

Managing Use of Alternative Water for Irrigation

This is part of a two-course series on use of wastewater for irrigation. The course will focus on using municipal reclaimed water and greywater in landscape and industrial applications. These are:

Landscape Wastewater Irrigation I: *Permitting of Alternative Water for Irrigation* (8 hours)

Landscape Wastewater Irrigation II: *Managing Use of Alternative Water for Irrigation* (8 hours)

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Wastewater Irrigation I Agenda

- I. Introduction and Overview of Wastewater Reuse in Texas
- II. Overview of Rules/Regulations
- III. Permit Application Requirements
- IV. Regulations on Use of Wastewater for Irrigation
- V. Water Balance Calculations

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Wastewater Irrigation I (Review)

Water Balance Calculations

- Evapotranspiration
- Effective rainfall
- Leaching requirement
- Water / Irrigation requirement
- Conversion from “inches” to “gallons”

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Wastewater Irrigation II Agenda

Consumptive Use Estimates

On-site storage of water and Pump Selection

Rules and Regulation

- Review of Landscape Irrigation Design Regulations
- Reclaimed Water Special Requirements

Irrigation Zones and Irrigated Blocks Concepts

Irrigation Systems and Design Considerations

- Domestic Gray Water
- Domestic Gray Water Interconnected
- Large Turf Areas
- Industrial Reclaimed Water Systems

Managing Water Quality

- Filtration & Chemigation
- Salinity Management
- Nutrient Loading

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Wastewater Irrigation II Agenda

Real-time Irrigation Water Management

- Concepts
- Irrigation Scheduling
- Soil Moisture Sensors

Soil Sampling and Nutrient Loading

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Wastewater Irrigation I (Review)

30TAC Chapter 210 – Reclaimed Water and Graywater

30TAC Chapter 285 – On-Site Sewage Facilities (OSSF – “septic tank systems and other sewage on-site systems)

- 285 (h) Disposal of Graywater

30TAC Chapter 344 – Landscape Irrigation

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Reclaimed Water – Use in Irrigation

Providers are required to provide reclaimed water to users “*on-demand*” which eliminates the need for on-site storage or the application of water when it is not needed.

The user of reclaimed water must reasonably control application rates onto irrigation areas in order to ensure:

- the efficient use of reclaimed water and
- avoid excessive application of reclaimed water that results in surface runoff or excessive percolation below the root zone.

Providers and users must determine and document typical irrigation demands for the proposed use based on type of vegetation and land area to be irrigated (i.e., a water balance set of calculations)

The provider must conduct periodic audits of reclaimed water use. Water use records are required and submitted to the TCEQ periodically.

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Reclaimed Water – Use in Irrigation

Provider and Users designing or operating an irrigation system using reclaimed water must ensure that reclaimed water overflow, crop stress, and undesirable soil contamination by salt does not occur.

Irrigation application rates and times must be developed so as to minimize “wet grass” conditions in unrestricted landscaped areas during the periods the area could be in use.

Spray irrigation systems must be designed to prevent water from reaching any privately-owned premises outside the designated irrigation area or public drinking fountains.

There shall be no application of effluent when the ground is water saturated or frozen.

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Consumptive Use Estimates

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Consumptive Use

Consumptive use is an estimate of the total amount of water that plants and crops use expressed in

- Inches per unit of time (day, month, season)
- Commonly used for sizing irrigation systems, water rights allocation, and in permitting

Consumptive use may also be determined using ET (evapotranspiration) concepts

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Consumptive Use

In Texas, Bulletin 6019 is widely used for consumptive

Bulletin 6019 is available from libraries and is posted on websites

On TexasET (<http://TexasET.tamu.edu>), Bulletin 6019 is listed under "Useful Information"

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Consumptive Use Estimates using Evapotranspiration Concepts

ET (evapotranspiration)

- Refers to the total amount of water used by plants
- Includes water *evaporated* from the soil and plant surface AND water *transpired* by the plant
- ET rates vary widely depending on the plant/crop

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Consumptive Use Estimates using Evapotranspiration Concepts

Reference Evapotranspiration (ET_o) refers to the amount of water used by a "reference crop"

- Defined as cool-season grass, growing 4 inches tall under well-watered conditions

ET_o is used as a "reference" to which the ET for all other plant types is related.

For example, the ET for common bermudagrass is approximately 60% of ET_o:

$$ET_{\text{bermuda}} = 0.60 \times ET_o$$

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Reference Evapotranspiration (ET_o)

ET_o is calculated using local climate parameters:

- Wind speed
- Relative humidity
- Temperature
- Solar Radiation

Should not be confused with pan evaporation or lake evaporation

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Example: ET Weather Station



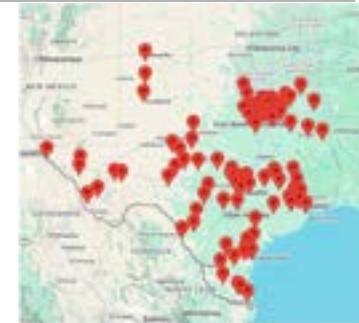
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TexasET Network

Contains:

- Current weather and ET data
- Irrigation scheduling tools
- Average historic ET_o data for Texas



Location of weather stations

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Historic ET_o Records

Average Monthly ET _o (PET) (inches/month)													
City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Abilene	2.08	2.57	4.14	5.48	6.47	7.65	8.36	7.46	5.48	4.21	2.67	2.08	58.65
Amarillo	1.84	2.27	3.73	5.06	5.89	7.51	8.08	7.29	5.61	4.05	2.4	1.78	55.51
Austin	2.27	2.72	4.34	5.27	6.39	7.15	7.22	7.25	5.57	4.38	2.74	2.21	57.51
Brownsville	2.65	3.03	4.48	5.17	6.03	6.32	6.68	6.65	5.21	4.34	3.01	2.59	56.16
College Station	2.2	2.71	4.22	5.2	6.25	6.89	7.1	6.85	5.6	4.3	2.8	2.2	56.32

City	Years of Data
Abilene	52
Amarillo	52
Austin	70
Brownsville	79
College Station	47

Historic ET Available for 19 Cities across Texas
Source: Texas ET Network
<http://texaset.tamu.edu>

How to Estimate Turfgrass ET from ET_o

Crop coefficients (also referred to as “plant or turf coefficients”)

Abbreviated as K_c, T_c, etc.

Represents the percentage of ET_o a specific plant type will use for maximum growth

Common Turf Classifications

Warm season turfgrasses

- Bermudagrass
- St. Augustinegrass
- Centipede grass
- Zoysia grass
- Buffalograss
- Carpetgrass
- Paspalum

Cool season turfgrasses

- Fescue
- Kentucky bluegrass
- Bentgrass
- Ryegrass

Typical Crop Coefficients for Turfgrasses

City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Abilene	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Amarillo	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Austin	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Brownsville	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
College Station	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8

City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Abilene	0.0	0.1	0.3	0.6	0.6	0.6	0.6	0.6	0.6	0.3	0.1	0.0
Amarillo	0.0	0.0	0.2	0.6	0.6	0.6	0.6	0.6	0.6	0.3	0.1	0.0
Austin	0.1	0.2	0.3	0.6	0.6	0.6	0.6	0.6	0.6	0.3	0.1	0.0
Brownsville	0.3	0.3	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.3	0.3
College Station	0.3	0.3	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.3

Source: Texas ET Network
<http://texaset.tamu.edu>

ASABE Standard Landscape Coefficients

Table 1 – Annual average fraction of ET_o for acceptable appearance of established landscape plants

Plant Type	Recommended Plant Factor
Turf, cool season	0.8
Turf, warm season	0.8
Annual flowers	0.8
Woody plants and herbaceous perennials, wet ¹⁾	0.7
Woody plants and herbaceous perennials, dry	0.5
Desert plants	0.3

¹⁾ Tropical plants: for tropical plants with precipitation the majority of months, a plant factor of 0.7 applies. Where monsoonal climates are present, 0.7 applies for the wet season, and 0.5 during the dry season.

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Basic Plant Water Requirement Equation

$$ET = ET_o \times K_c$$

ET = water requirements (inches/month, inches/week)

ET_o = evapotranspiration rate (inches/month, inches/week)

K_c = plant or crop coefficient (decimal)

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Calculating Plant ET

Given:

- Bermudagrass turfgrass
- College Station
- July

$$ET = ET_o \times K_c$$

$$ET_o = 7.1 \text{ inches (from table)}$$

$$K_c = 0.6 \text{ (from table)}$$

Required:

- July ET

$$ET = 7.1 \times 0.6$$

$$ET = 4.26 \text{ inches}$$

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Other Coefficients

K_c for Major Crops in Texas – see: <http://TexasET.tamu.edu>

FAO Crop Coefficients

- For most plants and crops
- <http://www.fao.org/3/X0490E/x0490e0b.htm#crop%20coefficients>
- Also listed on the TexasET website

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Section 2: On-Site Storage of Reclaimed Water

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Typical Water Sources versus Treated Wastewater

Traditional water resources are used as both water supply sources and storage facilities

- Groundwater
- Lakes
- Rivers

Treated wastewater is continuously generated. What cannot be used must be stored or disposed of in some manner.

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Storage Considerations

May be a significant part of the design

Has a substantial impact on capital cost

Impacts operation and maintenance expenses

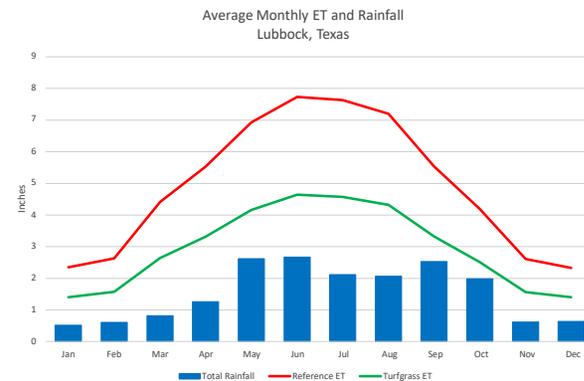
- Especially if water is degraded due to storage and requires re-treatment before use (algae growth)

Design capacity must be sized for peak use and to prevent discharge

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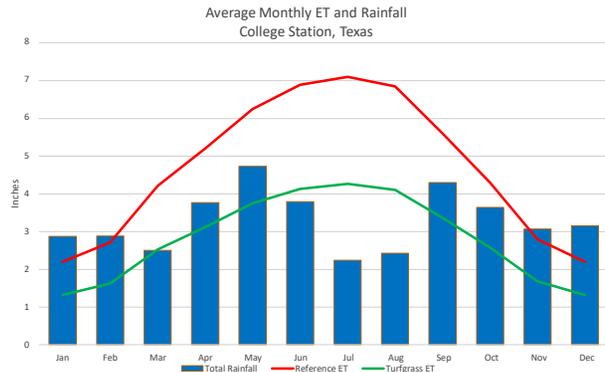
No Storage Needed in Dry Climates (with properly sized wastewater application systems)



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Storage Needed in Wetter Climates



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Seasonal Irrigation Requirements

Determined using the following data:

- Potential evapotranspiration (ET_p)
- Plant types (K_c)
- Effective rainfall
- Irrigation system efficiency
- Leaching requirement

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Volume of Water Required to Meet Irrigation Needs

Irrigation and wastewater application usually are in terms of inches (depth)

To determine volume from depth:

- Need total irrigated area (square feet)

Common (English) volumetric units:

- Gallons
- Cubic feet
- Acre-feet
- Acre-inch

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Volume Conversion Factors

$$\text{Gallons} = \text{Inches} \times \text{Acres} \times 43,560 \times 0.6234$$

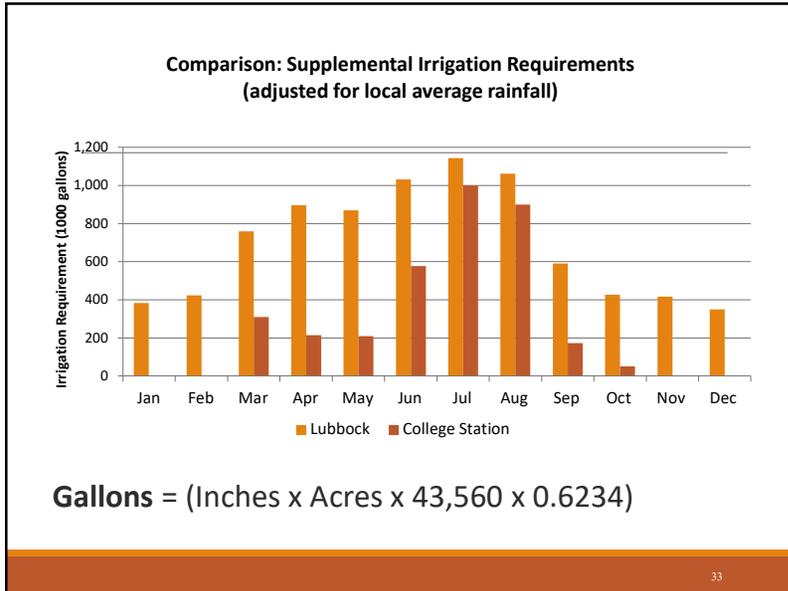
$$\text{Gallons} = \text{Inches} \times \text{Square feet} \times 0.6234$$

$$\text{Cubic feet} = \frac{\text{Gallons}}{7.48}$$

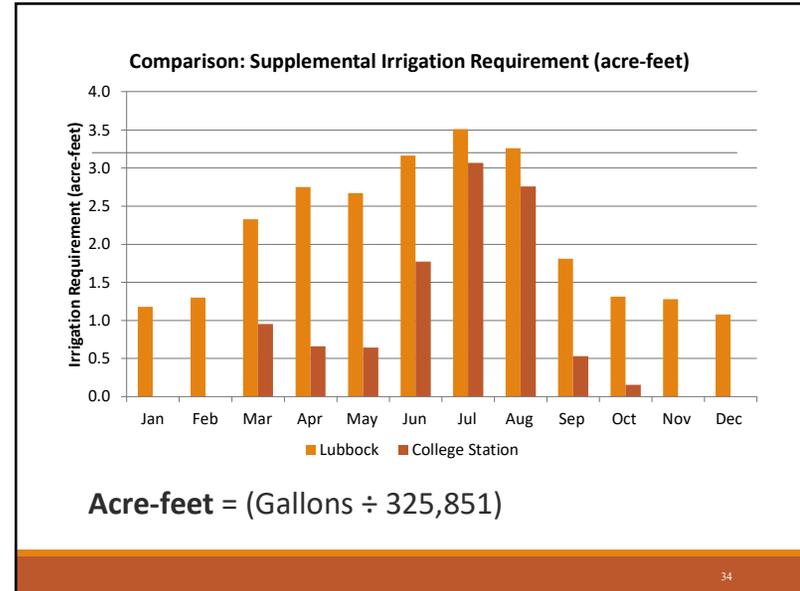
$$\text{Acre-feet} = \frac{\text{Gallons}}{325,851}$$

