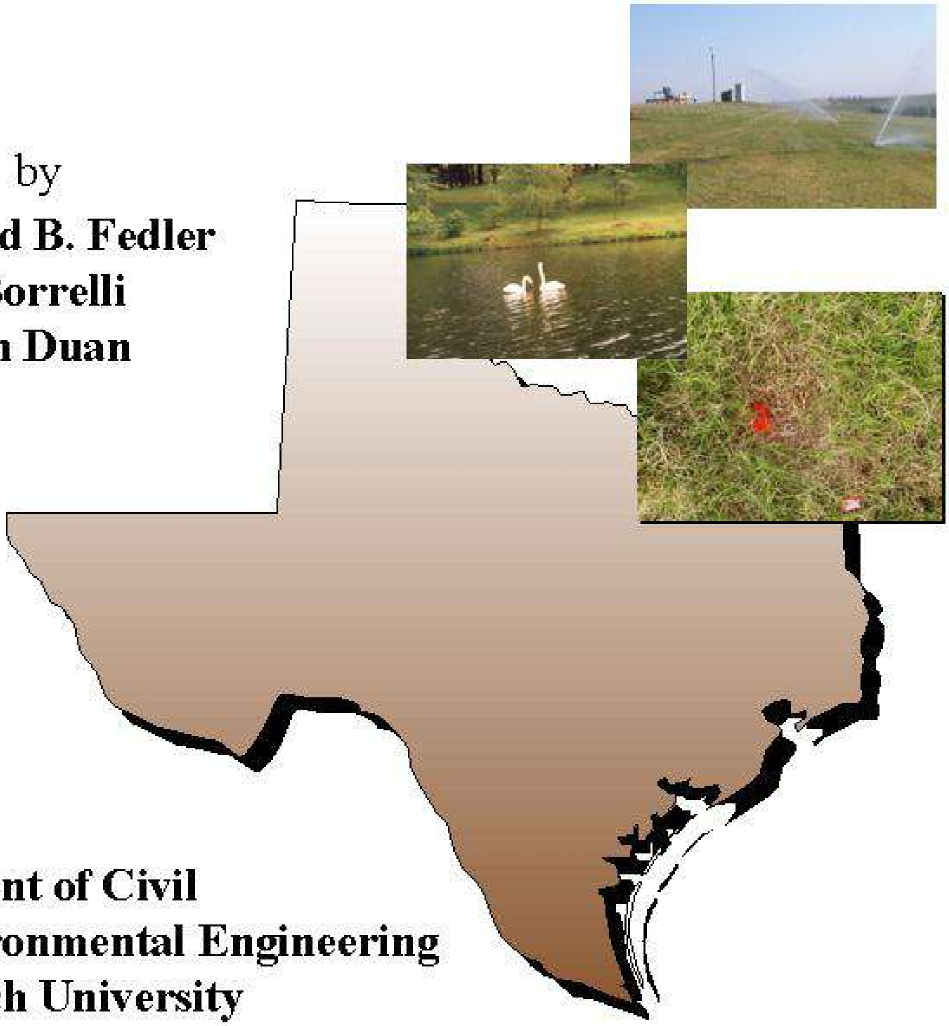
Manual for Designing Surface Application of OSSF Wastewater Effluent

by
Clifford B. Fedler
John Borrelli
Runbin Duan



Department of Civil
and Environmental Engineering
Texas Tech University
Lubbock, TX 79409-1023

Texas On-Site Wastewater Treatment
Research Council
Grant No. 582-8-88017
1 December 2009

Glossary of Terms

Application Rate: The amount of water applied to a given area measured in inches per hour.

Aeration System: The piping, diffusers, air source, vents, and all other necessary devices for an active aeration process (CIDWT, 2007)

Available Soil Moisture: Water in the root zone that can be extracted by plants. The available soil moisture is the difference between field capacity and wilting point (Hill, 1994).

Base Intake Rate: The almost constant rate that a soil will take in water after large cracks, pores and cavities are filled.

Consumptive Use: The total amount of water taken up by vegetation for transpiration or building of plant tissue, plus the unavoidable evaporation of soil moisture, snow, and intercepted precipitation associated with vegetal growth; synonymous with evapotranspiration (Jensen et al., 1990).

Design: The process of selecting, sizing, locating, specifying, and configuring treatment train components that match site characteristics and facility use as well as creating the associated written documentation (CIDWT, 2007).

Distribution Pattern: The pattern of water application by a sprinkler over the area the sprinkler covers. The area is generally circular in form; synonymous with sprinkler pattern.

Distribution, spray: The application of effluent over an infiltrative surface via pressurized nozzles and associated devices and parts (including pump, filters, controls and piping) (CIDWT 2007).

Drainage: A network of natural or artificial groundwater or surface water features including agricultural drain tile, cut banks, and ditches which intercept and divert surface water and/or lower groundwater (CIDWT, 2007).

Dwelling: A structure or building, or any portion thereof which is used, intended, or designed to be occupied for temporary or permanent human living purposes including, but not limited to: houses, houseboats, mobile homes, motor homes, travel trailers, hotels, motels, and apartments (CIDWT, 2007).

Effective Rainfall: The amount of precipitation that infiltrates and is held in surface storage (CIDWT, 2007).

Evapotranspiration: The combined processes by which water is transferred from the earth surface to the atmosphere; evaporation of liquid or solid water plus transpiration from plants (Jensen et al., 1990).

Field Capacity: The moisture content of a soil following an application of water and after the downward movement of excess water (from gravitational forces) has essentially ended. Usually it is assumed that this condition is reached about two days after a full irrigation or heavy rain (Hill, 1994).

Floodplain (100-year): Any area susceptible to inundation by flood waters from any source and subject to the statistical 100-year flood; such an area has a 1 percent chance of flooding each year (CIDWT, 2007).

Floodway: A channel of a water course and the adjacent land areas (within a portion of the 100-year floodplain) that must be reserved in order to disdcharge the 100-year flood without cumulatively increasing the water surface elevation more than one foot above the 100-year flood elevation before encroachment into the 100-year floodplain (CIDWT, 2007).

Flow, average daily: The average volume of wastewater in a 24-hour period; calculated from values measured over a period of time (e.g., week, month, year, etc.) (CIDWT, 2007).

Flow, daily design: The estimated volume of wastewater for any 24-hour period; parameter used to size systems (CIDWT, 2007).

Flow, design: The estimated volume of wastewater per unit of time for which a component or system is designed (CIDWT, 2007).

Head to Head Spacing: Spacing of sprinklers so that the radius of the sprinkler match the spacing of the sprinklers. Also referred to a 100 percent coverage, head to head coverage or 100 percent overlap.

Head, total dynamic (TDH): The measure of the cumulative energy that a pump must impart to a liquid to move it from one point to another, consisting of the sum of friction head (as based upon pipe diameter , system configuration, and flow rate) and static head (the sum of elevation head and operating pressure) (CIDWT, 2007).

Hydraulic conductivity: A measurement of the flow of liquid through an area of the soil or porous media perpendicular to the flow direction (CIDWT, 2007).

Infiltration: The entry of water or effluent into the soil (CIDWT, 2007).

Influent: The liquid entering a component or device (CIDWT, 2007).

Irrigation Frequency: The maximum number of days that can be allowed between irrigations during periods of peak water use, without causing plants to suffer. Rainfall can change irrigation frequency requirements.

Irrigation Period: Refers to the number of days used to apply irrigation water in the volume needed for a given area during the peak consumptive water use period of the crop being irrigated.

Land application: The process in which biosolids or liquid waste treatment residuals are spread over, sprayed onto, or injected into the soil (CIDWT, 2007).

Lateral Lines: The lines equipped with sprinkler heads.

Leaching: The process of water movement through and below the crop root zone by gravitation. It occurs whenever the infiltrated irrigation water and rainfall exceed the crop evapotranspiration and the water storage capacity of the soil profile (SCS, 1993).

Loading rate, hydraulic: The quantity of water applied to a given treatment component, usually expressed as volume per unit of infiltrative surface area per unit time, e.g., gallons per day per square foot (gpd/ft^2) (CIDWT, 2007).

Main Lines: In sprinkler irrigation, they are the lines that convey the water from the supply line or water source to the lateral lines.

Nitrogen, total: The measure of the complete nitrogen content in wastewater including nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH3), ammonium (NH_4^+), and organic nitrogen, expressed as mg/l of N; all these forms of nitrogen, (as well as nitrogen gas (N_2), can be biochemically converted from one form to another and are constituents of the nitrogen cycle (CIDWT, 2007).

Operating Pressure Range: The range from minimum to maximum pressure under which the head will deliver designed distribution of water throughout it's entire area of coverage.

Overlap: The amount one sprinkler pattern overlaps another sprinkler pattern when installed in a specific pattern. Usually expressed as a percentage of the.

Permeability: The ability of a porous medium such as soil to transmit fluids (liquids or gases) (CIDWT, 2007).

Radius or Diameter of Throw: The actual distance, determined by the manufacture's testing, that a sprinkler head will spread water.

Riser: A length of pipe, affixed to a lateral line, sub-main or main water line, for the purpose of supporting a valve or sprinkler head; diameters of risers are normally less than that of the pipe-line and in the case of sprinklers should be from six inches to several feet in length to counteract the effect of turbulence caused when water is diverted from its original direction of flow. A nipple to which the sprinkler is attached.

Root Zone: The depth to which plant roots invade the soil and where water extraction occurs (Hill, 1994).

Runoff: The precipitation, snow melt, or irrigation in excess of what can infiltrate the soil surface in an area and thus flows on the surface (CIDWT, 2007).

Section: (noun) A group of heads and/or valves that operate as one station or a controller or at one time on a manual system.

Sets: Any area of a field that can be supplied water until the soil profile requirements are met and not exceeded before changing or moving the apparatus used for distributing or applying the irrigation water.

Spray field: The above-grade soil treatment area where final treatment and dispersal occurs via application of effluent to the infiltrative surface via pressurized distribution head utilizing nozzles (CIDWT, 2007).

Tank, dosing: A tank or compartment which provides storage of effluent and contains a devise (pump or siphon) and associated appurtenances used to convey effluent to another pretreatment process or a final treatment and dispersal component (CIDWT, 2007).

Underspaced: The unusual situation in which sprinkler heads are spaced closer than required for efficient operation of the system.

Wall-to-Wall Coverage: Indicates complete coverage of the area to be irrigated from one border to the other. This requires part circle border sprinkler heads for total coverage.

Water Application Efficiency: The ratio of the average depth of irrigation water infiltrated and stored in the root zone to the average depth of irrigation water applied, expressed as a percentage.

Wilting Point: The soil moisture content at which a plant can no longer obtain sufficient moisture to satisfy its requirements and, therefore, will wilt permanently (Hill, 1994).

List of Symbols

App_rate	The application rate for the selected sprinkler head operated at the selected pressure, inches/hr
Area	The design area for the spray field, ft^2
$Area_n$	The minimum area of the spray field assuming nitrogen is the land-limiting factor, ft^2
$Area_{hyd}$	The minimum area of the spray field assuming the intake rate of the soil or the hydraulic loading rate is the land-limiting factor, ft^2
C	Hazen-Williams pipe roughness factor
C_n	The estimated concentration of total nitrogen in the wastewater effluent, mg/l
D	The pipe inside diameter, inches
D_d	The annual depth of precipitation and irrigation that passes through the root zone, inches
D_{irr}	The depth of irrigation water being applied, inches
$D_{irr+rain}$	The sum of the irrigation applied plus the portion of the precipitation infiltrating the soil or precipitation minus runoff from precipitation, inches
D_{irrm}	The average monthly depth of irrigation, inches
D_w	The wetted diameter for a sprinkler head for a given orifice and operating pressure, ft
$Depth_{per\ day}$	The average daily depth of water applied to spray field, ft
E_a	The water application efficiency, percent
EC_{emax}	The estimated electrical conductivity of the average saturation extract of the soil root zone profile for an approximate 100 percent yield reduction, mmhos/cm
EC_{irr}	The electrical conductivity or the irrigation water or effluent, mmhos/cm
EC_w	The electrical conductivity of the water infiltrating the soil, mmhos/cm
ET_c	the crop (or vegetation being irrigated) evapotranspiration rate, inches

ET_{cm}	the average monthly evapotranspiration for the vegetation in the spray field, inches
ET_i	The evapotranspiration in month i, inches/mon
EC_{e10}	The estimated electrical conductivity of the average saturation extract of the soil root zone profile for an approximate 10 percent yield reduction, mmhos/cm
g	Gravitational acceleration, 32.2 ft/sec^2
hf	The friction headloss in the pipe, ft
hf_{total}	The friction loss in the lateral between the first and distal sprinkler heads, psi
i	The counter for the months.
I_i	The irrigation in month i, inches/mon
I_B	The base water intake rate (minimum) for the soil, inches/hr
K	The saturated hydraulic conductivity of the soil, inches/hr
L	Distance from the pump to the spray field or the connection to main line, ft
L	The length of the pipe, ft
L_i	The leaching that occurs in month i, inches/mon
LR	The leaching requirement ratio for sprinkle or surface irrigation, decimal
MAR	Maximum application rate for surface irrigation of treated effluent in Texas, gal/ft^2/day
n	The total number of observations for calculating the Christiansen Uniformity Coefficient
$N_{applied}$	The nitrogen applied to the spray field or portion of spray field, lb/yr
$N_{leached}$	Amount of nitrogen leaching below root zone of spray field or portion of spray field, lb/yr
No_{set}	The number of sets making up the sprinkler system
N_{used}	Amount of nitrogen used by crop in spray field or portion of spray field, lb/yr

N_y	The estimated yearly uptake of nitrogen by the vegetation proposed for the spray field, lb/acre/yr
No_{sb}	The number of spray blocks needed for spray field system
P	The annual precipitation for the site, inches
P_a	Average pressure in the lateral, psi
P_d	Desired operating pressure of sprinklers, psi
P_f	Friction loss in the lateral, psi
P_i	The average monthly precipitation, inches
$P_{inlet\ cont\ valve}$	The pressure at the inlet of the control valve, psi
P_n	Pressure at sprinkler head nearest the pump, psi
P_{net}	the average net annual precipitation, inches
P_o	Pressure at sprinkler head at distal end of lateral, psi
$P_{outlet\ cont\ valve}$	The pressure at the outlet of the control valve, psi
$P_{pump\ outlet}$	The pressure at the outlet of the pump, psi
P_{run}	The annual surface runoff of precipitation from the site, inches
P_{runm}	The average monthly depth of runoff from precipitation, inches
P_{supply}	The pressure at the supply line at the inlet of the tee, psi
PL_{minor}	The headloss caused by a fitting, ft
$PRESLOSS_{cont\ valve}$	The headloss caused by the control valve, psi
Q	The estimated daily volume of water to be applied, gal/day
Q_{endlat}	The total flow into the end laterals of the proposed sprinkler system, gpm
Q_{midlat}	The total flow into the middle lateral(s) of the proposed sprinkler system, gpm
Q_R	The maximum application rate adjusted for surface storage and time of application, inches/hr

Q_{set}	Average flow rate for all sets, gpm
Q_{spr}	Discharge rate from full-circle sprinkler head, gpm
S_l	The sprinkler spacing along the lateral, ft
S_m	The lateral spacing along the main, ft
SL	Elevation difference between the pump and the spray field, ft
SM_i	the soil moisture in month i, inches
SM_{i-1}	the soil moisture in the previous month, inches
SS	Maximum surface storage for sprinkler system, inches
T_A	Time of application of effluent on to the spray field, hr
T_d	Time required to drain the storage tank given the average flow rate for all sets, min
T_n	The estimated pounds of total nitrogen being applied as a constituent of the wastewater effluent, lb/yr
T_{set}	The normal time of application for the proposed sprinkler system, min
TDH	The total dynamic head which the pump will supply, ft
UCC	Christiansen's Uniformity Coefficient, percent
V	The pipe velocity, ft/sec
Vol	Volume of storage tank between the alarm-on level and the pump-on level, gal
$Vol_{per\ day}$	The design daily volume of effluent, ft^3
X	X is the fraction of area having a dimensionless depth of Y or less
X_i	The i^{th} single observation of depth of application by a sprinkler system, inches or volume per unit area
$\overline{X}$	The mean observation of depth of application by a sprinkler system, inches or volume per unit area
Y	The dimensionless depth or actual depth divided by the average depth applied (field average) to the spray field

Y_{max}	The maximum actual depth applied divided by the average depth applied (field average) to the spray field
Y_{min}	The minimum actual depth applied divided by average depth applied (field average) to the spray field
Θ	The soil moisture content, ft^3/ft^3

Chapter 1: Introduction

The rural lifestyle of many people in Texas necessitates the use of on-site sewage treatment systems since centralized systems are not available. In Texas, there are approximately 600,000 on-site systems (TCEQ 2009) that utilize a surface disposal system. One of the concerns with the use of these systems is the potential for nitrate pollution of groundwater resources. The most appropriate design of on-site surface irrigation systems for the treatment and disposal of effluent from aerobic on-site treatment systems is very important. In order to address the design of the surface application system for effluent from an aerobic system, an assumption that no denitrification has occurred was made, therefore the primary form of inorganic nitrogen in the effluent is nitrate. One component of the overall system design for sprinkler systems for on-site surface irrigation systems is to minimize nitrogen movement below the root zone of the irrigated vegetation.

In the United States, approximately 25 percent of the housing units utilize on-site treatment and disposal systems (EPA 1980). With the increasing population and a trend toward rural life, the number of on-site systems in use is increasing. Even though the majority of the on-site systems consist of an aerobic or anaerobic treatment system combined with a soil adsorption configuration, surface disposal systems are widely used in areas where the soil is not suitable for an adsorption field. Most of these surface disposal systems use solid-set sprinklers to distribute the effluent on to the soil surface.

It is easy to dismiss the extent of the potential problem of nitrogen pollution, salt accumulation in the soil, or creation of saturated soil for extended periods of time because a typical country home utilizing a sprinkler system for effluent disposal requires approximately one-quarter of an acre. However, in aggregate, the total land needed is over 170,000 acres for disposing of the effluent from over 2,000,000 people. If one were to design a land application system for a city of 2,000,000 people, one would ensure that there would not be any excess nitrogen leaving the site, the soil would not accumulate salt so it could be used for agricultural purposes in the future, and water would not run off the site or create saturated soils for extended periods of time. These same principles for good design of land application systems for disposal of effluent from a municipality should also be applied to the individual home systems.

As common as surface application systems for wastewater disposal are in the United States, design of these systems is still less than optimum. One problem is the lack of the understanding the various components involved with designing these systems. Design of wastewater surface application systems is a complicated process that must include the principles of land limiting constituents, irrigation and the respective inefficiencies, water balance, evapotranspiration, and crop selection, which includes nutrient assimilation and leaching requirements. Each of the principles must be carefully analyzed both independently and collectively to provide an environmentally sound design.

Changes to the current procedures for designing surface application systems for on-site sewage facilities (OSSFs), with an emphasis on aerobic systems (Figure 1.1), in Texas are being considered. Concerns with the current procedures for designing associated sprinkler systems include the sizing of the spray field area based on a total mass balance approach, the volume of effluent storage required, and the absence of considering the uniformity of the sprinkler distribution patterns. The design used needs to be adaptable to the many climates and soils that exist within the state, while maintaining the integrity of the environment. To meet this goal, an alternative design procedure is proposed. The proposed design method incorporates the concept of water application rate, soil infiltration rate, crop water use, crop nutrient uptake rate, water application efficiency, and irrigation layout design.

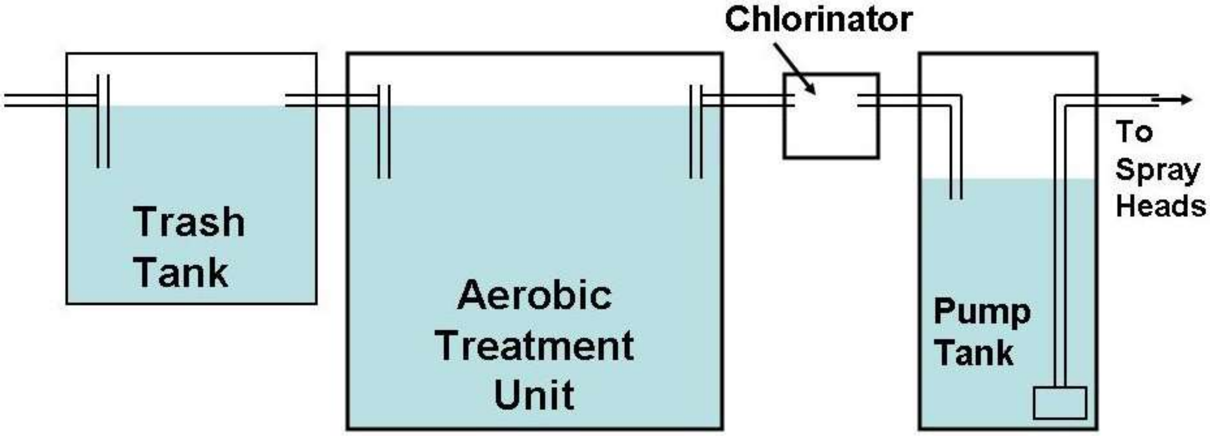


Figure 1.1. Diagram of a typical aerobic OSSF system with surface application of the effluent.

Design Factors to Consider

An important component of surface application of wastewater is the simultaneous evaluation of the mass balance for water, nitrogen, and salt. Indeed, all these components are important individually, but the combined effects and interactions are especially critical in wastewater surface application systems. Due to the higher concentrations of salts in wastewater effluents compared to freshwater and the need to apply wastewater to meet leaching requirements increases the potential leaching of nitrogen. Furthermore, the presence of high quantities of salts and water in the soil profile can influence many important processes in the nitrogen cycle such as denitrification, nitrification, plant uptake, and mineralization. Finally, salinity can negatively influence plant growth and infiltration rates, which influence the nutrient and water balances within a system.

Great strides have been made in proving that the surface application process can be accomplished in an environmentally safe way. Using a mass balance approach to designing surface application systems for on-site systems, such problems as water mounding will not exist (Fedler, 2000). Designing any surface application system requires similar steps for both on-site systems and large-scale land application systems. Design factors include soil infiltration rate, soil water holding capacity, plant nitrogen uptake, plant water uptake (evapotranspiration, ET), nitrogen consumption within the soil (such as nitrification, denitrification, etc.), salt tolerance of the plants and the subsequent leaching, and the quantity of storage available. Considering all of these factors and the interaction between many of them, it may appear that the system is quite complicated, but the reality of it is that when a mass-balance approach is used, the design of an environmentally sound system is easily achievable.

Wastewater surface application rates for either full-scale land application systems or on-site sewage facilities (OSSF) in Texas can range from 2 to 8 inches per month throughout the year with frequencies of application being 30 days per month in specific cases in order to achieve the desired application of water. During summer months, the water in the soil profile of the crops root zone is seldom at field capacity, thus the nitrogen applied is either taken up by the plant or is lost due to nitrification or denitrification processes. During the winter months, soil within the root zone of the plant is always near or at field capacity as a result of irrigation in order to leach accumulated salts from the root zone. During this winter period while most of the leaching occurs, plant uptake of nitrogen is reduced as compared to summer.

Procedures for Designing Surface Application Systems

The Texas Commission on Environmental Quality (TCEQ) has established standards for the design of surface application systems as presented in Texas Administrative Code (TAC) Chapter 285 (Texas Administrative Code 2009). The surface application systems refer to sprinkler irrigation systems used for the application of effluent from on-site treatment systems. Chapter 285 specifies the method for sizing the spray field and determining the volume of effluent storage. While there are numerous details specified, one concern to consider is the sizing of the spray field area and the volume of effluent storage required for the most efficient design.

The spray field area is determined by taking the estimated daily volume of water to be applied and dividing it by the maximum surface application rate (MAR) (Figure 1.1). Figure 1.1 was developed by determining the irrigation requirement (evapotranspiration – precipitation) across the State of Texas. The MAR presented shows a relatively small application allowed in the eastern part of the state (an area of high precipitation) and a large application allowed in the western part of the state (an area of low precipitation). No other consideration is specified such as type of crop, water intake rate of the different soil types, or other design factors.

For systems controlled by commercial irrigation timers and required to irrigate between midnight and 5:00 a.m., the required storage volume of effluent is at least one daily design volume of effluent between the alarm-on level and the pump-on level and a storage volume of one-third the daily volume between the alarm-on level and the inlet to the pump tank. There appears to be no consideration given to sizing storage tanks with regard to the variation of effluent from day to day throughout the year.

