler on the pivot, plus 75 percent of the wetted radius of that terminal sprinkler. It does not include the end gun. The maximum application rate can also be determined graphically from Figure 7.2.

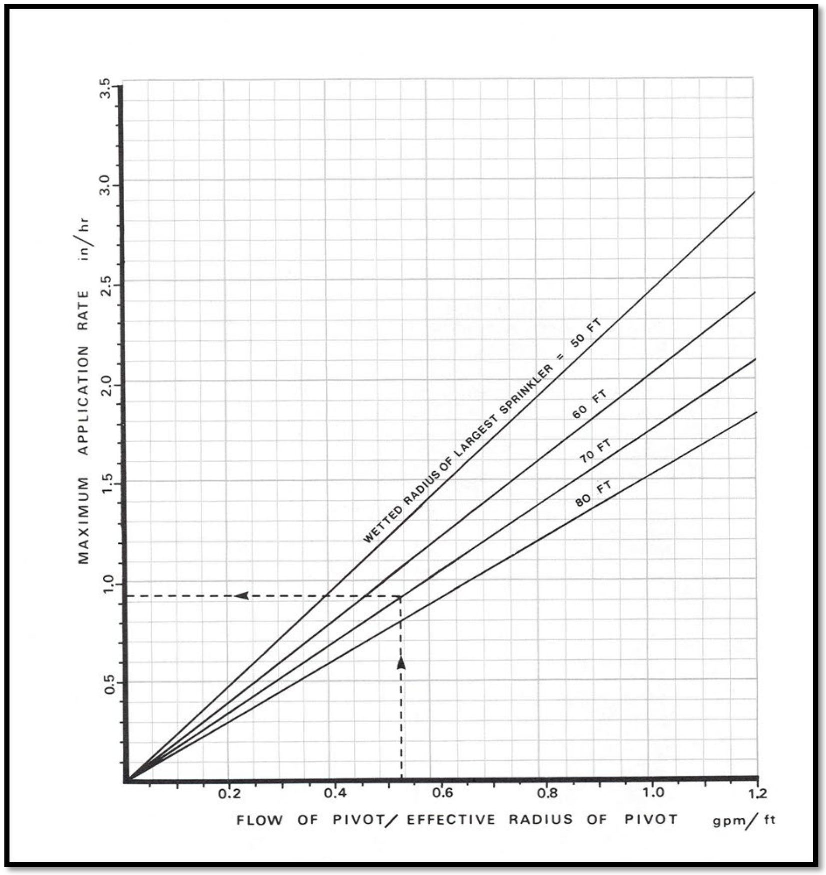

Figure 7.2 Determination of Maximum Application Rates for Centre Pivots

7.2 System Design

A systematic procedure for centre pivot design can be achieved by the following steps:

1. Determine the **effective wetted radius of coverage (R)** by dividing the shortest dimension of the field by two. The physical length of the pivot is often less than this due to the radius of throw of the terminal sprinkler on the pivot. This does not include the end gun.

2. Determine the **peak evapotranspiration** and **irrigation efficiency**. The peak evapotranspiration can be obtained from Table 4.5 or by actual climatic data for peak conditions. The irrigation efficiency will vary depending on the type of sprinklers used (Table 7.1).

Table 7.1 Pivot Application Efficiency	
Sprinkler Type	**Application Efficiency**
Overhead Impact	72%
Drop Spinner	78%
Drop Rotator	80%

3. Determine the **irrigated area**.

The irrigated area is calculated for the pivot lateral minus the end gun (Equation 7.2). The area is used to determine the pivot flow rate.

Equation 7.2 Irrigated Area (with No End Gun)

$$A = \frac{\prod R^2 \times P}{43{,}560}$$

where
- A = Area irrigated (acres)
- R = effective wetted radius of pivot (ft)
- P = Percentage of full circle irrigated (decimal)

4. Determine the **pivot flow rate** using Equation 7.3.

Equation 7.3 Pivot Flow Rate

$$Q = \frac{18.90 \times ET \times A}{AE}$$

where
- Q = Pivot flow rate (US gpm)
- ET = Peak Evapotranspiration (in/day)
- A = Area irrigated (acres)
- AE = application efficiency (decimal)

If the pivot has an end gun, the flow rate for the end gun needs to be calculated separately. To determine the end gun discharge, the flow rate is based on the extra radius covered for the entire arc of the pivot even if it only operates periodically. This is done so that the end gun application rate matches that of the pivot. If the end gun flow rate was only designed for the actual area covered, the application rate would be low and under watering would occur.

