Lecture 7: Irrigation Systems

Prepared by
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Surface Irrigation
Surface Irrigation

- Water flows across the soil surface to the point of infiltration
- Oldest irrigation method and most widely used world-wide (90%)
- Used primarily on agricultural or orchard crops

Types of Systems

- **Water Spreading or Wild Flooding**
  - Relatively flat fields -- allow water to find its own way across the surface
  - Minimal preparation and investment

- **Basin**
  - Dikes used to surround an area and allow for water ponding (no runoff)
  - Basins are usually level
Rice Field
Types of Systems, Contd…

- **Border**
  - Strips of land with dikes on the sides
  - Usually graded but with no cross slope
  - Downstream end may be diked

- **Furrow**
  - Small channels carry the water
  - Commonly used on row crops
  - Lateral as well as vertical infiltration
  - Furrows are usually graded
Water Supply

• Methods of water supply
  – Head ditch with siphon tubes or side-opening gates
  – Gated pipe (aluminum or plastic pipe with small gates that can be opened and closed)
  – Buried pipeline with periodically spaced valves at the surface

Water Management

• Runoff recovery systems
  – Drainage ditches for collecting and conveying runoff to the reservoir
  – Reservoir for storing the runoff water
  – Inlet facilities to the reservoir
  – Pump and power unit
  – Conveyance system for transporting water (to same or different field)
Runoff recovery systems
Surface Irrigation Hydraulics

• **Advance**: Movement of water from the inlet end to the downstream end.
  
  – Curve of Time vs. Distance is NOT linear
  
  – Rule-of-Thumb: 1/3 of the total advance time is needed to reach midpoint of the furrow length

• **Recession** (التوقيف/الركود): Process of water leaving the surface (through infiltration and/or runoff) after the inflow has been cut off
  
  – Usually begins to recede at the upstream end
  
  – Can also be plotted as Time vs. Distance
  
  – “Flatter" curve than the Advance Curve
Surface Irrigation Hydraulics, Cont’d

- **Infiltration**
  - Opportunity Time: difference between Recession and Advance curves
  - Infiltration Depth: a function of the opportunity time and the infiltration rate of the soil
Curve of Time Vs. Distance

Distance from inlet end (ft)

Advance and recession curves for surface irrigation.
Opportunity Time

Opportunity time for surface irrigation.
Infiltration vs. Opportunity Time

<table>
<thead>
<tr>
<th>Opportunity Time (h)</th>
<th>Infiltration (ln)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1.7</td>
</tr>
<tr>
<td>4</td>
<td>2.4</td>
</tr>
<tr>
<td>6</td>
<td>2.2</td>
</tr>
<tr>
<td>8</td>
<td>3.4</td>
</tr>
<tr>
<td>10</td>
<td>3.6</td>
</tr>
<tr>
<td>12</td>
<td>4.2</td>
</tr>
</tbody>
</table>

Infiltration vs. opportunity time.
Infiltration Profile

Distance from Inlet End (ft)

Infiltration profile.

\[ d_{LO} = 2.8 \text{ in} \]

Average depth in the Low Quarter

\[ d_Z = 3.6 \text{ in} \]
Uniformity

- Inherent non-uniformity because recession and advance curves are not parallel
- Factors affecting
  - Inflow rate
  - Slope
  - Soil infiltration
  - Roughness
  - Channel shape
  - Inflow time
  - Length of run
Efficiency

• Volume balance
  – $V_g = V_z + V_s + V_r$
  – $g \rightarrow$ gross
  – $z \rightarrow$ infiltration
  – $s \rightarrow$ surface storage
  – $r \rightarrow$ runoff

• (or depth basis): $d_g = d_z + d_s + d_r$

• Part of infiltration may go to deep percolation
Calculating $d_g$ (Gross Application Depth)

- **Single furrow:**
  \[
  d_g = 1155 \left( \frac{q_s t_{co}}{W L} \right)
  \]

- **Furrow set:**
  \[
  d_g = 1155 \left( \frac{Q t_{co}}{NWL} \right)
  \]

- **Basin/border:**
  \[
  d_g = 96.3 \left( \frac{Q t_{co}}{W_b L_b} \right)
  \]