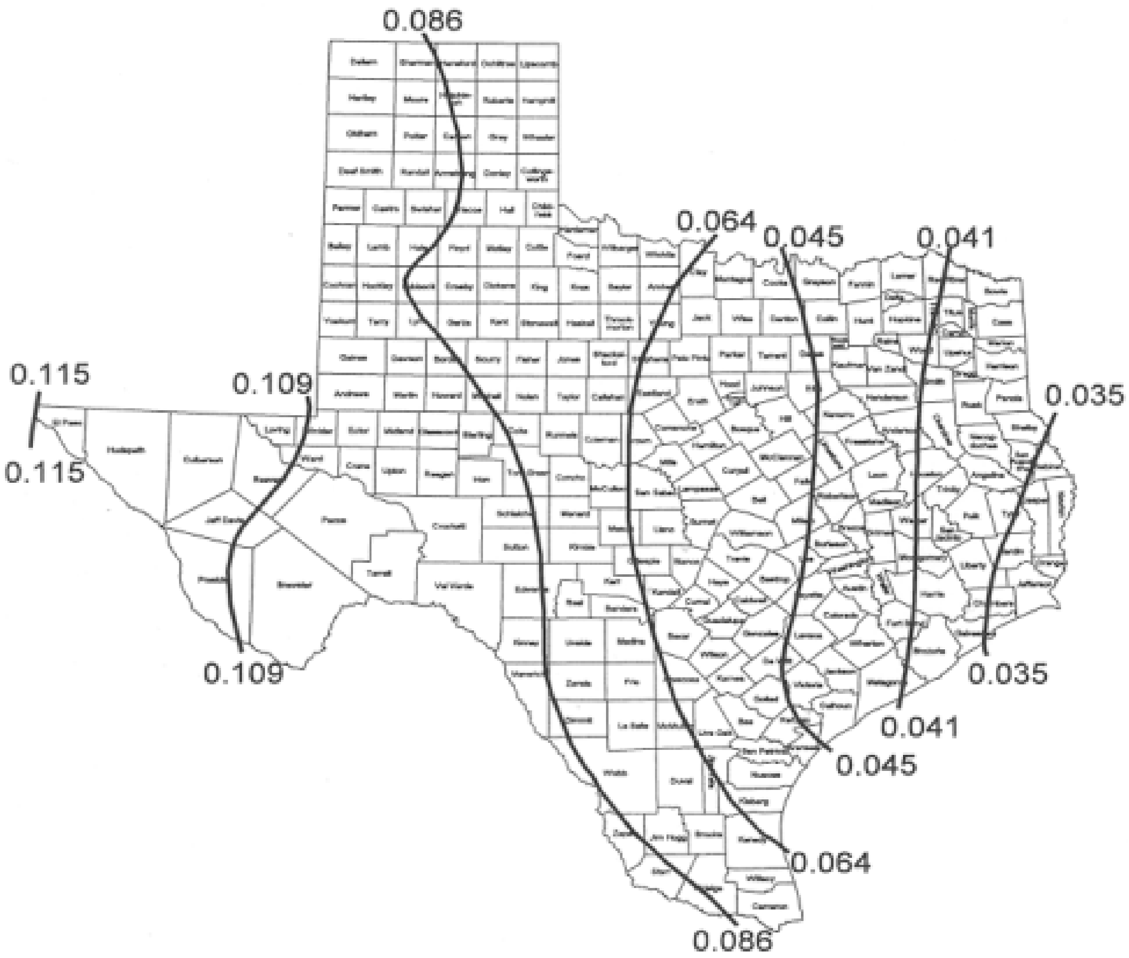
The sprinkler layout may be any design from those with sprinkler overlap and subsequent high coefficients of uniformity to sprinklers with no overlap of the wetted area.

Since there are no specifications of the uniformity of sprinkler distribution patterns, the least expensive design, one without any overlap of the sprinkler patterns, is often the design choice.

Operational Concerns to Consider

Designs for any surface application system are based on long-term average climatic data along with average crop production data. Obviously, average conditions do not exist on a consistent basis. Another complicating factor that influences the performance of an on-site surface application system is that there are times when you have no flow and times when the flows are much above average. During those times of lower than average flows, the crop being irrigated will often receive far less water than is required to provide optimum growth conditions but even worse, no leaching of the salts contained in the effluent.

One of management factors the owner or operator must pay attention to is the salting out of the soil surface. Signs of this are either the white coloration of the soil or the lack of good healthy growth of the plants being irrigated. If the crop is not growing properly, then the nutrients within the effluent are not properly begin assimilated according to the design. Testing the soil for moisture content is one way to understand what management step should be taken next. Another approach is using the “checkbook” method of keeping track of the water applied to the crop, from both the irrigation of the effluent or from precipitation. In either case, if there is a serious lack of water to keep the crop healthy or a lack of leaching over time, then supplemental water will need to be applied to the surface application site. Understanding the water balance for the crop irrigated will allow the user to provide sufficient water to maintain proper growing conditions for the crop.



Note: To obtain the application rate for any particular area, refer to the isopleth line to the left of the area.

Figure 1.2. Maximum Application Rates for Surface Application of Treated Effluent in Texas (gallons/ft^2/day) (Texas Administrative Code 2009).

Chapter 2: General Design Procedure for OSSF Surface Application System

Introduction

Designing the treatment component of an on-site wastewater system is only half the process. For surface application systems, the second half of the process is designing the sprinkler irrigation system. Since this type of system involves wastewater effluent, the sprinkler design is not to simply have the water cover a specified area. The water must be applied in such a way that the nutrients within that water is applied in the most uniform fashion as possible so that the distribution of those nutrients can most efficiently be absorbed by the plants irrigated. Another factor to consider is the application of the salts contained in the water and the resulting leaching required so that inhibition to plant growth is minimized.

A general design procedure for designing the sprinkler system of an OSSF system is presented using typical design values. References for detailed design information can be found in the following chapters as indicated in Table 2.1. Additional design examples are provided in the appendix of this manual.

Required Data and Assumptions

To start the design of the sprinkler application system, a set of data concerning the characteristic of the effluent and the site where the effluent will be applied is required. In addition, there are some assumptions that need to be made about how the system will be designed. Table 2.1 shows the basic data and assumptions of a typical OSSF system that will be the basis for the sprinkler system design example.

Design Procedure

The design procedure considers the size of the spray area and type of sprinkler system, sizing of the pump to properly operation the sprinkler system, and sizing of the effluent storage tank. For the example presented here, the data used in the calculations are those presented in Table 2.1.

Step 1. Determine the size of the dosing tank.

This particular system is serving a single home with three bedrooms. The working volume of a dosing tank is 240 gallons. Note, this follow the TAC 285 Chapter 30 rules for aerobic treatment of the wastewater for an average daily water use of 60 gallons per day per bedroom.

Vol = 240 gallons

Table 2.1 Data required for designing a surface application OSSF system and the values chosen for the example design

Parameter	Symbol	Units	Example Design Value	Chapter for Reference
Flow Rate	Q	gallons/day	240	Ch. 3
Effluent TN	C_n	mg/L	30	Ch. 3
Crop			pulpwood	Ch. 5
Annual crop nitrogen uptake	N_y	pounds/year	150	Ch. 5
Base soil intake rate	I_B	inches/hr	0.2	Ch. 4
Elevation difference from pump to spray field	S_L	feet	20	Ch. 6
Distance from pump to spray field	L	feet	100	Ch. 6
Sprinkler operating pressure	P_d	psi	30	Ch. 6
Sprinkler spacing, lateral	S_l	feet	30	Ch. 6
Sprinkler spacing, main	S_m	feet	30	Ch. 6
Maximum surface water storage	SS	inches	0.2	Ch. 4
Number of bedrooms being served			3	Ch. 3

Step 2. Determine the amount of nitrogen being applied per year.

The following equation calculates the total nitrogen in lbs/yr:

$$T_n = \frac{C_n \cdot Q \cdot 8.34 \cdot 365}{1000000}$$

where

T_n is the estimated pounds of total nitrogen being applied as a constituent of the wastewater effluent (lb/yr);
C_n is the estimated concentration of total nitrogen in the wastewater effluent (mg/l);
Q is the estimated average daily volume of water to be applied (gal/day, assumes the volume of water per day is applied daily); and
8.34 and 1,000,000 are conversion factors from pounds, mg/L, and million gallons per day of flow.

$T_n = 21.9$ lb/yr

Step 3. Determine the spray field area based on nitrogen application rate.

The following equation calculates the area needed to utilize the total nitrogen in the effluent:

$$Area_n = \frac{T_n}{N_y} \cdot 43560$$

where

$Area_n$ is the minimum area of the spray field assuming nitrogen is the land-limiting factor (ft^2);
T_n is the estimated pounds of total nitrogen being applied as a constituent of the wastewater effluent (lb/yr); and
N_y is the estimated yearly uptake of nitrogen by the vegetation proposed or found in the spray field (lb/acre/yr).
$Area_n = 6365\ ft^2$

Step 4. Determine the required spray field area based on hydraulic loading rate.

One needs to assume a reasonable time of application of effluent being applied to the spray field. The value for the time of application of effluent could be as long as five hours according to TAC-285.33 (Texas Administrative Code 2009), as discussed in Chapter 4. For this system it is assumed that the time of application of effluent is 0.5 hours, or $T_A = 0.5$ hr and the base soil water intake rate is 0.2 in/hr. In this case, the final area required from the hydraulic standpoint is

$Area_{hyd} = 3850\ ft^2$

where

$Area_{hyd}$ is the minimum area of the spray field assuming the intake rate of the soil or the hydraulic loading rate is the land-limiting factor (ft^2);

Design Options/Cautions

The time of application (T_A) is an engineering judgment at this time. A small value for T_A will result in a large area and a large value of T_A will result in a small area. The size of the sprinklers and pump will dictate the value for T_A unless the base infiltration rate (I_B) is extremely small. Once the sprinkler heads and pump are selected, one should check to make sure the time of application will result in an area less than that needed to meet the nitrogen uptake rate for the crop. Unless the base infiltration rate (I_B) is extremely small, the area required for nitrogen most often is the limiting factor that controls the minimum size of the spray field.

Step 5. Select the largest of the areas in Step 3 and Step 4.

To determine the area needed for the spray field, select the largest area between the area using nitrogen as the land-limiting constituent and the area using the hydraulic loading rate as the land-limiting area.

$\text{Area}_n = 6365\ \text{ft}^2$ $\text{Area}_{hyd} = 3850\ \text{ft}^2$

Therefore, the area selected for the design will be the larger of the two cases, thus

$\text{Area} = 6365\ \text{ft}^2$

where

Area is the design area for the spray field (ft^2);
Area_n is the minimum area of the spray field assuming nitrogen is the land-limiting factor (ft^2); and
Area_{hyd} is the minimum area of the spray field assuming the intake rate of the soil or the hydraulic loading rate is the land-limiting factor (ft^2).

Step 6. Determine the number of spray blocks--use even number.

A spray block within the irrigated area is the area encompassed by S_l (lateral line spacing) times S_m (main line spacing). Determining the number of spray blocks merely helps in laying out the spray field: the number of laterals and the number of sprinkler heads per lateral. This is rounded up to an even number anytime the calculation results in more than one block. Spacing of the lateral and main irrigation lines is assumed to be 30 feet for each. To determine the number of blocks required, the required area is divided by the lateral and main line spacing lengths. The number of blocks required are:

$N_b = 7.1$ for a final value of 8 blocks.

where

N_b is the number of spray blocks needed for the spray field system;

Step 7. Layout blocks and sprinkler head (see Figure 2.1).

The layout of the sprinkler heads depends on the site geography and on meeting the criteria for pressure loss along the laterals and along the mainline. One wants the smallest size pipes that will meet the pressure loss requirements as presented in Chapter 6. Generally, one tries for symmetry as shown in the preliminary layout for this example (see Figure 2.1). If the site has significant slope, it is best to lay the laterals along the contour to meet the pressure loss criteria along the laterals.

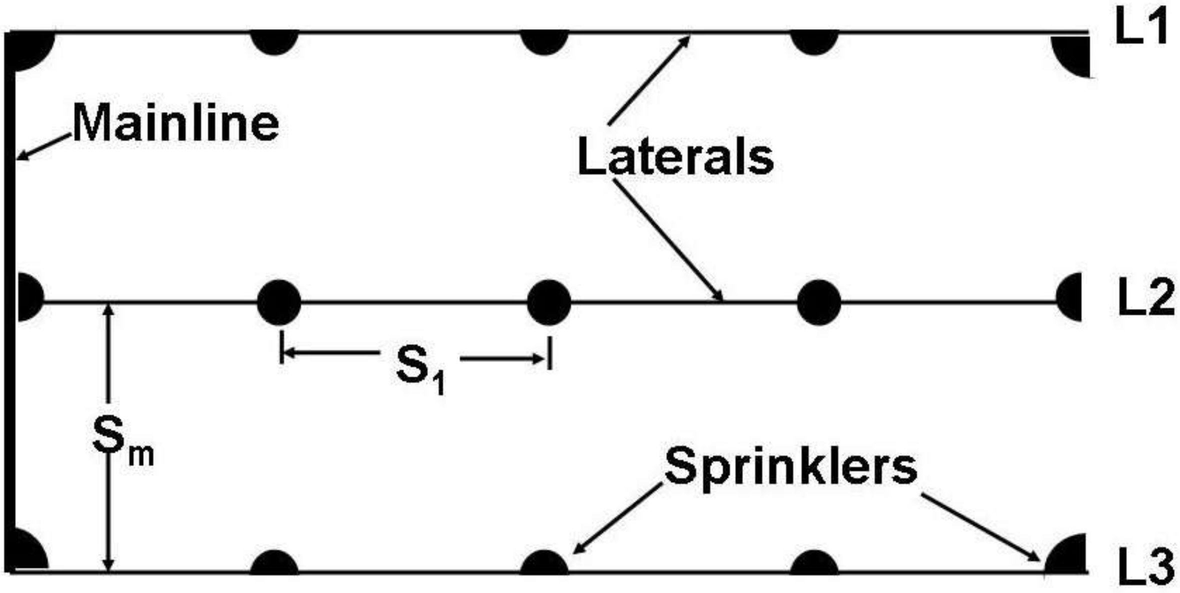


Figure 2.1 Example layout of a sprinkler system with the 30 ft by 30 ft sprinkler spacing and 8 blocks as required.

Step 8. Determine maximum sprinkler discharge for a full circle sprinkler head using the base intake rate of the soil (I_B).

The sprinklers should apply water at a rate equal to or less than the base intake rate of the soil. Therefore, there will be no surface runoff. There is no consideration of surface storage while the sprinklers are operating.

$I_B = 0.2$ inches/hr $S_l = 30$ ft $S_m = 30$ ft

$$Q_{spr} = \frac{I_B \cdot S_l \cdot S_m}{96.3} = \frac{0.2 \cdot 30 \cdot 30}{96.3} = 1.869 \text{ gpm}$$

where

Q_{spr} is the discharge rate from a full-circle sprinkler head (gpm);
I_B is the base water intake rate (minimum) for the soil (inches/hr);
S_l is the sprinkler spacing along the lateral line (ft); and
S_m is the sprinkler spacing along the main line (ft).

Design Options/Cautions

The area determined in Step 5 and the number of blocks in Step 6 represents the minimum area required to prevent surface runoff and excess nitrogen movement toward the groundwater. In laying out the spray field, the area encompassed by the outside laterals and the end sprinklers on the outside laterals represent the minimum area. Normally this area will be rectangular, should be irrigated with the recommended overlap of sprinklers, and will require the use of half-circle and quarter-circle sprinkler heads. One can use all full-circle sprinklers, but the wetted area will be greater. It is strongly recommended that the spray field be designed with the proper sprinkler overlap to ensure a uniform application of the wastewater and thus make it easier to provide the proper leaching. This is especially necessary in areas having annual precipitation rates less than 30 inches per year.

Step 9. Determine maximum sprinkler discharge based on T_A and SS.

The sprinklers will apply water at a rate to meet the base intake rate and the reasonable depth of surface storage during the time of application selected for the sprinkler system.

$T_A = 0.5$ hr $I_B = 0.2$ inches/hr $SS = 0.2$ inches

$$Q_R \equiv \frac{I_B \cdot T_A + SS}{T_A} \qquad \text{or } Q_R = 0.6 \text{ inches/hr}$$

$$Q_{spr} \equiv \frac{Q_R \cdot S_l \cdot S_m}{96.3} \qquad \text{or } Q_{spr} = 5.61 \text{ gallons per minute (gpm)}$$

where

Q_R is the maximum application rate adjusted for surface storage and time of application (inches/hr);
I_B is the base water intake rate (minimum) for the soil (inches/hr);
T_A is the time of application of effluent on to the spray field (hr);
SS is the maximum surface storage for the sprinkler system (inches);

Q_{spr} is the discharge rate from a full-circle sprinkler head (gpm);
I_b is the base water intake rate (minimum) for the soil (inches/hr);
S_l is the sprinkler spacing along the lateral line (ft); and
S_m is the sprinkler spacing along the main line (ft).
96.3 is a conversion factor for 12 inches/ft, 7.48 gallons/ft^3, and 60 minutes/hr

Step 10. Select the sprinkler heads.

For an OSSF system, the design should make sure the application rate does not exceed the base intake rate of the soil or there will be surface runoff. However, for an OSSF system, the irrigation frequency is usually every other day or every day and the depth of application will generally be less than 0.25 inches of effluent. Since the OSSF surface application system have an actual time of application that will be small, the intake rate will almost always be greater than the base intake rate. This is not a problem because it takes time for the intake rate to decrease to the base intake rate. Furthermore, one can take advantage of surface storage and apply effluent at a rate somewhat greater than the base intake rate of the soil (see Chapter 4).

With the above considerations in mind, an application rate could be very small or large enough so that the maximum discharge from the sprinkler is achieved as calculated in Step 9. Thus, for this design, one could select a full-circle sprinkler discharge rate from something near 1.87 gpm (see Step 8) to 5.61 gpm and still have an acceptable design.

After a review of various commercial sprinkler heads, a discharge rate of 4 gpm was selected for a full-circle sprinkler head. An example is the K-rain Dial-a-nozzle 12-degree low-angle sprinkler head operated at a pressure of 30 psi where

nozzle #1	$D_w = 60$ ft	$Q_{spr-q} = 1.0$ gpm	Use for quarter-circle sprinkler head.
nozzle #2	$D_w = 64$ ft	$Q_{spr-h} = 2.0$ gpm	Use for half-circle sprinkler head.
nozzle #4	$D_w = 64$ ft	$Q_{spr-f} = 4.0$ gpm	Use for full-circle sprinkler head.

The 4 gpm is less than the maximum of 5.61 gpm determined in Step 9, but the wetted diameter (D_W) of 60 feet is acceptable in order to achieve the 50 percent overlap recommended to coincide with the 30 feet sprinkler grid spacing.

where

Q_{spr-f} is the discharge rate from a full-circle sprinkler head (gpm);
Q_{spr-h} is the discharge rate from a half-circle sprinkler head (gpm);
Q_{spr-q} is the discharge rate from a quarter-circle sprinkler head (gpm);
D_w is the wetted diameter for a sprinkler head for a given orifice and operating pressure.

Step 11. Check the application rate for selected sprinkler head.

In checking the application rate from a sprinkler head, one should use the flow rate from the full-circle sprinkler head. The application rate would be the same for the quarter-circle and the half-circle sprinkler heads since the flow rates are decreased by a like amount (see Step 10). The general formula for determining the application rate from a sprinkler head was developed for a full-circle sprinkler head.

$Q_{spr} = 4.0$ gpm $S_l = 30$ ft $S_m = 30$ ft

$$App\_rate = \frac{Q_{spr}\cdot 96.3}{S_l\cdot S_m} = \frac{4.0\cdot 96.3}{30\cdot 30} = 0.428 \text{ inches/hr}$$

where

App_rate is the application rate for the selected sprinkler head operated at the selected pressure, inches/hr
Q_{spr} is the discharge rate from a full-circle sprinkler head, gpm
S_l is the sprinkler spacing along the lateral line, ft
S_m is the sprinkler spacing along the main line, ft

The actual application rate is less than the maximum application rate (Q_R). Therefore, the selected sprinkler head is acceptable.

Step 12. Determine the total discharge from each lateral.

On the outside laterals, there are two quarter-circle and three half-circle sprinkler heads. The total flow would be eight gpm. On the inside laterals, there are two half-circle and three full-circle sprinkler heads. The total flow would be 16 gpm.

$Q_{endlat} = 8$ gpm $Q_{midlat} = 16$ gpm

Q_{endlat} is the total flow into the two end laterals of the proposed sprinkler system (gpm); and
Q_{midlat} is the total flow into the middle laterals of the proposed sprinkler system (gpm).

Step 13. Determine the irrigation sets or sections for the spray field.

Please refer to Figure 2.2 for a preliminary layout of the sets.

$Q_{endlat} = 8$ gpm $Q_{midlat} = 16$ gpm $No_{set} = 1$

The average discharge per set is:

$$Q_{set} \equiv \frac{\left(2\cdot Q_{endlat} + 1\cdot Q_{midlat}\right)}{No_{set}} \qquad Q_{set} = 32 \text{ gpm}$$

Minimum time to drain a full tank is:

$$T_d \equiv \frac{Vol}{No_{set} \cdot Q_{set}} \qquad T_d = 7.5 \text{ min}$$

The above appears to be a reasonable time to drain a full tank. The time needed is less than the five-hour window for application required by TAC-285.33.

where

T_d is time required to drain the storage tank given the average flow rate for all sets (min);
T_A is the time of application of effluent on to the spray field (hr);
Q_{endlat} is the total flow into the end laterals of the proposed sprinkler system (gpm);
Q_{midlat} is the total flow into the middle laterals of the proposed sprinkler system (gpm);
Vol is volume of storage tank between the alarm-on level and the pump-on level (gal); and
No_{set} is the number of sets making up the sprinkler system.

Step 14. Layout the pipe, sprinkler heads, control valves, and connections to the supply line.

The layout of the sprinkler system depends on the level of automation one wants in the system. It is recommended that the system be automated so the operating decisions are made by the designer rather than the homeowner (who may not understand all the design constraints and requirements for an OSSF system).

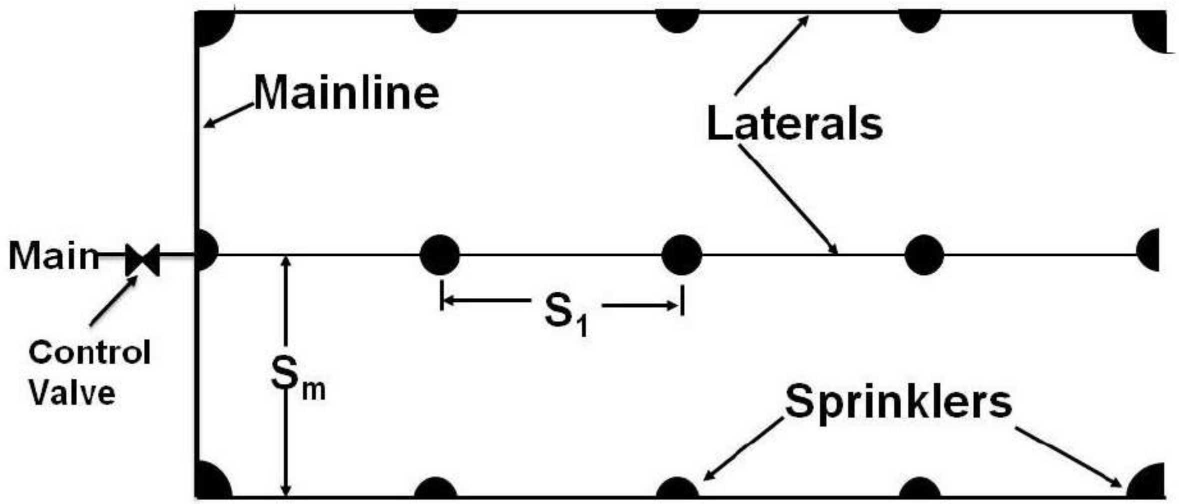


Figure 2.2 Example layout of single set required for this spray field.

Step 15. Size the laterals.

As readers will find in Chapter 6, there must be less than 20 percent pressure loss along the lateral. Calculate the pressure loss by starting with the last segment of pipe (attached to the sprinkler head at the distal end of the lateral) and go to the first sprinkler head at the top of the lateral. Use the Hazen-Williams equation for estimating friction headloss in pipe.

> *Please note: for someone familiar with sprinkler system design, there are other procedures that can accurately determine the correct size of lateral and mainlines. In addition, the headloss caused by the risers coming off the laterals is approximately offset by the increase in pressure due to change in flow rate and thus velocity of the water flowing in the pipe.*

Use sch 40 PVC pipe. Hazen-Williams coefficient C is 140 for PVC pipe.

$C = 140$

Use one-inch nominal diameter pipe.

$D = 1.049$ inches

The Hazen-Williams equation is:

$$f = \frac{L \cdot 3.0226 \cdot \left(\dfrac{Q}{\dfrac{\pi \cdot D^2 \cdot 448.9}{4 \cdot 144}} \right)^{1.852}}{C^{1.852} \cdot \left(\dfrac{D}{12} \right)^{1.167}}$$

where

f is the friction headloss in the pipe (ft);
L is the length of pipe segment (ft);
Q is the flow rate in the pipe segment (gpm);
D is the pipe inside diameter (inches); and
C is the Hazen-Williams coefficient for pipe friction.

Table 2.2 Headloss for laterals 1 and 3.

Segment	Length (ft)	Flow Rate (gpm)	hf (ft)
1	30	1	0.026
2	30	3	0.202
3	30	5	0.519
4	30	7	0.968
Total			1.715

The total headloss due to friction is 1.715 feet, or 0.743 psi. One foot of pressure is equal to 2.31 psi.

Table 2.3 Headloss for lateral 2.

Segment	Length (ft)	Flow Rate (gpm)	hf (ft)
1	30	2	0.095
2	30	6	0.728
3	30	10	1.874
4	30	14	3.495
Total			6.192

The total headloss due to friction is 6.192 feet, or 2.681 psi.

Select a one-inch sch 40 PVC pipe for laterals 1 through 3. This pipe size meets the pressure loss criterion of less than 20 percent pressure loss between the distal sprinkler head and the first head on the lateral. Furthermore, the next smaller pipe size would cause excess pressure loss, i.e., greater than 20 percent (Cuenca 1989).

Step 16. Determine the pressure at the first and distal sprinkler heads.

Use the lateral with the greatest headloss: lateral 2.

$f_{total} = P_f = 2.681$ psi See Step 14 above.