Equation 7.4 End Gun Flow Rate

$$Q_E = Q \times \frac{R_E^2 - R^2}{R^2}$$

where
Q_E = End gun flow rate (US gpm)
Q = Pivot flow rate (US gpm)
R_E = Pivot radius with end gun (ft)
R = Effective wetted radius of pivot (ft)

Source: Design and Operation of Farm Irrigation Systems

Warning – Pivot System Design

Much like a travelling gun system or a stationary gun system, care should be taken in designing a pivot system near electrical transmission lines. Many pivots have an end gun to increase the pivot coverage and the operator must be very careful that the gun stream does not contact the power line. High voltage power lines can arc over to an irrigation stream if sufficient stream break up has not occurred. Section 6.7 provides information on the minimum clearances between the gun jet stream and high voltage power lines that should be met for safety reasons.

5. Determine the **minimum travel design speed** of the centre pivot lateral at which potential runoff starts.

The duration of application is a critical factor in determining the minimum design speed. The maximum design application rates shown in Table 4.4 are based on set times exceeding four hours. Most soils permit a higher system application rate during the first one or two hours of application as compared to an eight or twelve hour set time. Table 7.2 can be used as a guide in determining an appropriate application rate for short duration applications.

Table 7.2 Maximum Application Rate Adjustment for Short Durations

Duration of Water Application [min] (T_m)	Multiplication Factor (F)
15	2.50
20	2.25
30	2.00
60	1.75
90	1.50
120	1.25

The minimum travel speed of the last tower is determined by Equation 7.5.

Equation 7.5 Minimum Travel Speed

$$S = \frac{2r}{T_m}$$

where S = Minimum travel speed of wetted area at the end of the pivot (ft/min)
r = Wetted radius of sprinklers near the end tower (ft), not end gun
T_m = Maximum duration of application (min)

The maximum duration of water application (T_m) is determined from Table 7.2. The multiplication factor (F) can be calculated by using Equation 7.6.

Equation 7.6 Multiplication Factor

$$F = \frac{PAR}{MAR}$$

where F = Multiplication factor
PAR = Maximum application rate of centre pivot (in/hr) - Equation 7.1
MAR = Maximum application rate accepted by the soil (in/hr) (Table 4.4)

6. Determine the **rotation speed (N)** of the pivot. This calculation of N will determine the maximum rotation speed (Equation 7.7). If the pivot moves any slower, then runoff may occur.

Equation 7.7 Rotation Speed

$$N = \frac{\Pi \, R}{30 \, S}$$

where N = Rotation speed of pivot (hr/rev)
R = Effective wetted radius of pivot (ft)
S = Minimum travel speed of wetted area at the end of the pivot (ft/min)

7. Determine the **gross water applied** (GWAr) by the pivot per revolution (Equation 7.8).

Equation 7.8 Gross Water Applied per Revolution

$$GWAr = \frac{Q \times N}{A \times 453}$$

where GWAr = Gross water applied per revolution (in)
Q = Centre pivot flow rate (US gpm)
N = Rotation speed of pivot (hr/rev)
A = Area irrigated (ac)

Table 7.3 can be used to determine the GWAr by a centre pivot system for a rotation time of 24 hours.

Table 7.3 Amount Applied per Day by Centre Pivot Systems (inches) (Rotation Time (N) = 24 hr)

Effective Radius (ft)	Area (ac)	Pivot Flow (gpm)										
		200	300	400	500	600	700	800	900	1000	1100	1200
200	2.9	3.67	5.52	–	–	–	–	–	–	–	–	–
300	6.5	1.63	2.45	3.27	4.09	4.90	5.72	–	–	–	–	–
400	11.5	0.92	1.38	1.84	2.30	2.75	3.22	3.68	4.14	4.60	5.06	5.52
500	18.0	0.59	0.88	1.18	1.47	1.76	2.06	2.35	2.65	2.94	3.24	3.53
600	26.0	0.41	0.62	0.82	1.02	1.23	1.43	1.63	1.84	2.04	2.25	2.45
700	35.3	0.30	0.45	0.60	0.75	0.90	1.05	1.20	1.35	1.50	1.65	1.80
800	46.2	0.23	0.34	0.46	0.57	0.69	0.80	0.92	1.03	1.15	1.26	1.38
900	58.4	0.18	0.27	0.36	0.45	0.54	0.64	0.73	0.82	0.91	1.00	1.09
1000	72.1	0.15	0.22	0.29	0.37	0.44	0.51	0.59	0.66	0.74	0.81	0.88
1100	87.3	0.12	0.18	0.24	0.30	0.36	0.43	0.49	0.55	0.61	0.67	0.73
1200	103.9	0.10	0.15	0.20	0.26	0.31	0.36	0.41	0.46	0.51	0.56	0.61
1300	121.9	0.09	0.13	0.17	0.22	0.26	0.30	0.35	0.39	0.44	0.48	0.52
1400	141.4	0.08	0.11	0.15	0.19	0.23	0.26	0.30	0.34	0.38	0.41	0.45
1500	162.3	0.07	0.10	0.13	0.16	0.20	0.23	0.26	0.29	0.33	0.36	0.39
1600	184.6	0.06	0.09	0.11	0.14	0.17	0.20	0.23	0.26	0.29	0.32	0.34