$W =$ spacing between raw, $L =$ Length of raw, $N =$ number of raw, $W_b =$ basin width
Example:

For the furrow-irrigation field with a loam soil described in the attached figures. Determine the gross application depth, runoff depth and percentage of runoff. $Q_t = 760$ gpm, $L = 1200$ ft, $t = 12$ hours, 70 furrow watered per set, raw spacing 30 inches.

\[ d_g = 1155 \left( \frac{Q_t}{\text{NWL}} \right) \]

\[ d_g = 1155 \left( \frac{760 \times 12}{70 \times 30 \times 1200} \right) = 4.2 \text{ inch} \]

\[ d_g = d_z + d_s + d_r \]

\[ d_r = d_g - d_z - d_s = 4.2 - 3.6 - 0 = 0.6 \text{ inch} \]

Percent runoff = $0.6/4.2 = 14\%$
Average depth in the Low Quarter

Infiltration profile.
Micro-irrigation
Microirrigation

• Delivery of water at low flow rates through various types of water applicators by a distribution system located on the soil surface, beneath the surface, or suspended above the ground
• Water is applied as drops, tiny streams, or spray, through emitters, sprayers, or porous tubing

Water Application Characteristics

• Low rates
• Over long periods of time
• At frequent intervals
• Near or directly into the root zone
• At low pressure
• Usually maintain relatively high water content
• Used on higher value agricultural/horticultural crops and in landscapes and nurseries
**Advantages**

- High application efficiency
- High yield/quality
- Decreased energy requirements
- Reduced salinity hazard
- Adaptable for chemigation
- Reduced weed (الاعشاب الضارة) growth and disease problems
- Can be highly automated

**Disadvantages**

- High initial cost
- Maintenance requirements (emitter clogging, etc.)
- Restricted plant root development
- Salt accumulation near plants (along the edges of the wetted zone)
Salt Movement Under Irrigation with Saline Water

Subsurface Drip

Salt accumulation leached radially outward from drip tubing

Sprinkler/Flood

Salt accumulation leached downward by successive water applications
Types of Systems

1. Surface trickle (drip)
   - Water applied through small emitter openings to the soil surface (normally less than 3 gal/hr per emitter)
   - Most prevalent type of micro-irrigation
   - Can inspect, check wetting patterns, and measure emitter discharges

2. Spray
   - Water applied (spray, jet, fog, mist) to the soil surface at low pressure (normally less than about 1 gal/min per spray applicator)
   - Aerial distribution of water as opposed to soil distribution
   - Reduced filtration and maintenance requirements because of higher flow rate
Point Source Emitters in a New Orchard
3. Bubbler

- Water applied as a small stream to flood the soil surface in localized areas (normally less than about 1 gal/min per discharge point)
- Application rate usually greater than the soil's infiltration rate (because of small wetted diameter)
- Minimal filtration and maintenance requirements

4. Subsurface trickle

- Water applied through small emitter openings below the soil surface
- Basically a surface system that's been buried (few inches to a couple feet)
- Permanent installation that is "out of the way"
Typical Subsurface Drip Tubing Installation for Row Crops

Non Wheel-Track Row

76 cm

30 – 35 cm

Drip Tubing

Wetting Pattern

152 cm

152-cm dripline spacing is satisfactory on silt loam & clay loam soils
System Components

• Pump
• Control head
  – Filters
  – Chemical injection equipment (tanks, injectors, backflow prevention, etc.)
  – Flow measurement devices
  – Valves
  – Controllers
  – Pressure regulators

• Mainlines and Submains (manifolds)
  – Often buried and nearly always plastic (PVC)
• Laterals
  – Plastic (PE)
  – Supply water to emitters (sometimes "emitters" are part of the lateral itself)
Schematic of a Typical Micro-irrigation System

* A backflow preventer or vacuum breaker is required in some areas.
Applicator Hydraulics

• General
  – Need pressure in pipelines to distribute water through the system, but the applicator needs to dissipate that pressure

\[ q_e = KH^x \]

  – \( q_e \) = emitter discharge
  – \( K \) = emitter discharge coefficient
  – \( H \) = pressure head at the emitter
  – \( X \) = emitter discharge exponent
    (varies with emitter type)
## Emitter Hydraulics