$P_a = P_d = 30$ psi

$P_a = P_o + 0.25 \cdot P_f$

$P_o = P_a - 0.25 \cdot P_f = 30 - 0.25 \cdot 2.681 = 29.33$ psi

$P_n = P_f + P_o = 29.330 + 2.681 = 32.011$ psi

where

P_o is the pressure at the sprinkler head at the distal end of the lateral (psi);
P_n is the pressure at the first sprinkler head on the lateral (psi);
P_a is average pressure in the lateral (psi);
P_d is the desired average operating pressure of the sprinkler heads (psi);
P_f is the friction loss in the lateral between the first and distal sprinkler heads (psi); and
f_{total} is the friction loss in the lateral between the first and distal sprinkler heads (psi).

Step 17. Determine the pressure at the outlet and inlet of the control valve.

The pressure losses from the first sprinkler to the outlet of the valve will be the result of pipe friction losses (estimated by using the Hazen-Williams equation) and minor losses caused by bends, valves, etc. The equation for estimating the minor losses is:

$$PL_{minor} = K \cdot \frac{V^2}{2 \cdot g}$$

where

PL_{minor} is the headloss caused by a fitting, ft
K is a loss coefficient for a fitting
V in the pipe, ft/sec
g is gravitational acceleration, 32.2 ft/sec^2

The loss coefficients needed for a typical system fittings are detailed below.

Table 2.4 Loss Coefficients for Commercial Pipe Fittings

Fitting	K
Solenoid valve	1.2
Gate valve	0.2
Strainer	9.3
Check valve	2.2
Union	0.2
Tee	1.3
90 deg elbow	0.7
Foot valve	1.7
Entrance	0.5
Exit	1.0

There is 15 feet of one-inch sch 40 pipe ($D = 1.049$ inches) and one 90-degree elbow and one tee.

L = 15 ft D = 1.049 inches QL = 8 gpm C = 140

$$hfL := \frac{L \cdot 3.0226 \cdot \left(\frac{QL}{\frac{\pi \cdot D^2 \cdot 448.9}{4 \cdot 144}} \right)^{1.852}}{C^{1.852} \cdot \left(\frac{D}{12} \right)^{1.167}} \qquad hfL = 0.62 \quad \text{ft}$$

The headloss may be slightly greater depending on the length of the pipe between the control valve and the tee. For this example, it was assumed to be one foot.

hfL = 0.268 psi

The K value is 1.3 for the tee. The Q is 32 gpm for the tee.

$$V_{32} := \frac{QT}{\frac{448.9 \cdot \pi \cdot D^2}{4 \cdot 144}} \qquad \text{Or } V_{32} = 11.877 \text{ ft/sec}$$

$PL_{minor} = 2.848$ ft for the tee

The pressure at the outlet of the control valve will be the pressure at the first sprinkler on lateral 2 plus the headloss due to friction and minor losses from the sprinkler head to the inlet of the valve.

$$P_{outlet\_cont\_valve} = P_n + hfL + PL_{minor} = 32.011 + 0.26 + 1.233 = 33.5 \text{ psi}$$

The manufacturer's pressure loss for the control valve is 4.5 psi.

$$P_{inlet\ cont\ valve} = P_{putlet\ cont\ value} + PRESSLOSS_{cont\ valve} = 33.5 + 4.5 = 38.0 \text{ psi}$$

> *Please note that the effluent velocities in the one-inch pipes are greater than five ft/sec. Because of the danger of water hammer, it is not recommended to have velocities greater than five ft/sec in PVC pipe. However, in this case, the sprinkler heads provide protection against water hammer. There is no way the water can be suddenly stopped in the laterals. This will not be the case for the pipes on the inlet side of the control valves. Note, there are some other minor losses that could be considered, such as the reducer on the tee that was ignored in this case since it was negligible.*

where

$P_{inlet\ cont\ valve}$ is the pressure at the inlet of the control valve (psi);
$P_{outlet\ cont\ valve}$ is the pressure at the outlet of the control valve (psi);
$PRESLOSS_{cont\ valve}$ is the headloss caused by the control valve (psi);
P_n is the pressure at the first sprinkler head on the lateral (psi);
L is the length of the pipe (ft);
D is the inside diameter of the pipe (inches);
Q is the flow rate in the pipe (gpm);
C is the Hazen-Williams pipe roughness factor;
PL_{minor} is the headloss caused by a fitting(s) (ft); and
f is the friction headloss for the pipe (ft).

Step 18. *Determine the size of the main line.*

The pressure loss in the main line should be less than 10 percent of the average operating pressure of the sprinkler system. In this case, the main line will be sized the same as the lateral since the system will be operating in only one set. The only pressure of concern here is the supply line, which is operating near 38 psi.

Step 19. Calculate the headloss in the supply line.

The sizing of the supply line is generally based on economics. It is a tradeoff between the capital cost of the pipe and pump and the operating cost of pumping the water.

Design Options/Cautions

For PVC pipe, the maximum velocity is five fps. Also according to TAC-285.33, the minimum pipe size for a supply line is three inches and the pipe should be sch 40.

For this example based on economics, the decision is between a two-inch sch 40 PVC pipe and a 1.5-inch sch 40 PVC pipe. A two-inch pipe would have a friction headloss of 1.96 psi and the 1.5-inch pipe would have a friction headloss of 6.63 psi. There is no way to guess which is best without an economic evaluation. On the other hand, an economic evaluation would take a few hours of professional time. It is clear that a pipe smaller than 1.5 inches would have a high friction headloss and a pipe greater than two inches would not significantly reduce the friction headloss. Regardless, TAC-285.33 (Texas Administrative Code 2009) requires we use a three-inch sch 40 PVC pipe for the supply line.

Calculate the headloss for the highest flow rate which is irrigating 32 gpm. Besides the friction headloss in the supply line, there will be the headloss caused by the tee connecting to the main line ($K = 1.3$), a tee for the pressure relief valve if needed, and a tee for the air-relief/vacuum relief valve. There is also a gate valve ($K = 0.2$) just downstream from the pump and a required check valve ($K = 2.2$). These relief valves are required regardless of the velocity according to typical pipe standards. They are used to protect the supply line.

$Q = 32$ gpm $\quad L = 100$ ft $\quad D = 3.084$ inches $\quad C = 140$

The friction loss for the supply line is 0.282 ft. The minor losses for this part of the system total 0.185 ft. Summing these two losses with that of the supply line, the total pressure is 38.2 psi.

Step 20. Calculate the minor losses and pipe friction headloss in suction pipe.

The pipe friction headloss is for a length of suction pipe of 20 feet. Almost all pumps have a suction pipe diameter one size larger than the discharge side of the pump. For this example, the discharge side is three inches so the suction side would be 3.5 inches. However, the flow rate is small and three-inch pump is not needed. One can use reducers to meet the change in pipe size. Therefore, a two-inch pump will be selected and it will use a 2.5-inch sch 40 PVC pipe for the suction pipe. The suction pipe would hook up to the effluent storage tank. The friction headloss is:

L = 20 ft Q = 32 gpm C = 140 D = 2.469 inches

Using the same equation for calculating headloss due to friction as before, the total loss is 0.167 ft or 0.07 psi.

There will be a gate valve on both sides of the pump to isolate the pump for maintenance. Besides the gate valve (K = 0.2) the other fittings are a strainer (K = 2.2), a union (K = 0.2), a foot valve (K = 1.7), and an entrance loss (K = 0.5). These minor losses total 1.006 ft or 0.436 psi.

Step 21. Calculate the total dynamic head and specify pump.

The total dynamic head is the pressure or head the pump must supply to the system. The elevation difference between the spray field and the pump needs to be included. The total dynamic head is:

$SL = 20$ ft or 8.658 psi

$P_{\text{pump outlet}} = 38.5$ psi

The total dynamic head (TDH) will be the sum of the losses and elevation difference and is:

$TDH = P_{\text{pump outlet}} + SL + \text{friction} + \text{minor losses} = 38.5 + 8.66 + 0.07 + 0.44 = 47.37$ psi

Therefore, the TDH is equal to 110 ft.

where

TDH is the total dynamic head which the pump will supply (ft);
SL is the elevation difference between the pump and the spray field (ft);
$P_{pump\ outlet}$ is the pressure at the outlet of the pump (psi);

One will need to select a pump that will pump 32 gpm at a total dynamic head of 110 feet. There are other parameters to check in the selection of the pump such as the net positive suction head.

Step 22. Check to see if there is adequate leaching.

The technical details for determining the leaching requirement are presented in Chapter 5. The following values were determined for this particular OSSF system:

Moderate salt-tolerant trees and shrubs
EC_{irr} = 3.2 mmhos or 2050 ppm
EC_{emax} = 16 mmhos
P = 43.22 inches
D_{irr} = 22.09 inches
ET_c = 57.6 inches

where

EC_{irr} is the electrical conductivity or the irrigation water or effluent (mmhos/cm);
EC_{emax} is the estimated electrical conductivity of the average saturation extract of the soil root zone profile for an approximate 100 percent yield reduction (mmhos/cm);
P is the annual precipitation for the site (inches);
D_{irr} is the depth of irrigation water being applied (inches); and
ET_c is the crop (or vegetation being irrigated) evapotranspiration rate (inches).

Calculate the surface runoff:

$P_{run} = 0.510 \cdot P - 13.35$ for $P \geq 31.5$ inches

$P_{run} = 0.510 \cdot 43.22 - 13.35 = 8.69$ inches

$D_{irr+rain} = D_{irr} + P - P_{run} = 22.09 + 43.22 - 8.69 = 56.62$ inches

$$EC_W = \frac{D_{irr} \cdot EC_{irr}}{D_{irr} + P - P_{run}} = \frac{22.09 \cdot 3.2}{22.09 + 43.22 - 8.69} = 1.25 \text{ mmhos}$$

$$LR = \frac{EC_W}{2 \cdot EC_{emax}} = \frac{1.25}{2 \cdot 16} = 0.039$$

$$LR = \frac{D_d}{D_{irr+rain}}$$

$$D_d = LR \cdot D_{irr+rain} = 0.039 \cdot 56.62 = 2.21 \text{ inches}$$

where

P_{run} is the annual surface runoff of precipitation from the site (inches);
P is the annual precipitation for the site (inches);

$D_{irr+rain}$ is the sum of the irrigation applied plus the portion of the precipitation infiltrating the soil or precipitation minus runoff from precipitation (inches);
D_d is the annual depth of precipitation and irrigation that passes through the root zone (inches);
LR is the leaching requirement ratio for sprinkle or surface irrigation (decimal);
D_d is the annual depth of precipitation and irrigation that passes through the root zone (inches);
EC_w is the electrical conductivity of the water infiltrating the soil (mmhos/cm);
EC_{emax} is the estimated electrical conductivity of the average saturation extract of the soil root zone profile for an approximate 100 percent yield reduction (mmhos/cm);
EC_{irr} is the electrical conductivity of the effluent being applied (mmhos/cm); and
D_{irr} is the depth of irrigation water being applied (inches).

Using Table 2.5, the depth of leaching is 5.01 inches. This is greater than the required 2.21 inches so it is estimated to have adequate leaching for this particular leach field. If the depth of leaching is less than desired, one could use a more salt-tolerant crop or one could use a crop that would utilize more nitrogen, which would increase the depth of applied effluent and thus a smaller spray field. Caution should be used when interrupting the data shown in Figure 2.5 in that it only contains a checkbook approach to the water balance and not according to the approach outlined in Chapter 5 of this manual. The main point to take from this analysis is that the average leaching requirements will be met because most if that water will infiltrate into the soil rather than actually run off of the site. If this water balance is completed according to that shown in Chapter 5, the total leaching that would occur would be 19 inches, or the equivalent of excess water applied in the months of Dec through May.

Table 2.5. Water balance to determine the depth of leaching (inches)

Mon	Prec inch	Surface Runoff inch	Irrigation inch	ET inch	Soil Moisture at End of Previous Mon., inch	*Soil Moisture End of Mon. inch	Deep Percolation inch
	P_i	P_{runm}	D_{irrm}	ET_{cm}	S_{i-1}	S_i	D_d
D	3.93	0.72	1.88	2.30	--	4.87	--
J	3.83	0.72	1.88	2.22	4.87	6.12**	1.52**
F	3.55	0.72	1.69	2.55	6.12	6.12**	1.87**
M	3.27	0.72	1.88	4.07	6.12	6.12**	0.36**
A	5.04	0.72	1.81	4.87	6.12	6.12**	1.26**
M	4.32	0.72	1.88	5.65	6.12	5.95	0.00
J	3.30	0.72	1.81	6.77	5.95	3.57	0.00
J	2.93	0.72	1.88	7.79	3.57	0.00	0.00
A	2.40	0.72	1.88	7.80	0.00	0.00	0.00
S	3.59	0.72	1.81	5.89	0.00	0.00	0.00
O	3.10	0.72	1.88	4.72	0.00	0.00	0.00
N	3.96	0.72	1.81	2.97	0.00	2.08	0.00
D	3.93	0.72	1.88	2.30	2.08	4.87	0.00
Total							5.01

* It is estimated that the available moisture in the root zone is 6.12 inches of moisture. If the calculated soil moisture is greater than 6.12, the soil moisture is set back to 6.12 inches. If calculated soil moisture is less than 0.00 inches, the soil moisture is set back to 0.00 inches. These are necessary conditions to meet the constraints of a soil moisture balance of water in the root zone. Note: $S_i = S_{i+1} + P_i - P_{runm} + D_{irrm} - ET_{cm}$

where

D_d is the annual depth of precipitation and irrigation that passes through the root zone (inches);
D_{irr} is the annual depth of irrigation (inches);
P_{net} is the average net annual precipitation (inches);
P_i is the average monthly precipitation (inches);
P_{runm} is the average monthly depth of runoff from precipitation (inches);
D_{irrm} is the average monthly depth of irrigation (inches);
ET_{cm} is the average monthly evapotranspiration for the vegetation in the spray field (inches);
SM_i is the soil moisture in month i (inches);
SM_{i-1} is the soil moisture in the previous month (inches); and
i is the counter for the months.

**The deep percolation is difference between the amount of soil water as calculated minus 6.12 inches. If this number is less than 0.00, then deep percolation is 0.00 inches.

Chapter 3: OSSF Effluent Quantity and Quality

Introduction

In order to design an on-site system, the designer requires some guidance on estimating the flow rate of effluent that can be expected from the system, whether it is used for a single-family home or a combined system for multiple families. Other factors to be considered in the design of the surface application component are the constituents in the effluent, particularly the concentrations of total nitrogen and total dissolved solids. The nitrogen content of the effluent often controls the depth of water that can be applied to the spray field because of the crops ability to assimilate nitrogen. Another design factor for the surface application area and the associated sprinkler system is the volume of the storage or dosing unit. Unlike a leach field that accepts the flow from an on-site treatment system as it is generated, a sprinkler disposal system operates for only a small period of time during a given day, and there may be days when pumping does not occur. Thus, the sizing of the storage tank is critical for a well-engineered OSSF system using a surface application system for final disposal, particularly during those days when the daily flow rate of effluent is far greater than the designed average daily flow rate.

Expected Daily Volume of Effluent

Standards vary across states in the US. Design flows in Pennsylvania are for a 2.5 day retention time at 400 gpd for a three-bedroom single family home to a total septic tank volume of 1000 gallons (BF Environmental Consultants 2009). Mississippi requires the dosing tank of a surface application system to have 1.5 times the maximum volume produced (Mississippi State Department of Health 2009). Texas assumes a three bedroom home consumes on average 300 gpd for residences without water saving devices and 240 gpd for those with water saving devices. These flows translate into the need for a 1000-gallon septic tank for the residence without water saving devices and a 750-gallon unit for those with water saving devices, similar to Pennsylvania. For the aerobic system, the home in Texas requires a 400 gallon tank or essentially a one-day retention time for treatment. In the design of septic or aerobic systems, the design flows are normally based on an average flow rate related to water consumption and retention time and not based on the level of reliability or frequency of an event occurring. In addition, systems built on the basis of the number of bedrooms or average daily flow do not account for extreme events. It is necessary, therefore, to consider an alternative approach to designing onsite surface application systems as a function of probability, similar to the design of full-scale municipal wastewater treatment systems and typical water systems.

The onsite system design manual published by the EPA (2002) has summarized a large number of studies (approximately 1200 locations) that determined the mean per capita domestic indoor water use. As expected, the per capita water use varies considerably both spatially and temporally. Using the relative frequency of occurrence curve from the EPA (2002) study, the average per capita domestic water use was determined to be approximately 70 gpd with a standard deviation of approximately 40 gpd per person. This deviation in the flows reflects high variability and the resulting coefficient of variation is 57%, a somewhat unstable system. Shown in Figure 3.1 is the normalized frequency of exceedence of the ratio of daily water use to average daily water use per person. It should be noted that all the daily water use is taken from high to low without any regard to when the usage occurred. Figure 3.1 provides information on the flow rate and frequency of the various flows. For example, a flow rate two times the average daily per capita rate will occur four percent of the time. Therefore, one can expect that there will be 15 days (0.04 x 365) each year on average when the per capita water use will be more than two times the average.

The flow from a septic or aeration system is assumed to be the same as the average daily domestic water use in a household. There should be no loss of water in either system, especially if the gray water is not being reused. With the EPA (2002) study that found the average daily water consumption to be 70 gpd per person—60 gpd if water saving devices are in place, this rate coincides with the 150 gpd per bedroom (assuming two people per bedroom) recommended by other regulatory agencies in the US.. In contrast when municipal wastewater systems are designed, the average daily flow is doubled for designing many of the system components in order to account for the extreme flows and maintain the quality of the effluent required for discharge.

The question to consider when determining the design flows for an onsite system is how many days of the year is it acceptable to pump effluent onto the spray field at a frequency of more than once per day. If the system is designed for only 1.5 times the average daily flow, then the spray field will have to be used more than once per day 60 days per year on average (Figure 3.1). If the system is designed only for the average daily flow, then the number of days per year at which the system is expected to have more effluent to be discharged to the spray field is 160 days. To maintain this risk at 4 percent or less, the treatment system should be designed for a flow rate compatible with the EPA (2002) study averages of 140 gpd per bedroom or 120 gpd per bedroom if the home is equipped with water saving devices (see Table 3.1). This design requirement then sets the average expected flow rate to the dosing tank for the OSSF system using sprinklers and the associated surface application field.

Table 3.1 Design Flow Daily Rate for Domestic Wastewater OSSF Systems

Bedrooms	Assumed Number of Persons	Gallons 60 gpcd	Gallons 70 gpcd
1	2	120	140
2	4	240	280
3	6	360	420
4	8	480	560
5	10	600	700

In any situation, the designer is referred to Texas Administrative Code 30 section 285 for the latest design guidelines, more specifically, the 285.91(3) (http://info.sos.state.tx.us/fids/200804579-3.html) for wastewater usage rate and 285.91 (2) (http://info.sos.state.tx.us/fids/200804579-2.html) for the septic tank and aerobic treatment unit sizing. If the OSSF system is being designed for a facility other than a domestic dwelling, it is recommended that the designer consult the EPA (2002) manual for water flow rates from other types of facilities.

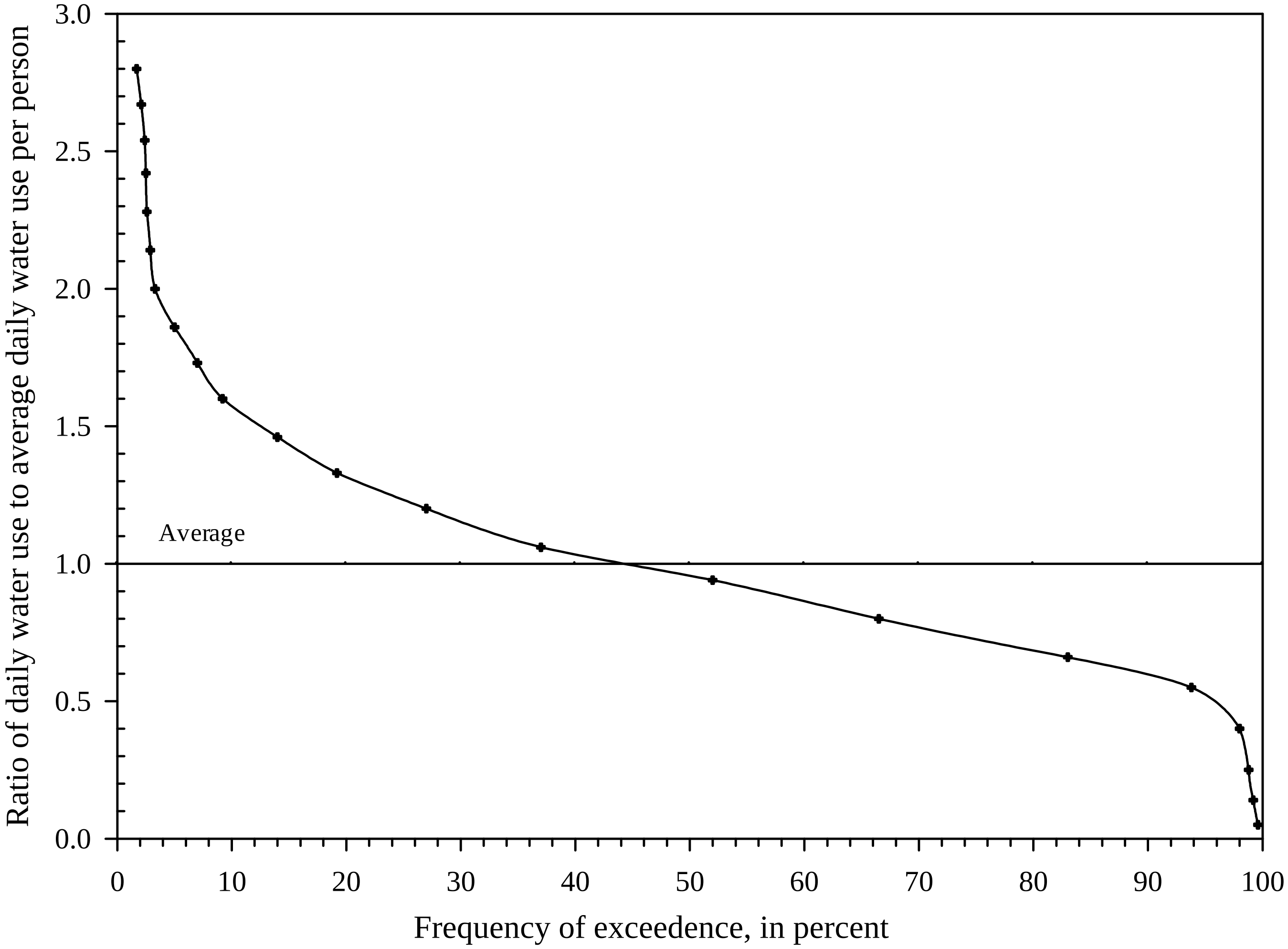


Figure 3.1. Frequency of exceedence for the normalized average daily per capita water usage. (Based on data presented in EPA 2000).

Sizing the Dosing Tank

A review of the average daily per capita water use in the EPA (2002) study reveals that the standard deviation is approximately one-half the average daily per capita water use. Thus, there will be significant variation in the per capita water use from day to day. The dosing tank should hold more water than the average daily usage. A review of Figure 3.1 illustrates that there is still a very small chance that the dosing tank will be filled in less than 24 hours even if the dosing tank is three times the average water use. Due to health concerns, there is a limited time frame that water can be pumped onto the spray field. It is desired to minimize aerosol drift or the chance that someone may be in the spray field when irrigation is ongoing. Therefore, irrigation should occur during very early morning hours (Texas Administrative Code 2009), such as between midnight and 5:00 am. This will require that the dosing tank be large enough so pumping can occur only once a day except in extreme circumstances.

Given the above conditions, it is recommended that the working capacity of the dosing tank be a minimum of two times the design flow rate to the aeration system. This assumes the critical period of operation will be when two people occupy all bedrooms. It also assumes that water is being used at the maximum rate for one day plus one average day water usage to account for variation in pumping time For example, a two bedroom home without water saving devices would require a minimum working tank capacity of 560 gallons (140 x 2 x 2 = 560 gallons). See Table 3.2 for the recommended size of the dosing tank.

Table 3.2 Minimum Working Capacity of Dosing Tank

Bedrooms	Assumed Number of Persons	Gallons 60 gpcd	Gallons 70 gpcd
1	2	240	280
2	4	380	560
3	6	720	740
4	8	860	1120
5	10	1200	1400

Effluent Quality

The constituents in the effluent from an aerobic sewage system or a septic system can affect the way the spray field operates and can negatively affect groundwater. Since OSSF systems have been operated at domestic dwellings for years, the limitations and potential problems are well understood. For OSSF systems using sprinklers, one of the concerns is nitrogen movement into groundwater, especially the water soluble fraction of nitrate. Shown in Table 3.3 and 3.4 are typical values for nitrogen for typical OSSF systems. In the absence of site-specific data, these values can be used to insure that the utilization of nitrogen by the vegetation on the spray field is greater than the amount being applied. See Chapter 5 for specific information on nitrogen utilization by vegetation.

For facilities other than domestic dwellings, one should determine specific constituents of the wastewater for the particular facility. The EPA (2002) publication provides effluent quality for numerous types of facilities. These values can be used if site-specific information is unavailable.

Table 3.3 Mean and range of effluent quality from an aerobic on-site sewage facility (Hutzler et al. 1978 except as noted).

Constituent	Mean	Range
BOD	65[a]	0-208[a]
SS	78[a]	3-252[a]
Total N	36	15-78
NH_3-N	0.9	0-60
NO_3-N	30	0.3-72

[a] Values consider the additional data by various investigators cited in Hutzler et al. (1978)

Table 3.4 Mean and range of effluent quality from a septic tank on-site sewage facility (EPA 1980).