8. Calculate the net water applied as per equation 7.9.

Equation 7. 9 Net Water Applied (NWA)

$$NWA = GWAr \times AE$$

where NWA = Net water applied (in)
GWAr = Gross water applied per revolution (in)
AE = Application efficiency (decimal) - Table 7.1

Clarification – Center Pivot Design – Maximum Irrigation Interval

The maximum irrigation interval for a centre pivot is not calculated as the pivot is applying water daily to meet the peak evapotranspiration rate. Much like a drip irrigation system that replenishes the soil moisture daily to match the amount withdrawn by a crop, a centre pivot system operates the same way. The maximum irrigation interval is therefore only one day or slightly longer.

Using the design principles outlined in this manual, the net water applied (as calculated by equation 7.9) on a 24 hour basis will likely closely match the peak ET rate used in the design. If the net water applied is significantly less than the peak ET rate then the design should be re-evaluated.

Clarification – Center Pivot Design – Peak Flow Rate

The peak flow rate of a center pivot can be calculated two ways. If Equation 7.3 is used the center pivot system efficiency is incorporated into the calculation. For example 7.1 the flow rate using equation 7.3 is 466 gpm. An efficiency of 80% is used in the example. The information from Table 4.6 indicates a flow rate of 5.25 gpm/acre at a peak ET rate of 0.21 in/day. The 94 acres covered by the pivot would require a flow rate of 493 gpm. Since the efficiency used in the table is 72%, a higher flow is determined using this methodology.

Helpful Tips – Irrigation Design Parameters

The centre pivot irrigation design plan shown here is also provided in Appendix C with the corresponding design parameters shown on the adjacent page. The design parameter summary is useful for evaluating the irrigation system design and performance characteristics. This information should be included with every irrigation system plan.

Example 7.1 Centre Pivot Irrigation in Armstrong

Question: A farmer near Armstrong intends to grow alfalfa on a deep, sandy loam soil. The area to be irrigated will accommodate a pivot with an effective wetted radius of 1,320 ft. The pivot will operate over a three quarter circle. The end gun will operate in the corners only. For a centre pivot irrigation system, what flow rate, rotation speed, and amount of water applied will be required? Drop tube rotator sprinklers will be used in this application.

Information:

Farm location	*Armstrong*	1	
Maximum soil water deficit (MSWD) (Example 4.1)	*3*	2	in
Maximum application rate (Max AR) (Table 4.4)	*0.45*	3	in/hr
Peak evapotranspiration (ET) (Table 4.5)	*0.21*	4	in/day
Effective wetted radius (R) without end gun	*1,320*	5	ft
Effective wetted radius (R_E) with end gun	*1,440*	6	ft
Percentage of full circle irrigated (P)	*0.75*	7	
Application efficiency (AE)	*0.80*	8	

Answer:

1. Calculate the irrigated area for the pivot

Equation 7.2

$$A = \frac{\Pi R^2 \times P}{43560}$$

$$= \frac{3.14 \times (\ 1{,}320\ [5]\ \text{ft})^2 \times 0.75\ [7]}{43560}$$

$$= 94\ [9]\ \text{ac}$$

2. Calculate the system flow rate.

a). Calculate the pivot flow rate.

Equation 7.3

$$Q = \frac{18.90 \times ET \times A}{AE}$$

$$= \frac{18.90 \times 0.21\ [4]\ \text{in/d} \times 94\ [9]\ \text{ac}}{0.80\ [8]}$$

$$= 466\ [10]\ \text{gpm}$$

b). Calculate the end gun flow rate.

Equation 7.4

$$Q_E = Q \times \frac{R_E^2 - R^2}{R^2}$$

$$= 466\ [10]\ \text{US gpm} \times \frac{1{,}440\ [6]^2 - 1{,}320\ [5]^2}{1{,}320\ [5]^2}$$

$$= 88.6\ [11]\ \text{US gpm}$$

3. Determine the minimum design travel speed of the centre pivot lateral at which potential runoff starts.

a). Select sprinkler type.

Wetted radius of the largest sprinkler at the end of pivot (r) | *35* | **12** | ft

b). Calculate the maximum application rate applied by the pivot.