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Storage Facilities

- Holding ponds
 - Golf courses
 - Large commercial properties
- Above-ground containers
 - Non-irrigation uses (dust suppression for road construction or gas/oil well locations)

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Storage Pond Consideration

- Typically have an aesthetic value
- Need to maintain an “acceptable” water level – minimize too much drawdown
- May be supplemented by rainfall runoff or other source (well)
- Must be designed to prevent unauthorized discharge or deep percolation
- Must be maintained to prevent excessive algae bloom

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Storage Pond Capacity

Based upon depth, width, length and side slope

Generally over-designed to prevent excessive drawdown due to pumping

Water level maintained to prevent overflow from normal rainfall events

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Calculating Storage from Runoff

Natural Resource Conservation Service (NRCS)

National Engineering Handbook-Hydrology Chapters

- Note: if this link doesn't work, do a web search on "National Engineering Handbook – Hydrology Chapters"
- <https://directives.nrcs.usda.gov/sites/default/files/2017/1712930634/Part%20630%20-%20Hydrology.pdf>

Engineering Software and Design tools

- <https://www.nrcs.usda.gov/getting-assistance/technical-assistance/engineering/engineering-field-tools>

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Drawdown from Storage Ponds

Drawdown = (inflows) - (Irrigation water extraction) - (surface evaporation)

- Volume depends upon the size of the pond
- Dictates how often the pond must be refilled to maintain an acceptable level

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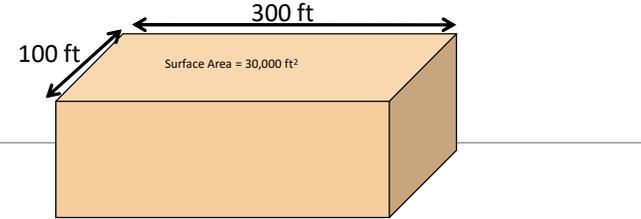
Determining Drawdown from Irrigation - Example

In April, a 3-acre commercial property irrigates 2.5 inches during the week from a lined, rectangular-shaped storage pond.

- The storage pond is 100 feet wide by 300 feet long.
- Assuming no rainfall, how far will the water level decline each week due to irrigation?

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100 ft

300 ft

Surface Area = 30,000 ft²

1) weekly irrigation volume (ft³) = (2.5 in/12) x 3 acres x 43,560 ft²/acre
 weekly irrigation = 27,225 ft³

2) Drawdown = 27,225 ft³ ÷ 30,000 ft² = **0.91 feet (~10.9 inches)**

3) + surface evaporation from storage pond

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Surface Water Evaporation

Texas Water Development Board maintains record of monthly and annual Gross Lake Evaporation Rates for Texas

- Database contains daily, monthly, yearly and historical averages

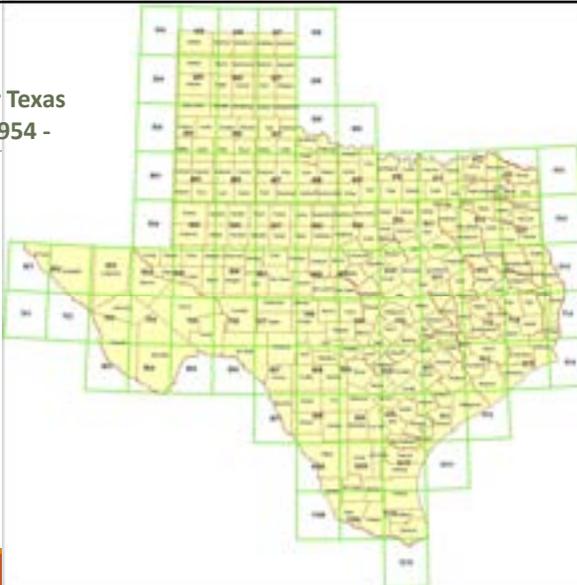
<https://waterdatafortexas.org/lake-evaporation-rainfall>

- Select Quad ID, Start Date & End Date
- Download Data: "Quad Statistics" for Average Monthly Data

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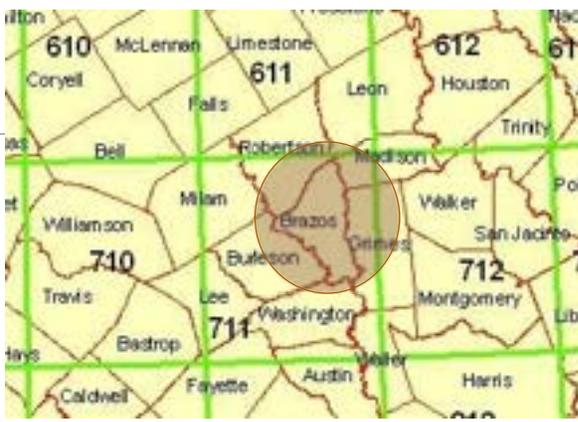
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TWDB: Historic Evaporation for Texas Quadrangles. 1954 - 2025



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TWDB: Historic Evaporation for Texas Quadrangles. 1954 - 2025

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***** Quadrangle: 711 *****
***** Data Units: Inches *****
***** Monthly Evap *****
***** Statistics *****

-----
      n      Min      Max      Median      Mean      10%ile      90%ile
-----
      472      0.97      9.47      4.32      4.40      2.11      7.03

Month  n      Min      Max      Median      Mean      10%ile      90%ile
-----
Jan 56      1.08      5.83      2.11      2.14      1.54      2.70
Feb 56      0.97      4.27      2.34      2.47      1.89      3.25
Mar 56      2.15      5.45      3.65      3.67      2.91      4.32
Apr 56      2.19      5.97      4.38      4.38      3.62      5.39
May 56      3.41      6.35      4.82      4.89      4.01      6.01
Jun 56      4.65      8.85      6.22      6.23      5.17      7.13
Jul 56      4.94      9.32      7.18      7.12      6.00      8.44
Aug 56      5.16      8.38      6.78      6.77      5.58      7.82
Sep 56      3.86      7.03      5.15      5.32      4.34      6.49
Oct 56      2.91      9.47      4.41      4.51      3.46      5.22
Nov 56      2.18      4.77      3.07      3.04      2.36      3.66
Dec 56      1.11      3.45      2.19      2.24      1.53      2.93

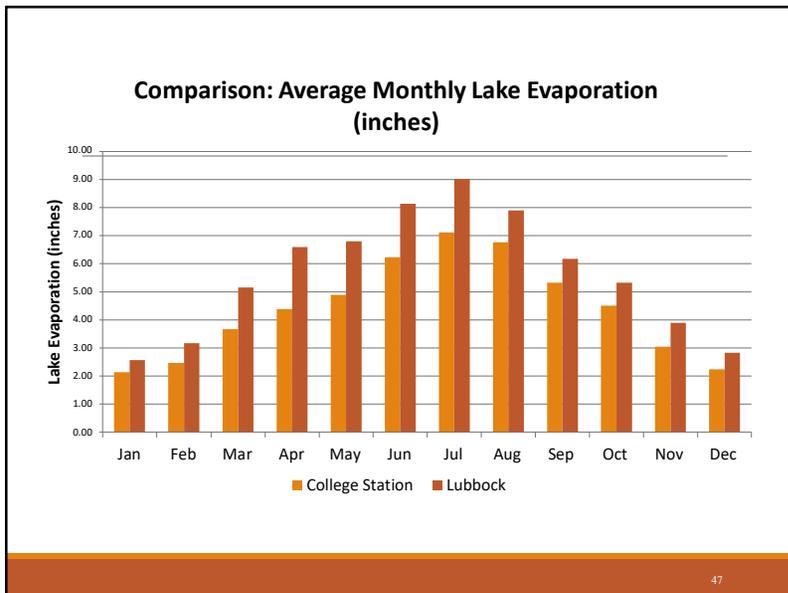
***** Annual Evap *****
***** Statistics *****

-----
      n      Min      Max      Median      Mean      10%ile      90%ile
-----
      56      45.95      63.40      52.60      52.79      46.98      59.26
    
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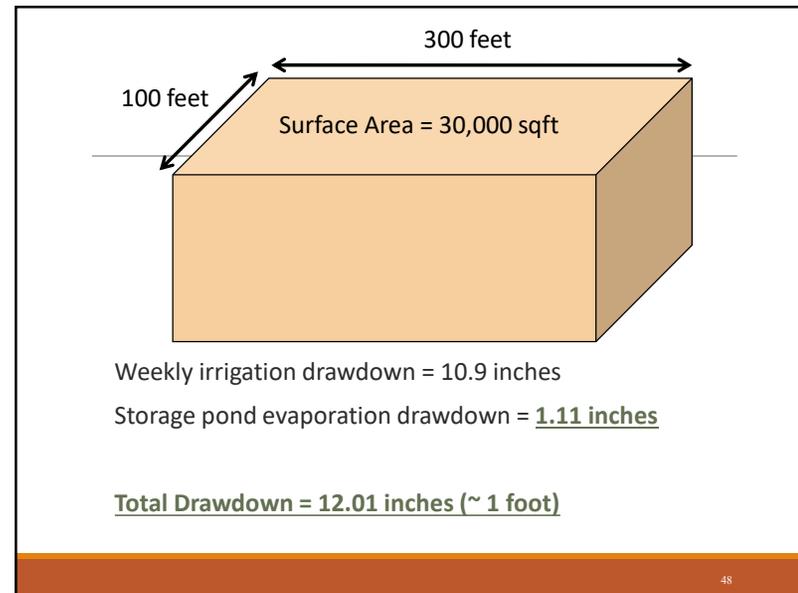
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Quadrangle: 711 (1954-2025 - Updated 6/2025)						
	net_evap_mean	net_evap_median	net_evap_min	net_evap_max	net_evap_10%	net_evap_90%
JAN	-0.74	-0.39	-9.53	2.53	-3.17	1.44
FEB	-0.36	-0.07	-6.28	3.09	-3.3	2.03
MAR	0.94	1.15	-4.07	5	-1.6	3.15
APR	1.11	1.93	-8.55	6.7	-2.48	3.93
MAY	0.18	0.78	-9.3	6.11	-3.87	3.79
JUN	2.59	3.1	-6.95	8.12	-0.9	6.5
JUL	5.05	5.29	-1.93	9.84	1.92	7.73
AUG	4.38	4.96	-12.95	9.58	0.82	7.32
SEP	1.75	1.86	-5.33	8.28	-2.03	5.05
OCT	0.45	1.08	-9.85	6.81	-5.05	4.33
NOV	-0.19	-0.04	-7.22	5	-3.21	2.28
DEC	-0.98	-0.81	-6.48	2.11	-3.86	1.55

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Pumping Water From Storage

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Pumps

Irrigation Systems require pressure to operate correctly

Gravity alone from on-site storage may not produce the minimum pressure to operate the irrigation system

- Elevated storage can be expensive

Centrifugal Pump, often referred to as “booster pumps” are the most common means to add pressure to the irrigation system

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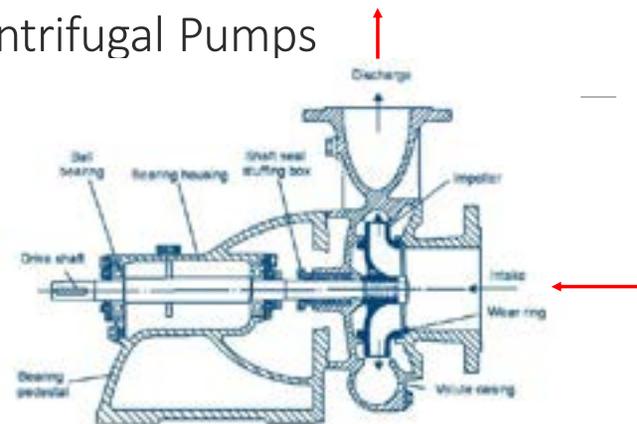
Centrifugal Pumps



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Centrifugal Pumps

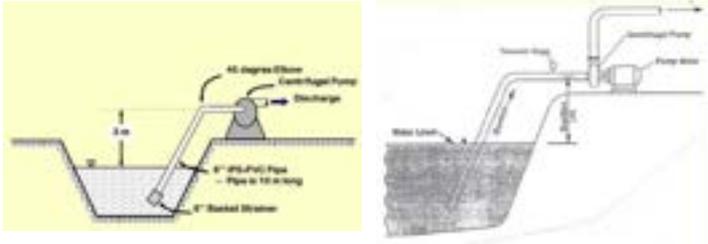


Cross-section of a centrifugal pump

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Centrifugal Pumps



Centrifugal pump setting components

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Centrifugal Pumps

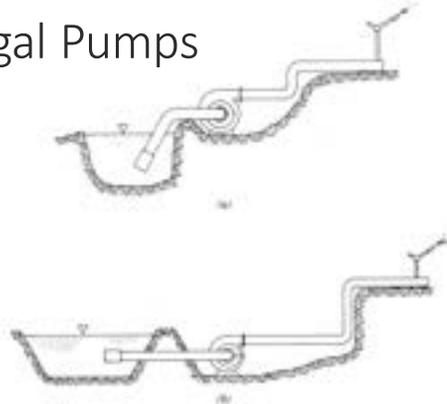
Centrifugal Pumps

- Pull water (suction)
- Often used for pumping surface water
 - Such as from ponds, rivers or storage tanks
- Requires careful design consideration when sizing
 - Need to know the pumps pulling capacity and pushing-referred to as "Head Requirement"
- Often are used to boost pressure in irrigation systems
- Flexible to Power Units
 - Electric Motors, Diesel Engines, Tractor PTO
- Each manufacturers pump will have a different rated performance
 - "Pump Curves" vary by size, motor, etc.

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Centrifugal Pumps



Typical mounting positions for horizon centrifugal pumps:

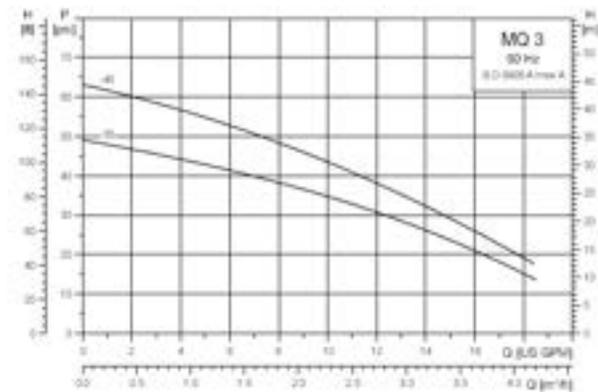
- (a): located above the water surface;
- (b): located below the water surface, the pump does not require priming prior to start.