Constituent	Mean	Range
BOD	139[a]	7-385[a]
SS	81[a]	8-695[a]
Total N	53[a]	9-125 [a]
NH_3-N	54[b]	49-59[b]
Total Dissolved Solids	500[c]	300-600[c]

[a] Includes data from Siegrist (1978).
[b] From Siegrist (1978)
[c] EPA 2002

Chapter 4: Determining Soil and Plant Design Parameters

Introduction

A sprinkler irrigation system is designed using site specific information. A properly designed sprinkler system will always have an application rate less than or equal to the intake rate of the soil to ensure there will be no surface runoff from an irrigation event. For agricultural sprinkler systems, it is recommended that the capacity of all sprinkler systems be able to apply sufficient water to meet the crop water needs in the absence of precipitation (Pair et al., 1983). Lastly, a sprinkler system used for an OSSF system must be able to deliver the maximum expected volume of effluent to the soil in a reasonable time period to meet the restricted time of application (Texas Administrative Code, 2009) and minimize the dosing storage capacity (see Chapter 3).

To start the design process, the following design information is required:

- Volume of water to be applied (see Chapter 3)
- Wastewater constituent concentration in the effluent (see Chapter 3)
- Soil properties
    - Texture
    - Intake rate
    - Water holding capacity
- Crop being irrigated (Chapter 5)
    - Evapotranspiration
    - Salt tolerance
- Precipitation

The Soil-Water System

Soil is made up of solids and voids with the voids occupied by air and water. In managing the water applied to soil, it is important to know how much of the voids is occupied by water and how much is occupied by air. Figure 4.1 shows the interaction within the soil-water system. The following conditions are generally used to describe the various water volumes in the soil.

- *Saturation*--all the voids are occupied with water.
- *Field Capacity*--the water remaining in the soil after all the gravitational water has drained from the soil. The water remaining will not drain and is often called capillary water.
- *Permanent Wilting Point*--the water remaining when plants can no longer remove water from the soil. The water remaining is unavailable to plants.
- *Available Water*-- the water in the soil available for plant growth. It is the volume of water remaining after subtracting the water in the soil at Permanent Wilting Point from the amount of water in the soil at Field Capacity.

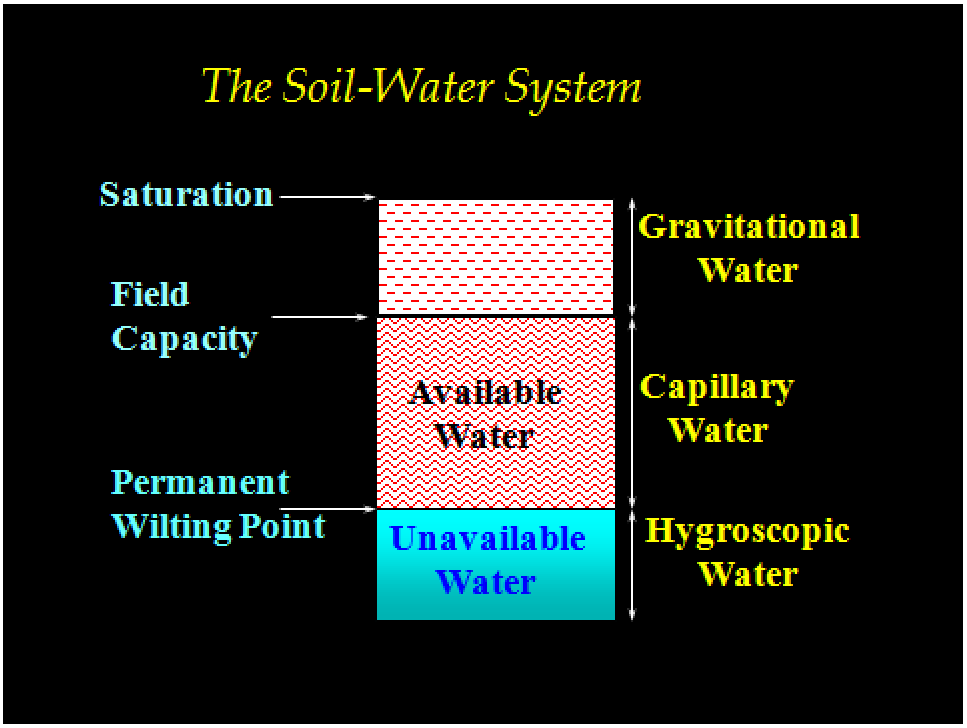


Figure 4.1 The soil-water system showing the various stages of water through saturation.

The soil's ability to retain water or hold water against gravity depends on the soil particles or the texture of the soil, e.g., the quantity of sand, silt, and clay in the soil. Table 4.1 shows the moisture levels as a function of the texture of a soil. The arrangement of the soil particles is the soil's structure. The finer grained soil has more surface area than course-grain soil for a given volume. Since water is held by the forces of surface tension and capillary action, the finer the soil, the more water holding capacity (available water) a soil will have (Table 4.1).

Table 4.1 Moisture Content of Soil, inches per foot of soil depth

Soil Texture	Field Capacity	Permanent Wilting Point	Total Available Moisture
Sandy	1.8 (1.2 - 2.4)	0.8 (0.4 - 1.2)	1.0 (0.8 - 1.2)
Sandy Loam	2.5 (1.8 - 3.2)	1.1 (0.7 - 1.4)	1.4 (1.1 - 1.8)
Loam	3.7 (3.0 - 4.4)	1.7 (1.3 - 2.0)	2.0 (1.7 - 2.4)
Clay Loam	4.4 (3.7 - 5.0)	2.1 (1.8 - 2.4)	2.3 (1.9 - 2.6)
Silty Clay	4.8 (4.2 - 5.5)	2.3 (2.0 - 2.7)	2.5 (2.2 - 2.8)
Clay	5.3 (4.6 - 5.8)	2.6 (2.2 - 2.8)	2.7 (2.4 - 3.0)

Adapted from Hansen et al., 1980

Application Rate and Water Intake Rate

The application rate for a sprinkler system is the amount of water applied to a given area measured in inches per hour. The most frequently used criterion is to make the water application rate equal to or less than the soils water intake rate. This ensures that there will be no surface runoff. For extended periods of irrigation, the intake rate will decrease to the base intake rate of the soil. The base water intake rate is highly correlated to the saturated hydraulic conductivity of the soil (Karmeli et al. 1978).

For an OSSF system, the depth of application most likely will be one inch or less per irrigation event. When nutrient loading limits are taken into consideration and when irrigation events occur as frequently as once per day for an OSSF system, the actual depth of application may be less than 0.2 inches per event.

In contrast, for the design of center pivot systems used in large-scale municipal land application systems, the water application rates are often greater than the water intake rates of the soil. The amount of surface storage has been studied to determine the potential for surface runoff. Allowable surface storage rates are set at 0.5 inches for slopes up to one percent and 0.3 inches for slopes between one and three percent (Jensen 1983). Thus, even for a soil with an extremely low intake rate, the allowable surface storage will prevent any surface runoff for the depth of application expected for the average OSSF system.

For OSSF systems, where the irrigation frequency is every one to two days, or longer, the recommended application rate should be equal to or less than the base water intake rate of the soil. In certain situations, the application rate can be adjusted so that the total depth of application is equal to or less than the application rate defined by the following equation:

$$Q_R = (I_B \times T_A + SS)/T_A$$

where

Q_R is the application rate (inches/hr);
I_B is the base intake rate of soil (inches/hr);
T_A is the time of application (hr); and
SS is the maximum surface storage for sprinkler system (inches).

Because it is difficult to obtain intake rates for sprinkler systems, a conservative recommendation is that the base infiltration rate be set equal to the saturated hydraulic conductivity of the top 18 inches of soil.

Estimating Base Intake Rate of Soil

The typical soil exhibits an initially high infiltration rate that decreases with time to a *base intake rate*. A typical infiltration curve is shown in Figure 4.2. While the infiltration of water is a function of soil structure, chemistry of the water and soil, temperature of the water, and soil texture, the base water intake rate is primarily related to the saturated hydraulic conductivity of the soil (Karmeli et al., 1978). Furthermore, Karmeli et al. (1978) states that the base intake rate of the soil is equal to the saturated hydraulic conductivity. Thus, if the saturated hydraulic conductivity can be estimated, the base intake rate can also be estimated.

Saxton et al. (1986) developed an equation that relates saturated hydraulic conductivity to soil texture. The equation is:

$$K = 0.3937 \cdot \left\{ exp\left[A + \left[\frac{B}{\theta} \right] \right] \right\}$$

where

$$A = 12.012 - 0.0755 \cdot (\%sand)$$

$$B = 3.8950 + 0.03671 \cdot (\%sand) - 0.1103 \cdot (\%clay) + 8.7546 \cdot 10^{4} \cdot (\%clay)^{2}$$

$$\theta = 0.332 - 7.251 \cdot 10^{4} \cdot (\%sand) + 0.1276 \cdot \log_{10}(\%clay)$$

and where

K is the saturated hydraulic conductivity (inches/hr);
θ is the soil moisture content (ft^3/ft^3);
sand is the sand in the soil (percent); and
clay is the clay in the soil (percent).

The soil moisture content at saturation for various textural classes of soils is shown in Table 4.2. The soil moisture content values listed are an average for each soil texture class provided. Fortuitously, the soil moisture content at saturation has very little variation (plus or minus 5 percent or less) within a soil textural class. Once the texture of the soil is determined (percent sand, silt, and clay), the soil texture class can be determined from Figure 4.3.

In the absence of field data, the base water intake rate should be determined by using the equation developed by Saxton et al. (1986) assuming that the base water intake rate is equal to the saturated hydraulic conductivity. The information needed can be obtained by finding the texture of the soil, the soil textural class (Figure 4.3), and the soil moisture content at saturation for the soil textural class (Table 4.2). The National Resources Conservation Service has soil surveys for all parts of Texas that can be found online at http://soils.usda. gov/survey/online_surveys/texas/ and at http://soils.usda.gov/survey/printed_surveys/state. asp?abbr=TX&state=Texas.

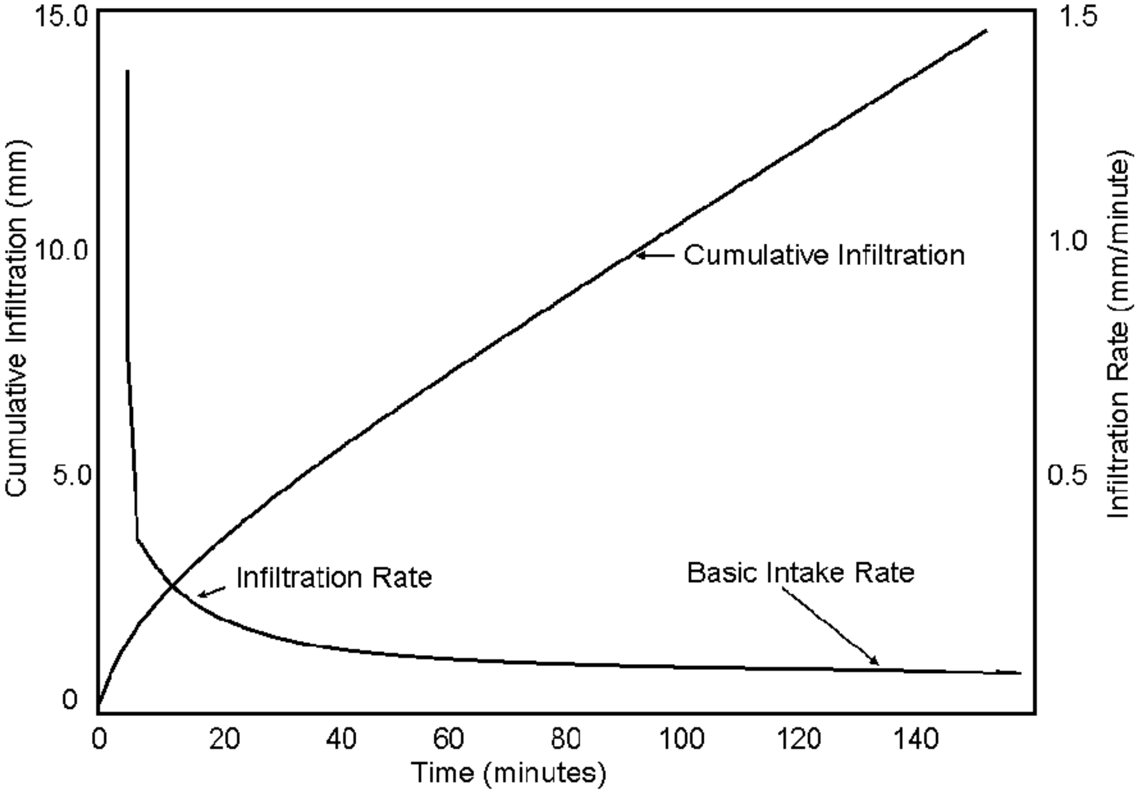


Figure 4.2 Example infiltration rate curve for a typical soil (adapted from Karmeli et al. 1978).

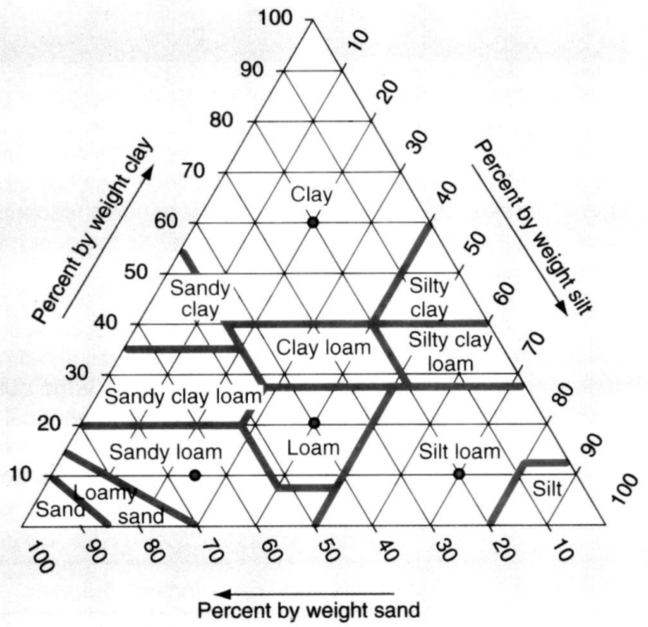


Figure 4.3 Soil textural triangle used to identify the class of soil (taken from Miller and Gardner, 2001).

Table 4.2. Generalized soil-water characteristics based on the soil texture (adapted from Saxton, et al. 1986)

Soil Textural Class	Percent Sand	Percent Clay	Saturated Moisture Content (in/ft of depth)	Saturated Hydraulic Conductivity (inches/hr)
Sand	90	7	4.6	2.14
Loam Sand	82	10	4.8	1.15
Sand Loam	65	11	5.0	0.91
Sand Clay Loam	58	29	5.8	0.11
Sand Clay	50	45	6.1	0.05
Loam	43	18	5.5	0.41
Clay Loam	31	33	6.0	0.13
Clay	30	50	6.4	0.06
Silt Loam	23	16	5.6	0.64
Silt Clay Loam	12	33	6.2	0.18
Silt Clay	9	44	6.5	0.11
Silt	7	10	5.5	1.37

Interception

The most common assumption (or misconception) made with regard to irrigation is that all the water applied reaches the soil surface. Once in the soil, the water is either stored, percolates below the root zone, or is used by vegetation. Before the water reaches the soil, it must go through the plant canopy. In this process a significant percentage of the water is intercepted. There are two important concepts that must be understood. First, interception occurs for natural precipitation as well as for water applied by sprinkler irrigation. Second, plants use intercepted water to meet their cooling requirements and the intercepted water, when evaporated, is considered to be part of the evapotranspiration water use. It is important to understand intercepted water because of the concern for surface runoff in OSSF systems.

Viessman et al. (1989) reported that a spruce-fir forest intercepts up to 30 percent of the precipitation. This was determined by placing rain gauges in a pasture and in a spruce-fir forest and determining the differences in the catch. Grasses and crops also intercept a portion of the precipitation. Viessman et al. (1989) reported the annual precipitation interception rates for alfalfa, corn, soybeans, and oats to be 36, 16, 15, and 7 percent, respectively. In a study where 0.5 inch of water was applied in 30 minutes by a sprinkler irrigation system, the percent interception for little bluestem, big bluestem, tall panic grass, bindweed, and buffalo grass were 50, 57, 57, 17, and 31 percent (the grass height was up to 36 inches). The conclusion that can be drawn from these data is that the vegetation will intercept some of the water applied to the spray field and thus reduce the possibility of surface runoff. It should be noted that the depth of water applied per irrigation for a typical OSSF surface application system typically will be 0.25 inches or less. Therefore, this application rate can occur even if the soil has a low intake rate or if the irrigation frequency is one to two days.

A concern about the plants' use of intercepted water is often voiced. Frequently, intercepted water is not taken into consideration when determining the water needs of crops. However, the intercepted water will be evaporated and will help meet the cooling needs of plants rather than the plant extracting water from the available soil moisture. The intercepted water, although never reaching the soil, is used by the crop. The intercepted water should not be subtracted from the water balance of a sprinkler irrigation system. Also of importance for OSSF systems is the fact the intercepted water will help prevent runoff since the incepted water provides temporary storage of the applied water.

Time of Application:

Given the characteristics of OSSF systems, the time of application should not be greater than one hour per day and 0.5 hours should be used as the initial estimate in the design process for sprinkler irrigation systems. Considering the constraints of most soils, the nitrogen content of effluent, the design flow rate of an OSSF system, and the available effluent storage capacity, the time of application will generally be less than one hour per day.

If a soil has a relatively high intake rate and the water being applied does not hinder the application of large depths of water, the time of application can be several hours per day if there is no consideration given to only replacing the evapotranspiration requirements of a crop (e.g., let the hydraulic loading rate be a function of nutrient content rather than the moisture requirement of the crop). Some consideration must be given to the growing environment of the crop because the continuous application of water would create the equivalent of a wetland and not a field suitable for the vigorous growth of vegetation. Thus the time of application is a design decision and can vary over a wide range of values and still be a sound design decision.

When the only consideration is maintaining adequate soil moisture for optimum crop growth, there are different constraints for applying the water. The time of application as used in the irrigation of a typical crop is the time necessary to apply sufficient water to bring the spray field up to field capacity. The soil moisture is allowed to deplete (for most practical purposes) until only 50 percent of the available soil moisture remains. Irrigation is then initiated and continued until the soil moisture in the field reaches field capacity. The length of time when the water is being applied is called the time of application (T_A). There are many strategies for irrigating a field and the time of application is modified to meet the different strategies. For example, a center pivot may apply one inch of water in 2.5 days to a field but the actual time of application may be 15 minutes due to the movement of the pivot. In a solid set system, water may be applied for only 10 minutes with frequent irrigations because of a very low water intake rate of the soil, or one may apply water for 3 hours at a rate equal to the base intake rate of the soil. The time of application is a function of evapotranspiration rates, available moisture, desired application rates, and frequency of irrigations. The determination of the proper time of application requires a rational, calculated decision.

Crop Consumptive Use

For a crop to remove nitrogen, it should be growing near its optimum rate, which means that adequate moisture should be available to the crop. Estimating how much water a crop will use is a difficult task. To provide a reasonable estimate for the crop consumptive use (also called evapotranspiration), a manual was prepared for most major crops in Texas: (Borrelli et al. 1998). The mean crop consumptive used and free water evaporation for Texas manual can be viewed or downloaded at http://www.webpages.ttu.edu/cfedler/downloads/finalreports.html.

For the purposes of planning and designing OSSF systems, the mean monthly consumptive use for crops is all that is needed. The manual (Borrelli et al. 1998) provides the crop consumptive use for Texas.

The term *consumptive use* is synonymous with the term *evapotranspiration*. *Evapotranspiration* is most often used in technical publications on crop water use while *consumptive use* is most often used in the general water resources and environmental engineering technical publications.

Consumptive use (evapotranspiration) was defined by Jensen (1983) as "the combined process by which water is transferred from the earth's surface to the atmosphere [and] includes evaporation of liquid or solid water from the soil and plant surfaces plus transpiration of liquid water through plant tissue expressed as the latent heat transfer per unit area or its equivalent depth of water per unit area." Consumptive use is difficult to measure but can be estimated using climatological data consisting of minimum and maximum temperature, wind speed, humidity or dew point temperature, and solar radiation or percent sunshine. The process of making the estimate is difficult and is the reason for using the recommended manual (Borrelli et al. 1998).

Chapter 5: Water, Nitrogen and Salt Balance

Introduction

One of the guiding principles of any surface application of wastewater effluent site is to manage the land treatment system so the land can be used for other purposes once the land is no longer used for wastewater treatment. An equally important principle is to design and operate the surface application system to prevent pollution of water and land resources. The goal of both principles can be met if sound agricultural principles are practiced. Therefore, it is important to examine the nitrogen, water, and salt balance of the wastewater applied to the application site to ensure they meet the goals of the above principles.

Nitrogen Balance

Nitrogen in the municipal wastewater has a few forms, such as organic nitrogen, ammonia-nitrogen, nitrate-nitrogen, and nitrite-nitrogen. The residual nitrogen of treated municipal wastewater mainly includes incompletely degraded or non-degraded organic nitrogen, ammonia-nitrogen, and nitrate-nitrogen. The transformations and cycle of nitrogen are complicated in the land application system (Figure 5.1). It is required to state the nitrogen cycle in the land application system in order to completely understand the model of nitrogen balance used in this research. The boundary of the nitrogen balance model is the plant root zone plus the plants growing on the surface of the soil involved with the plant root zone.

Nitrogen may be input into the land application system in the forms of organic nitrogen, nitrate-nitrogen, and ammonia-nitrogen by the pathway of wastewater application, rainwater, plant residues and animal manures, possibly fertilizers (Muchovej and Rechcigl 1994), and even nitrogen fixation by the bacteria growing on the surface of leguminous plant root system if leguminous plants are growing at sites. Some of nitrogen is released from the system in the forms of gaseous NH_3, nitrogen gas, N_2O, and NO to the atmosphere as a result of denitrification, and some of nitrogen is leached down to the groundwater. In the root zone, organic nitrogen can be converted to ammonia and ammonium ion, which is defined as mineralization (Broadbent and Reisenauer 1985), but nitrate and ammonium ion can be uptaken by some microorganisms, in a process called immobilization (Mulvaney et al. 1993). Ammonium ion can be converted to nitrite in nitrification I and finally nitrate in nitrification II (Lloyd 1993; Quastel and Scholefield 1951). Nitrite can be converted to nitrate in nitrification II (Quastel and Scholefield 1951) and to nitrogen gas or N_2O in denitrification II. Nitrate can be converted to nitrite in denitrification I, and then nitrogen gas or N_2O in denitrification II (Payne 1986). Due to its high mobility, nitrate can be leached down within leachate to groundwater. The complete model of nitrogen balance for a wastewater surface application system may be explained with Equation 5.1 (Duan and Fedler 2009).

$$V_n C_n = V_p C_p + V_g C_g + V_i C_i + N_r + N_f + N_l - N_{pl} - N_d - N_a - \Delta N_s \quad (5.1)$$

where

N=mass of total nitrogen (mg);

n=total nitrogen in the leaching water;
V=volume (L);
C=concentration of total nitrogen (mg/L);
p=precipitation;
g=groundwater;
i=irrigation;
r=total nitrogen from plant residuals fallen onto or into soils;
f=total nitrogen from fertilizer if applicable;
l=total nitrogen due to nitrogen gas fixation with legume growing;
pl=total nitrogen loss by harvesting crops;
d=total nitrogen loss by denitrification;
a=total nitrogen loss by ammonia volatilization; and
ΔNs=loss of total nitrogen from soil water to soil in the root zone due to nitrogen immobilized by soil microbes (+) or adsorption, or add of total nitrogen from soil to soil water due to nitrogen mineralization or desorption (-).

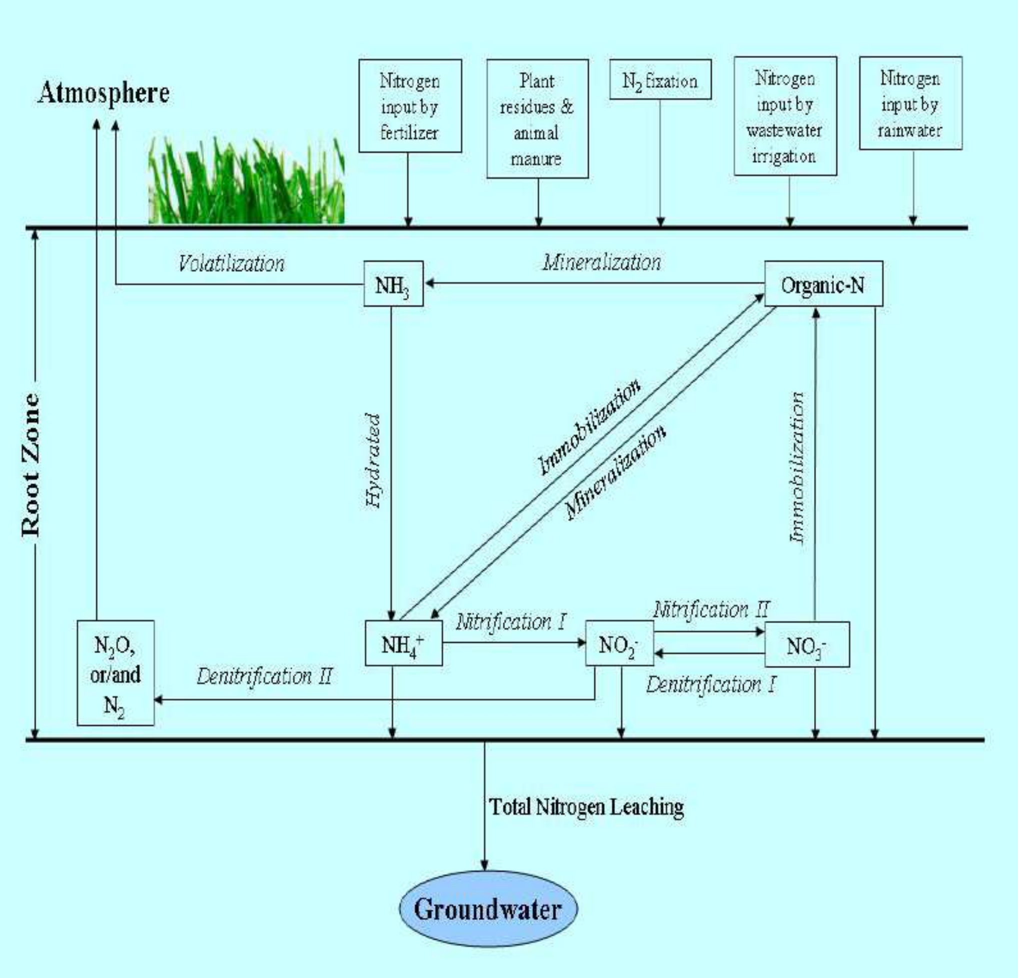


Figure 5.1 Nitrogen cycle and balance at a typical wastewater land application site (Duan 2009).