Equation 7.1

$$\text{PAR} = \frac{122.5 \times Q}{R \times r}$$

$$= \frac{122.5 \times \boxed{466}\ \boxed{10}\ \text{gpm}}{\boxed{1{,}320}\ \boxed{5}\ \text{ft} \times \boxed{35}\ \boxed{12}\ \text{ft}}$$

$$= \boxed{1.24}\ \boxed{13}\ \text{in/hr}$$

c). Calculate the maximum duration of application.

Equation 7.6

$$\text{F} = \frac{\text{PAR}}{\text{MAR}}$$

$$= \frac{\boxed{1.24}\ \boxed{13}\ \text{in/hr}}{\boxed{0.45}\ \boxed{3}\ \text{in/hr}}$$

$$= \boxed{2.75}\ \boxed{14}$$

With the F factor, duration of water application (T_m) (Table 7.2) | *15* | **15** | min

d). Calculate the minimum travel speed.

Equation 7.5

$$\text{S} = \frac{2r}{T_m}$$

$$= \frac{2 \times \boxed{35}\ \boxed{12}\ \text{ft}}{\boxed{15}\ \boxed{15}\ \text{min}}$$

$$= \boxed{4.7}\ \boxed{16}\ \text{ft/min}$$

4. Determine the rotation speed.

Equation 7.7

$$\text{N} = \frac{\Pi\ \text{R}}{30\ \text{S}}$$

$$= \frac{3.14 \times \boxed{1{,}320}\ \boxed{5}\ \text{ft}}{30 \times \boxed{4.7}\ \boxed{16}\ \text{ft/min}}$$

$$= \boxed{29.4}\ \boxed{17}\ \text{hr/rev}$$

5. Determine the maximum gross amount applied per revolution (GWA_R).

Equation 7.8

$$GWA_R = \frac{Q \times N}{A \times 453}$$

$$= \frac{466 \; \boxed{10} \text{ gpm} \times 29.4 \; \boxed{17} \text{ hr/rev}}{94 \; \boxed{9} \text{ ac} \times 453}$$

$$= 0.32 \; \boxed{18} \text{ in}$$

Equation 7.9

$$NWA = GWA_R \times AE$$

$$= 0.32 \; \boxed{18} \text{ in} \times 0.80 \; \boxed{8}$$

$= 0.26$ **19** Inch applied for a 29.4 **17** hr/rev

Comment:

The actual rotation speed of a centre pivot system should be determined by field measurements during operation. The design procedure given above is useful in determining whether the type of pivot selected can be made to match the crop and soil parameters that exist.

Helpful Tips – Centre Pivot Operation

Pivot operators often do not apply sufficient water to keep up with crop demand during the peak of the irrigation season. There are a few reasons for this.

First, for forage crops the pivot system is not operating while the crop is being cut, dried and removed from the field. Since the pivot is applying water that matches peak conditions it is difficult to gain on the water lost during the harvesting period if weather conditions are at peak.

Secondly the pivot is applying a relatively small amount of water during every revolution. The water applied does not have an opportunity to move down into the root zone during peak climatic conditions. The lower part of the soil profile can therefore dry out. Crops need moisture through their entire root zone to ensure that all of its roots can help support the crop's growth during peak conditions.

Thirdly, an operator could be fooled that there is plenty of moisture available to the crop as the soil surface may appear moist but there actually is very little moisture further down in the root zone.

Earlier in the season, when there is usually plenty of water available due to spring freshet, centre pivots should be operated to build up soil moisture to within 75% – 90% of field capacity. The pivots should then be operated on a schedule for the rest of the season that keeps the soil moisture at a level around 75% of field capacity. During harvest periods or should water shortages occur later in the season the soil storage that has been built up is then available to offset the potential shortfalls that may occur due to interruptions in pivot operation.

Figure 7.3

CENTRE PIVOT SYSTEM

SAMPLE SPRINKLER IRRIGATION PLAN

GENERAL FARM INFORMATION

• CROP	ALFALFA
• AREA IRRIGATED BY PIVOT (acres)	94.2
• AREA IRRIGATED BY END GUN (acres)	9
• TOTAL AREA IRRIGATED (acres)	103.2

PUMP SPECIFICATIONS

• HORSEPOWER (hp)	40
• FLOW RATE (US gpm)	555
• TOTAL DYNAMIC HEAD (feet)	197

PIVOT SPECIFICATIONS

• LENGTH OF PIVOT (feet)	1320
• MAXIMUM ROTATION SPEED (hrs/revolution)	32
• MINIMUM TRAVEL SPEED (feet/min.)	4.7
• PIVOT FLOW RATE (US gpm)	466
• END GUN FLOW RATE (US gpm)	89

LEGEND

PROPERTY LINE

ELEVATION

TREES AND BUSH

ROAD AND FARM LANE

BUILDINGS

MAINLINE

PIVOT WITH END GUN