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Centrifugal Pump Performance

Pump Curves Performance range, MQ 60 Hz

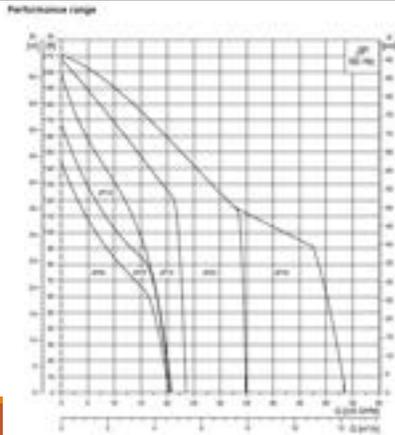


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Selecting Pumps Example

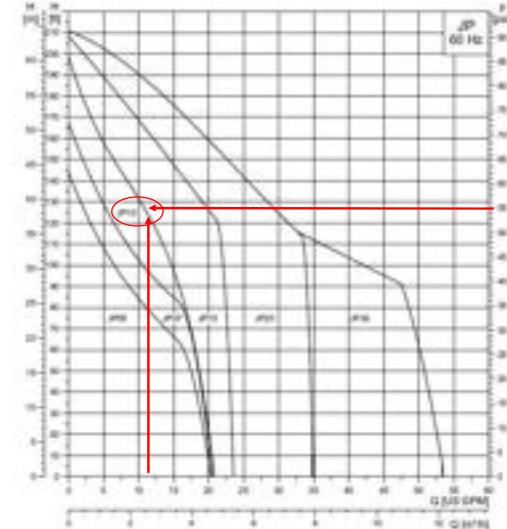
Use the Pump Curve to select a pump to produce 55 PSI and 12 GPM



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Performance range



55 GPM @
12 PSI:
Model JP10

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Section 3: Rules and Regulations

- Review of Landscape Irrigation Design Requirements
- Reclaimed Water Special Requirements

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Texas Commission on Environmental Quality

LANDSCAPE IRRIGATION DESIGN RULES

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TCEQ Definition: Design

The act of determining the various elements of a landscape irrigation system that will include, but not limited to, elements such as:

- Collecting site specific information
- Defining the scope of the project
- Defining plant watering needs
- Selecting and layout out emission devices
- Locating system components
- Conducing hydraulics calculations
- Identifying any local regulatory requirements
- Scheduling irrigation work at a site

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Minimum Design and Installation Requirements

Defined by TCEQ Chapter 344.62

- No irrigation design or installation shall require the use of any component, including the water meter, in a way which exceeds the manufacturers published performance limitations for the component
 - Be familiar with manufacturers product literature

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Minimum Design and Installation Requirements

Spacing

- Must not exceed manufacturers published radius or spacing of a device
- No above ground spray devices in areas less than 48 inches
 - Many ordinances exceed this
- Some areas may be exempt if the runoff drains into a landscaped area

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48 Inch Rule, 5ft Rule

Example: the landscape between roads and sidewalks



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Minimum Design and Installation Requirements

Water Pressure

- Must operate at the minimum and not above the maximum based on the nozzle and spacing used

Piping

- Designed not to exceed 5 ft/s for PVC pipe

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High Pressure



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Low Pressure



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Low Pressure....



High Pressure.....



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Pressure Regulators

Some systems may require pressure regulators to achieve manufacturers recommended pressure requirement

Some devices have pressure regulators built in

Regulators should be sized based on flow rate and output pressure



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Minimum Design and Installation Requirements

Irrigation Zones

- Irrigation system shall have separate zones based on:
 - Plant Material Type
 - Microclimate Factors
 - Topographic Features
 - Soil Conditions
 - Hydrological requirements
- Often referred to as "hydrozones"

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Minimum Design and Installation Requirements

Matched Precipitation Rate

- Zones must be designed so all devices in the zone irrigate at the same precipitation rate

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Minimum Design and Installation Requirements

Overspray

- Cannot spray over surfaces made of :
 - Concrete
 - Asphalt
 - Brick
 - Wood
 - Stone set in mortar
 - Or any other impervious material (walls, fences, sidewalks, streets, ect...)

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Special Design Considerations for Alternative Water Sources

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Design of Irrigation Systems

Hydraulics (pipe sizing) for treated wastewater is no different than with typical water sources

- Based upon flow rate, pressure and friction loss

Special design requirements for:

- Pipe material (color)
- Backflow prevention devices
- Valves
- Filters and screens
- Application devices

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Design of Irrigation Systems

Special design requirements for:

- Pipe separation from potable lines
- Pipe separation from sewer lines
- Covers and caps for valve boxes, meter boxes and application devices
- Restricted access to system components
- Public awareness and safety

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Management of Irrigation Systems

Special emphasis on:

- Preventing runoff into State waters (streams, rivers, lakes, etc.)
- Avoiding irrigation during wet or saturated conditions
- Managing irrigation applications to prevent soil contamination buildup
- Preventing foliar damage to landscape plants

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Major Irrigation Issues Regarding Reclaimed Water

Dixon, R. W., and Ray, D. J. 2008. *Reclaimed water use for irrigation of Texas golf courses*. Applied Turfgrass Science.

- Survey of 487 golf course superintendents
- 150 respondents, 40 currently use reclaimed water
- Purpose was to obtain a better perspective of issues associated with reclaimed water use for landscape irrigation

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Major Irrigation Issues Regarding Reclaimed Water

Ranking of potential problems of using reclaimed water (1 = most important, 5 = least important)

Problem / rank	1	2	3	4	5
Salinity	30	4	3	0	0
Algae growth	5	16	6	3	0
Clogged irrigation heads	7	8	10	3	4
Equipment rust	2	1	8	15	5
Complaints from golfers/neighbors	1	2	2	7	19

Source: (Dixon, 2008)

78

78

Regulations

The *Office of Water* at the Texas Commission on Environmental Quality permits and governs the use of reclaimed water in Texas

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Regulatory Requirements

Chapter 210 – Use of Reclaimed Water

- Pipe:
 - Buried pipe installed after February 12, 1997 must be:
 - Manufactured in purple
 - Painted purple
 - Taped with purple metallic tape
 - Bagged in purple
 - Exposed pipe should be stenciled in white with the words "NON-POTABLE WATER"
- All exposed and buried reclaimed water pipes at a wastewater treatment facility is exempt from the color-coding requirements
- Color coding also applies to graywater

80

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Piping

Purple Piping

Pipe Sleeves



81

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Regulatory Requirements

Chapter 210 – Use of Reclaimed Water

- Pipe separation:
 - Must be separated from potable water piping by a horizontal distance of 9 feet (exemptions exist)
 - Must be separated from sewer lines by a horizontal distance of 3 feet with the reclaimed water line at the level or above the sewer line.
 - Where a reclaimed water line crosses a sewer line, the reclaimed water line must be at least 2 feet above the sewer line

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Regulatory Requirements

Hose bibs:

- All hose bibs and faucets must be painted purple
- Must be designed so that they prevent connection to a standard water hose
- Must be located:
 - Below ground
 - In vaults
 - Locked
 - Labeled as non-potable
- **Exception:** Above-ground non-lockable service boxes are allowed if they can only be operated with special tools

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Regulatory Requirements

Chapter 344 – Landscape Irrigation Reclaimed Water

- Definition: Domestic or Municipal water which has been treated to a quality suitable for beneficial use, such as landscape irrigation.

Non-Potable Water

- Definition: Water that is not suitable for human consumption. Includes irrigation systems, lakes, ponds, streams, gray water, water vapor condensate, reclaimed water and harvested rainwater

84

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Valves

Constructed with materials that withstand high chlorine and other harsh chemicals - chemical resistant components

Diaphragms reinforced to protect against corrosion

Stainless steel, self-flushing filter screens

Purple handles for easy identification

Lockable valve boxes to prevent unauthorized operation

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Specialized Application Devices

Purple ID caps and covers for conventional rotors and spray heads

Check valves reduces low-head drainage

Low angle nozzles minimizes spray drift

Filters prevent clogged nozzles

86

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Backflow Prevention Devices

The domestic potable water line must be connected using an air gap or a reduced pressure principle backflow prevention device

Backflow prevention on the reclaimed water line must follow water purveyor regulations

Check with local water utility for rules on cross connection of water to other wastewater sources, if allowed



30TAC Chapter 344.65 – Reclaimed Water

87

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Public Safety and Awareness

The irrigation system may not spray water across property lines

A minimum 8"x8" sign must be displayed in English and Spanish in the area being irrigated and stored. It must read:

"RECLAIMED WATER – DO NOT DRINK" and

"AQUA DE RECUPERACION – NO BEBER"

30TAC Chapter 344.65 – Reclaimed Water

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Public Safety and Awareness

There can be no contact with edible crops, unless the crop is pasteurized before consumption

Application rates and times must be managed so as to minimize "wet" grass conditions in unrestricted landscaped areas

Irrigation spray must not reach public drinking fountains

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Public Safety and Awareness

Irrigation system must not allow application when the ground is saturated or frozen

- Rain sensors
- Freeze sensors
- Soil moisture sensors

Systems must be designed to restrict unauthorized operation



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Soil Moisture Sensor Operation

Typically take the place of Rain Sensors on landscape irrigation Controllers

- Use of Sensor Ports or in Series with Common Wire/Port

Operate by opening the circuit until the soil moisture content reaches a programmed deficit at which point the circuit is closed and the controller can begin its scheduled irrigation until the circuit is opened again.

Most require setting irrigation runtime, frequency, etc.

Most agricultural irrigation control systems has special ports and software for soil moisture sensors.

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Using Soil Moisture Sensors

Installing Multiple Sensors at Multiple Depths improves accuracy.

Depth of Placement should be representative of the effective root zone.

Difficult to obtain accurate readings in the top 2 inches of soil



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Using Soil Moisture Sensors

Can be expensive and challenging to use in large or elaborate landscapes

- Finding a representative install location in the landscape
- Often different plant materials will require their own sensors
 - Changes in Soil type
 - Different root zone depth

Sensor	Sensor Type	Sensor Reading	Costs (Comparability)	Sensitivity to Salinity	Affected by Temperature	Sensor Response
Granular Matrix	Matrix Potential	cFlors	Low	Generally No	No	Slow
Capacitance	Volumetric Water Content	%	Moderate	Yes	No	Moderate-High
TDR/TDT	Volumetric Water Content	%	Moderate-High	Generally No	No	Moderate-High

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Environmental Protection

Must ensure that reclaimed water overflow, crop stress, and undesirable soil contamination by salt does not occur.

The irrigated property must be maintained with vegetative cover at all times when reclaimed water is used

Reclaimed water must not cause a nuisance, degrade groundwater quality, or be discharged into State waters

94

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Special Management Needs

Periodic soil and water tests to track levels of salinity and other constituents

Leaching to remove salt accumulation

Plant evaluation for foliar toxicity

Advanced irrigation scheduling methods and tools

Documentation of irrigation use, water quality and soil quality

System audits, filter cleaning and routine maintenance

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Special Considerations

CORROSION

96

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Corrosion

Definition:

The chemical or electrochemical reaction between a material, usually a metal, and its environment that produces a deterioration of the material and its properties

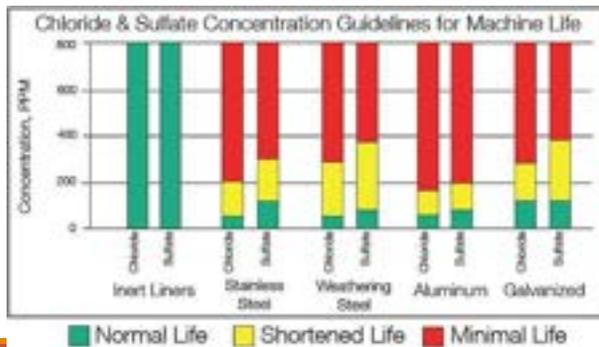
Piping

Poly Liners for metal pipes with corrosive water

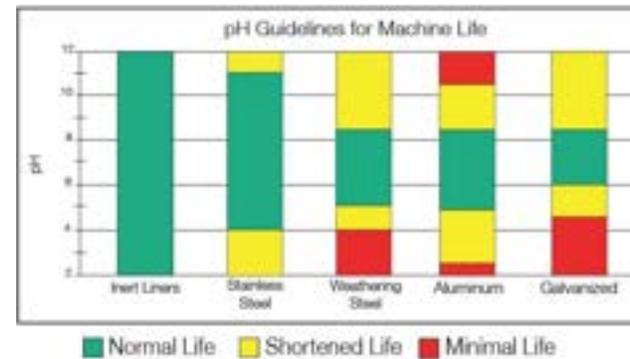
- Ex. Valley Irrigation - PolySpan



Corrosion Management – Pipeline Chlorides



Corrosion Management- Pipeline pH



Irrigation Zone and Irrigated Block Concepts

101

101

How many zones?



102

Zoning

Poor designs will often have multiple zones located within a station

- Example
 - Irrigating Shrubs, flowers and turf on the same zone
 - Often results in something being over or under watered



103

Zoning

Characteristics of a poorly zoned landscape:

- Impractical turf areas
- Impractical shrub or tree plantings



104

Zoning

Often established plants (non-turf) can be zoned into one of 3 water use categories

- Frequent Watering
 - Ex. Annual Flowers
- Occasional Watering
 - Ex. Perennial Flowers, groundcovers, tender woody shrubs and vines
- Natural Rainfall
 - Ex. Tough woody shrubs and vines, shade trees

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Irrigated Block

Large irrigation systems are often divided into multiple irrigation blocks due to water supply, pressure availability, or due to management requirements.

Typically, the entire system irrigates same plant/crop, so the zoning definition does not apply.

The number of blocks needed is determined during the design process.

Irrigation controllers connected to the valve for each block can operate the system automatically

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Irrigation System Considerations for Application of Graywater & Reclaimed Water

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Domestic Gray Water

Most domestic gray water systems only produce enough water to irrigate small areas

For example, if a site produces 100 gallons of graywater per day and the landscape require 0.25 inches per day, how much landscape can be irrigated per day?

$$Area, ft^2 = \frac{Gallons}{Irrigation, inches \times 0.623}$$

$$\frac{100 \text{ Gallo}}{0.25 \text{ inches} \times 0.623} = 642 \text{ ft}^2 \text{ per day (} \sim 20\text{ft} \times 32\text{ft)}$$

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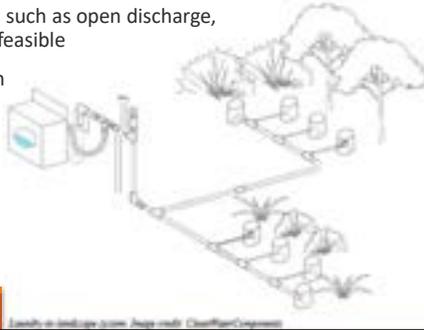
Domestic Gray Water Interconnected to the Landscape Irrigation System?