Equation 5.1 can be used to readily and completely understand the mass balance of nitrogen; however, it is not practical to be used for the design of OSSF systems. Land is almost always in limited supply for a spray field used to treat wastewater effluent. Thus, it is imperative to size the spray field to minimize land use. However, at all times, the spray field must be sized to meet three important criteria: the vegetation on the land must be able to assimilate the nutrients (nitrogen is usually the land limiting nutrient), the soil must be able to absorb the water without allowing surface runoff or mounding of the water table that would create soil saturation within the root zone, and there must not be a build of salt in the soil that would reduce the growth of vegetation.

The nutrient uptake by vegetation will generally control the size of the spray field. Most OSSF systems apply water to native vegetation or turf grass where the clippings are not removed. Native vegetation does not have high nitrogen uptake rates. Consequently, the land area required can be much higher when nitrogen limitations are considered as compared to the land required when considering soil hydraulic limitations. Tables 5.1–5.3 show the nitrogen uptake rates for several different types of vegetation to aid in the determination of the land area required for the spray field.

Salt Balance

All irrigation water contains salts and these salts remain in the soil after evapotranspiration occurs unless they are flushed below the crops root zone. To maintain the salt balance in the soil (no increase in the amount of salt in the soil), the salts must be flushed or leached below the root zone. In many cases the leaching requirements are met by unavoidable deep percolation losses during irrigation and winter precipitation (Westcot and Ayers, 1986; Oster and Rhoades 1986). Keller and Bliesner (1990) computed the leaching requirement for sprinkler and surface irrigation by Equation 5.2.

$$LR = \frac{EC_w}{5 \cdot EC_{e10} - EC_w} \qquad (5.2)$$

Table 5.1 Annual nitrogen uptake rates for selected forests

Forest Trees	Annual Nitrogen Uptake (lb/ac)
Mixed hardwoods*	178
Red pine*	143
White spruce (old field vegetation)*	223
Pioneer succession vegetation*	223
Pulpwood**	150
Slash Pine**	190

* Overcash and Pal (1979)
** Pettygrove and Asano (1988)

Table 5.2 Annual average nitrogen uptake rates for selected forage crops

Forage	Average Annual Nitrogen Uptake (lb/ac)

Alfalfa*	340
Brome grass*	158
Coastal Bermuda grass*	479
Kentucky bluegrass*	209
Quackgrass*	229
Reed canary grass*	350
Rye grass*	214
Sweet clover*	156
Tall fescue*	211
Orchard grass*	267
Bent grass**	152
Mixed pasture hay**	94
Pasture**	68
Johnson grass (regularly harvested)***	500
Red clover***	90
Lespedeza hay***	116

* EPA (1981)
** Pettygrove and Asano (1988)
*** Overcash and Pal (1979)

Table 5.3 Annual average nitrogen uptake rates for selected field crops

Crop	Average Annual Nitrogen Uptake (lb/ac)
Barley*	112
Corn*	167
Cotton*	83
Grain sorghum*	120
Potatoes*	205
Soy beans*	223
Wheat*	143
Oats (grain)*	56

* EPA (1981)

where

LR is the leaching requirement ratio for sprinkler or surface irrigation (decimal);
EC_W is the electrical conductivity of the irrigation water (mmhos/cm); and
EC_{e10} is the estimated electrical conductivity of the average saturation extract of the soil root zone profile for an approximate 10 percent yield reduction (mmhos/cm).

For an OSSF system, Ayers and Westcot (1976) propose a similar formula for high frequency sprinkler and drip irrigation (near daily application) (Equation 5.3.

$$LR = \frac{EC_W}{2 \cdot EC_{emax}} \qquad (5.3)$$

where

LR is the leaching requirement ratio for sprinkler or surface irrigation (decimal);
EC_w is the electrical conductivity of the water infiltrating the soil (mmhos/cm); and
EC_{emax} is the estimated electrical conductivity of the average saturation extract of the soil root zone profile for an approximate 100 percent yield reduction (mmhos/cm).

The electrical conductivity of the irrigation water should account for precipitation. The electrical conductivity is that of the average water—irrigation water and precipitation—infiltrating the soil. Note that the electrical conductivity for precipitation is zero. The weighted EC_w can be calculated as follows:

$$EC_w = \frac{D_{irr} \cdot EC_{irr}}{D_{irr} + P - P_{run}} \qquad (5.4)$$

where

EC_w is the electrical conductivity of the water infiltrating the soil;
D_{irr} is the annual depth of the effluent applied to the spray field;
EC_{irr} is the electrical conductivity of the effluent being applied;
P is the annual depth of precipitation; and
P_{run} is the average annual surface runoff (inches).

The next step is to determine how much leaching water must pass through the root zone. According to SCS (1993), the depth of water for leaching can be calculated by Equation 5.5.

$$LR = \frac{D_d}{D_{irr+rain}} \qquad (5.5)$$

$$D_{irr+rain} = D_{irr} + P_{net} \qquad (5.6)$$

$$D_d = \sum_{1}^{12} P_i + \left(-P_{runm} + D_{irrm} - ET_{am}\right)_I \qquad (5.7)$$

where

LR is the leaching requirement ratio for sprinkle or surface irrigation (decimal);
$D_{irr+rain}$ is the sum of the irrigation applied plus the portion of the precipitation infiltrating the soil or precipitation minus runoff from precipitation;
D_d is the annual depth of precipitation and irrigation that passes through the root zone;
D_{irr} is the annual depth of irrigation;
P_{net} is the average net annual precipitation (inches);
P_i is the average monthly precipitation;
P_{runm} is the average monthly depth of runoff from precipitation;

D_{irrm} is the average monthly depth of irrigation;
ET_{am} is the average monthly evapotranspiration for the vegetation in the spray field; and
i is the counter for the months.

The net annual precipitation (P_{net}) is the annual precipitation minus the average annual surface runoff (P_{run}). The net precipitation can be estimated using the following equations (Reed et al. 1997):

$$P_{run} = 0.00064 \cdot P \cdot \exp(0.15494 \cdot P) \quad \text{for } P < 31.5 \text{ inches} \qquad (5.8)$$

$$P_{run} = 0.510 \cdot P - 13.35 \quad \text{for } P \geq 31.5 \text{ inches} \qquad (5.9)$$

$$P_{net} = P - P_{run} \qquad (5.10)$$

where

P_{net} is the average net annual precipitation (inches);
P is the average annual precipitation (inches); and
P_{run} is the average annual surface runoff (inches).

To calculate the average monthly depth of runoff from precipitation (P_{runm}) divide the average annual surface runoff from precipitation (P_{run}) by 12.

Water Balance

The water balance for a land treatment system is the capstone for the whole design of the surface application treatment system. In the wastewater surface application system, there are a few components to be considered while doing a water balance (Figure 5.2). If the root zone is regarded as a system, the input is wastewater applied and effective precipitation. Some water that has fallen onto soil surface is utilized by plants and evaporated from the soil (the incorporation of plant transpiration and evaporation is called evapotranspiration), some of water deep percolates down to groundwater through the root zone, and the other part of water stays in the root zone. Because evapotranspiration and water added vary with the plant growth and the variation of climate conditions, the water stored in the root zone also varies. Therefore, the basic equation used to develop a water balance and develop the irrigation schedule is shown in Equation 5.11 (Fedler and Borrelli, 2001).

$$SM_i = SM_{i-1} + P_i + I_i - ET_i - L_i \qquad (5.11)$$

where

SM_i is the soil moisture in month i, (inches/month);
SM_{i-1} is the soil moisture in the previous month, (inches/month);
P_i is the precipitation in month i, (inches/month);
I_i is the irrigation in month i, (inches/month);
ET_i is the evapotranspiration in month i, (inches/month); and

and L_i is the leaching that occurs in month i, (inches/month).

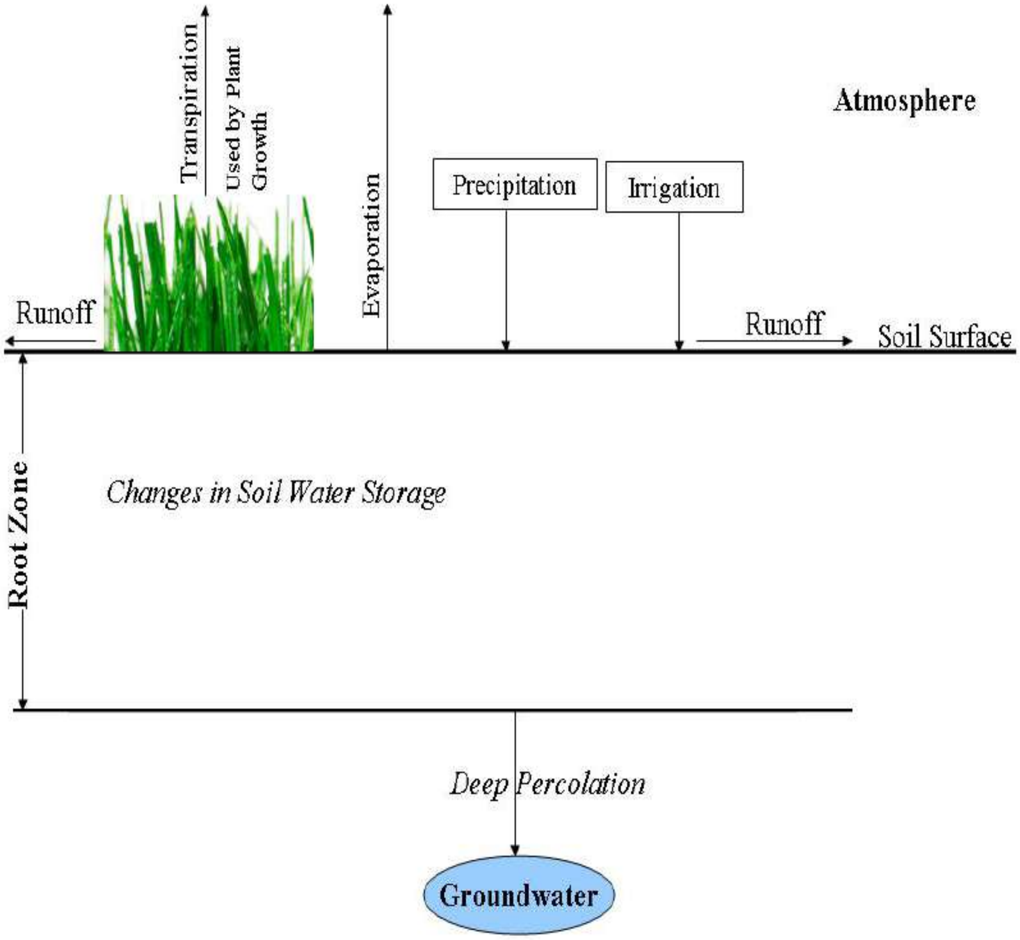


Figure 5.2 Water balance and components in the wastewater land application system (Duan 2009).

Note that all the variables in Equation 5.11 have units of depth per month (e.g. inches per month or centimeters per month) and the soil moisture cannot be less than zero nor more than the available water-holding capacity of the soil within the plant root zone. The change of soil water storage in the root zone with time of month can be calculated by the difference of the soil moisture in month i and the soil moisture in month i-1. Any water applied in excess of the water holding capacity and less than saturation condition is called deep percolation, or leaching water, and this water passes through the plant root zone eventually reaching the ground water. There are two assumptions inherent in Equation 5.11 are 1) irrigation events are designed and controlled well enough to have no runoff on the soil surface, and 2) the groundwater level is deep enough to make sure there is no groundwater entering into the crops root zone. By determining the variables in Equation 5.11, the irrigation schedule can be determined.

To determine the depth of water passing through the root zone, a simulation of historical evapotranspiration and precipitation can be made for the soil type in the spray field. However, for an OSSF system, this is beyond the precision needed for a design that does not cause excessive nitrogen to be leached below the root zone. A simplified water balance can be made to determine the depth of drainage (D_d). The following table is used to illustrate the procedure.

Table 5.4 Monthly water balance for a simulated surface application system of an OSSF (inches) (Example using Waco, TX).

Month	Precipitation	Surface Runoff	Irrigation	Evapotranspiration	Drainage
	P_i	P_{runm}	D_{irrm}	ET_{cm}	D_d
J	1.72	0.21	1.88	2.22	1.17
F	2.14	0.20	1.69	2.55	1.08
M	2.28	0.20	1.88	4.07	0
A	3.78	0.21	1.81	4.87	0.51
M	4.58	0.21	1.88	5.65	0.59
J	2.75	0.21	1.81	6.77	0
J	1.94	0.21	1.88	7.79	0
A	1.89	0.21	1.88	7.80	0
S	3.05	0.21	1.81	5.89	0
O	2.96	0.20	1.88	4.72	0
N	2.14	0.21	1.81	2.97	0.76
D	1.93	0.21	1.88	2.30	1.29
Total	31.16	2.00	22.09	57.60	5.40

The above monthly water balance determines the depth of leaching based on long term averages. The determined leaching in the example provides us with sufficient information to make a sound engineering judgment about the salt balance.

With most land application systems, most of the leaching occurs during the winter and spring periods. During the warmest part of the growing season (eg. June through August) the evapotranspiration of the crop is greater than the precipitation and the applied water in the more arid parts of the State. During this period the crop will be somewhat stressed for water and there will be a buildup of salt. During the cool season, the evapotranspiration decreases and thus, leaching will increase. Actual precipitation and evapotranspiration is not the same year to year. However, the average precipitation and evapotranspiration over a period of three to five years will approach the long term averages. Hydrologic studies such as the (Reed et al. 1997) study that looked at surface runoff from precipitation show that most of the precipitation infiltrates into the soil.

Example

The example presented follows the calculations needed to determine if adequate leaching is occurring to prevent the buildup of salts in the soil. The example uses the following values:

Moderate salt-tolerant trees and shrubs
EC_{irr} = 3.2 mmhos or 2050 ppm
EC_{emax} = 16 mmhos
P = 31.16 inches
D_{irr} = 22.09 inches
ET_c = 57.6 inches

Calculate the surface runoff.

$$P_{run} = 0.00064 \cdot P \cdot \exp(0.15494 \cdot P)$$

$$P_{run} = 0.00064 \cdot 31.16 \cdot \exp(0.15494 \cdot 31.16) = 2.49 \text{ inches}$$

$D_{irr+rain} = D_{irr} + P - P_{run} = 22.09 + 31.16 - 2.49 = 50.76$ inches

$$EC_W = \frac{D_{irr} \cdot EC_{irr}}{D_{irr} + P - P_{run}} = \frac{22.09 \cdot 3.2}{22.09 + 31.16 - 2.49} = 1.39 \text{ mmhos}$$

$$LR = \frac{EC_W}{2 \cdot EC_{emax}} = \frac{1.39}{2 \cdot 16} = 0.044$$

$$LR = \frac{D_d}{D_{irr+rain}}$$

$$D_d = LR \cdot D_{irr+rain} = 0.044 \cdot 50.76 = 2.23 \text{ inches}$$

Using Table 5.4, the depth of leaching is 5.40 inches without the adjustment for available moisture. If it is adjusted for available moisture as discussed above and three inches is used as the readily available moisture, the leaching depth would be 2.40 inches. This is greater than the required 2.23 inches so it is estimated to have adequate leaching for this particular leach field. If the depth of leaching is less than desired, one could use a more salt-tolerant crop or one could use a crop that would utilize more nitrogen, which would increase the depth of applied effluent and thus require a smaller spray field.

Chapter 6: Sprinkler System Design

Introduction

The design of solid set sprinkler systems for an OSSF is more like the design for turf grass than for agricultural crops. One wants to contain the water on a relatively small area and with no water going outside the boundaries of the irrigated area. To do this, part-circle and full-circle sprinkler heads are used rather than having all full-circle sprinkler heads. Care must be given to the overlap pattern of the sprinkler heads so that no water is distributed outside the designated area or spray field.

In addition to controlling the area wetted by the sprinkler system, there is a need to distribute the effluent uniformly. It must be realized that nutrient distribution is similar in proportion to the effluent being distributed. Thus poor distribution of the effluent may cause excess nutrients to be applied on portions of the spray field. In actuality, the terms uniform and poor distribution are relative terms because no sprinkler system distributes water with absolute uniformity. Sprinklers typically distribute water in a cone shaped pattern (Figure 6.1) and uniform distribution, relatively speaking, occurs as a result of overlapping the water coming from the individual sprinkler heads (Figure 6.2).

Design Recommendations for OSSF Sprinkler Systems

Detailed design procedures for typical solid-set sprinkler systems can be found in Keller and Bliesner (1990) and in Watkins (1977). These references provide additional information on many aspects of sprinkler system design.

Sprinkler Spacing

There are two major design considerations for selecting the spacing of sprinkler heads: the spacing must result in an acceptable uniformity of water distribution and the effluent must be contained within the spray field. The spacing that is most often recommended and generally accomplishes these two design considerations is the spacing of the sprinkler heads at 0.5 times the sprinkler's wetted diameter. The wetted diameter is the spread of water by the sprinkler head. The wetted area that results when operating in the absence of wind is considered to be a circle. The operating pressure, sprinkler nozzle orifice size, and sprinkler head type that will provide the wetted diameter needed for the surface application site being designed are determined or selected in order to obtain the required sprinkler spacing.

While there are some sprinkler heads that are adjustable to control the wetted diameter, these sprinklers should be avoided. The sprinkler spacing of 0.5 times the wetted diameter will allow for a good match for quarter-, half-, three-quarter-, and full-circle sprinklers within the spray field without the problem of throwing water beyond the spray field designed boundary. Most importantly, this sprinkler spacing should distribute the water with a high coefficient of uniformity (80 percent or greater is preferred). The coefficient of uniformity is a measure of uniform water application across a field or irrigation set. Christiansen’s Uniformity Coefficients is generally used for the coefficient of uniformity and is described in detail below. A uniformity of 85 percent is recommended by Keller and Bliesne (1990) for turf systems, which is greater than the 70 percent minimum required for agricultural sprinkler systems (Pair et al., 1983). The above assumption is predicated on the sprinkler head being operated within the manufacturer’s range of recommended operating pressures, the sprinkler spacing (s_l), the lateral spacing along the main (s_m) being one-half the wetted diameter (see Figure 6.3), and the system being properly maintained.

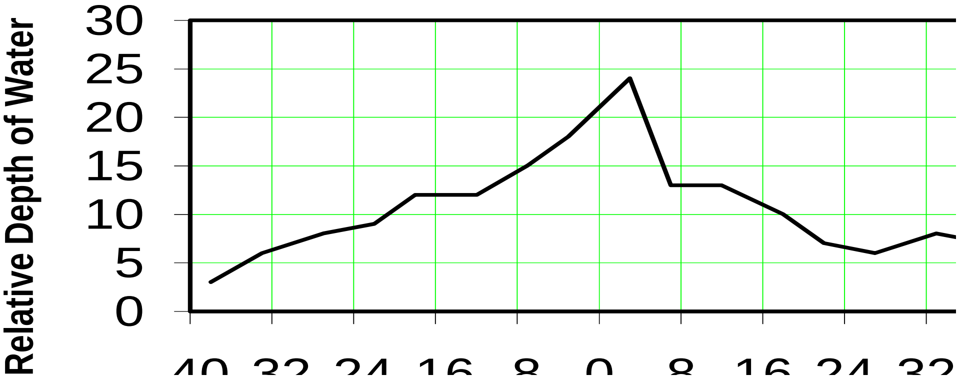


Figure 6.1. Typical shape of sprinkler pattern for an individual sprinkler. Sprinkler is located at the zero point on the graph.

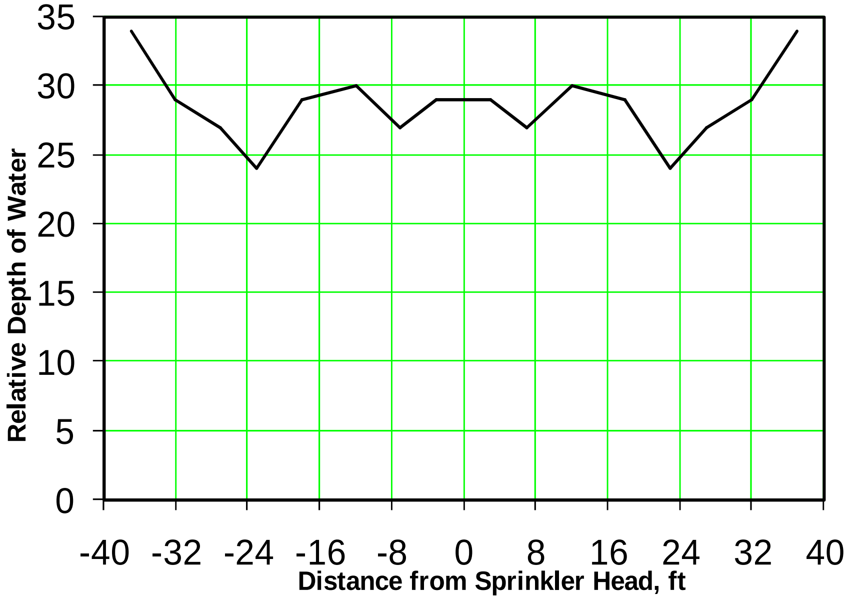


Figure 6.2. Typical sprinkler pattern where overlap of the spray pattern is provided. Sprinkler is located at the zero point on the graph.

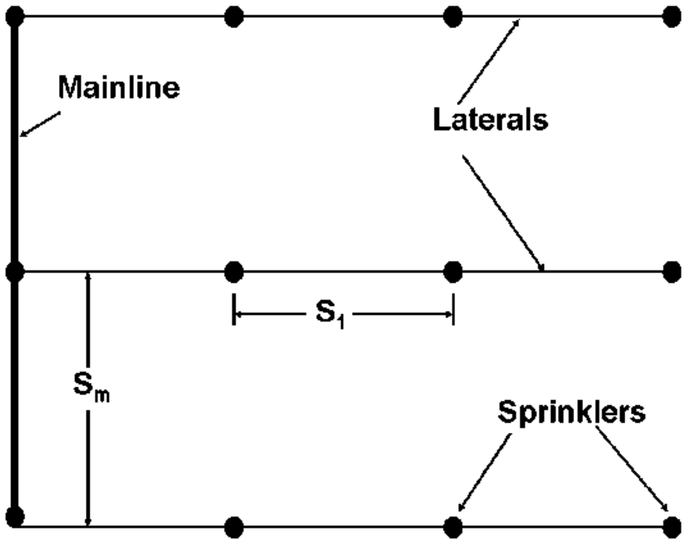


Figure 6.3. Graphic definition of an example sprinkler spacing layout.
S_m and S_l are the main and lateral line spacings.

To achieve a high coefficient of uniformity, the operating pressure for the sprinkler head should be selected as close as possible to the midrange of the manufacturer's recommended operating pressures. This is desirable because a pressure that is too low will cause the water to exit the sprinkler head as a pencil stream with very little breakup into droplets over the wetted diameter. A pressure that is too high will cause the discharge stream to breakup into a larger percentage of small droplets causing a greater potential for the spray to drift beyond the spray field. Operating at pressures midrange of the manufacturer's recommended operating pressures will generally ensure a more uniform distribution pattern.

Wind is also recognized as a factor in selecting the sprinkler spacing for a sprinkler system. In an OSSF sprinkler system, the irrigation frequency for most systems will be once per day or once every two days. With such frequent irrigation, most days will have acceptable wind speeds for operation of a sprinkler system and a few days will have excessive winds.

Wind will be a factor on some days; for example, there could be a major climatic event in the area. However, wind should be a very minor factor relative to achieving high coefficients of uniformity for systems designed with s_l and s_m at 0.5 times the wetted diameter of the sprinkler. Pair et al. (1983) state that even for relatively high velocity winds, a sprinkler spacing approaching a square (as recommended in this report) gives a more uniform distribution than other spacing patterns. Keller and Bliesner (1990) presented tables of data for various sprinkler head spacings with winds in the 15 to 20 mph range that had coefficients of uniformity greater than 80 percent for the square spacing arrangement.

The typical monthly average wind speed in Texas may be 13 mph for areas of high winds and nine mph or less for areas with low winds. The wind is typically measured at 11.5 to 13 feet in height above the ground surface. The wind speed at the height of the typical sprinkler (less than 3.28 feet) will be approximately 0.75 times that reported in climatological data. Jensen et al. (1990) reported that the ratio of daytime wind speeds to nighttime wind speeds was 2.0, more or less. Thus, nighttime wind speeds are 0.67 times the average wind speeds. Therefore, if the sprinkler irrigation occurs at night, the average speed at these usual sprinkler heights will be approximately 0.5 times the average wind speed reported. No adjustment is thus recommended due to wind. One must recognize that there may be a few days each year when irrigation should not occur due to high winds. This cessation of operation during high winds is a management concern.