<table>
<thead>
<tr>
<th>Emitter Type</th>
<th>Coefficient, K</th>
<th>Exponent, X</th>
<th>5.6 m</th>
<th>8.4 m</th>
<th>11.2 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porous Pipe</td>
<td>0.112</td>
<td>1.00</td>
<td>9.0</td>
<td>13.6</td>
<td>18.2</td>
</tr>
<tr>
<td>Tortuous Path</td>
<td>0.112</td>
<td>0.65</td>
<td>3.3</td>
<td>4.3</td>
<td>5.2</td>
</tr>
<tr>
<td>Vortex/Orifice</td>
<td>0.112</td>
<td>0.42</td>
<td>1.7</td>
<td>2.0</td>
<td>2.2</td>
</tr>
<tr>
<td>Compensating</td>
<td>0.112</td>
<td>0.20</td>
<td>0.9</td>
<td>0.9</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Other Design and Management Issues

- **Clogging**
  - Physical (mineral particles)
  - Chemical (precipitation)
  - Biological (slimes, algae, etc.)

- **Filtration**
  - Settling basins
  - Sand separators (centrifugal or cyclone separators)
  - Media (sand) filters
  - Screen filters
Filtration Requirements for Drip Emitters

Filter openings should be 1/7th – 1/10th the size of the emitter orifice.

80 Mesh = 175 Microns
100 Mesh = 147 Microns
150 Mesh = 104 Microns
200 Mesh = 74 Microns
## Plugging Potential of Irrigation Water for Microirrigation

Plugging Potential of Irrigation Water for Microirrigation (Bucks et al., 1979).

<table>
<thead>
<tr>
<th>Potential Problem</th>
<th>Unit of Measure</th>
<th>Minor</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physical</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suspended Solids</td>
<td>ppm</td>
<td>&lt; 50</td>
<td>50 - 100</td>
<td>&gt; 100</td>
</tr>
<tr>
<td><strong>Chemical</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>-</td>
<td>&lt; 7</td>
<td>7 - 8</td>
<td>&gt; 8</td>
</tr>
<tr>
<td>Salts</td>
<td>ppm</td>
<td>&lt; 500</td>
<td>500 - 2000</td>
<td>&gt; 2000</td>
</tr>
<tr>
<td>Manganese</td>
<td>ppm</td>
<td>&lt; 0.1</td>
<td>0.1 - 1.5</td>
<td>&gt; 1.5</td>
</tr>
<tr>
<td>Iron</td>
<td>ppm</td>
<td>&lt; 0.1</td>
<td>0.1 - 1.5</td>
<td>&gt; 1.5</td>
</tr>
<tr>
<td>Hydrogen Sulfide</td>
<td>ppm</td>
<td>&lt; 0.5</td>
<td>0.5 - 2.0</td>
<td>&gt; 2.0</td>
</tr>
<tr>
<td><strong>Biological</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bacteria Populations</td>
<td>Number/ml</td>
<td>&lt;10,000</td>
<td>10,000-50,000</td>
<td>&gt;50,000</td>
</tr>
</tbody>
</table>
• **Chemical treatment**
  – Acid: prevent calcium precipitation
  – Chlorine
    • control biological activity: algae and bacterial slime
    • deliberately precipitate iron

• **Flushing**
  – after installation or repairs, and as part of routine maintenance
  – valves or other openings at the end of all pipes, including laterals

• **Application uniformity**
  – manufacturing variation
  – pressure variations in the mainlines and laterals
  – pressure-discharge relationships of the applicators
Subsurface Drip Irrigation Advantages

- High water application efficiency
- Uniform water application
- Lower pressure & power requirements
- Adaptable to any field shape
- No dry corners (vs. center pivot)
- Adaptable to automation

Subsurface Drip Irrigation Disadvantages

- High initial cost
- Water filtration required
- Complex maintenance requirements
  - Flushing, Chlorination, Acid injection
- Susceptible to gopher damage (القوارض)
- Salt leaching limitations
Schematic of **Subsurface Drip Irrigation (SDI) System**