Gray water systems (laundry) produce limited flow and pressure.

Application via sprinklers may require filtration and pump for adequate distribution (increases costs)

Gravity based surface irrigation such as open discharge, bubbler or flood is often more feasible

Installation of a 3-way diversion valve to send discharge to either the sewer or irrigation



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Large Turf Areas

Reality Check

1 inch irrigation over 1,000 ft² = 623 gallons
1 inch irrigation over 1 acre = 27,154 gallons

To adequately irrigate large turfgrass areas graywater or alternative water generation capabilities would need to be increased

Industrial or Municipal Reclaimed Water can often be generated or provided at higher volumes better suited for large turfgrass areas.

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Large Turf Areas

Industrial Reclaimed Example:

A food processing facility in Katy, Texas generates 150 GPM washing produce before processing. If the facility operates 12 hours per day it can generate 108,000 gallons per day.

If a plant has a daily water requirement of 0.25 inches per day, how much area could be irrigated?

$$\text{Area, ft}^2 = \frac{\text{Gallons}}{\text{Irrigation, inches} \times 0.623}$$

$$\frac{108,000 \text{ Gallons}}{0.25 \text{ inches} \times 0.623} = 693,419 \text{ ft}^2 \text{ per day (15.9 acres)}$$

111

111

Large Turf Landscape Areas

Large Turf areas are often ideal landscapes to use Reclaimed and alternative water supplies

- Golf Course
- Sports Complexes
- Football, Soccer, Baseball, etc.

Irrigation Design and Management can vary for large turf landscape areas

- Use of Larger Sprinklers such as Impacts to cover more area
- Sprinkler layout
- Controller Operation – managing flow and pressure

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Considerations for Large Turf Areas

Irrigation Blocks vs Valve in Head Management

- Irrigation Blocks – 1 Valve controls multiple sprinkler heads
 - Designed for a target flow and pressure
- Valve in Head – Each Sprinkler head has it own control valve.
 - More wiring, managing available flow and pressure



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Considerations for Large Turf Areas

Runoff

- Large Turf areas like golf courses often have a mix of sloped to flat areas
- Sports Fields and Golf Course often use larger sprinklers



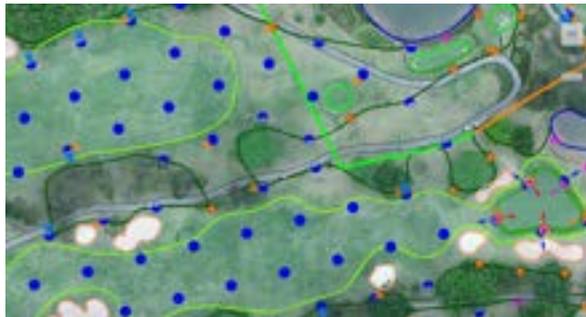
114

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Considerations for Large Turf Areas

Sprinkler layouts – Square vs Triangular Design

Irrigation of the Critical/Target Areas



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Industrial Reclaimed Water Irrigation Systems

Most likely to be used in Industrial wastewater reuse and for use in agriculture

- Center Pivots/Linear Move Systems

Less Frequently Used

- Solid set
- Big guns
- Surface Irrigation
 - Basin
 - Furrow
- Drip

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Industrial Reclaimed Water Irrigation Systems



Center Pivots

- Cost effective on a per irrigated acre basis
- Low labor requirements, can be set up for automatic operation
- Requires underground water supply pipeline and power to be run to the center point

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Center Pivot Terminology – water application systems

On top of mainline (*least efficient*)

MESA

LESA

LEPA (*most efficient*)

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On top of main line



Source: Senninger Irrigation

119

MESA
(medium elevation spray application system)



120

MESA



121

LEPA (low energy precision applicators)



122

LEPA
with alternate row furrow dikes



123

LESA (low elevation spray applicators)



124

Drag line system (“mobile drip”)



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Drag-line evaluation at the Texas A&M University Farm – Fipps, 2016

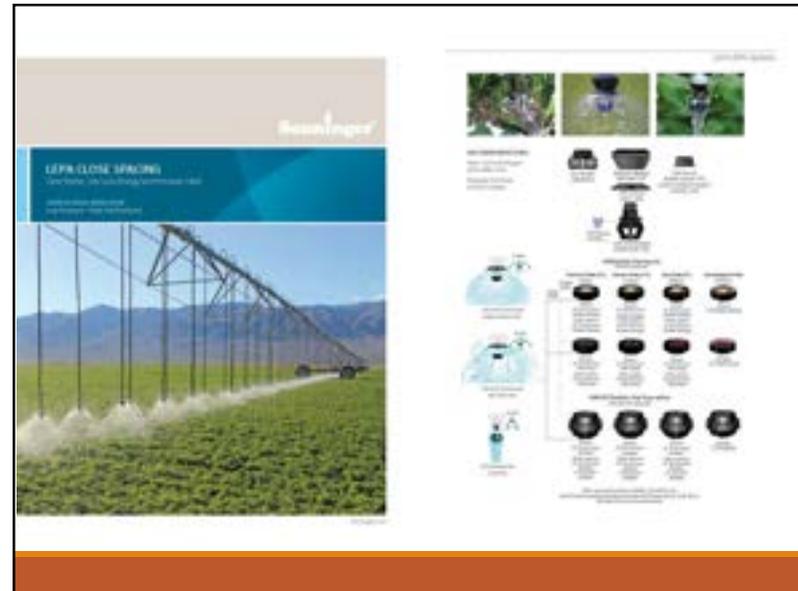


126

Terminology – water application systems

On top of mainline	On top of mainline
MESA	Above-canopy
LESA	In-canopy
LEPA	Close drop spacing (with either LESAs or LEPA)

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Pivot Design Key Points

1. Actual lowest and highest elevations in field with relation to the pivot point were used in the computer design printout.
2. Actual measured flow rate and pressure available from pump or water source was used in the computer design printout.
3. Friction loss in pivot mainline is no greater than 10 psi for quarter-mile long systems.
4. Mainline outlets are spaced a maximum of 60 to 80 inches apart or, alternately, no farther apart than two times the crop row spacing.

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Pivot Design

5. For non-leveled fields, less than 20 percent pressure variation in system-design operating pressure is maintained when pivot is positioned at highest and lowest points in the field (computer design printout provided for each case).
6. Pressure regulators were evaluated for fields with more than 5 feet of elevation change from pad to the highest or the lowest points in the field.
7. Tower wheels and motor sizes were selected based on soil type and slope following manufacturers' recommendations.
8. Dealer has provided a copy of pivot design printout.

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Accessories

Propeller flow meter or other type of flow measurement device having accuracy to ± 3 percent.

- Reads flow rate (i.e., gpm) and total gallons
- The flow meter should be installed in a long straight section of pipeline at least 10 pipe diameters upstream and 5 pipe diameters downstream from any changes in pipeline.

System includes two pressure gauges, one on the mainline near the pivot point and one in the last drop,

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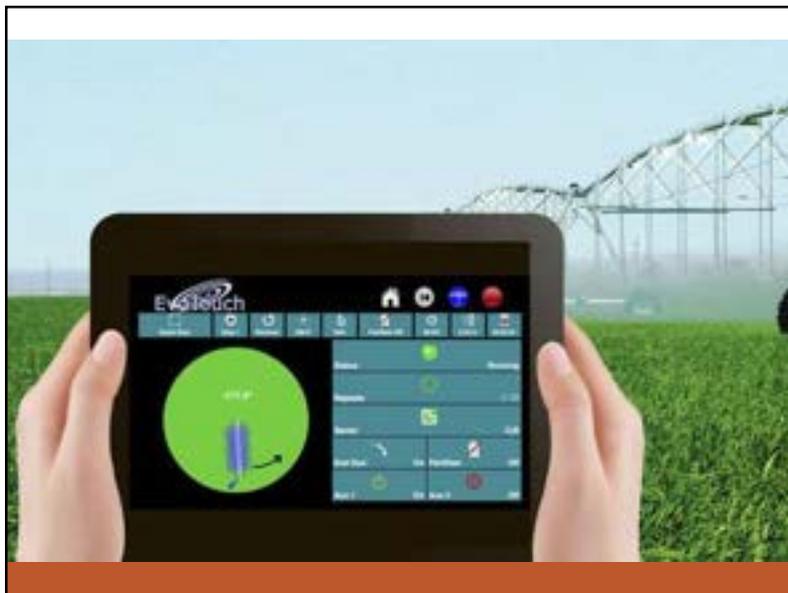
133

Control and Management Systems

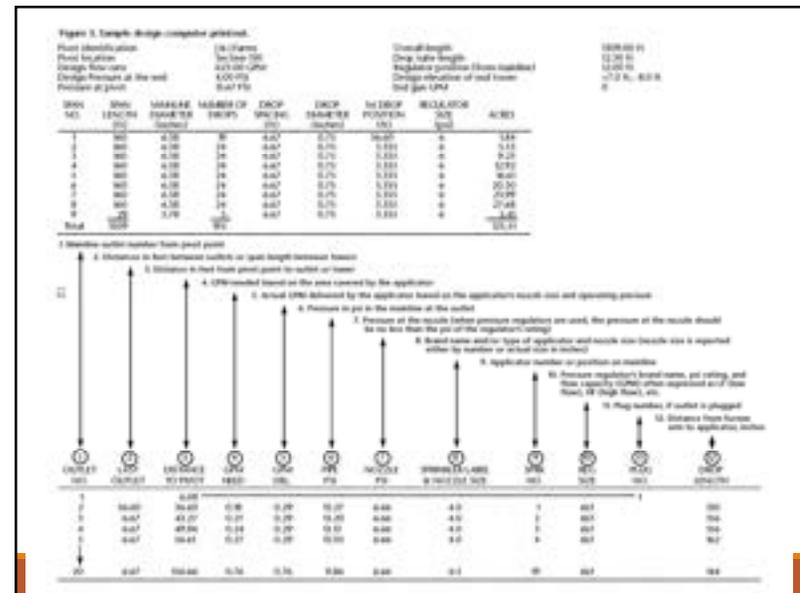
Control Panel

The image shows a control panel for a precision agriculture system. It features a large monitor displaying a field map with various data points and a smaller tablet showing a similar interface. The system is labeled 'FELDMET' and 'Control Panel'.

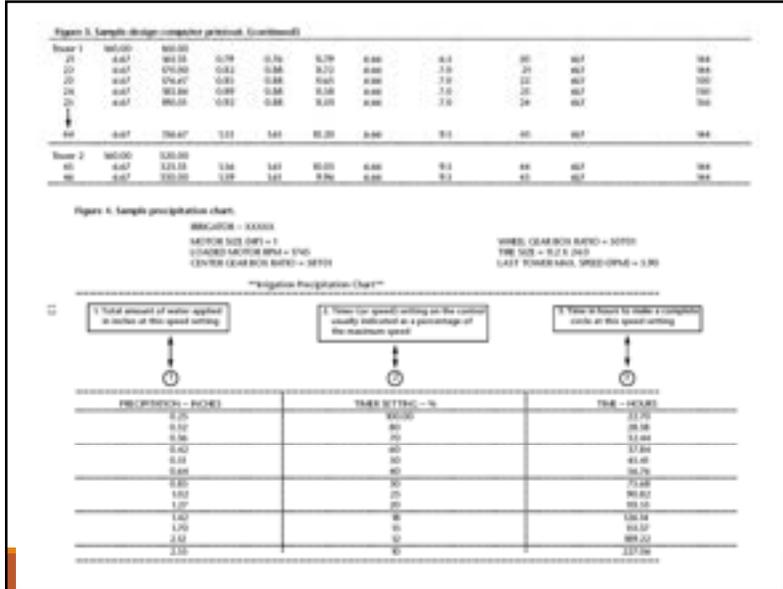
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Surface Irrigation

“Flood Irrigation”

Field Layout

- Land Leveling
- Furrow Length

Irrigation Management

- Cut-Back irrigation
- Tailwater management

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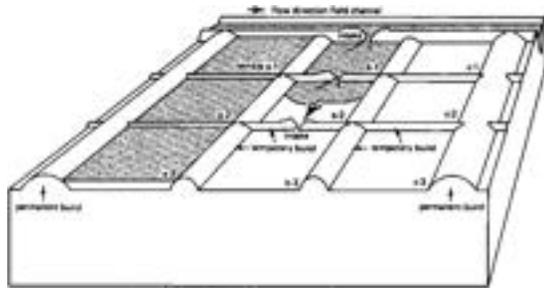
Furrow Irrigation

- NRCS (Natural Resources Conservation Service), an agency of the USDA, has developed the design guidelines for furrow irrigation
- Check with your regional NRCS office or with the NRCS state headquarters in Temple, Texas

<https://www.nrcs.usda.gov/wps/portal/nrcs/site/tx/home/>

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Basin Irrigation Systems



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Basin Irrigation Systems

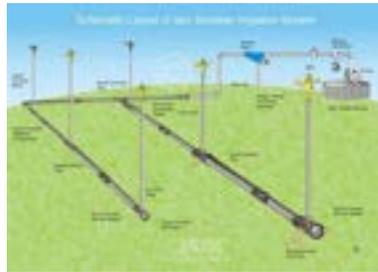
Good resource:

<http://www.fao.org/3/S8684E/s8684e03.htm>

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Sprinkler Packages

Solid Set



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Big Gun Sprinklers



Source: Nelson Irrigation

146

Merry Christmas Tree Farm – a choose and cut operation.
Occasional irrigation, no pipes or sprinklers in field when public comes.



147

Big gun – travelers (*reel-move*)



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Managing Water Quality

Filtration

Chemigation

Salinity Management

Soil Sampling & Nutrient Loading

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Irrigation Filtration

Water quality is the determining factor in choosing the proper filtration equipment

Is the water pumped under pressure directly from a supply line or is the water temporarily stored on site?

Common concerns for irrigation systems:

- Algae
- Suspended solids
- Pipe debris
- Sand

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Clogging Control

Biological

- Algae
- Bacteria

Minerals

- Iron
- Calcium/Lime
- Salts
- Etc.