Operating Pressure of Systems

The pressures at several locations in the system are important for the proper operation of a sprinkler system. The pressure most important to uniform distribution is the operating pressure at the orifice of the sprinkler head. This pressure should correspond to the operating pressure required for optimum operation of the sprinkler head as previously discussed. The selection of appropriate pipe sizes for the mains and laterals are important for maintaining an acceptable operating pressure at all sprinkler heads.

Pressure at the sprinkler head with the highest operating pressure should not be greater than 20 percent of the sprinkler head with the lowest operating pressure. This will ensure that the discharge rate between the lowest and highest pressured sprinkler heads will not be greater than 10 percent. Thus, for the concerns of an OSSF system, the nutrient application rates resulting from the sprinklers will be within 10 percent at all locations within the spray field.

The design capacity for sprinklers on a lateral is based on average operating pressure. On a sprinkler line, or lateral, the average pressure is approximately (Cuenca 1989):

$$P_a = P_o + 0.25\times P_f$$

or $P_a = P_o + 0.25(P_n - P_o)$

where

P_a is the average pressure in the lateral (psi);
P_o is the pressure at the distal end of the lateral (psi);
P_f is the friction loss in the lateral (pressure units (psi); and
P_n is the pressure at sprinkler head nearest the pump (psi).

Based on the above equations, the allowable variation of pressure within a set of sprinkler heads is:

$$Pn \leq 1.2\times P_o$$

For flexibility, a pump should be selected that has a relatively flat pump curve (total dynamic head versus flow rate) over the range of flow rates likely to be demanded by the system. This will minimize discharge variations when different sets are being operated within the irrigation system.

Note that there is a tradeoff between a low-pressure system and a high-pressure system in terms of the sprinkler spacing. A low-pressure system (20 to 30 psi) will restrict s_l and s_m (spacing of the sprinkler head along the lateral and the spacing of the laterals along the main, respectively) to a maximum of 35 feet. A system operating at 40 to 50 psi can have a sprinkler spacing of 40 to 45 feet. Regardless of the angle at which the water exits the sprinkler head, there is a limit on the wetted diameter for a given sprinkler type. As a general rule, the maximum wetted diameter available at low pressures is 70 ft. If one follows the recommendation to select the sprinkler spacing (s_l and s_m) of 0.5 times the wetted diameter, the sprinkler spacing would be a maximum of 35 feet for a low pressure system.

Selection of Sprinkler Heads

The design of a sprinkler system involves a series of compromises. This is most evident when one selects the sprinkler heads. The sprinkler spacing, operating pressure, orifice size, application rate, and the angle of the nozzle with the horizontal all must be matched or coordinated for an efficient design. The selection of sprinkler heads involves some consideration of droplet size, orifice size to obtain the proper application rate, the nozzle angle, and consideration for handling a liquid with particulate matter included such as with the wastewater effluent.

Spray heads, or fixed nozzle sprinklers, do not have moving parts and generally have small wetted diameters and are generally not the better choice for applying wastewater effluent. The droplet sizes are relatively small compared to gear drive and impact sprinklers. Spray head sprinklers are most useful for irrigation of small areas or where clean water is used. Caution should be used when selecting spray heads that indicate a square wetted pattern. Kerr (1978) found that, even though the wetted pattern was indeed square for such sprinklers, the water was not distributed adequately to achieve high coefficients of uniformity.

Gear drive heads have greater wetted diameters when operated at medium and high pressures and can meet most application rates. The water is broken into droplets by the water’s resistance to air. If the pressure is too low, the stream will not break apart to obtain adequate water distribution thus giving a donut-shaped distribution. Consequently, these sprinklers generally are not the best if the desired operating pressure is less than 30 psi. Based on the examination of distribution patterns, gear drive heads produce a nice elliptical distribution pattern that results in high coefficients of uniformity provided the heads are operated at the recommended pressures and the proper overlap is provided. They appear to be a good selection when a square spacing arrangement between 30 and 40 feet is used and the operating pressure is between 30 and 45 psi. Again, an operating pressure that ensures that the sprinkler operation will be in the middle of the recommended range of operating pressures should be selected. This design will provide a superior distribution pattern with a droplet size that will provide proper water distribution without an excess of small droplet sizes that could cause wind drift problems.

Pressure Losses in Main Pipeline

The main pipeline pressure loss should be held to less than 10 percent of the average operating pressure in the lateral (P_a). If the pressure loss is greater than 10 percent of P_a, the diameter of the main pipeline must be increased. A small pressure loss in the main pipeline will also minimize the cost of pumping the water.

Risers

Risers are an important component in achieving good water distribution. When water is diverted from the lateral to the sprinkler head, turbulence is produced that can carry through to the nozzle of the sprinkler. The turbulence will cause a premature stream breakup that will reduce the capacity of the stream to carry the distance (wetted diameter) shown by the manufacturer of the sprinkler. The riser will bring the stream back together and will emit from the nozzle in a clean, well-knit stream that will provide the desired wetted diameter and water distribution. Another reason risers are used is dependent upon the irrigated crop. If the crop that is irrigated is continuously low cut grass, then risers are not important, but if uncut grass or trees are being irrigated, then it is important for risers to be present to make sure the water is distributed properly and not inhibited by the standing crop.

For a discharge rate of up to 12 gpm, a riser length of six inches is recommended. A 12-inch riser is recommended for discharge rates between 12 and 26 gpm. Discharge rates greater than 26 gpm are unlikely for low and medium pressure irrigation systems, such as those of OSSFs.

Application Rate

The application rate for a sprinkler system is the amount of water applied to a given area measured in inches per hour. The most frequently used criterion is to have the application rate equal to or less than the water intake rate of the soil. This ensures that there will be no surface runoff. For extended periods of irrigation, the intake rate will decrease to the base intake rate of the soil. The base intake rate is highly correlated to the saturated hydraulic conductivity of the soil (Karmeli et al., 1978).

For an OSSF system, the depth of application most likely will be one inch or less per irrigation event. When nutrient loading limits are taken into consideration and when irrigation events occur as frequently as once per day, the actual depth of application may be less than 0.2 inches per event.

For OSSF systems, where the irrigation frequency is every one to two days or longer, the recommended application rate should be equal to or less than the base intake rate of the soil. In certain situations, the application rate can be adjusted so that the total depth of application is equal to or less than the application rate defined by the following equation:

$$Q_R = (I_B \times T_A + SS)/T_A$$

where

Q_R is the application rate (inches/hr);
I_B is the base intake rate of soil (inches/hr);
T_A is the time of application (hr); and
SS is the maximum surface storage for sprinkler system (inches).

Because it is difficult to obtain intake rates for sprinkler systems, a conservative recommendation is that the base infiltration rate be set equal to the saturated hydraulic conductivity of the top 18 inches of soil

Chapter 1: References

Borrelli, J., Fedler, C. B., and Gregory, J. M. (1998). Mean crop consumptive use and free water evaporation for Texas, Project Report No. 95-483-137, Texas Water Development Board, Austin, TX.

Broadbent, F. E., and Reisenauer, H. M. (1985). Fate of wastewater constituents in soils and groundwater: nitrogen and phosphorous, Chapter 12 in irrigation with reclaimed municipal wastewater – A guidance manual, Pettygrove, G.S. and T. Asano, eds. Lewis Publishers, Inc. 1985.

BF Environmental Consultants. (2009). Septic tank systems. Accessed at: http://www.webdesignpros.net/consult/septic/septictank.htm#septic. Accessed on 22 November 2009. Dallas, PA 18612.

Cuenca, R. H. (1989). Irrigation System Design, Englewood Cliffs, New Jersey, Prentice Hall.

Duan, Runbin. (2009). Design and Operation of Land Application Systems from a Water, Nitrogen, and Salt Balance Approach. PhD Dissertation. Texas Tech University, Lubbock, TX.

Duan R. and C.B. Fedler. (2009). Field Study of Water Mass Balance in a Wastewater Land Application System. Irrigation Science, 27 (5): 409-416.

EPA. (1980). Design Manual—Onsite Wastewater Treatment and Disposal Systems. U.S. Environmental Protection Agency, Center for Environmental Research Information, Cincinnati, Ohio, pgs. 121, 149, 282.

EPA. (1981). Process Design Manual—Land Treatment of Municipal Wastewater. EPA-625/1-81-013. U.S. Environmental Protection Agency, Center for Environmental Research Information, Cincinnati, Ohio.

EPA. (2002). Onsite Wastewater Treatment Systems Manual. Manual No. EPA/625/R-00/008. U.S. Environmental Protection Agency, Center for Environmental Research Information, Cincinnati, Ohio. Accessed at: http://www.epa.gov/nrmrl/pubs/625r00008/html/625R00008.htm. Accessed on 1 November 2009.

Fedler, C. B., and Borrelli, J. (2001). Re-evaluating Surface Application Rates for Texas OSSF Systems. Texas On-Site Wastewater Treatment Research Council.

Fedler, C. B. and Borrelli, J. (1995). Designing For Optimum Land Application Systems. Presented at the International Summer Meeting of the ASAE. Chicago, IL. June 18-23. Paper No. 952407. ASAE, 2950 Niles Road, St. Joseph, MI 49085-9659. USA.

Fedler, C. B. (2000). Impact of Long-Term Application of Wastewater. Presented at the International Summer Meeting of the ASAE. Chicago, IL. July 9-12. Paper No. 002055. ASAE, 2950 Niles Road, St. Joseph, MI 49085-9659. USA.

Hansen, V.E., O. W. Israelsen, and G. E. Stringham. (1980). Irrigation Principles and Practices, fourth edition, New York: John Wiley and Sons.

Hutzler, N. J., Waldorf, L.E., and Fancy, J. (1978). Performance of Aerobic Treatment Units. Proceedings of the Second National Home Sewage Treatment Symposium. St. Joseph, MI. pgs. 149-163.

Jensen, M. E. (1983). Design and Operation of Farm Irrigation Systems. American Society of Civil Engineers. St. Joseph, Michigan. 829 pages.

Jensen, M. E., and Burman, R.D., and Allen, R.G.. (1990). Evapotranspiration and Irrigation Water Requirements. ASCE Manuals and Reports on Engineering Practice No. 70. American Society of Civil Engineers. New York. 332 pages.

Karmeli, D., Salazar, L.L., and Walker, W.R.. (1978). Assessing the Spatial Variability of Irrigation Water Applications. EPA-600/2-78-041. U.S. Environmental Protection Agency, Robert S. Kerr Environmental Research Laboratory. Ada, Oklahoma.

Keller, J. and Bliesner, R.D. (1990). Sprinkler and Trickle Irrigation. avi Book, Van Nostrand Reinhold, New York. 652 pages.

Kerr, Greg L., (1978), Lawn Sprinkler Distribution Patterns, Master Thesis, University of Wyoming, Department of Agricultural Engineering, May, 1978.

Lloyd, D. (1993). Aerobic Denitrification in Soils and Sediments: From Fallacies to Facts. Tree, 8(10), 352-355.

Miller, R.W. and Gardner, D. T. (2001). Soils in Our Environment. Prentice Hall, Upper Saddle River, New Jersey, 642 pages.

Mississippi State Department of Health. (2009). Design Standard VI-Spray Irrigation Disposal System. Accessed at: http://www.msdh.state.ms.us/msdhsite/_static/resources/58.pdf. Accessed on 22 November 2009. Jackson, MI 39215-1700.

Muchovej, R.M.C., and Rechcigl, J.E. (1994). Impact of Nitrogen Fertilization of Pastures and Turfgrasses on Water Quality, in Soil Processes and Water Quality, Lal, R. and Stewart B.A., editors. Lewis Publishers, Boca Raton, Fl. 113-114.

Oster, J.D. and Rhoades, J.D. (1986). Water Management for Salinity and Sodicity Control, in Irrigation With Reclaimed Municipal Wastewater—A Guidance Manual, Pettygrove, G.S. and Takashi, A., editors. Lewis Publishers, Chelsea, MI. Chapter 7.

Overcash, M. R., and Pal, D. (1979). Design of Land Treatment Systems for Industrial Wastes: Theory and Practice. Ann Arbor Science, Ann Arbor, Michigan. 684 pages.

Pair, C. H., Hinz, W.H., Frost, K.R., Sneed, R.E., and Schiltz, T.J. (1983). Irrigation. The Irrigation Association. Silver Spring, Maryland. 686 pages.

Payne, W.J. (1986). 1986: Centenary of the Isolation of Denitrifying Bacteria. ASM News, 52(12), 627-629.

Pettygrove, G. S. and Asano, T. (1985). Irrigation with Reclaimed Municipal Wastewater—A Guidance Manual. Luis Publishers, Chelsea, Michigan.

Quastel, J. H., and Scholefield, P. G. (1951). Biochemistry of Nitrification in Soil. *Bacteriol Rev.*, 15(1), 1–53.

Saxton, K. E., Rawls, W.J., Romerger, J.S., and Papendick, R.I. (1986). Estimating Generalized Soil-water Characteristics from Texture. American Society of Soil Science Journal. Vol. 50, pages 1031-1036.

Soil Conservation Service (1993), "Irrigation Water Requirements." Part 623 National Engineering Handbook, United States Department of Agriculture, Washington, D.C. Soil Conservation Service (1970). Technical Release No. 21, (Revision 2, 1970.

Siegrist, R. L. (1978). Waste Segregation to Facilitate On-site Wastewater Disposal Alternatives. Proceedings of the Second National Home Sewage Treatment Symposium. St. Joseph, MI. pgs. 271-281.

TCEQ. (2009). On-Site Activity Reporting System (OARS). Accessed from: http://www.tceq.state.tx.us/compliance/compliance_support/regulatory/ossf/on-site-activity-reporting-system/OARS.html. Accessed on 1 November 2009.

Texas Administrative Code. (2009). On-Site Sewage Facility Program. Texas Commission on Environmental Quality. Accessed on 21 November 2009. Accessed at: http://info.sos.state.tx.us/pls/pub/readtac$ext.ViewTAC.

Reed, S.M., D.R. Maidment, and JZ Patoux. (1997). Surface Water Balance. Accessed at: http://www.crwr.utexas.edu/reports/1997/rpt97-1/SECT5.HTM. Accessed on November 30, 2009. Taken from CRWR Online Report 97-1, Spatial Water Balances of Texas. Accessed in full at: http://www.crwr.utexas.edu/reports/1997/rpt97-1/WBTEXAS.HTM.

Viessman, W., Jr., Lewis, G.L., and Knapp, J.W. (1989). Introduction to Hydrology. Harper & Row, Publishers, New York. 780 pages.

Watkins, James A. (1977). Turf Irrigation Manual, A Telsco Publication. Dallas, Texas.

Wescot, D.W. and Ayres, R.S. (1986). Irrigation Water Quality Criteria, in Irrigation With Reclaimed Municipal Wastewater—A Guidance Manual, Pettygrove, G.S. and Takashi, A., editors. Lewis Publishers, Chelsea, MI. Chapter 3.

Appendix A

Required Data

Effluent Total Nitrogen	$C_n \equiv 30$	mg/l
Crop Pulpwood		
Annual crop nitrogen uptake	$N_y \equiv 150$	pounds/year
Base soil intake rate	$I_B \equiv 0.2$	inches/hr
Elevation difference from pump to spray field	$S_L \equiv 10$	ft
Distance from pump to spray field	$L \equiv 100$	ft
Sprinkler operating pressure	$P_d \equiv 30$	psi
Sprinkler Spacing lateral	$S_l \equiv 30$	ft
Sprinkler Spacing main	$S_m \equiv 30$	ft
Maximum surface water storage	$SS \equiv 0.2$	inches
Number of bedrooms being served	$NB \equiv 3$	number of bedrooms
Number of homes	$NH \equiv 1$	number of homes
Average design daily volume of water use per person	$ADVW \equiv 60$	gallons/day/capita

Step 1. Determne the size of dosing tank

Formula is the one currently recommended by TCEQ

$Vol \equiv (NB + 1) \cdot NH \cdot ADVW$ $\quad Vol = 240$ gallons

where

Vol is the volume of the dosing tank, gallons
NB is the number of bedrooms being served
ADVW is the average design daily volume of water use per person

$Q \equiv Vol$ gallons per day

where

Q is the design flow rate for the sprayfield

Step 2. Determine the amount of nitrogen being applied per year

$$T_n \equiv \frac{C_n \cdot Q \cdot 8.34 \cdot 365}{1000000} \qquad T_n = 21.918 \quad \text{lb/yr}$$

where

Tn	The estimated pounds of total nitrogen being applied as a constituent of the wastewater effluent, lb/yr
Cn	The estimated concentration of total nitrogen in the wastewater effluent, mg/l
Q	The estimated daily volume of water to be applied, gal/day

Step 3. Determine the spray field area based on nitrogen application rate

$$\text{Area}_n \equiv \frac{T_n \cdot 43560}{N_y} \qquad \text{Area}_n = 6.365 \times 10^3 \quad \text{ft}^2$$

Step 4. Determine the required spray field area based on hydraulic loading rate

One needs to assume a reasonable time of application of effluent being applied to the spray field. The value for the time of application of effluent could be as long as 5 hours according the TCEQ regulation, Chapter 285. This is discussed in Chapter 4. For This system it is assumed a reasonable time of application of effluent is 0.5 hours.

$$T_A \equiv 0.5 \quad \text{hours}$$

$$\text{Vol}_{per\_day} \equiv \frac{Q}{7.48} \qquad \text{Vol}_{per\_day} = 32.086 \quad \text{ft}^3\text{/day}$$

$$\text{Depth}_{per\_day} \equiv \frac{I_B \cdot T_A}{12} \qquad \text{Depth}_{per\_day} = 8.333 \times 10^{-3} \quad \text{ft/day}$$

$$\text{Area}_{hyd} \equiv \frac{\text{Vol}_{per\_day}}{\text{Depth}_{per\_day}} \qquad \text{Area}_{hyd} = 3.85 \times 10^3 \quad \text{ft}^2$$

Design Options/Cautions

The time of application, T_A, is an engineering judgment at this time. A small value for T_A will result in a large area and a large value of T_A will result in a small area. The size of the sprinklers and pump will dictate the value of T_A unless the base infiltration rate, I_B, is extremely small. Once the sprinkler heads and pump are selected, one should check to make sure the time of application will result in an area less than that needed to meet the nitrogen uptake rate for the crop. Unless the base infiltration rate, I_B, is extremely small, the area required for nitrogen should always be the limiting factor that controls the minimum size of the spray field.

Step 5. Select the largest of the areas in Step 3 and Step 4

$$Area_n = 6.365 \times 10^3$$

$$Area_{hyd} = 3.85 \times 10^3$$

$Area \equiv Area_n$ $\quad$ $\text{if}\left(Area_n > Area_{hyd}, Area, Area_{hyd}\right)$ $\quad$ $Area = 6.365 \times 10^3$ ft^2

where

$Area$ The design area for the spray field, ft^2

$Area_n$ The minimum area of the spray field assuming nitrogen is the land-limiting factor, ft^2

$Area_{hyd}$ The minimum area of the spray field assuming the intake rate of the soil or the hydraulic loading rate is the land-limiting factor, ft^2

Step 6. Determine the number of spray blocks--use even number

A spray block is the area encompassed by Sl time Sm. Determining the number of spray blocks merely helps in the decision on how to lay out the spray field--the number of laterals and sprinkler heads per lateral. On should round up to an even number anytime the calculation results in more than one block.

$Nosb \equiv \dfrac{Area}{S_l \cdot S_m}$ $\quad$ $Nosb = 7.072$

$Nosb \equiv \text{trunc}(Nosb + 1)$ $\quad$ $Nosb \equiv \dfrac{Nosb}{2}$

$Nosb \equiv \text{trunc}(Nosb + 0.999)$

$$Nosb \equiv 2 \cdot Nosb$$

$Nosb = 8$ spray blocks needed of size S_l x S_m

where

Nosb	The number of spray blocks needed for the spray field system
Area	The design area for the spray field, ft^2
Sl	The sprinkler spacing along the lateral, ft
Sm	The lateral spacing along the main, ft

Step 7. Layout blocks and sprinkler head (see Figure 2.1)

The layout of the sprinkler heads depends on the site geography and in meeting the criteria for pressure loss along the laterals and along the mainline. One wants the smallest size pipes that will meet the pressure loss requirements as presented in Chapter 6. Generally, one tries for symmetry as shown in the preliminary layout for this example (see Figure 2.1). If the site has significant slope, it is best to lay the laterals along the contour to meet the pressure loss criteria along the laterals.

Design Options/Cautions

The area determined in Step 5 and the number of blocks in Step 6 represent the minimum area required to prevent surface runoff and nitrogen pollution of the groundwater. In laying out the spray field, the area encompassed by the outside laterals and the end sprinklers on the outside laterals represent the minimum area. Normally this area will be rectangular, should be irrigated with the recommended overlap of sprinklers, and will require the use of half-circle and quarter-circle sprinkler heads. One can use all full-circle sprinklers but the wetted area will be greater. The area encompassed by the outside laterals and the end sprinklers on the outside laterals will still be the minimum area, should have the recommended sprinkler pattern overlap, but will receive less water because the full-circle sprinklers will be irrigating outside the minimum area. This may affect the leaching requirement. It is strongly recommended that the spray field be properly overlapped to insure proper leaching. This is especially necessary in areas having annual precipitation rates less than 30 inches per year.

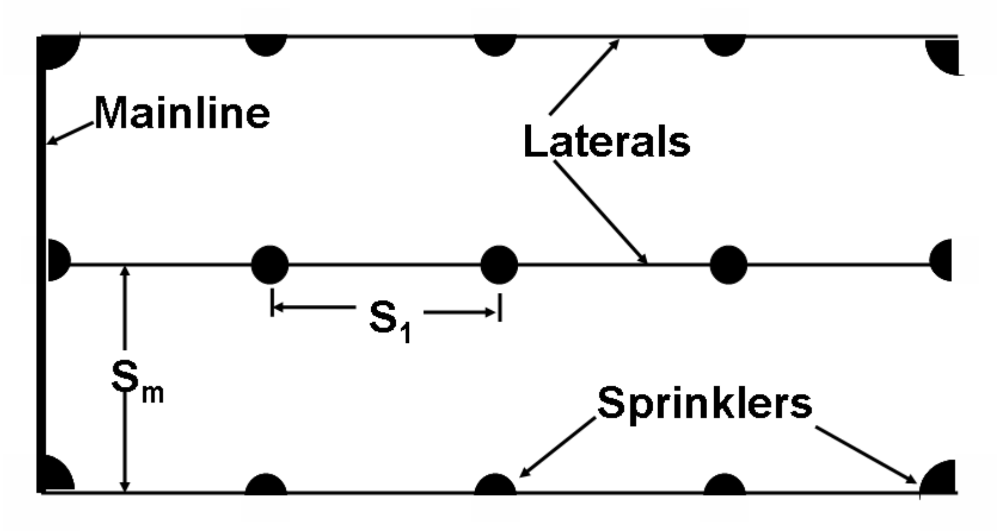


Figure 2.1. Example layout of a sprinkler system with a 30 ft by 30 ft head spacing and the 8 blocks required.

Step 8. Determine the maximum sprinkler discharge for a full circle sprinkler head using the base intake rate of the soil, I_B

The sprinklers should apply water at a rate equal to or less than the base intake rate of the soil. Therefore, there will be no surface runoff. There is no consideration of surface storage while the sprinklers are operating.

$$Q_{spr} \equiv \frac{I_B \cdot S_l \cdot S_m}{96.3} \qquad Q_{spr} = 1.869 \quad \text{gpm}$$

where

Qspr	Discharge rate from full-circle sprinkler head, gpm
Sl	The sprinkler spacing along the lateral, ft
Sm	The lateral spacing along the main, ft
I_B	The base water intake rate (minimum) for the soil, inches/hr

Stem 9. Determine maximum sprinkler discharge based on T_A and SS

The sprinklers will apply water at a rate to meet the base intake rate and the reasonable depth of surface storage during the time of application selected for the sprinkler system.

$Q_R \equiv \frac{I_B \cdot T_A + SS}{T_A}$ $Q_R = 0.6$ inches/hr

$Q_{spr} \equiv \frac{Q_R \cdot S_l \cdot S_m}{96.3}$ $Q_{spr} = 5.607$ gpm

where

Q_{spr}	Discharge rate from full-circle sprinkler head, gpm
S_l	The sprinkler spacing along the lateral, ft
S_m	The lateral spacing along the main, ft
I_B	The base water intake rate (minimum) for the soil, inches/hr
Q_R	The maximum application rate adjusted for surface storage and time of application, inches/hr
SS	Maximum surface storage for sprinkler system, inches
T_A	Time of application of effluent on to the spray field, hr

Step 10. Select the sprinkler head

nozzle #1	D_w = 60 ft	Q_{spr} = 1.0 gpm--Use for quarter-circle sprinkler head
nozzle #2	D_w = 64 ft	Q_{spr} = 2.0 gpm--Use for half-circle sprinkler head
nozzle #4	D_w = 64 ft	Q_{spr} = 4.0 gpm--Use for full-circle sprinkler head

The 4.0 gpm is less than the maximum of 5.61 gpm determined in Step 9.
The wetted diameter, D_w, is acceptable.

where

Qspr	Discharge rate from full-circle sprinkler head, gpm
Sl	The sprinkler spacing along the lateral, ft
Sm	The lateral spacing along the main, ft

$Q_{spr} \equiv 4.0$ gpm

The design of a sprinkler system for an OSSF system differs from the design of a turf irrigation system. When designing a turf irrigation system, one is concerned with replenishing water in the soil profile and applying 1 to 2 inches of water per irrigation. For an OSSF system, the design should make sure the application rate does not exceed the base intake rate of the soil or there would be surface runoff.