- **Pump Station**
- **Backflow Prevention Device**
- **Flowmeter**
- **Chemical Injection System**
- **Air & Vacuum Release Valve**
- **Pressure Gage**
- **Flush Valve**
- **Zone Valve**

**Key Components:**
- **Filtration System**
- **Submain**
- **Dripline Laterals**
- **Flushline**
- **Zones 1 and 2**
SDI System Maintenance

- Lateral flushing schedule (sediment)
- Chlorine injection schedule (biological growths)
- Acid injection schedule (chemical precipitates & scaling)
Trenching across the drip tubing ends for PVC manifold installation
Flush Risers on Distal End

Ball Valve for Manual Flushing of Drip Laterals

Air Vent to Release Trapped Air from Laterals
### SDI Water Application Rates (mm/hr)
(152 cm tubing spacing)

<table>
<thead>
<tr>
<th>Emitter Spacing</th>
<th>30.5 cm</th>
<th>45.7 cm</th>
<th>61.0 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.60 Liter/hr</td>
<td>1.10</td>
<td>0.86</td>
<td>0.66</td>
</tr>
<tr>
<td>0.78 Liter/hr</td>
<td>1.4</td>
<td>1.1</td>
<td>0.86</td>
</tr>
<tr>
<td>1.24 Liter/hr</td>
<td>2.2</td>
<td>1.8</td>
<td>1.4</td>
</tr>
<tr>
<td>2.0 Liter/hr</td>
<td>3.6</td>
<td>2.9</td>
<td>2.2</td>
</tr>
</tbody>
</table>

[Diagram of emitter spacing and tubing]
Hazen Williams- Equation

\[ H_f = \frac{K_1 \cdot V^{1.852} \cdot L}{C^{1.852} \cdot D^{1.167}} \]

where:
- \( K_1 = 0.0837 \) for SI Units.
- \( H_f \) = Friction Drop, (m).
- \( L \) = Pipe Length, (m).
- \( D \) = Inside Diameter, (m).
- \( C \) = Roughness coefficient.

• For a total discharge:

\[ H_f = \frac{K_2 \cdot Q^{1.852} \cdot L}{C^{1.852} \cdot D^{4.871}} \]

where:
- \( K_2 = 2.264 \times 10^7 \) for the SI Units.
- \( Q \) = Expressed liters per second
- \( D \) = Expressed in centimeters.
Equation 2 calculates the friction drop using total discharge, which is constant in the pipe.

For lateral line or sub main, the discharge in the line decrease with respect to the length of the line.

The total friction drop at the end of the line can be calculated by applying a correction factor which is determined as, \[ \frac{1}{2.852} \], by Wu and Gitlin.
The total energy drop due to friction at the end of a lateral line or sub main can be expressed as: **equation 2 multiplied by (1/2.852)**

\[
\Delta H = \frac{K_3 \times Q^{1.852} \times L}{C^{1.852} \times D^{4.871}}
\]

where:
\( K_3 = 7.94 \times 10^6 \) for SI Units.
\( \Delta H = \) The total friction drop at the end of a lateral line or sub main, in (meters).

Assuming the emitter flow \( q \) is uniform or is designed with a certain variation, one can re-arrange equation 3 into:

\[
\Delta H = \frac{K_3 \times q^{1.852} \times L^{2.852}}{C^{1.852} \times S_p^{1.852} \times D^{4.871}}
\]

where:
\( q = \) Average emitter flow, (liters per second)
\( S_p = \) The emitter spacing, (meters).
In a drip irrigation design, the terms \( q, S_p, \) and \( D \) are usually known, therefore:

\[
\Delta H = KL^{2.852}
\]

where:

\[
K = \frac{K_3 q^{1.852}}{C^{1.852} S_p^{1.852} D^{4.871}} = \text{Constant} - - - \text{-------- 5}
\]

The total friction drop shown in equation 5 is the total friction drop over the full length of the line.

If the total friction drop, \( \Delta H \), is divided by total length \( L \). It is considered as a dimensionless term \( S \), equation 5 can be expressed as:

\[
S = Kl^{1.852} - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - 6
\]
The friction drop along the line can be determined from a dimensionless energy
gradient line as derived by Wu and Gitlin. It can be expressed as follows:

\[ \Delta H_p = [1 - \{1 - \frac{P}{L}\}^{2.852}] \times \Delta H - - - - - - - - - - - 7 \]

where: \( \Delta H_p = \) The total friction drop at a distance \( P \), from the inlet.