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Screen Filters

Most common and least expensive

Used primarily to remove hard particulates from water, such as sand

Not effective at removing

- Algae
- Mold
- Slime

May be removed and cleaned by hand

Some models can be flushed by backwashing



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Media Filters

Cleans water by forcing it through a container filled with a small, sharp-edged “media” (commonly sand)

Effective at removing organic material (algae, slime, etc.)

Common method for cleaning water at a high volume from rivers and ponds

Cleaned by backwashing

Must be properly sized to system flow rate



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Disk Filters

Consist of a stack of round disks covered with various sizes of small bumps with sharp points

Particulates are filtered by the small openings

Organic matter is snagged by the sharp edges

Disks may be cleaned automatically or may be moved and cleaned by hand



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Centrifugal Filters (sand separators)

Used primarily for removing particulates such as sand

“Dirty” water is pumped into the filter where centrifugal force causes sand to move to the outside edge of the filter. Sand then slides down the outside edge to a holding tank at the bottom

Commonly used to filter well-water

May require additional downstream filtration depending on the application



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How much filtration do you need?

Depends upon:

- Type of irrigation system you have
 - Drip
 - Spray
- Emitter orifice size
- Allowable pressure loss through system
- Durability, construction, and quality of solenoid valves
 - Small sand grains are a common source of valve failure
 - Savings in valve repairs can pay for the extra cost of a filter in a short period of time

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Approximate Filter Size Equivalents

Micron	mm	Mesh		Micron	mm	Mesh
800	0.8	20		100	0.1	150
500	0.5	30		80	0.08	200
300	0.3	50		50	0.05	300
250	0.25	60		40	0.04	350
200	0.2	75		30	0.03	500
180	0.18	80		25	0.025	600
150	0.15	100		15	0.015	1000
130	0.13	120				

“Mesh” is based upon the number of wires in 1 linear inch of the screen.
Drip product manufacturers will specify the level of filtration required.

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Chemigation

General term that includes:

Fertigation
Insectigation
Fungigation
Nematigation

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Advantages of Chemigation

Uniformity of application
Precise application
Economics
Timeliness
Reduced soil compaction and plant damage
Operator safety

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Disadvantages of Chemigation

High management
Additional equipment
Must calculate injection rates and volumes

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Chemigation and Regulations

General Classes

- Controlled Substances
 - Pesticides and Herbicides
- Fertilizers and Nutrients
- Drip Maintenance/Clogging Control Chemicals
 - Chlorine and Acids

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Chemigation Injectors and Pumps

The most common types:

Mechanical

- Piston (positive displacement) pumps
- Diaphragm pumps

Venturi meters

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Piston/Positive Displacement Pumps

Uses a "piston" to inject chemical into the irrigation water

Rate is determined by the

- length of the stroke
- number of strokes per minutes

Chemicals come into contact with piston, so materials should be matched

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Piston/Positive Displacement Pumps

Injection rate remains constant and does not change if the irrigation pipeline pressure varies

Injection rates cannot be adjusted while operating

Commonly used to inject fertilizer (large rate injection)

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Piston/Positive Displacement Pumps



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Diaphragm Pumps

a membrane separates chemical from the drive mechanism (piston)

Easy to adjust flow rate while operating

Commonly used for low-rate injection (pesticides, etc.) or continuous injections (chlorine or acid to lower pH)

Easy to calibrate and maintain

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Diaphragm Pump



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Venturi Meters

Simple device with no moving parts

The meter uses a reduced diameter throat tube (or a tube with a needle valve or orifice plate)

Velocity changes in tube create vacuum to pull chemical into stream



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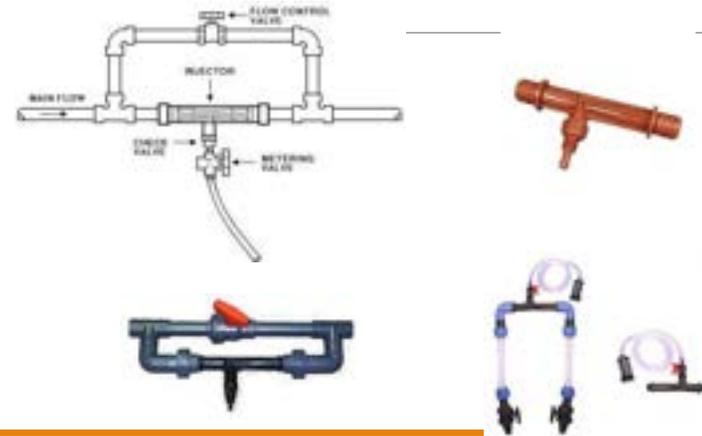
Venturi Meters

- Most low-end venturi injectors are not adjustable and have a constant proportion injection rate such as 1:50 (one gallon injected for every 50 gallons flowing through meter)



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Venturi Meters



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Table 4. Recommended injector per chemical substance

Injector type	Pesticides (Herbicides)	Fertilizers	Acids	Chlorine
Positive displacement	Yes	Yes	Yes	Yes
Diaphragm	Yes	Yes	Yes	Yes
Venturi	No	Yes	Yes	Yes
Proportional mixers	No	Yes	Yes	Yes

Source: Chemigation Equipment, Management and Calibration

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Chlorine

Injected to control biological clogging of lines and emitters

Household bleach is often used in small systems (5.25% chlorine)

Higher concentrations (up to 100 ppm) if iron bacteria and/or organic matter are problems



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Chlorine

Chlorine concentration at the end of the drip line should be:

- 1 to 2 ppm for occasional treatment
- 0.5 to 1 ppm for continuous treatment

Begin with a low concentration (5 ppm to 10 ppm) for one hour

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Acid Injection

Acid is injected to control mineral clogging of emitters

Water with a high pH (>7.5) or

"moderate" to "hard water" (>60 ppm Ca) more likely to cause problems

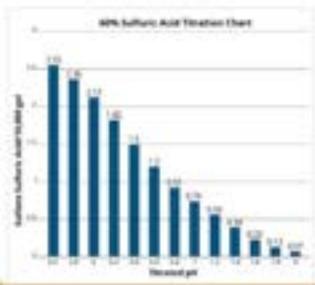
178

Acid Injection

98% sulfuric acid is commonly used in drip irrigation

Citric acid or vinegar can be used in organic farming

Titration can be used to determine concentration of acid need



(adding acid to a sample of the water to see how much is required to lower pH)

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Acid Injection

Experimentation is used in absence of titration

Acid is injected until pH is lowered to 6.5

(measured at end of drip line)

Higher concentrations are added if needed, lowering pH to as low as ~4

Acid is corrosive – inject downstream of filter if made of metal

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Calculations Injection Rates

Calculate injection rate based on concentration (ppm) of solution to be injected

$$IR = (0.006 \times F \times C) \div P$$

IR = injection rate (gal/hr)

F = flow rate of irrigation system (gal/hr)

C = concentration of chemical wanted (ppm)

P = Percentage of chemical in solution

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Chemigation Calculations - Example 1

I want to inject chlorine at a concentration of 5 ppm for one hour.

My irrigation system has a flow rate of 100 gpm, and I'm using household bleach (5.25% chlorine)

$$IR = (0.006 \times F \times C) \div P$$

$$IR = (0.006 \times 100 \text{ gpm} \times 5 \text{ ppm}) \div 5.25\%$$

$$IR = 0.571 \text{ gal/hr of bleach}$$

IR = injection rate (gal/hr)

F = flow rate of irrigation system (gpm)

C = concentration of chemical wanted (ppm)

P = Percentage of chemical in solution

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Chemigation Calculations - Example 2

Determining amount of solution for fixed ratio injectors

For example 2, my venturi injector has a 100:1 ration

(injecting chlorine at a concentration of 5 ppm for one hour, a flow rate of 100 gpm, and using household bleach)

$$IR = 0.571 \text{ gal/hr of bleach}$$

Step 1: Calculate total flow of irrigation system in one hour

$$100 \text{ gpm} \times 60 \text{ min/hr} = 6000 \text{ gallons per hour}$$

Step 2: Calculate total gallons of solution to be injected

(divide Step 1 by ratio)

$$6000 \text{ gph} \div 100 = 60 \text{ gallons of solution}$$

Step 3: Mix the 0.571 gallons of bleach with 60 gallons of water in the injection tank

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Managing Saline and Sodic Soils

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Why is salinity important?

Most common problem associated with irrigating with treated wastewater

Can be toxic to some "salt-sensitive" plants

Can cause surface sealing of soils, decrease infiltration and increase runoff

Can accumulate in the soil, reduce plant productivity, and make plants more prone to disease

Can damage and corrode equipment

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Inorganic Salts

Anions (- charge)

- Carbohydrates
- Chlorides
- Sulfates
- Nitrates
- Phosphates

Cations (+ charge)

- Potassium
- Magnesium
- Calcium
- Sodium

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Dissolved Salts in Irrigation Waters

Chemical Name	Symbol
Sodium chloride	NaCl
Sodium sulfate	Na ₂ SO ₄
Calcium chloride	CaCl ₂
Calcium sulfate (gypsum)	CaSO ₄
Magnesium chloride	MgCl ₂
Magnesium sulfate	MgSO ₄
Potassium chloride	KCl
Potassium sulfate	K ₂ SO ₄
Sodium bicarbonate	NaHCO ₃
Calcium carbonate	CaCO ₃
Sodium carbonate	Na ₂ CO ₃
Borates	BO ⁻³
Nitrates	NO ⁻³

Adapted from Table 1
(Fipps, 2003)

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Salinity (continued)

Water salinity is usually measured by:

- EC (electric conductivity) or
- TDS (total dissolved solids)

High salt concentrations:

- Can be toxic to plants as they absorb through leaf tissue
- Sensitivity levels differ significantly among plants
- Can accumulate in surface soils
 - Surface sealing
 - Reduced infiltration and drainage
 - Reduce water uptake in plants by lowering the osmotic potential of the soil

(Haering, 2009)

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Salinity Sources

Non-point sources

- Underlying geologic formations
 - Ancient marine sediments
- Erosion and weathering of sedimentary rocks
- Groundwater intrusion
- Arid and semi-arid regions (high evaporation)
- Precipitation (trace amounts)
- Agricultural and urban water runoff and sediment displacement

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Salinity Sources

Point sources

- Residential
 - Water softeners
 - Detergents and cleaners
- Commercial
 - Car-wash bays (detergents)
- Industrial
 - Food processing (cleaning agents and preservatives)
 - Water and wastewater treatment processes

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Salinity

Salts in treated wastewater originate from:

- Elemental ions naturally found in water
- Ions retained in dissolved form after separation of solids during the treatment process
- Salts added during the treatment process

Water salinity is usually measured by:

- EC (electric conductivity) or
- TDS (total dissolved solids)

(Haering, 2009)

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Electrical Conductivity (EC)

EC is a measure of the flow of electrical current in water

The more ions (salts), the higher the EC

Measured in units of:

- deci-Siemens per meter (dS/m), or
- milli-mhos per centimeter (mmhos/cm)
- 1 dS/m = 1 mmhos/cm

*Note: 1,000 umhos/cm = 1 mmhos/cm

(Fipps, 2003)

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Total Dissolved Solids (TDS)

Measured by allowing a sample of water to evaporate and then weighing the remaining solids (salts)

TDS is usually reported in:

- milligrams of solids per liter of water (mg/L), or
- parts per million (ppm)
- 1 mg/L = 1 ppm

(Fipps, 2003)

Equivalency of EC and TDS

EC can be used to approximate TDS using the following equation:

- $TDS (mg/L \text{ or } ppm) = EC (mmhs/cm \text{ or } dS/cm) \times 640$

(Fipps, 2003)

Water Analysis Report
Soil, Water and Forage Testing Laboratory
Department of Soil and Water Sciences
2101 Rouse Hall, 1675 TAMU
College Station, TX 77843
409/254-7500

Client: [Redacted]
Location: [Redacted]
Sample ID: [Redacted]
Date: [Redacted]

Water Analysis Report

Parameter	Results	Units	Method	Y. Limiting	Limiting	Acceptable
Calcium (Ca)	1	ppm	ICP			*****
Magnesium (Mg)	1	ppm	ICP			*****
Sodium (Na)	154	ppm	ICP			*****
Potassium (K)	1	ppm	ICP			*****
Sulfate (SO ₄)	0.28	ppm	ICP			*****
Carbonate (CO ₃)	0	ppm	Ti			*****
Bicarbonate (HCO ₃)	0.19	ppm	Ti			*****
Sulfate (SO ₄)	0.28	ppm	ICP			*****
Chloride (Cl)	0.27	ppm	ICP			*****
Nitrate (NO ₃ -N)	0.27	ppm	ICP			*****
Ammonia (NH ₄ -N)	0.27	ppm	ICP			*****
Phosphate (P)	0.27	ppm	ICP			*****
pH	8.23		tit			*****
Conductivity	880	microhm/cm	Cond			*****
Hardness	0	grains CaCO ₃ /gallon	Calc			*****
Alkalinity	1	ppm CaCO ₃	Calc			*****
Total Dissolved Solids (TDS)	312	ppm	Calc			*****

Water Analysis from Texas A&M Soil, Water and Forage Testing Laboratory
<https://soiltesting.tamu.edu/>

Water Source: [Redacted] Water Use: Irrigation

Parameter analyzed	Results	Units	Method	Y. Limiting	Limiting	Acceptable
Calcium (Ca)	1	ppm	ICP			*****
Magnesium (Mg)	1	ppm	ICP			*****
Sodium (Na)	154	ppm	ICP			*****
Potassium (K)	1	ppm	ICP			*****
Sulfate (SO ₄)	0.28	ppm	ICP			*****
Carbonate (CO ₃)	0	ppm	Ti			*****
Bicarbonate (HCO ₃)	0.19	ppm	Ti			*****
Sulfate (SO ₄)	0.28	ppm	ICP			*****
Chloride (Cl)	0.27	ppm	ICP			*****
Nitrate (NO ₃ -N)	0.27	ppm	ICP			*****
Ammonia (NH ₄ -N)	0.27	ppm	ICP			*****
Phosphate (P)	0.27	ppm	ICP			*****
pH	8.23		tit			*****
Conductivity	880	microhm/cm	Cond			*****
Hardness	0	grains CaCO ₃ /gallon	Calc			*****
Alkalinity	1	ppm CaCO ₃	Calc			*****
Total Dissolved Solids (TDS)	312	ppm	Calc			*****
Salinity	21.1		Calc	*****		
Iron (Fe)						
Zinc (Zn)						
Copper (Cu)						
Manganese (Mn)						
Aluminum (Al)						
Barium (Ba)						
Nickel (Ni)						
Cadmium (Cd)						
Lead (Pb)						
Chromium (Cr)						
Fluoride (F)						
Charge Balance (percent error)	100		Calc			

Effects on Plants

Plants vary in their “sensitivity” and “tolerance” to salinity

Short-term effects:

- Leaf tip and marginal leaf burn
- Bleaching (discoloration)
- Defoliation

Long-term effects:

- Decreased osmotic pressure – water flows out of the plant to achieve equilibrium

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Foliar Salt Damage

Increases with higher salinity concentrations in irrigation water

Plants more susceptible to damage if irrigation is:

- Applied during high ET hours
- Applied overhead (foliar spray)
- Applied frequently in light amounts

(Miyamoto, 2002)

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Relative Tolerances of Common Turfgrass Species to Soil Salinity

Sensitive (<3 dS/m)	Moderately Sensitive (3 to 6 dS/m)	Moderately tolerant (6 to 10 dS/m)	Tolerant (>10 dS/m)
Annual bluegrass	Annual ryegrass	Perennial ryegrass	Alkaligrass
Colonial bentgrass	Creeping bentgrass	Tall fescue	Bermudagrasses
Kentucky bluegrass	Fine-leaf fescues	Zoysiagrasses	Seashore paspalum
Rough bluegrass	Buffalograss		St. Augustinegrass

Adapted from Table 2 (Harivandi, 1999)

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Effects on Soils

Surface sealing

- Phenomenon occurs when salts “precipitate” on the surface of the soil as water evaporates, leaving the surface in an impermeable, crust-like state
- Drastically reduces infiltration rate
- As water ponds, then evaporates, salt accumulation continues
- Common in arid southwestern U.S.