However, for an OSSF system, the irrigation frequency is usually every other day or every day and the depth of application will generally be less than 0.25 inches of effluent. The actual time of application will be small and the intake rate will almost always be greater than the base intake rate because it takes time for the intake rate to decrease to the base intake rate. Furthermore, on can take advantage of surface storage and apply effluent at a rate somewhat greater than the base intake rate (see Chapter 4).

With the above considerations in mind, an application rate could be very small or large enough so that the maximum discharge from the sprinkler is achieved as calculated in Step 9. Thus for this design, one could select a full-circle sprinkler discharge rate from something near 1.87 gpm to 5.61 gpm and still have an acceptable design.

After a review of various commercial sprinkler heads, a discharge rate of 4 gpm was selected for a full-circle sprinkler head.

Use a K-rain Dial-a-nozzle 12 deg low angle sprinkler head operated at a pressure of 30 psi.

Step 11. Check the application rate for selected sprinkler head

In checking the application rate from a sprinkler head, on should use the flow rate from the full-circle sprinkler head. The application rate would be the same for the quarter-circle and the half-circle sprinkler heads since the flow rates are decreased by a like amount (see Step 10). The general formula for determining the application rate from a sprinkler head was developed for a full-circle sprinkler head.

$$\text{App\_rate} \equiv \frac{Q_{spr} \cdot 96.3}{S_l \cdot S_m} \qquad \text{App\_rate} = 0.428$$ inches/hr

where

App_rate	The application rate for the selected sprinkler head operated at the selec pressure, inches/hr
Q_{spr}	Discharge rate from full-circle sprinkler head, gpm
S_l	The sprinkler spacing along the lateral, ft
S_m	The lateral spacing along the main, ft

The actual application rate is less than the maximum application rat, Q_R. Therefore, th selected sprinkler head is acceptable.

Step 12 Determine the total discharge from each lateral

On the outside laterals (both of the two laterals needed will be outside laterals), there are 2 quarter-circle and 3 half-circle sprinkler heads. The total flow would be 8 gpm. The total flow for the system would be 16 gpm.

$Q_{endlat} \equiv 8$ gpm $\qquad Q_{midlat} \equiv 16$ gpm

where

Qendlat	The total flow into the end laterals of the proposed sprinkler system, gp
Qmidlat	The total flow into the middle lateral(s) of the proposed sprinkler syste gpm

Step 13. Determine the irrigation sets or sections for the spray field

Please refer to Figure 2.2 which is the preliminary layout of the sets.

$No_{set} \equiv 1$

The average discharge per set is:

$$Q_{set} \equiv \frac{\left(2 \cdot Q_{endlat} + 1 \cdot Q_{midlat}\right)}{No_{set}} \qquad Q_{set} = 32 \text{ gpm}$$

Minimum time to drain a full tank is:

$T_d \equiv \frac{Vol}{No_{set} \cdot Q_{set}}$ $T_d = 7.5$ min

Design Options/Cautions

As you can see from Figure 2.2 there is one set indicated. The flow rate will be 32 gpm.

$T_A \equiv T_d$ $T_{set} \equiv T_A$ $T_{set} = 7.5$ minutes for the maximum

The above appears to be a reasonable time to drain the design flow and to drain a full tank if needed. The time needed is less than the 5 hour window per application required by TNRCC-285.33.

where

T_A	Time of application of effluent on to the spray field, min
T_{set}	The normal time of application for the proposed sprinkler system, min
T_d	Time required to drain the storage tank given the average flow rate for all sets, min
Q_{endlat}	The total flow into the end laterals of the proposed sprinkler system, gpm
Q_{midlat}	The total flow into the middle lateral(s) of the proposed sprinkler system, gpm
No_{set}	The number of sets making up the sprinkler system
Vol	Volume of storage tank between the alarm-on level and the pump-on level, ga

Step 14. Layout the pipe, sprinkler heads, control valves, and connections to the supply line.

The layout (Figure 2.2) of the sprinkler system depends on the level of automation one wants in the system. It is recommended that the system be automated so the operating decisions are made by the designer rather than the home owner who may not understand all the design constraints and requirements for an OSSF system.

Step 15. Size the laterals

As presented in Chapter 6, there must be less than 20 percent pressure loss along the lateral. Calculate the pressure loss by starting with the last segment of pipe (attached to the sprinkler head at the distal end of the lateral) and go to the first sprinkler head at the top of the lateral. Use the Hazen-Williams equation for estimating friction headloss in pipe. Please note for someone familiar with sprinkler system design, there are other procedures that can accurately determine the correct size of lateral and mainlines. In addition, the headloss caused by the risers coming off the laterals is approximately offset by the increase in pressure due to change in flow rate (velocity) of the water.

Use sch 40 PVC pipe. Hazen-Williams coefficient C is 140 for PVC pipe.

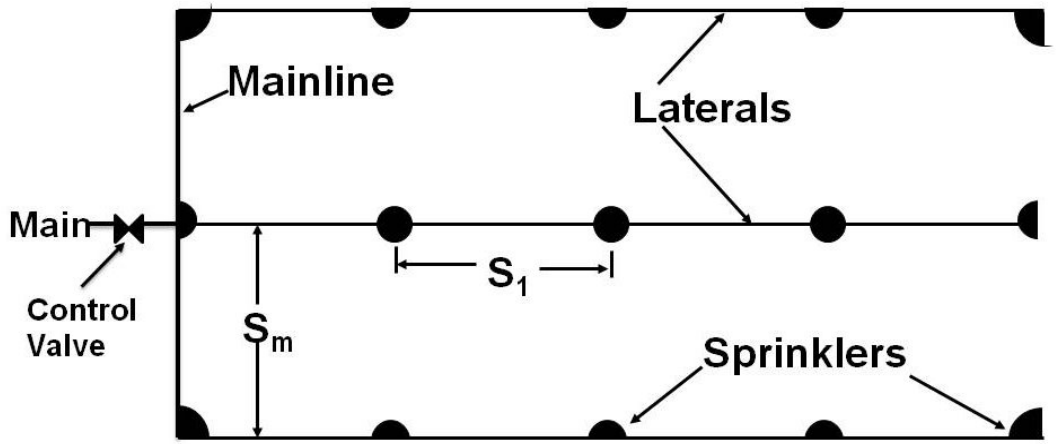


Figure 2.2. Example layout of single set required for this spray field

$C \equiv 140$

Use 1-inch nominal diameter pipe.

$D \equiv 1.049$ inches

$j \equiv 0 .. 3$

For laterals 1 and 2.

$$L_j := \begin{array}{|c|}\hline 30 \\ \hline 30 \\ \hline 30 \\ \hline 30 \\ \hline \end{array} \qquad Q_j := \begin{array}{|c|}\hline 1 \\ \hline 3 \\ \hline 5 \\ \hline 7 \\ \hline \end{array}$$

$$hf_j := \frac{L_j \cdot 3.0226 \cdot \left(\dfrac{Q_j}{\dfrac{\pi \cdot D^2 \cdot 448.9}{4 \cdot 144}} \right)^{1.852}}{C^{1.852} \cdot \left(\dfrac{D}{12} \right)^{1.167}}$$

$hf_j =$

The 1 gpm is the flow rate in the last

j
0.026
0.202
0.519
0.968

$$\sum_{j=0}^{3} hf_j = 1.715$$ ft

section of the lateral, the 3 gpm is the flow rate is the next to last section of the lateral, the 5 gpm the next, and the 9 gpm is the flow rate in the first section of the lateral.

where

hf	The friction headloss in the pipe, ft
L	Distance from the pump to the spray field or the connection to main line, f
Q	The flow rate of water in the lateral, gal/min
C	Hazen-Williams pipe roughness factor
D	The pipe inside diameter, inches

For the outside laterals, 1 and , the total headloss is 1.715 ft or 0.743 psi.

.

Select a 1-inch sch 40 PVC pipe for laterals one through ten. This pipe size meets the pressure loss criterion of less than 20 percent pressure loss between the distal sprinkler head and the first head on the lateral. Remember the average pressure for the system was selected to be 30 psi. Furthermore, the next small pipe size would cause excess pressure loss, i.e., greater than 20 percent pressure loss.

Step 16. Determine the pressure at the first and distal sprinkler heads

Use the lateral with the greatest headloss. Use lateral 1.

See Step 15 above.

$P_f := \sum_{j=0}^{3} hf_j$ $P_f := 6.192$ ft $P_f := \frac{P_f}{2.31}$ $P_f = 2.681$ psi

$P_a := P_d$ $P_a = 30$ psi

$P_a := P_o + 0.25 \cdot P_f$

$P_o := P_a - 0.25 \cdot P_f$ $P_o = 29.33$ psi

$P_n := P_f + P_o$ $P_n = 32.01$ psi

where

P_a	Average pressure in the lateral, psi
P_d	Desired operating pressure of sprinklers, psi
Pf	Friction loss in the lateral, psi
P_n	Pressure at sprinkler head nearest the pump, psi
P_o	Pressure at sprinkler head at distal end of lateral, psi

Step 17. Determine the pressure at the outlet and inlet of the control box

The pressure losses from the first sprinkler to the outlet of the valve will be the result of pipe friction losses (estimated by using the Hazen-Williams equation) and minor losses caused by bends, valves, etc. The equation for the minor losses is:

$$PL_{minor} := \frac{K \cdot V^2}{2 \cdot g}$$

where

PL_{minor}	is the headloss caused by a fitting, ft
K	is the loss coefficient for a fitting
V	is the velocity in the pipe, ft/sec
g	is the gravitational acceleration, 32.2 ft/sec^2

The loss coefficients needed for typical system fittings are:

Fitting	**K**
Solenoid valve	1.2
Gate valve	0.2
Strainer	9.3
Check valve	2.2
Union	0.2
Tee	1.3
90 deg elbow	0.7
Foot valve	1.7
Entrance	0.5
Exit	1.0

There is 15 ft of 1-inch sch 40 pipe (D = 1.049 inches) and one 90 degree elbow and one tee.

$L := 15$ ft $\quad D := 1.049$ inches $\quad QL := 8$ gpm $\quad C := 140$

$$hfL := \frac{L \cdot 3.0226 \cdot \left(\dfrac{QL}{\dfrac{\pi \cdot D^{2} \cdot 448.9}{4 \cdot 144}} \right)^{1.852}}{C^{1.852} \cdot \left(\dfrac{D}{12} \right)^{1.167}} \qquad hfL = 0.62 \text{ ft}$$

The headloss may be slightly greater depending on the length of the pipe between the control valve and the tee. For this example, it was assumed to be one foot.

$$hfL := \frac{hfL}{2.31} \qquad hfL = 0.268 \text{ psi}$$

The K value is 1.3 for the tee. The flow rate is 32 gpm for the tee.

$QT := 32$ gpm $\quad K := 1.3 \quad g := 32.2$ ft/sec^{2}

$V_{32} := \dfrac{QT}{\dfrac{448.9 \cdot \pi \cdot D^2}{4 \cdot 144}}$ $V_{32} = 11.877$ ft/sec

$PLT_{minor} := K \cdot \dfrac{{V_{32}}^2}{2 \cdot g}$ $PLT_{minor} = 2.848$ ft for the tee

$QL := 16$

$V_{16} := \dfrac{QL}{\dfrac{448.9 \cdot \pi \cdot D^2}{4 \cdot 144}}$ $V_{16} = 5.939 \ \dfrac{ft}{sec}$ $K := 0.7$

$PLE_{minor} := \dfrac{K \cdot {V_{16}}^2}{2 \cdot g}$ $PLE_{minor} = 0.383$ ft for the 90 deg elbow

$PL_{minor} := PLT_{minor} + PLE_{minor}$ $PL_{minor} = 3.231$ ft

$PL_{minor} := \dfrac{PL_{minor}}{2.31}$ $PL_{minor} = 1.399$ psi

The pressure at the outlet of the control valve will be the pressure at the first sprinkler on lateral number 2 plus the headloss due to friction and minorlosses from the sprinkler head to the out let of the valve.

$P_{outlet\_cont\_valve} := P_n + PL_{minor} + hfL$ $P_{outlet\_cont\_valve} = 33.678$ psi

$P_{inlet\_cont\_valve} := P_{outlet\_cont\_valve} + 4.5$ $P_{inlet\_cont\_valve} = 38.178$ psi

Please note that the effluent velocities in the 1-inch pipes are greater than 5 ft/sec. Because of the danger of water hammer, it is not recommended to have velocities greater than 5 ft/sec in PVC pipe. However, in this case the sprinkler heads provide protection against water hammer. There is no way the water can be suddenly stopped in the laterals. This will not be the case for the pipes on the inlet side of the control valves.

where

$P_{\text{inlet cont valve}}$ is the pressure at the inlet of the control valve, psi

$P_{\text{outlet cont valve}}$ is the pressure at the outlet of the control valve, psi

P_n is the pressuDre at the first sprinkler head on the lateral, psi

L is the length of the pipe, ft

V is the velocity in the pipe, ft/sec
D is the inside diameter of the pipe, inches
Q is the flow rate in the pipe, gpm
C is the Hazen-Williams pipe roughness factor
PL_{minor} is the headloss caused by a fitting, ft
hf is the friction headloss for the pipe, ft

Step 18. Determine the size of the main line.

No main line is needed.

$$hfm := 0$$

$$P_{supply} := P_{inlet\_cont\_valve} + hfm \qquad P_{supply} = 38.178 \quad \text{psi}$$

where

P_{supply} is the pressure at the supply line at the inlet of the tee, psi
$P_{inlet\ cont\ valve}$ is the pressure at the inlet of the control valve, psi
hfm is the friction loss in the supply line, psi
D is the inside diameter of the supply line pipe, inches
Q is the flow rate in the supply line, gpm
C is the Hazen-Williams pipe roughness factor

Step 19 Calculate the headloss in Supply Line

The sizing of the supplly line is generally based on economics. It is a tradeoff between the capital cost of the pipe and pump and the operating cost of pumping the water.

Design Options/Cautions

For PVC pipe, the maximum velocity is fps. Also according to TAC-285.33, the minimum pipe size for a supply line is 3-inches and the pipe should be sch-40.

For this example based on economics, the decision is between a 2-inch sch 40 PVC and 1.5-inch sch 40 PVC pipe. A 2-inch pipe would have a friction headloss of 1.96 psi and the 1.5-inch pipe would have a friction headloss of 6.63 psi. There is no way to guess which is best without an economic evaluation. On the other hand, an economic evaluation would take a few hours of professional time. It is clear that a pipe smaller than 1.5-inches would have a high friction headloss and a pipe greater than 2-inches would not significantly reduce the friction headloss. Regardless, TAC-285.33 requires we use a 3-inch sch 40 pipe for the supply line.

Calculate the headloss for the highest flow rate which is irrigating with a middle set (32 gpm). Besides the friction headloss in the supply line there will be the headloss caused by the tee connection to the main line (K = 1.3), a tee for the pressure relief valve if needed, and a tee for the air-relief/vacuum relief valve. There is also a gate valve (K = 0.2) just downstream from the pump and a required check valve (K = 2.2). These relief valves are required regardless of the velocity according to ASAE S376.1 pipe standard. They are used to protect the supply line.

$QM := 32$ gpm $\quad$ $L := 100$ ft $\quad$ $D := 3.084$ inches $\quad$ $C := 140$

The friction loss for the supply line is:

$$hf := \frac{L\cdot 3.0226\cdot\left(\frac{QM}{\frac{\pi\cdot D^2\cdot 448.9}{4\cdot 144}}\right)^{1.852}}{C^{1.852}\cdot\left(\frac{D}{12}\right)^{1.167}} \qquad hf = 0.282 \text{ ft} \qquad hf := \frac{hf}{2.31}$$

$hf = 0.122$ psi

The minor losses are:

$K := 1.3\cdot 3 + 0.2 + 2.2 \qquad K = 6.3$

$$V := \frac{QM}{\frac{448.9\cdot\pi\cdot D^2}{4\cdot 144}} \qquad V = 1.374 \text{ ft/sec}$$

$$PL_{minor} := K\cdot\frac{V^2}{2\cdot 32.2} \qquad PL_{minor} = 0.185 \text{ ft} \qquad \frac{PL_{minor}}{2.310} = 0.080$$

$$P_{pump\_outlet} := P_{supply} + hf + PL_{minor} \qquad P_{pump\_outlet} = 38.484 \text{ psi}$$

where

Ppump inlet is the pressure at the outlet of the pump, psi
Psupply is the pressure in the supply line at the inlet of the tee in main line, psi

L is the length of the pipe, ft
D is the inside diameter of the pipe, inches
QM is the flow rate in the pipe, gpm
C is the Hazen-Williams pipe roughness factor
K is the friction loss factor for fittings
PLminor is the headloss caused by the fitting(s), ft or psi
hf is the friction headloss in the pipe, ft or psi

Step 20. Calculate the minor losses and pipe friction headloss in suction pipe

The pipe friction headloss is for a length of suction pipe of 20 ft. Almost all pumps have a suction pipe diameter one size larger than the discharge side of the pump. For this example, the discharge side is 3-inch so the suction side would be 3.5 inches. However, the flow rate is small and 3-inch pump is not needed. One can use reducers to meet the change in pipe size. Therefore, a 2-inch pump will be selected and it will use a 2.5-inch sch 40 PVC pipe for the suction pipe (some would prefer to use steel pipe for this purpose). The suction pipe would go into the effluent storage or dosing tank. The friction headloss is:

$L := 20$ ft $\qquad QM = 32\ \text{gpm} \qquad C := 140 \qquad D := 2.469$ inches

$$hf := L \cdot 3.0226 \cdot \frac{\left(\dfrac{QM}{\dfrac{\pi \cdot D^2 \cdot 448.9}{4 \cdot 144}}\right)^{1.852}}{C^{1.852} \cdot \left(\dfrac{D}{12}\right)^{1.167}} \qquad hf = 0.167 \text{ ft} \qquad hf := \frac{hf}{2.31} \qquad hf = 0.072 \text{ psi}$$

There will be a gate valve on both sides of the pump to isolate the pump for maintenance. Besides the gate valve (K = 0.2), the other fittings are a strainer (K = 2.2), an union (K = 0.2), a foot valve (K = 1.7), and an entrance loss (K = 0.5).

$$V := \frac{QM}{\dfrac{\pi \cdot D^2 \cdot 448.9}{4 \cdot 144}} \qquad V = 2.144 \text{ ft/sec}$$

$$K := 0.2 + 9.3 + 2.2 + 0.2 + 1.7 + 0.5 \qquad K = 14.1$$

$$PL_{minor} := \frac{K \cdot V^2}{2 \cdot 32.2} \qquad PL_{minor} = 1.006 \text{ ft} \qquad PL_{minor} := \frac{PL_{minor}}{2.31}$$

$PL_{minor} = 0.436$ psi

where

L is the length of the suction pipe, ft
Q is the flow rate of the pump, gpm
C is the Hazen-Williams pipe roughness factor
PLminor is the headloss caused by the fittings, ft or psi
hf is the friction loss in the suction pipe, ft or psi
V is the velocity in the pipe, ft/sec

Step 21. Calculate the total dynamic head and specify pump.

The total dynamic head is the pressure or head the pump must supply to the system. The elevation difference between the spray field and the pump needs to be included. The total dynamic head is:

$SL := 20$ ft $\quad SL := \frac{SL}{2.31} \quad SL = 8.658$ psi

$hf = 0.072$ psi $\quad PL_{minor} = 0.436$ psi

$P_{pump\_outlet} = 38.484$ psi

$TDH := P_{pump\_outlet} + SL + hf + PL_{minor} \quad TDH = 47.65$ psi

$TDH := TDH \cdot 2.31 \quad TDH = 110.072$ ft

Let $TDH := 110$ ft

One will need to select a pump that will pump 16 gpm at a total dynamic head of 110 ft. There are other parameters to check in the selection of the pump such as the net positive suction head. The following terms are used above.

where

TDH is the total dynamic head which the pump will supply, ft
SL is the elevation difference between the pump and the spray field, ft
$P_{pump\ outlet}$ is the pressure at the outlet of the pump, ft or psi
PL_{minor} is the headloss caused by the fittings, ft or psi
hf is the friction headloss in the pipe, ft or psi

Calculated Values

$Q = \begin{pmatrix} 1 \\ 3 \\ 5 \\ 7 \end{pmatrix}$	Design flow rate, gallons/day
$Vol = 240$	Volume of dosing tank, gallons
$T_n = 21.918$	The estimated pounds of total nitrogen being applied as a constituent of the wastewater effluent, lb/yr
$Area_n = 6.365 \times 10^3$	The minimum area of the spray field assuming nitrogen is the land-limiting factor, ft^2
$Area_{hyd} = 3.85 \times 10^3$	The minimum area of the spray field assuming the intake rate of the soil or the hydraulic loading rate is the land-limiting factor, ft^2
$Area = 6.365 \times 10^3$	The design area for the spray field, ft^2
$Nosb = 8$	Number of spray blocks of size S_l x S_m
$Q_{spr} = 4$	Design flow rate of the selected sprinkler head, gpm
$App\_rate = 0.428$	The application rate for the selected sprinkler head operated at the selected pressure, inches/hr

Alternative Recommendation for Volume of dosing tank and flow rate of effluent to spray field.

$ADVWCF \equiv 70$ gallons/day/capita

$VolCF \equiv 2 \cdot NB \cdot 2 \cdot ADVWCF$ $\quad VolCF = 840$ gal

$QCF \equiv 2 \cdot NB \cdot ADVWCF$ $\quad QCF = 420$ gallons/day

where

ADVWCF is the average design daily volume of water per person, gal
VolCF is the volume of dosing tank, gal
QCF is the design flow rate to spray field, gallons/day
NB is the number of bedrooms being served

Appendix B

Required Data

Effluent Total Nitrogen	$C_n \equiv 30$	mg/l
Crop Pulpwood		
Annual crop nitrogen uptake	$N_y \equiv 150$	pounds/year
Base soil intake rate	$I_B \equiv 0.2$	inches/hr
Elevation difference from pump to spray field	$S_L \equiv 20$	ft
Distance from pump to spray field	$L \equiv 500$	ft
Sprinkler operating pressure	$P_d \equiv 30$	psi
Sprinkler Spacing lateral	$S_l \equiv 30$	ft
Sprinkler Spacing main	$S_m \equiv 30$	ft
Maximum surface water storage	$SS \equiv 0.2$	inches
Number of bedrooms being served	$NB \equiv 13$	number of bedrooms
Number of homes	$NH \equiv 3$	number of homes
Average design daily volume of water use per person	$ADVW \equiv 60$	gallons

Step 1. Determne the size of dosing tank

There are 2 persons per bedroom and the volume is 4 times the design daily water use.

$Vol \equiv (NB + NH)\cdot ADVW$ $\quad Vol = 960$ gallons

where

Vol is the volume of the dosing tank, gallons
NB is the number of bedrooms being served
ADVW is the average design daily volume of water use per person

$Q \equiv Vol$ gallons per day

where

Q is the design flow rate for the sprayfield

Step 2. Determine the amount of nitrogen being applied per year

$T_n \equiv \frac{C_n \cdot Q \cdot 8.34 \cdot 365}{1000000}$ $T_n = 87.67$ lb/yr

where

Tn	The estimated pounds of total nitrogen being applied as a constituent of the wastewater effluent, lb/yr
Cn	The estimated concentration of total nitrogen in the wastewater effluent, mg/l
Q	The estimated daily volume of water to be applied, gal/day

Step 3. Determine the spray field area based on nitrogen application rate

$Area_n \equiv \frac{T_n \cdot 43560}{N_y}$ $Area_n = 2.546 \times 10^4$ ft^2

Step 4. Determine the required spray field area based on hydraulic loading rate

One needs to assume a reasonable time of application of effluent being applied to the spray field. The value for the time of application of effluent could be as long as 5 hours according the TCEQ regulation, Chapter 285. This is discussed in Chapter 4. For This system it is assumed a reasonable time of application of effluent is 0.5 hours.

$T_A \equiv 0.5$ hours

$Vol_{per\_day} \equiv \frac{Q}{7.48}$ $Vol_{per\_day} = 128.342$ ft^3/day

$Depth_{per\_day} \equiv \frac{I_B \cdot T_A}{12}$ $Depth_{per\_day} = 8.333 \times 10^{-3}$ ft/day

$Area_{hyd} \equiv \frac{Vol_{per\_day}}{Depth_{per\_day}}$ $Area_{hyd} = 1.54 \times 10^4$ ft^2

Design Options/Cautions

The time of application, T_A, is an engineering judgment at this time. A small value for T_A will result in a large area and a large value of T_A will result in a small area. The size of the sprinklers and pump will dictate the value of T_A unless the base infiltration rate, I_B, is extremely small. Once the sprinkler heads and pump are selected, one should check to make sure the time of application will result in an area less than that needed to meet the nitrogen uptake rate for the crop. Unless the base infiltration rate, I_B, is extremely small, the area required for nitrogen should always be the limiting factor that controls the minimum size of the spray field.

Step 5. Select the largest of the areas in Step 3 and Step 4

$\text{Area}_n = 2.546 \times 10^4$

$\text{Area}_{hyd} = 1.54 \times 10^4$

$\text{Area} \equiv \text{Area}_n$ $\quad$ $\text{if}\left(\text{Area}_n > \text{Area}_{hyd}, \text{Area}, \text{Area}_{hyd}\right)$ $\quad$ $\text{Area} = 2.546 \times 10^4$ ft^2

where

Area	The design area for the spray field, ft^2
Area_n	The minimum area of the spray field assuming nitrogen is the land-limiting factor, ft^2
Area_{hyd}	The minimum area of the spray field assuming the intake rate of the soil or the hydraulic loading rate is the land-limiting factor, ft^2

Step 6. Determine the number of spray blocks--use even number

A spray block is the area encompassed by Sl time Sm. Determining the number of spray blocks merely helps in the decision on how to lay out the spray field--the number of laterals and sprinkler heads per lateral. On should round up to an even number anytime the calculation results in more than one block.