When a lateral line or sub-main is laid on uniform slopes, the total energy gain
(down slope situation) or loss (up slope situation) due to change in elevation
can be expressed as:

\[ \Delta H' = S_o \times L - - - - - - - - - - - - - - - - - 8 \]

where:

\( \Delta H' = \) The total energy gain or loss due to uniform slope at the end of the line (m)

\( S_o = \) The line slope.
The energy gain or loss at a point along the line due to uniform slopes can be shown as:

\[ \Delta H'_p = S_o \cdot \Delta H' \]

where:

- \( \Delta H'_p \) = The energy gain or loss due to slopes at a length \( P \) measured from the inlet
- \( S_o \) = The land slope;
- \( \Delta H' \) = The energy gain or loss due to slope over the total length of the line.
PRESSURE PROFILES

The pressure head profile along the lateral or sub main can be determined from the inlet pressure, friction drop and energy change due to slopes.

\[ H_p = H - \Delta H_p \pm \Delta H_p' \] 11

where:

H = The inlet pressure or operating pressure expressed as pressure head, in (m), the plus sign mean down slope and the minus sign means up slope.

Substituting equations 7 and 10 into equation 11, we have:

\[ H_p = H - [1 - (1 - P/L)^{2.852}] \Delta H \pm P/L*\Delta H' \] 12

The equation 12 describes pressure profiles along a lateral line or sub main.

- The shape of profiles will depend on the inlet pressure (initial pressure), total friction drip and total energy change by slopes.
- There are five typical pressure profiles as shown in the figure 1 and these can be explained as follows:
Profile Type I

1. This occurs when the lateral line (or sub main) is on zero or uphill slope.
2. Energy is lost by both elevation change due to upslope and friction.
3. The pressure decreases with respect to the length of the line and the maximum pressure. $H_{\text{max}}$ is at the inlet and minimum pressure, $H_{\text{min}}$ is at the downstream end of the line.
Profile Type II: Type a

1. This occurs when the lateral line (or sub main) is on down slope situation, where a gain of energy by slopes at downstream points is greater than the energy drop by friction but the pressure at the end of the line is still less than the inlet pressure.

2. The maximum pressure, $H_{\text{max}}$ is at the inlet and a minimum pressure is located somewhere along the line.
Profile Type II: Type b

1. This is similar to Type IIa but the profile is such that the end pressure is equal to the inlet pressure. The maximum pressure, $H_{\text{max}}$ is at the inlet and the end of the line. The minimum pressure, $H_{\text{min}}$ is located somewhere near the middle section of the line.
Profile Type II: Type c

1. This occurs when the line slope is even steeper so the pressure at the end of line is higher than the inlet pressure.

2. In this condition, the maximum pressure, $H_{\text{max}}$ is at the downstream end of the line and the minimum pressure is located somewhere along the line.
Profile Type III

3. This occurs when the lateral line (or sub-main) is on steep down slope conditions where the energy gain by slopes is larger than the friction drop for all sections along the line.

4. In this condition, the maximum pressure is at the downstream end of the line and minimum pressure is at the inlet.

• The location of the minimum pressure along the pressure profile II-a-b-c, can be determined by differentiating equation 12 with respect to the length P and setting the derivative equal to zero.

\[
\{2.852 * (1 - P/L)^{1.852} \Delta H/L\} - \Delta H'/L = 0
\]

• If the term \( \Delta H/L \), the ratio of total friction drop to length, is set as energy slope \( S \), equation 13 becomes:

\[
\{2.852 * (1 - P/L)^{1.852} S\} - S_o = 0
\]

• Simplifying:

\[
P/L = 1 - [0.3506 S_o /S]^{0.54}
\]

Equation 15 shows the location of the point of minimum pressure when both \( S_o \) and \( S \) are known.
DESIGN EQUATIONS

Profile Type I

\[ L = \frac{H_{\text{var}} \times H}{K \times L^{1.852} + S_o} \]