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Effects on Soils

Root zone accumulation

- High salinity concentrations around plant roots can dehydrate plants by reversing osmotic conditions
- Water will flow out of the plant in an attempt to achieve equilibrium
- Can disrupt normal nutrient uptake of the plant

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Effects on Plants

The rate of salt accumulation in the soil depends upon:

- Concentration in the irrigation water
- The amount of water applied
- Precipitation patterns
- Evaporation rates
- Soil condition (texture/structure/compaction)
- Chemical characteristics

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Effects on Receiving Waters

Runoff containing high salt concentrations can create saline layers in receiving waters (lakes, ponds, etc.)

Saltwater has a higher density than freshwater, thus sinks to form a dense layer at the bottom – “*hypolimnion*”

The saline layer does not mix with the remainder of the lake, decreasing the dissolved oxygen levels in the hypolimnion

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Permissible Limits for Irrigation Water

Classes of Water	Concentration, total dissolved solids	
	Electrical Conductivity (umhos/cm)	Gravimetric (ppm)
Excellent	250	175
Good	250 – 750	175 – 525
Permissible ¹	750 – 2,000	525 – 1,400
Doubtful ²	2,000 – 3,000	1,400 – 2,100
Unsuitable ²	3,000	2,100

¹Leaching needed.

²Good drainage needed and sensitive plants will have difficulty

Adapted from Table 4 (Fipps, 2003)

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Sodium Effects on Plants

Most plants take up sodium through their roots where it accumulates in the leaves

Some plants absorb sodium through leaf surfaces

Sodium accumulation in some plants results in marginal scorching and defoliation

Because turfgrasses are mowed frequently (removing leaf tissue) sodium accumulation is usually not a problem

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Sodium Accumulation in Soils

Excess sodium can lead to a breakdown of clay particles in the soil (deflocculation)

- Clogs the soil's pore spaces
- Reduces air movement
- Reduces percolation rates

Generally a problem in clay and loam soils

A black crust on the soil surface is one sign of a sodic soil

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Sodium Adsorption Ratio (SAR)

Used to determine the likelihood that sodium present in irrigation water will affect soil permeability

Dependent upon the water's:

- Sodium concentration (Na)
- Calcium concentration (Ca)
- Magnesium concentration (Mg)

Ca and Mg tend to counter the effects of Na

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Sodium Adsorption Ratio (SAR)

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

Na = Sodium ion concentration (milliequivalents, meq)

Ca = Calcium ion concentration (milliequivalents, meq)

Mg = Magnesium ion concentration (milliequivalents, meq)

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Example: SAR

Na⁺ = 13 meq
 Ca⁺⁺ = 150 meq
 Mg⁺⁺ = 83 meq

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

$$SAR = \frac{13}{\sqrt{\frac{150 + 83}{2}}}$$

$SAR = 1.2$

Sodium Hazard of Water

SAR Values	Sodium Hazard of Water	Comments
1 – 10	Low	Use caution on sensitive plants
10 – 18	Medium	Amendment/leaching needed
18 – 26	High	Generally unsuitable for continuous use
>26	Very high	Generally unsuitable for use

Adapted from Table 5 (Fipps, 2003)

Parameter analyzed	Results	Units	Method	V. Limiting	Limiting	Acceptable
Calcium (Ca)	1	ppm	ICP			*****
Magnesium (Mg)	1	ppm	ICP			*****
Sodium (Na)	134	ppm	ICP			*****
Potassium (K)	1	ppm	ICP			*****
Boron (B)	0.26	ppm	ICP			*****
Carbonate (CO ₃)	0	ppm	Tit			*****
Bicarbonate (HCO ₃)	073	ppm	Tit			*****
Sulfate (SO ₄)	38	ppm	ICP			*****
Chloride (Cl)	43	ppm	Tit			*****
Nitrate-N (NO ₃ -N)	0.27	ppm	CA-100			*****
Phosphorus (P)	0.07	ppm	ICP			*****
pH	6.23		tit			*****
Conductivity	682	microhm/cm	Cond			*****
Hardness	0	grams CaCO ₃ /gallon	Calc			*****
Hardness	7	ppm CaCO ₃	Calc			*****
Alkalinity	223	ppm CaCO ₃	Calc			*****
Total Dissolved Solts (TDS)	012	ppm	Calc			*****
SAR	21.6		Calc	*****		
Iron (Fe)						
Zinc (Zn)						
Copper (Cu)						
Manganese (Mn)						
Artenic (As)						
Barium (Ba)						
Nickel (Ni)						
Calcium (Ca)						
Lead (Pb)						
Chromium (Cr)						
Fluoride (F)						
Charge Balance	100		Calc			

Interaction of Salts and Sodium

Salts and sodium do not act independently in soil
 The negative effects of soil particle dispersion (permeability) are counteracted by high soluble salt concentration
 Assess water's sodium hazard in conjunction with salinity levels

Interpreting Na Effect on Soil Infiltration

Soil Infiltration	Degree of restriction on use		
	None	Slight to Moderate	Severe
If SAR = 0 to 3 & ECw =	> 0.7	0.7 to 0.2	< 0.2
If SAR = 3 to 6 & ECw =	> 1.2	1.2 to 0.3	< 0.3
If SAR = 6 to 12 & ECw =	> 1.9	1.9 to 0.5	< 0.5
If SAR = 12 to 20 & ECw =	> 2.9	2.9 to 1.3	< 1.3
If SAR = 20 to 40 & ECw =	> 5.0	5.0 to 2.9	< 2.9

SAR = Sodium absorption ratio
ECw = Electrical conductivity (dS/m)

Adapted from Table 3 (Harivandi, 1999)

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Management Strategies

- Leaching
- Deep-tine aeration
- Gypsum applications
- Salt-tolerance plants
- Acid-based water treatment
- Irrigation design
- Irrigation scheduling
- Water and soil quality monitoring

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Leaching

Additional water applied in excess of plant water needs for the purpose of flushing soluble salts beyond the plant's root zone

Basic management tool for controlling salinity

Leaching amounts and intervals depend upon the severity of the salinity problem and salt tolerance of the plant

In some regions, normal rainfall provides adequate leaching

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Leaching Fraction

Leaching fraction is an additional amount of irrigation needed to flush salts beyond the root zone)

$$L = \frac{C_e}{C_l - C_e}$$

C_e = Electrical conductivity of the irrigation water (or effluent) (mmhos/cm or dS/m)

C_l = Maximum allowable conductivity of soil solution (mmhos/cm or dS/m)

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Relative Tolerances of Turfgrass Species to Soil Salinity (C_i)

Sensitive (<3 dS/m)	Moderately sensitive (3 to 6 dS/m)	Moderately tolerant (6 to 10 dS/m)	Tolerant (>10 dS/m)
Annual bluegrass	Annual ryegrass	Perennial ryegrass	Alkaligrass
Colonial bentgrass	Creeping bentgrass	Tall fescue	Bermudagrasses
Kentucky bluegrass	Fine-leaf fescues	Zoysiagrasses	Seashore Paspalum
Rough bluegrass	Buffalograss		St. Augustinegrass

Adapted from Harivandi, 2009.

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Calculating Leaching Fraction

Given:

- Electrical conductivity of irrigation water (effluent) = 2.0 dS/m
- Annual ryegrass (maximum allowable conductivity of soil solution = 6 dS/m)

Find:

- Leaching fraction

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Calculating Leaching Fraction (continued)

$$L = \frac{C_e}{C_i - C_e}$$

L = Leaching requirement (inches)

C_e = 2.0 dS/m

C_i = 6 dS/m

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Calculating Leaching Fraction

$$L = \frac{C_e}{C_i - C_e}$$

$$L = \frac{2.0}{6 - 2.0}$$

$$L = 0.5$$

Leaching fraction = 0.5 (50%)

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Leaching Requirement

$$L = \frac{C_e}{C_l - C_e} \times ET$$

ET = plant evapotranspiration (inches)

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Leaching Requirement

Weekly ET = 1 inch

Leaching fraction = 0.5

$$L = \frac{C_e}{C_l - C_e} \times ET$$

$$L = 0.5 \times 1$$

Leaching requirement = 0.5 inches

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Bringing it together ...

Irrigation requirement = (Plant ET + Leaching)

Weekly ET = 1 inch

Weekly leaching = 0.5 inch

Irrigation requirement = 1.5 inches

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Aeration

Physical process of creating holes in the soil to allow better infiltration and air movement through the soil surface layer

Aeration Methods:

- Hollow tines – remove cores
- Open spoons
- Spikes
- Deep-tines – (coring, spiking, drilling)
- Water injection systems
- Soil shattering units

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Gypsum Applications

Calcium Sulfate - CaSO_4

Ca replaces Na on clay soil particles improving structure, infiltration and air movement

Improvement in soil condition may take several years

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Irrigation Design

Pressure regulation – to prevent excessive misting and wind drift losses

Proper sprinkler spacing – to prevent uneven distribution uniformity

Maximize use of available flow rate – to enable irrigation with limited watering windows

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Irrigation Management

SMART irrigation control technology

- ET-based
- Soil moisture sensor based

Water budgeting and water use tracking

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Water and Soil Quality Monitoring

Irrigation quality testing plan

Soil quality testing plan

Recordkeeping

Leaching protocol

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Section 4: Real-time Irrigation Management

CONCEPTS

IRRIGATION SCHEDULING

SOIL MOISTURE SENSORS AND ET CONTROLLERS

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Irrigation Management Concerns

Preventing runoff into State waters (streams, rivers, lakes, etc.)

Avoiding irrigation during wet or saturated conditions

Managing irrigation applications to prevent soil contamination buildup

Preventing foliar damage to landscape plants

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Important Concepts

Precipitation rate (application rate)

Distribution uniformity

Soil infiltration rate

Soil water holding capacity

Leaching requirement

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Precipitation Rate

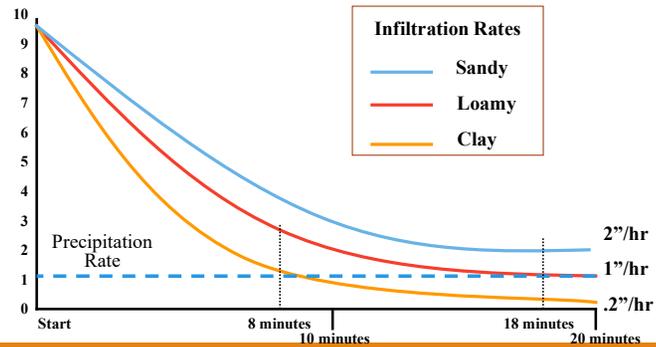
Defines how fast a the irrigation system applies water in inches per hour

May be different for individual station and zones in a landscape irrigation system

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Typical Infiltration vs. Precipitation Rates



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How is precipitation rate determined?

Area/flow (design) method – “estimated” based upon flow rate and coverage area

Meter method – calculated from the recorded amount of water applied over an area

Catch can method – measures the “average” amount of water applied

Manufacturer Specifications - based upon nozzle size of water applicator, spacing, pressure (and position for center pivots)

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Area/Flow (design) Method

Used to establish a “design” precipitation rate

Based on:

- Flow rate (GPM)
- Estimated Irrigated Area (Ft²)

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Basic Precipitation Rate Equation

$$PR = \frac{GPM \times 96.25}{A}$$

PR – precipitation rate (inches per hour)

GPM – flow rate (gallons per minute)

96.25 - Constant, coverts gallons and square feet to inches and minutes to hours

A – coverage area (square feet)

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Manufacturers Nozzle Performance Charts

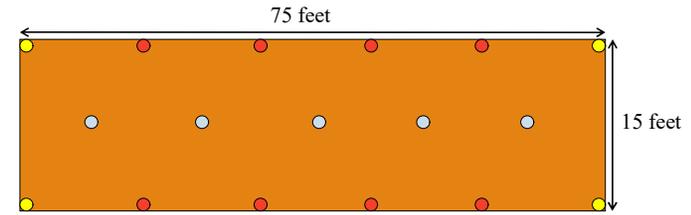
Spray radius and flow vary with pressure
 Precipitation rate assumes head-to-head coverage
 Performance data taken in zero wind conditions

20' Spray	Pressure psi	Radius Ft.	Flow gpm	Precip. in/h	Precip. in/h
15F	15	11	2.60	2.07	2.39
	20	12	3.00	2.01	2.32
	25	14	3.30	1.62	1.87
	30	15	3.70	1.58	1.83
15H	15	11	1.30	2.07	2.39
	20	12	1.50	2.01	2.32
	25	14	1.65	1.62	1.87
	30	15	1.85	1.58	1.83
15Q	15	11	0.65	2.07	2.39
	20	12	0.75	2.01	2.32
	25	14	0.82	1.62	1.87
	30	15	0.92	1.58	1.83

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Example: Area/Flow Method



- Quarter-circle = 0.5 GPM
- Half-circle = 1 GPM
- Full-circle = 2 GPM

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Example: Area/Flow Method

$$PR = \frac{GPM \times 96.25}{A}$$

Total GPM

- 4 quarter-circle heads x 0.5 GPM = 2 GPM
- 8 half-circle heads x 1 GPM = 8 GPM
- 5 full-circle heads x 2 GPM = 10 GPM

Total = 20 GPM

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Example: Area/Flow Method

$$PR = \frac{GPM \times 96.25}{A}$$

Total Area (A):

- For a rectangular area, A = length x width
- Length = 75 feet
- Width = 15 feet

A = 75 x 15, or **1,125 square feet**

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Example: Area/Flow Method

$$PR = \frac{GPM \times 96.25}{A}$$

$$PR = \frac{20 \times 96.25}{1,125}$$

PR = 1.71 inches per hour

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Precipitation Rate using the Meter Method

Utilizes water meter readings and coverage area

Measures "gross" precipitation rate

Does not account for water loss due to leaks, wind drift, and evaporation



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Calculating Precipitation Rate

$$PR = \frac{GPM \times 96.25}{A}$$

GPM is measured at flow meter

Area (A) is measured by using area equations for basic shapes (circle, square, rectangle)

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Guidelines for Measuring Flow Rate

Understand the units of measure (gallons, 1000 gallons, cubic feet, 100 cubic feet, etc.)