Profile II a

\[ L = \frac{H_{\text{var}} \times H}{K \times L^{1.852} + S_o \left[ 0.3687 \left( \frac{S_o}{K \times L^{1.852}} \right)^{0.54} - 1 \right]} \]

Profile Type II b

\[ L = \frac{H_{\text{var}} \times H}{0.3687 \times S_o} \]

Profile Type II c

\[ L = \frac{H_{\text{var}} \times H}{S_o \left[ 0.3687 \left( \frac{S_o}{K L^{1.852}} \right)^{0.54} \right] - H_{\text{var}} \left( S_o - K L^{1.852} \right)} \]
Profile Type III

\[ L = \frac{H_{\text{var}} \cdot H}{(S_0 - K L^{1.852}) \cdot (1 - H_{\text{var}})} \]
CRITERIA FOR THE SELECTION OF THE APPROPRIATE DESIGN EQUATION

1. The criteria for selecting which of the five design equations to use for a given land slope and flow situations are dependent on the relationship between S and So.

2. The criteria for the Type I profile is simplest, equation 16 is used when there is zero slope or for uphill slopes.

3. The criteria for choosing which of the four down slope design equations to use are based on the magnitude of S and So and on equation 15.

4. The Type II-a profile is characterized by S being greater than S_o:
   \[ S > S_o; \quad \frac{S}{S_o} > 1; \quad KL^{1.852} > 1 \]
   \[ \frac{KL}{S_o} > 1 \]

5. The profile type II-b is characterized because S is equal to S_o:
   \[ S = S_o; \quad \frac{S}{S} = 1; \quad KL^{1.852} = 1 \]
   \[ \frac{KL}{S_o} = 1 \]
6. The profiles II-c and type III are characterized, because $S$ is smaller than $S_o$: $S < S_o$; $S/S_o < 1$; $\frac{KL^{1.852}}{S_o} < 1$

7. If the land slope and flow conditions satisfy this inequality, it is possible to use equation 15 to determine which design equation to use for the Type II-c pressure profile.

8. The minimum point occurs at $P/L$ greater than zero and less than 1. This occurs if the following inequality holds true.
Example 1

- Lateral line on a 1% uphill slope.
- The following data are given, and it is necessary to determine the maximum L for the land slope and flow conditions using Type I profile design equation:
  \[ S_p = 0.61 \text{ m Emitter spacing.} \]
  \[ d = 0.2540 \text{ Emitter’s diameter.} \]
  \[ q = 2.1 \times 10^{-5} \text{ lps Design emitter flow.} \]
  \[ D = 1.42 \text{ cm Lateral line diameter.} \]
  \[ H = 3.17 \text{ m Inlet pressure.} \]
  \[ H_{\text{var}} = 0.10 \text{ Pressure variation magnitude.} \]
  \[ S_o = 0.01 \text{ Land slope uphill.} \]
  \[ C = 150 \text{ Roughness Coefficient.} \]
The equation 5 is written as:

\[
K = \frac{7.94 \times 10^6 \ q^{1.852}}{C^{1.852} \ S_p^{1.852} \ D^{4.871}}
\]

\[
K = \frac{7.94 \times 10^6 \ (2.1 \times 10^{-5})^{1.852}}{(150)^{1.852} \ (0.61)^{1.852} \ (1.42)^{4.871}}
\]

\[
K = 7.82 \times 10^{-8}
\]

• From the equation 16

\[
L = \frac{(0.19) \ (3.17)}{7.82 \times 10^{-8} \ L^{1.852} + 0.010}
\]

\[
L = 54.27 \text{ m}
\]

We can also obtain a graphical solution solving H for various L and tracing a graph to determine “L”. The particular type of line can extend approximately to 55 m over an up slope of 1%, before \(H_{\text{var}}\) will exceed 19%, that corresponds to a \(q_{\text{var}}\) of 10%. 

Example 2

- Lateral line on 1.5% downhill slope.
- The first design equation used is that for the Type II-a profile.
  
  \[
  S_p = 2.4 \text{ m Emitter spacing.}
  \]
  
  \[
  d = 0.48 \text{ mm Emitter diameter.}
  \]
  
  \[
  q = 1.55 \text{ cm Design emitter flow.}
  \]
  
  \[
  H = 8.65\text{mm Inlet pressure.}
  \]
  
  \[
  H_{\text{var}} = 0.19 \text{ Pressure variation magnitude.}
  \]
  
  \[
  S_o = 0.015 \text{ Land slope downhill.}
  \]
  
  \[
  C = 137 \text{ Roughness Coefficient.}
  \]
• Using these values, we obtain:

\[ K = 7.98 \times 10^6 (1.14 \times 10^{-14})^{1.852} \]

\[ K = 9.93 \times 10^7 \]

• From equation 17

\[ L = 9.93 \times 10^{-7} L^{1.852} + 0.015 \left[ \frac{0.3680.015}{9.93 \times 10^{-7} L^{1.852}} \right]^{0.54} - 1 \]

\[ L = 201 \text{ meters} \]
Sprinkler Irrigation
Definition

• Pressurized irrigation through devices called sprinklers
• Sprinklers are usually located on pipes called laterals
• Water is discharged into the air and hopefully infiltrates near where it lands

Types of Systems

• **Single sprinkler**
  – Only one sprinkler that is moved or automatically moves

• **Examples:**
  – Single lawn sprinkler
  – Large gun on a trailer that is moved or automatically moves (“traveler”)

• Often used for irregularly shaped areas
• Pressure and energy requirements can be high
Solid Set

- Laterals are permanently placed (enough to irrigate the entire area)
- Laterals are usually buried, with risers or pop-up sprinklers
- Easily automated and popular for turf and some ag/hort applications
- Capital investment can be high

Periodically Moved Lateral

- Single lateral is moved and used in multiple locations
- Examples:
  - Hand-move
  - Tow-line/skid-tow (lateral is pulled across the field)
  - Side-roll (lateral mounted on wheels that roll to move the lateral)
- Fairly high labor requirement
Moving Lateral

- Single lateral moves automatically (mounted on wheeled towers)
- Examples:
  - Center pivots (lateral pivots in a circle)
  - Linear or lateral move systems (lateral moves in a straight line)
- Fairly high capital investment
System Components

- **Sprinklers**
  - Devices (usually brass or plastic) with one or more small diameter nozzles

- **Impact sprinklers**
  - Drive or range nozzle (hits sprinkler arm and throws water out farther)
  - Spreader nozzle (optional; Applies more water close to the sprinkler)
  - Trajectory angles
  - Part-circle sprinklers
  - Used in all types of irrigation, but especially agricultural crops
Impact Sprinklers

Two-nozzle, bronze impact sprinkler

Range (Drive) Nozzle

Impact Arm

Spreader Nozzle

Trajectory Angle

Bearing
Sprinkler Performance

- **Discharge**
  - Depends on type of sprinkler, nozzle size, and operating pressure

\[ q_s = 29.82 C_d D^2 \sqrt{P} \]

- \( q_s \) = discharge (gpm)
- \( C_d \) = discharge coefficient for the nozzle and sprinkler \( \approx 0.96 \)
- \( D \) = inside diameter of the nozzle (inches)
- \( P \) = water pressure at the nozzle (psi)
Sprinkler Performance Cont’d.

• **Diameter of Coverage**
  – Maximum diameter wetted by the sprinkler at a rate that is significant for the intended use
  – Depends on operating pressure and sprinkler and nozzle design (including trajectory angle)
Laterals perpendicular to winds
## Maximum spacing between sprinklers

### Rectangular Spacing

<table>
<thead>
<tr>
<th>Average Wind Speed, mph</th>
<th>Maximum Spacing Between Sprinklers on the Lateral</th>
<th>Maximum Spacing Between Laterals Along the Mainline</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-3</td>
<td>50% of Diameter</td>
<td>60% of Diameter</td>
</tr>
<tr>
<td>4-7</td>
<td>45% of Diameter</td>
<td>60% of Diameter</td>
</tr>
<tr>
<td>8-12</td>
<td>40% of Diameter</td>
<td>60% of Diameter</td>
</tr>
</tbody>
</table>