Before test, make sure meter is not measuring flow

During test, make sure there are no other downstream users

Perform a test run to ensure proper interpretation of flow

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Options for Testing Flow Rate

Track volume of water discharged over a specific time

- Turn on station
- After flow has stabilized, mark "Time 1", record meter reading
- Wait one minute, mark "Time 2", record meter reading
- Repeat if necessary
- Calculate gallons per minute

Flow Rate Test	
Zone (Station) #:	1
Reading at "TIME 1" 0 minutes	346000
Reading at "TIME 2" 1 minute	346040
Flow Rate (40 gallons ÷ 1 minute)	40 GPM

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Options for Testing Flow Rate

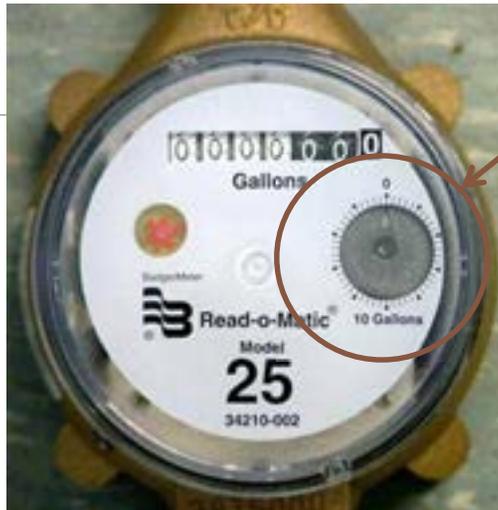
Track time needed to discharge a certain volume of water

- Turn on system, let flow stabilize
- Start stopwatch when meter dial is on known volume (e.g. "0")
- Let system run until dial has completed a known volume (e.g. one full rotation)
- Stop stopwatch and record time
- Calculate flow rate

Flow Rate Test	
Zone (Station) #:	1
Initial reading (gallons):	346000
Final reading (gallons):	346010 (1 full rotation)
Time expired:	30 seconds, 0.5 minutes
Flow Rate (10 gallons ÷ 0.5 minutes)	20 GPM

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1 rotation =
10 gallons

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Guidelines for Measuring Area

Sketch the landscape

Note the position of sprinkler heads and delineate individual stations

Use a tape measure or measuring wheel to measure dimensions

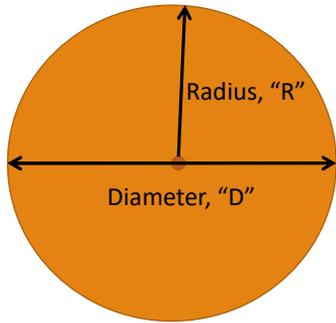
Approximate coverage areas into basic geometric shapes

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Area Equations for Basic Shapes

Circle



$$Area = 3.14 \times R^2$$

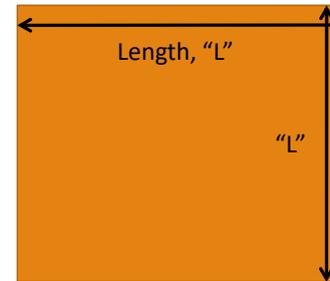
$$Area = \frac{3.14 \times D^2}{4}$$

249

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Area Equations for Basic Shapes

Square



$$Area = L \times L$$

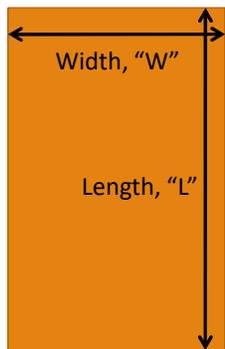
$$Area = L^2$$

250

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Area Equations for Basic Shapes

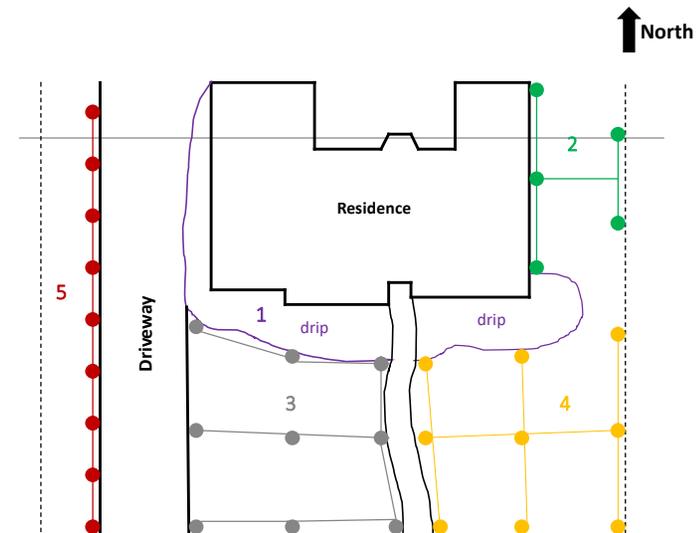
Rectangle



$$Area = L \times W$$

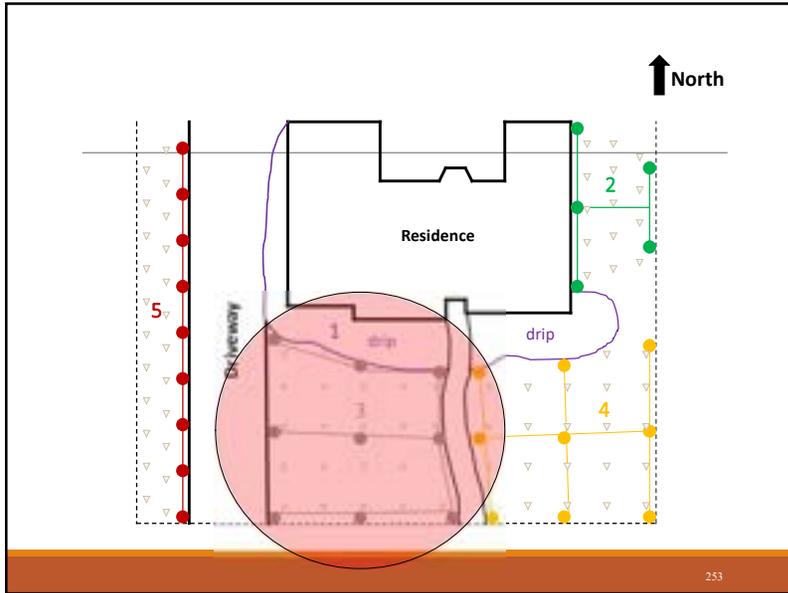
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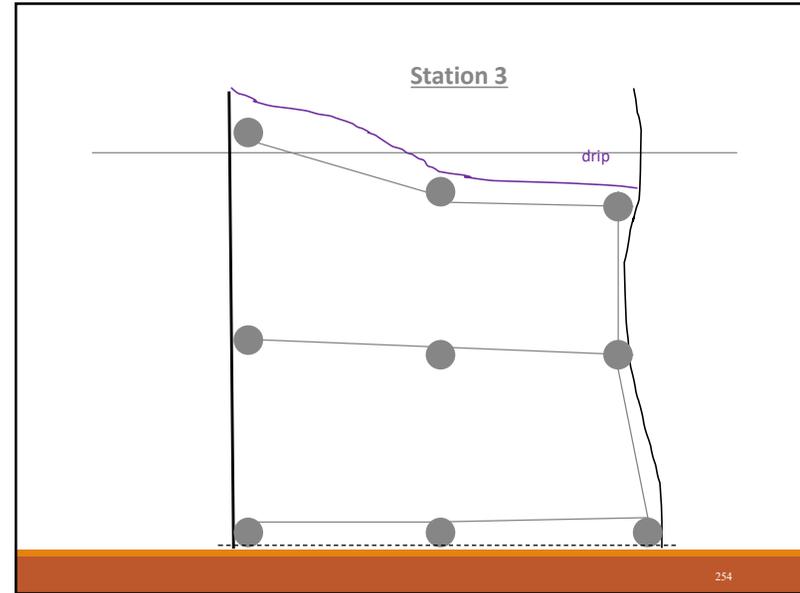


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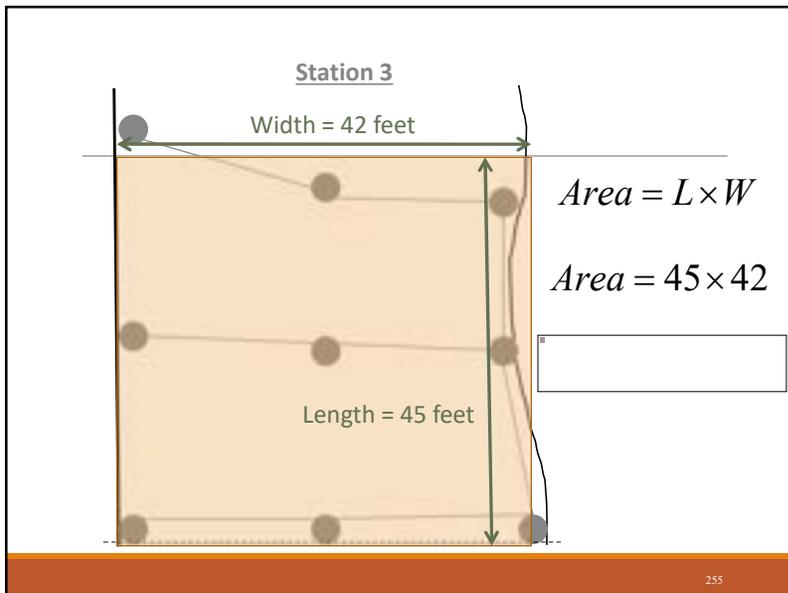
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Meter Method Review

$$PR = \frac{GPM \times 96.25}{A}$$

GPM from water meter readings (method of recording flow may vary)

Area (A) from station dimensions using common geometric shapes

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Catch Can Method

Most accurate method of determining station precipitation rate

Indicates how well water is distributed throughout coverage area

Requires multiple catch devices (cans)

Measurements can be either a depth (inches) or a volume (milliliters)

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Catch Can



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Catch Can Layout

Can be used for most sprinklers and center pivot applicators

Minimum recommendation for catch can layout is at a head and halfway between the heads

- At a head does not mean directly next to it, usually 10% of the throw away from the head

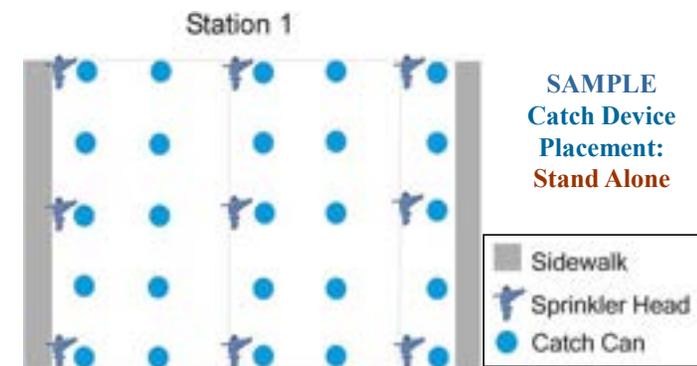
Try to maintain a "grid-like" pattern

With all the catch cans about equally spaced

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Catch Device Placement – Landscape irrigation, Stand-Alone Station



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Catch Can Placement



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Basic PR Equations

Readings in Milliliters

Readings in Inches

$$PR = \frac{\sum V \times 3.6612}{n \times a_i \times t_R}$$

$$PR = \frac{\sum D \times 60}{n \times t_R}$$

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Efficiency

Application efficiency – accounts for wind drift and evaporation losses

Distribution efficiency (uniformity) – how uniformly water is applied over a landscape

Overall system efficiency – factors include conveyance losses, application efficiency and distribution efficiency

Water management efficiency – applying the right amount of water, when you need it

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Distribution Uniformity (DU) (%)

Ratio: dry vs. wet areas

Based on irrigation system hardware

Easy to measure using catch devices

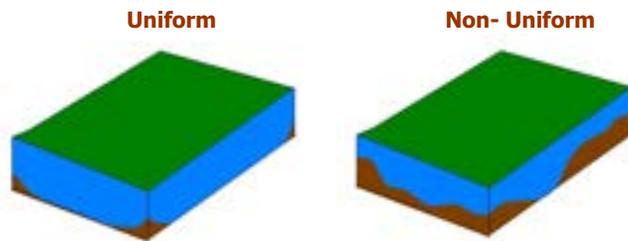
Limiting factor when producing good schedules

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Uniformity

Water Depths in Soil After Application



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What factors determine DU?

- Spray distribution profile of individual nozzles
- Wind distortion at the time of operation
- Spacing patterns and distance between sprinklers
- Operating pressure
- Speed of rotation
- Hardware problems (i.e., clogged nozzles, head misalignment, and sprinkler head rotation problems)

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Why is distribution uniformity important?

Systems with poor DU:

- must be operated longer to ensure "dry" areas get enough water (this may lead to ponding and runoff in some areas)
- lead to plant stress from over- and under-watering
- wastes water (must overwater some areas to ensure all areas get enough water)

Poor DU can lead to isolated areas of salt accumulation

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What can be done to minimize DU problems?

- Ensure matched precipitation rate nozzles within individual stations.
- Use proper sprinkler spacing and operating pressure according to manufacturers' product recommendations
- Utilize and maintain proper nozzle filtration
- Periodic inspection of system performance

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Catch Can Testing Procedures for Center Pivots

ASABE Standard Exists

ANSI/ASABE S456.2 JUN2020 (R2024)
Field Test Procedure for Determining Irrigation Water Distribution Uniformity of Center Pivot and Lateral Move Systems



Real-Time Irrigation Water Management

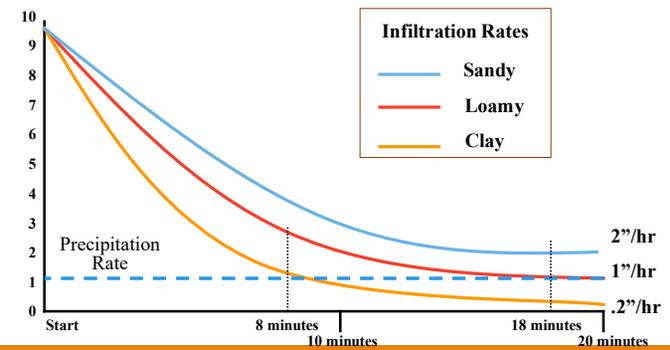
Soil Infiltration Rate

The rate at which water enters the soil surface

Influenced by:

- Antecedent moisture conditions (drier soils tend to accept water more rapidly than wet soils, with exceptions)
- Soil type/texture/structure
- Vegetative surface conditions
- Surface salinity concentration (sealing effect)

Typical Infiltration vs. Precipitation Rates



Infiltration Rate Concerns

Sandy soils (high infiltration rates)

- Must be careful not to apply too much water that can percolate below the root zone)

Clay soils (low infiltration rates)

- Must manage irrigation cycles to prevent ponding and surface runoff

Infiltration rates may change considerable over time with compaction and salt accumulation without leaching

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Double-Ring Infiltrometer



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Soil Water Holding Capacity

- Defines the amount of water that is available in the soil (inches water per foot of soil)
- Clays have high SWHC, sands have low SWHC
- Helps determine irrigation frequency

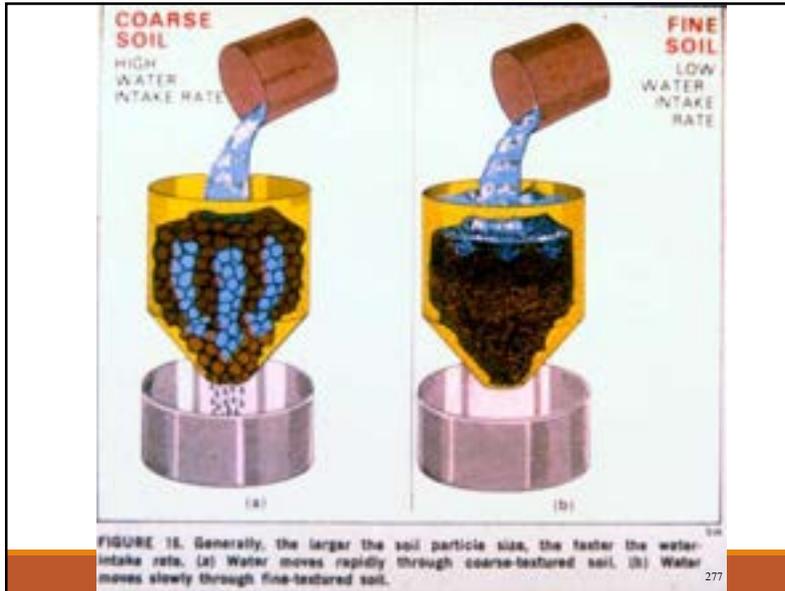
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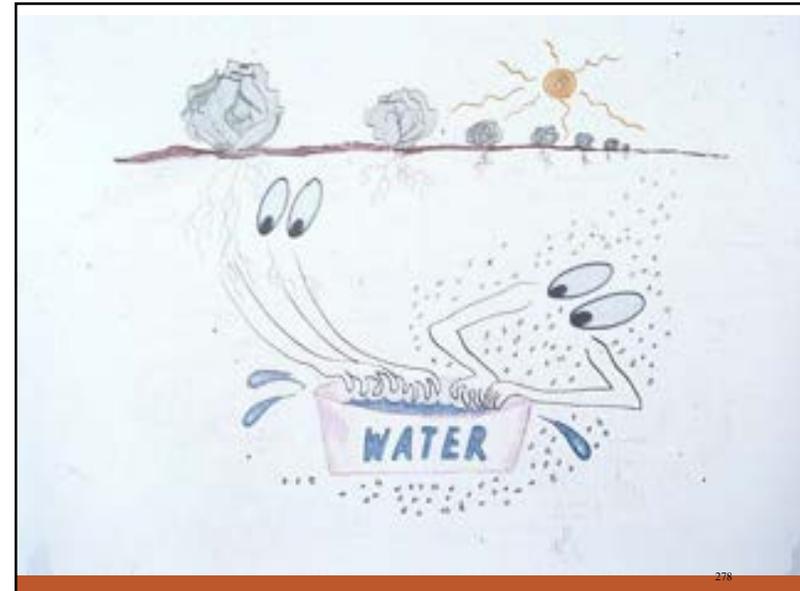


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Typical Water Holding Capacity (inches of water per foot of soil)

Soil Texture	At Field Capacity	At Permanent Wilting Point	Soil Water Holding Capacity	Plant Available Water (@ MAD = 50%)
Sand	1.0-1.4	0.2-0.4	0.8-1.0	0.45
Sandy Loam	1.9-2.3	0.6-0.8	1.3-1.5	0.70
Loam	2.5-2.9	0.9-1.1	1.6-1.8	0.85
Silt Loam	2.7-3.1	1.0-1.2	1.7-1.9	0.90
Clay Loam	3.0-3.4	1.1-1.3	1.9-2.1	1.00
Clay	3.5-3.9	1.5-1.7	2.0-2.2	1.05

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Effective Root Zone

The depth containing about 80% of the total root mass

Excludes "tap" and "feeder" roots

Easily measured with a soil probe



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Managed Allowable Depletion (MAD)

Percentage of water within the *effective* root depth allowed to deplete between irrigation events

Influences irrigation frequency

50% MAD is typically used for irrigation scheduling purposes

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Plant Available Water for Three Root Zone Depths at 50% MAD

Soil Texture	Soil Water Holding Capacity (in. water per ft. soil)	Available Water @ 50% MAD (in. water per ft. soil)	Available Water @ 50% MAD (in. water per in. soil)	Total Plant Available Water (inches)		
				2" root zone	4" root zone	6" root zone
Sand	0.90	0.45	0.038	0.08	0.15	0.23
Loam	1.70	0.85	0.071	0.14	0.28	0.48
Clay	2.10	1.05	0.088	0.18	0.35	0.53

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Factors that Influence Soil-Water Holding Capacities

Soil type/texture

Soil structure

Effective root zone depth

Excessive sodium concentration (deflocculates clay soil particles)

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Irrigation Scheduling Factors

Plant water requirements

- Seasonal evapotranspiration rates
- Microclimate adjustments

Soil and root zone limitations

- Soil water holding capacity
- Infiltration rate

Sprinkler system performance

- Precipitation rate

Leaching requirements

- May be regular or periodic depending on rainfall patterns

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Determining Weekly Irrigation Need

Step	Variable	Value	Units
1	Reference evapotranspiration (ET _o)	6	Inches per month
2	Crop coefficient (K _c)	0.6	Decimal
3	Adjustment factor (A _f)	0.8	Decimal
4	Monthly plant water requirement	2.88	Inches (#1 x #2 x #3)
5	Leaching requirement	0.58	Inches (#4 x 0.2) LF = 0.2
6	Total monthly irrigation need	3.46	Inches (#5 + #6)
7	Total weekly irrigation need	0.87	Inches (#6 ÷ 4)

Leaching Fraction (LF) calculated separately based upon irrigation quality test results.

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Determining Irrigation Frequency

Step	Variable	Value	Units
7	Total weekly irrigation need	0.87	Inches (#6 ÷ 4)
8	Effective root zone depth (D)	6	Inches
9	Soil water holding capacity (SWHC)	1.7	Inches H ₂ O/ft soil (loam)
10	Managed allowable depletion (MAD)	0.5	Decimal (MAD for turf = 50%)
11	Plant available water (PAW)	0.43	Inches (#7/12 x #8 x #9)
12	Irrigation frequency (I)	2	Whole number (#7 ÷ #11)

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Determining Station Run Time

Step	Variable	Value	Units
7	Total weekly irrigation need	0.87	Inches (#6 ÷ 4)
12	Irrigation frequency (I)	2	Whole number (#7 ÷ #11)
13	Precipitation rate	1.5	Inches per hour
14	Station run time	17	Minutes per irrigation event (#7 x 60) ÷ (#12 x #13)

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Section 5: Soil Sampling and Nutrient Loading

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Value of Reclaimed Water

Reclaimed water commonly contains small amounts of elements beneficial for plant growth

- Nitrogen
- Phosphorus
- Potassium
- Calcium
- Magnesium
- Manganese
- Zinc
- Boron

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Plant Nutrient Uptake

Depends upon:

- Concentration of nutrients in reclaimed water
- Amount of reclaimed water applied
- Residence time of reclaimed water in root zone
- Environmental factors

Turfgrasses are relatively efficient in extracting nutrients from reclaimed water

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How often should you sample?

May be dictated by local permitting authority

At least twice per year for nutrients

- Beginning of growing season
- End of growing season

May need more frequent sampling if salinity is a major issue

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Soil Sampling Supplies

Sampling containers

- Sample bags for this purpose are available from testing labs
- Plastic bags and other containers acceptable

Sampling tools

- Trowels
- Spades
- Augers
- Core samplers

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Sampling Process

Take multiple samples from various location throughout the landscape

- Small lawns and landscape (5 to 6 samples)
- Sports fields and large landscapes (8 to 10 samples)
- Golf courses (10 to 15 samples)

Combine all samples into 1 composite sample of at least 1 pint of soil

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Sample Depth

Sample from a depth within the plant's effective root zone

Depend upon normal root growth characteristics and soil type

Typical root depth for turfgrasses is 4 to 6 inches in good soil for most landscapes

Deep-rooted perennials may have deeper root depths

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Storage and Submission of Samples

Samples should not be stored for a long period of time prior to shipping to the lab

- Levels of nitrate-nitrogen may change if samples are stored wet

Do not oven dry samples

Air drying samples in the shade on clean brown paper is recommended

If possible, submit soil sample in original sample container

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Typical Analysis Options

Routine (pH, salinity, nitrates, primary nutrients) with basic N-P-K fertilizer recommendations

Micronutrients (Zn, Fe, Mn, Cu)

Boron

Detailed Salinity (EC, soluble salts, SAR)

Lime requirement to raise pH

Soil texture and organic matter content

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Calculating Nutrient Contribution from Reclaimed Water

Step 1: Find specific nutrient concentration from water quality report (in mg/l or ppm)

Step 2: Multiply this number by 2.71 (converts mg/l to lbs/acre-feet)

Step 3: Divide step 2 number by 43.56 (converts lbs/acre-feet to lbs/1,000 ft²)

This is how much of the nutrient is applied for each foot of irrigation water. You must adjust for different irrigation depths.

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Example: Calculating Nutrient Contribution from Reclaimed Water

Given:

Water Analysis Report	
Nutrient	Concentration (ppm)
Nitrogen (N)	30
Phosphorus (P)	10
Potassium (K)	20

Remember: 1 ppm = 1 mg/l

Find:

If 6 inches of water is applied over the summer, how many pounds of N, P and K per 1,000 square feet were applied?

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Nitrogen (N)

Step 1:

- N concentration = 30 mg/l

Step 2:

- 30 mg/l x 2.71 = 81.3 lbs. N/acre-foot

Step 3:

- 81.3 lbs. N/acre-foot ÷ 43.56 =

$$\text{Application Rate of N} = \frac{1.87 \text{ lbs. N}}{1,000 \text{ ft}^2} \quad (\text{for every 1 ft of water applied})$$

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Nitrogen (N)

Adjust from 12 to 6 inches of water applied

$$\text{Application Rate of N} = \frac{1.87 \text{ lbs. N}}{1,000 \text{ ft}^2} \quad (\text{for every 12'' of water applied})$$

$$\text{Application Rate of N} = \frac{1.87 \text{ lbs. N}}{1,000 \text{ ft}^2} \times \frac{6''}{12''}$$

$$\text{Application Rate of N} = \frac{0.93 \text{ lbs. N}}{1,000 \text{ ft}^2} \quad (\text{for every 6'' of water applied})$$

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Phosphorus (P)

Step 1:

- P concentration = 10 mg/l

Step 2:

- 10 mg/l x 2.71 = 27.1 lbs. P/acre-foot

Step 3:

- 27.1 lbs. P/acre-foot ÷ 43.56 =

$$\text{Application Rate of P} = \frac{0.62 \text{ lbs. P}}{1,000 \text{ ft}^2} \quad (\text{for every 1 ft of water applied})$$

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Phosphorus (P)

Adjust from 12 to 6 inches of water applied

$$\text{Application Rate of P} = \frac{0.62 \text{ lbs. P}}{1,000 \text{ ft}^2} \quad (\text{for every 12'' of water applied})$$

$$\text{Application Rate of P} = \frac{0.62 \text{ lbs. P}}{1,000 \text{ ft}^2} \times \frac{6''}{12''}$$

$$\text{Application Rate of P} = \frac{0.31 \text{ lbs. P}}{1,000 \text{ ft}^2} \quad (\text{for every 6'' of water applied})$$

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Potassium (K)

Step 1:

- K concentration = 20 mg/l

Step 2:

- 20 mg/l x 2.71 = 54.2 lbs. K/acre-foot

Step 3:

- 54.2 lbs. K/acre-foot ÷ 43.56 =

$$\text{Application Rate of K} = \frac{1.24 \text{ lbs. K}}{1,000 \text{ ft}^2} \quad (\text{for every 1 ft of water applied})$$

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Potassium (K)

Adjust from 12 to 6 inches of water applied

$$\text{Application Rate of K} = \frac{1.24 \text{ lbs. K}}{1,000 \text{ ft}^2} \quad (\text{for every 12'' of water applied})$$

$$\text{Application Rate of K} = \frac{1.24 \text{ lbs. K}}{1,000 \text{ ft}^2} \times \frac{6''}{12''}$$

$$\text{Application Rate of K} = \frac{0.62 \text{ lbs. K}}{1,000 \text{ ft}^2} \quad (\text{for every 6'' of water applied})$$

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Example Summary

Nutrient	Measured Sample Concentration (ppm)	Amount Received for 6" Water Application (lbs. per 1,000 ft ²)
Nitrogen (N)	30	0.93
Phosphorus (P)	10	0.31
Potassium (K)	20	0.62

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