### Square Spacing

<table>
<thead>
<tr>
<th>Average Wind Speed, mph</th>
<th>Maximum Spacing Between Sprinklers on the Lateral</th>
<th>Maximum Spacing Between Laterals Along the Mainline</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-3</td>
<td>55% of Diameter</td>
<td>---</td>
</tr>
<tr>
<td>4-7</td>
<td>50% of Diameter</td>
<td>---</td>
</tr>
<tr>
<td>8-12</td>
<td>45% of Diameter</td>
<td>---</td>
</tr>
</tbody>
</table>

### Equilateral Triangle Spacing

<table>
<thead>
<tr>
<th>Average Wind Speed, mph</th>
<th>Maximum Spacing Between Sprinklers on the Lateral</th>
<th>Maximum Spacing Between Laterals Along the Mainline</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-3</td>
<td>-</td>
<td>*</td>
</tr>
<tr>
<td>4-7</td>
<td>60% of Diameter</td>
<td>*</td>
</tr>
<tr>
<td>8-12</td>
<td>55% of Diameter</td>
<td>*</td>
</tr>
</tbody>
</table>

* For the equilateral triangle pattern, the spacing between laterals is 0.866 x sprinkler spacing.
Application Rate

Rectangular sprinkler layout

\[ A_r = \frac{96.3q_s}{S_l S_m} \]

- \( A_r \) = water application rate (inches/hour)
- \( q_s \) = sprinkler discharge rate (gpm)
- \( S_l \) = sprinkler spacing along the lateral (feet)
- \( S_m \) = lateral spacing along the mainline (feet)
## Application Rate & Soil Infiltration Rate

### Maximum recommended precipitation rates for soils (in/h).

<table>
<thead>
<tr>
<th>Slope, %</th>
<th>Light sandy soils (sands, fine sands) and loamy fine sands</th>
<th>Medium textured soils (sandy loams, fine sandy loams, and silt loam soils)</th>
<th>Heavy textured soils (silty clay loams, clay loams, and clayey soils)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 5</td>
<td>0.50 - 0.75</td>
<td>0.25 - 0.50</td>
<td>0.10 - 0.25</td>
</tr>
<tr>
<td>6 - 8</td>
<td>0.40 - 0.60</td>
<td>0.20 - 0.40</td>
<td>0.08 - 0.20</td>
</tr>
<tr>
<td>9 - 12</td>
<td>0.30 - 0.45</td>
<td>0.15 - 0.30</td>
<td>0.06 - 0.15</td>
</tr>
<tr>
<td>13 - 20</td>
<td>0.20 - 0.30</td>
<td>0.10 - 0.20</td>
<td>0.04 - 0.10</td>
</tr>
<tr>
<td>&gt; 20</td>
<td>0.10 - 0.20</td>
<td>0.05 - 0.10</td>
<td>0.02 - 0.05</td>
</tr>
</tbody>
</table>

### Soil Surface Not Protected

### Turfgrass or Heavy Residue Cover

<table>
<thead>
<tr>
<th>Slope, %</th>
<th>Light sandy soils (sands, fine sands) and loamy fine sands</th>
<th>Medium textured soils (sandy loams, fine sandy loams, and silt loam soils)</th>
<th>Heavy textured soils (silty clay loams, clay loams, and clayey soils)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 5</td>
<td>0.85 - 1.30</td>
<td>0.50 - 0.95</td>
<td>0.15 - 0.35</td>
</tr>
<tr>
<td>6 - 8</td>
<td>0.70 - 1.00</td>
<td>0.40 - 0.75</td>
<td>0.10 - 0.25</td>
</tr>
<tr>
<td>9 - 12</td>
<td>0.50 - 0.75</td>
<td>0.30 - 0.55</td>
<td>0.10 - 0.20</td>
</tr>
<tr>
<td>13 - 20</td>
<td>0.35 - 0.50</td>
<td>0.20 - 0.40</td>
<td>0.05 - 0.15</td>
</tr>
<tr>
<td>&gt; 20</td>
<td>0.15 - 0.35</td>
<td>0.10 - 0.20</td>
<td>0.03 - 0.05</td>
</tr>
</tbody>
</table>

1 Based on recommendations of the Rain Bird Corporation and Pair et. al., 1983.