$\text{Nosb} \equiv \dfrac{\text{Area}}{S_l \cdot S_m}$ $\quad$ $\text{Nosb} = 28.288$

$\text{Nosb} \equiv \text{trunc}(\text{Nosb} + 1)$ $\quad$ $\text{Nosb} \equiv \dfrac{\text{Nosb}}{2}$ $\quad$ $\text{Nosb} = 14.5$

$\text{Nosb} \equiv \text{trunc}(\text{Nosb} + 0.999)$ $\quad$ $\text{Nosb} = 15$

$Nosb \equiv 2 \cdot Nosb$

$Nosb = 30$ spray blocks needed of size S_l x S_m

where

Nosb	The number of spray blocks needed for the spray field system
Area	The design area for the spray field, ft^2
Sl	The sprinkler spacing along the lateral, ft
Sm	The lateral spacing along the main, ft

Step 7. Layout blocks and sprinkler head (see Figure 2.1

The layout of the sprinkler heads depends on the site geography and in meeting the criteria for pressure loss along the laterals and along the mainline. One wants the smallest size pipes that will meet the pressure loss requirements as presented in Chapter 6. Generally, one tries for symmetry as shown in the preliminary layout for this example (see Figure 2.1). If the site has significant slope, it is best to lay the laterals along the contour to meet the pressure loss criteria along the laterals.

Design Options/Cautions

The area determined in Step 5 and the number of blocks in Step 6 represent the minimum area required to prevent surface runoff and nitrogen pollution of the groundwater. In laying out the spray field, the area encompassed by the outside laterals and the end sprinklers on the outside laterals represent the minimum area. Normally this area will be rectangular, should be irrigated with the recommended overlap of sprinklers, and will require the use of half-circle and quarter-circle sprinkler heads. One can use all full-circle sprinklers but the wetted area will be greater. The area encompassed by the outside laterals and the end sprinklers on the outside laterals will still be the minimum area, should have the recommended sprinkler pattern overlap, but will receive less water because the full-circle sprinklers will be irrigating outside the minimum area. This may affect the leaching requirement. It is strongly recommended that the spray field be properly overlapped to insure proper leaching. This is especially necessary in areas having annual precipitation rates less than 30 inches per year.

Step 8. Determine the maximum sprinkler discharge for a full circle sprinkler head using the base intake rate of the soil, I_B

The sprinklers should apply water at a rate equal to or less than the base intake rate of the soil. Therefore, there will be no surface runoff. There is no consideration of surface storage while the sprinklers are operating.

$$Q_{spr} \equiv \frac{I_B \cdot S_l \cdot S_m}{96.3} \qquad Q_{spr} = 1.869 \quad \text{gpm}$$

where

Q_{spr} Discharge rate from full-circle sprinkler head, gpm
S_l The sprinkler spacing along the lateral, ft
S_m The lateral spacing along the main, ft
I_B The base water intake rate (minimum) for the soil, inches/hr

Stem 9. Determine maximum sprinkler discharge based on T_A and SS

The sprinklers will apply water at a rate to meet the base intake rate and the reasonable depth of surface storage during the time of application selected for the sprinkler system.

$$Q_R \equiv \frac{I_B \cdot T_A + SS}{T_A} \qquad Q_R = 0.6 \quad \text{inches/hr}$$

$$Q_{spr} \equiv \frac{Q_R \cdot S_l \cdot S_m}{96.3} \qquad Q_{spr} = 5.607 \quad \text{gpm}$$

where

Q_{spr}	Discharge rate from full-circle sprinkler head, gpm
S_l	The sprinkler spacing along the lateral, ft
S_m	The lateral spacing along the main, ft
I_B	The base water intake rate (minimum) for the soil, inches/hr
Q_R	The maximum application rate adjusted for surface storage and time of application, inches/hr
SS	Maximum surface storage for sprinkler system, inches
T_A	Time of application of effluent on to the spray field, hr

Step 10. Select the sprinkler head

The design of a sprinkler system for an OSSF system differs from the design of a turf irrigation system. When designing a turf irrigation system, one is concerned with replenishing water in the soil profile and applying 1 to 2 inches of water per irrigation. For an OSSF system, the design should make sure the application rate does not exceed the base intake rate of the soil or there would be surface runoff.

However, for an OSSF system, the irrigation frequency is usually every other day or every day and the depth of application will generally be less than 0.25 inches of effluent. The actual time of application will be small and the intake rate will almost always be greater than the base intake rate because it takes time for the intake rate to decrease to the base intake rate. Furthermore, on can take advantage of surface storage and apply effluent at a rate somewhat greater than the base intake rate (see Chapter 4).

With the above considerations in mind, an application rate could be very small or large enough so that the maximum discharge from the sprinkler is achieved as calculated in Step 9. Thus for this design, one could select a full-circle sprinkler discharge rate from something near 1.87 gpm to 5.61 gpm and still have an acceptable design.

After a review of various commercial sprinkler heads, a discharge rate of 4 gpm was selected for a full-circle sprinkler head.

Use a K-rain Dial-a-nozzle 12 deg low angle sprinkler head operated at a pressure of 30 psi.

nozzle #1	D_w = 60 ft	Q_{spr} = 1.0 gpm--Use for quarter-circle sprinkler head
nozzle #2	D_w = 64 ft	Q_{spr} = 2.0 gpm--Use for half-circle sprinkler head
nozzle #4	D_w = 64 ft	Q_{spr} = 4.0 gpm--Use for full-circle sprinkler head

The 4.0 gpm is less than the maximum of 5.61 gpm determined in Step 9.
The wetted diameter, D_w, is acceptable.

where

Qspr	Discharge rate from full-circle sprinkler head, gpm
Sl	The sprinkler spacing along the lateral, ft
Sm	The lateral spacing along the main, ft

$Q_{spr} \equiv 4.0$ gpm

Step 11. Check the application rate for selected sprinkler head

In checking the application rate from a sprinkler head, on should use the flow rate from the full-circle sprinkler head. The application rate would be the same for the quarter-circle and the half-circle sprinkler heads since the flow rates are decreased by a like amount (see Step 10). The general formula for determining the application rate from a sprinkler head was developed for a full-circle sprinkler head.

$$\mathrm{App\_rate} \equiv \frac{Q_{spr}\cdot 96.3}{S_l\cdot S_m} \qquad \mathrm{App\_rate} = 0.428 \ \text{inches/hr}$$

where

App_rate	The application rate for the selected sprinkler head operated at the selec pressure, inches/hr
Q_{spr}	Discharge rate from full-circle sprinkler head, gpm
S_l	The sprinkler spacing along the lateral, ft
S_m	The lateral spacing along the main, ft

The actual application rate is less than the maximum application rat, Q_R. Therefore, th selected sprinkler head is acceptable.

Step 12 Determine the total discharge from each lateral

On the outside laterals, there are 2 quarter-circle and 3 half-circle sprinkler heads. The total flow would be 8 gpm. On the inside laterals, there are 2 half-circle and 3 full-circle sprinkler heads. The total flow would be 16 gpm.

$$Q_{endlat} \equiv 10 \ \text{gpm} \qquad Q_{midlat} \equiv 20 \ \text{gpm}$$

where

Qendlat	The total flow into the end laterals of the proposed sprinkler system, gp
Qmidlat	The total flow into the middle lateral(s) of the proposed sprinkler syster gpm

Step 13. Determine the irrigation sets or sections for the spray field

Please refer to Figure 2.2 which is the preliminary layout of the sets.

$No_{set} \equiv 3$

The average discharge per set is:

$$Q_{set} \equiv \frac{\left(2 \cdot Q_{endlat} + 4 \cdot Q_{midlat}\right)}{No_{set}} \qquad Q_{set} = 33.333 \quad \text{gpm}$$

Minimum time to drain a full tank is:

$$T_d \equiv \frac{Vol}{Q_{set}} \qquad T_d = 28.8 \quad \text{min}$$

Design Options/Cautions

As you can see from Figure 2.2 there are 3 sets indicated. One could operate all sets at one time but the flow rate would be 100 gpm requiring a large diameter mainline, supply line, and a large pump. The time of application would be 10 minutes. The depth of application would be 0.06 inches for 960 gallons. If only one set is irrigated per application, the time of application would be 32 minutes for the exterior sets and 24 minutes for the interior sets. The maximum depth of application would be 0.18 inches for 960 gallons. This would also allow that each set be used once every 3 days that would minimize long periods of wet conditions for the field. It should be noted that there would be a few extreme days when irrigation may be needed more than once. Please note that it is the nitrogen loading rate that is controlling the design and not the depth of water being applied.

$$T_A \equiv 32 \qquad T_{set} \equiv T_A \qquad T_{set} = 32 \quad \text{minutes for the maximum}$$

The above appears to be a reasonable time to drain the design flow and to drain a full tank if needed. The time needed is less than the 5 hour window per application required by TAC-285.33.

where

T_A	Time of application of effluent on to the spray field, min
T_{set}	The normal time of application for the proposed sprinkler system, min
T_d	Time required to drain the storage tank given the average flow rate for all sets, min
Q_{endlat}	The total flow into the end laterals of the proposed sprinkler system, gpm
Q_{midlat}	The total flow into the middle lateral(s) of the proposed sprinkler system, gpm
No_{set}	The number of sets making up the sprinkler system
Vol	Volume of storage tank between the alarm-on level and the pump-on level, ga

Step 14. Layout the pipe, sprinkler heads, control valves, and connections to the supply line.

The layout (Figure 2.2) of the sprinkler system depends on the level of automation one wants in the system. It is recommended that the system be automated so the operating decisions are made by the designer rather than the home owner who may not understand all the design constraints and requirements for an OSSF system.

Step 15. Size the laterals

As presented in Chapter 6, there must be less than 20 percent pressure loss along the lateral. Calculate the pressure loss by starting with the last segment of pipe (attached to the sprinkler head at the distal end of the lateral) and go to the first sprinkler head at the top of the lateral. Use the Hazen-Williams equation for estimating friction headloss in pipe. Please note for someone familiar with sprinkler system design, there are other procedures that can accurately determine the correct size of lateral and mainlines. In addition, the headloss caused by the risers coming off the laterals is approximately offset by the increase in pressure due to change in flow rate (velocity) of the water.

Use sch 40 PVC pipe. Hazen-Williams coefficient C is 140 for PVC pipe.

$C \equiv 140$

Use 1-inch nominal diameter pipe.

$D \equiv 1.049$ inches

$j \equiv 0 .. 4$

For laterals 1 and 6.

$$L_j := \begin{pmatrix} 30 \\ 30 \\ 30 \\ 30 \\ 30 \end{pmatrix} \qquad Q_j := \begin{pmatrix} 1 \\ 3 \\ 5 \\ 7 \\ 9 \end{pmatrix}$$

$$hf_j := \frac{L_j \cdot 3.0226 \cdot \left(\dfrac{Q_j}{\dfrac{\pi \cdot D^2 \cdot 448.9}{4 \cdot 144}} \right)^{1.852}}{C^{1.852} \cdot \left(\dfrac{D}{12} \right)^{1.167}}$$

$$hf_j = \begin{pmatrix} 0.026 \\ 0.202 \\ 0.519 \\ 0.968 \\ 1.542 \end{pmatrix} \qquad \sum_{j=0}^{4} hf_j = 3.258 \quad \text{ft}$$

The 1 gpm is the flow rate in the last section of the lateral, the 3 gpm is the flow rate is the next to last section of the lateral, the 5 gpm the next, and the 9 gpm is the flow rate in the first section of the lateral.

where

hf	The friction headloss in the pipe, ft
L	Distance from the pump to the spray field or the connection to main line, f
Q	The flow rate of water in the lateral, gal/min
C	Hazen-Williams pipe roughness factor
D	The pipe inside diameter, inches

For laterals 2 thru 5.

$$Q_j := \begin{pmatrix} 2 \\ 6 \\ 10 \\ 14 \\ 18 \end{pmatrix}$$

The 2 gpm is the flow rate in the last section of the lateral, the 6 gpm is the flow rate is the next to last section of the lateral, the 10 gpm the next, and the 18 gpm is the flow rate in the first section of the lateral.

$$hf_j := \frac{L_j \cdot 3.0226 \cdot \left(\frac{Q_j}{\frac{\pi \cdot D^2 \cdot 448.9}{4 \cdot 144}} \right)^{1.852}}{C^{1.852} \cdot \left(\frac{D}{12} \right)^{1.167}}$$

$hf_j =$

0.095
0.728
1.874
3.495
5.567

$$\sum_{j=0}^{4} hf_j = 11.76 \quad \text{ft}$$

For the outside laterals, 1 and 6, the total headloss is 1.715 ft or 0.743 psi.

For the laterals 2 thru 9, the total headloss is 6.193 ft of 2.681 psi.

Select a 1-inch sch 40 PVC pipe for laterals one through ten. This pipe size meets the pressure loss criterion of less than 20 percent pressure loss between the distal sprinkler head and the first head on the lateral. Remember the average pressure for the system was selected to be 30 psi. Furthermore, the next small pipe size would cause excess pressure loss, i.e., greater than 20 percent pressure loss.

Step 16. Determine the pressure at the first and distal sprinkler heads

Use the lateral with the greatest headloss. Use lateral 2.

See Step 15 above.

$$P_f := \sum_{j=0}^{3} hf_j \qquad P_f = 6.193 \ \text{ft} \qquad P_f := \frac{P_f}{2.31} \qquad P_f = 2.681 \ \text{psi}$$

$$P_a := P_d \qquad P_a = 30 \ \text{psi}$$

$$P_a := P_o + 0.25 \cdot P_f$$

$$P_o := P_a - 0.25 \cdot P_f \qquad P_o = 29.33 \ \text{psi}$$

$$P_n := P_f + P_o \qquad P_n = 32.011 \ \text{psi}$$

where

P_a Average pressure in the lateral, psi
P_d Desired operating pressure of sprinklers, psi
Pf Friction loss in the lateral, psi
P_n Pressure at sprinkler head nearest the pump, psi
P_o Pressure at sprinkler head at distal end of lateral, psi

Step 17. Determine the pressure at the outlet and inlet of the control box

The pressure losses from the first sprinkler to the outlet of the valve will be the result of pipe friction losses (estimated by using the Hazen-Williams equation) and minor losses caused by bends, valves, etc. The equation for the minor losses is:

$$PL_{minor} := \frac{K \cdot V^2}{2 \cdot g}$$

where

PL_{minor} is the headloss caused by a fitting, ft
K is the loss coefficient for a fitting
V is the velocity in the pipe, ft/sec
g is the gravitational acceleration, 32.2 ft/sec^2

The loss coefficients needed for typical system fittings are:

Fitting	K
Solenoid valve	1.2
Gate valve	0.2
Strainer	9.3
Check valve	2.2
Union	0.2
Tee	1.3
90 deg elbow	0.7
Foot valve	1.7
Entrance	0.5
Exit	1.0

There is 20 ft of 1-inch sch 40 pipe (D = 1.049 inches) and one 90 degree elbow and one tee.

$L := 20$ ft $\qquad D := 1.049$ inches $\qquad QL := 16$ gpm $\qquad C := 140$

$$hfL := \frac{L \cdot 3.0226 \cdot \left(\frac{QL}{\frac{\pi \cdot D^2 \cdot 448.9}{4 \cdot 144}} \right)^{1.852}}{C^{1.852} \cdot \left(\frac{D}{12} \right)^{1.167}} \qquad hfL = 2.984 \text{ ft}$$

The headloss may be slightly greater depending on the length of the pipe between the control valve and the tee. For this example, it was assumed to be one foot.

$$hfL := \frac{hfL}{2.31} \qquad hfL = 1.292 \text{ psi}$$

The K value is 0.7 for the 90 deg elbow and 1.3 for the tee. The flow rate is 16 gpm for the elbow and 24 gpm for the tee.

$QT := 24$ gpm $\qquad K := 1.3 \qquad g := 32.2$ ft/sec^2

$$V_{24} := \frac{QT}{\frac{448.9 \cdot \pi \cdot D^2}{4 \cdot 144}} \qquad V_{24} = 8.908 \text{ ft/sec}$$

$$PLT_{minor} := K \cdot \frac{{V_{24}}^2}{2 \cdot g} \qquad PLT_{minor} = 1.602 \text{ ft for the tee}$$

$$V_{16} := \frac{QL}{\frac{448.9 \cdot \pi \cdot D^2}{4 \cdot 144}} \qquad V_{16} = 5.939 \ \frac{ft}{sec} \qquad K := 0.7$$

$$PLE_{minor} := \frac{K \cdot {V_{16}}^2}{2 \cdot g} \qquad PLE_{minor} = 0.383 \text{ ft for the 90 deg elbow}$$

$$PL_{minor} := PLT_{minor} + PLE_{minor} \qquad PL_{minor} = 1.985 \text{ ft}$$

$PL_{minor} := \frac{PL_{minor}}{2.31}$ $PL_{minor} = 0.859$ psi

The pressure at the outlet of the control valve will be the pressure at the first sprinkler on lateral number 2 plus the headloss due to friction and minorlosses from the sprinkler head to the out let of the valve.

$P_{outlet\_cont\_valve} := P_n + PL_{minor} + hfL$ $P_{outlet\_cont\_valve} = 34.162$ psi

$P_{inlet\_cont\_valve} := P_{outlet\_cont\_valve} + 4.5$ $P_{inlet\_cont\_valve} = 38.662$ psi

Please note that the effluent velocities in the 1-inch pipes are greater than 5 ft/sec. Because of the danger of water hammer, it is not recommended to have velocities greater than 5 ft/sec in PVC pipe. However, in this case the sprinkler heads provide protection against water hammer. There is no way the water can be suddenly stopped in the laterals. This will not be the case for the pipes on the inlet side of the control valves.

where

$P_{inlet\ cont\ valve}$ is the pressure at the inlet of the control valve, psi
$P_{outlet\ cont\ valve}$ is the pressure at the outlet of the control valve, psi
P_n is the pressuDre at the first sprinkler head on the lateral, psi
L is the length of the pipe, ft
V is the velocity in the pipe, ft/sec
D is the inside diameter of the pipe, inches
Q is the flow rate in the pipe, gpm
C is the Hazen-Williams pipe roughness factor
PL_{minor} is the headloss caused by a fitting, ft
hf is the friction headloss for the pipe, ft

Step 18. Determine the size of the main line.

The pressure loss in the main line should be less than 10 percent of the average operating pressure of the sprinkler system. The supply line will discharge into the main line.

Select a 2-inch sch 40 PVC pipe.

$D := 2.067$ inches

There are two conditions to test. First, the inside sets will have a flow rate of

32 gpm (L = 30 ft) and second, the end sets will have a flow rate of
24 gpm (L = 60 ft).

For the first condition: $L := 30$ ft $Q := 32$ gpm $C := 140$

$$hfm := \frac{L \cdot 3.0226 \cdot \left(\dfrac{Q}{\dfrac{\pi \cdot D^2 \cdot 448.9}{4 \cdot 144}} \right)^{1.852}}{C^{1.852} \cdot \left(\dfrac{D}{12} \right)^{1.167}} \qquad hfm = 0.594 \text{ ft}$$

For the second condition: $Q := 24$ gpm $L := 60$ ft $C := 140$

$$hfm := \frac{L \cdot 3.0226 \cdot \left(\dfrac{Q}{\dfrac{\pi \cdot D^2 \cdot 448.9}{4 \cdot 144}} \right)^{1.852}}{C^{1.852} \cdot \left(\dfrac{D}{12} \right)^{1.167}} \qquad hfm = 0.697 \text{ ft}$$

The greatest headloss is for the second condition. The headloss is 0.697 ft or 0.302 psi.

The pressure loss in the mail line is less than 10 percent of the operating pressure.
Howevser, this is also true for a 1.5 inch sch 40 PVC pipe.

$D := 1.610$ inches

For the first condition: $L := 30$ ft $Q := 32$ gpm $C := 140$

$$hfm := \frac{L \cdot 3.0226 \cdot \left(\frac{Q}{\frac{\pi \cdot D^2 \cdot 448.9}{4 \cdot 144}}\right)^{1.852}}{C^{1.852} \cdot \left(\frac{D}{12}\right)^{1.167}} \qquad hfm = 2.005 \quad \text{ft}$$

For the second condition: $Q := 24$ gpm $L := 60$ ft $C := 140$

$$hfm := \frac{L \cdot 3.0226 \cdot \left(\frac{Q}{\frac{\pi \cdot D^2 \cdot 448.9}{4 \cdot 144}}\right)^{1.852}}{C^{1.852} \cdot \left(\frac{D}{12}\right)^{1.167}} \qquad hfm = 2.354 \quad \text{ft}$$

$$hfm := \frac{hfm}{2.31} \qquad hfm = 1.019 \quad \text{psi}$$

Select the 1.5 inch sch 40 PVC pipe.

The pressure at the tee to the supply line is:

$$P_{supply} := P_{inlet\_cont\_valve} + hfm \qquad P_{supply} = 39.681 \quad \text{psi}$$

where

P_{supply} is the pressure at the supply line at the inlet of the tee, psi
$P_{inlet\ cont\ valve}$ is the pressure at the inlet of the control valve, psi
hfm is the friction loss in the supply line, psi
D is the inside diameter of the supply line pipe, inches
Q is the flow rate in the supply line, gpm
C is the Hazen-Williams pipe roughness factor

Step 19 Calculate the headloss

The sizing of the supplly line is generally based on economics. It is a tradeoff between the capital cost of the pipe and pump and the operating cost of pumping the water.

Design Options/Cautions

For PVC pipe, the maximum velocity is fps. Also according to TNRCC-285.33, the minimum pipe size for a supply line is 3-inches and the pipe should be sch-40.

For this example based on economics, the decision is between a 2-inch sch 40 PVC and 1.5-inch sch 40 PVC pipe. A 2-inch pipe would have a friction headloss of 1.96 psi and the 1.5-inch pipe would have a friction headloss of 6.63 psi. There is no way to guess which is best without an economic evaluation. On the other hand, an economic evaluation would take a few hours of professional time. It is clear that a pipe smaller than 1.5-inches would have a high friction headloss and a pipe greater than 2-inches would not significantly reduce the friction headloss. Regardless, TNRCC-285.33 requires we use a 3-inch sch 40 pipe for the supply line.

Calculate the headloss for the highest flow rate which is irrigating with a middle set (32 gpm). Besides the friction headloss in the supply line there will be the headloss caused by the tee connection to the main line (K = 1.3), a tee for the pressure relief valve if needed, and a tee for the air-relief/vacuum relief valve. There is also a gate valve (K = 0.2) just downstream from the pump and a required check valve (K = 2.2). These relief valves are required regardless of the velocity according to ASAE S376.1 pipe standard. They are used to protect the supply line.

$Q := 32$ gpm $\quad$ $L := 500$ ft $\quad$ $D := 3.084$ inches $\quad$ $C := 140$

The friction loss for the supply line is:

$$hf := \frac{L\cdot 3.0226\cdot\left(\dfrac{Q}{\dfrac{\pi\cdot D^{2}\cdot 448.9}{4\cdot 144}}\right)^{1.852}}{C^{1.852}\cdot\left(\dfrac{D}{12}\right)^{1.167}}$$

$hf = 1.409$ ft

$hf := \frac{hf}{2.31}$

$hf = 0.61$ psi

The minor losses are:

$K := 1.3\cdot 3 + 0.2 + 2.2 \qquad K = 6.3$

$$V := \frac{Q}{\dfrac{448.9\cdot\pi\cdot D^{2}}{4\cdot 144}}$$

$V = 1.374$ ft/sec

$PL_{minor} := K \cdot \frac{V^2}{2 \cdot 32.2}$ $PL_{minor} = 0.185$ ft $\frac{PL_{minor}}{2.310} = 0.080$

$P_{pump\_outlet} := P_{supply} + hf + PL_{minor}$ $P_{pump\_outlet} = 40.476$ psi

where

Ppump inlet is the pressure at the outlet of the pump, psi
Psupply is the pressure in the supply line at the inlet of the tee in main line, psi
L is the length of the pipe, ft
D is the inside diameter of the pipe, inches
Q is the flow rate in the pipe, gpm
C is the Hazen-Williams pipe roughness factor
K is the friction loss factor for fittings
PLminor is the headloss caused by the fitting(s), ft or psi
hf is the friction headloss in the pipe, ft or psi

Step 20. Calculate the minor losses and pipe friction headloss in suction pipe

The pipe friction headloss is for a length of suction pipe of 20 ft. Almost all pumps have a suction pipe diameter one size larger than the discharge side of the pump. For this example, the discharge side is 3-inch so the suction side would be 3.5 inches. However, the flow rate is small and 3-inch pump is not needed. One can use reducers to meet the change in pipe size. Therefore, a 2-inch pump will be selected and it will use a 2.5-inch sch 40 PVC pipe for the suction pipe (some would prefer to use steel pipe for this purpose). The suction pipe would go into the effluent storage or dosing tank. The friction headloss is:

$L := 20$ ft $Q := 32$ gpm $C := 140$ $D := 2.469$ inches

$$hf := L \cdot 3.0226 \cdot \frac{\left(\frac{Q}{\frac{\pi \cdot D^2 \cdot 448.9}{4 \cdot 144}}\right)^{1.852}}{C^{1.852} \cdot \left(\frac{D}{12}\right)^{1.167}}$$

$hf = 0.167$ ft $hf := \frac{hf}{2.31}$ $hf = 0.072$ psi

There will be a gate valve on both sides of the pump to isolate the pump for maintenance. Besides the gate valve (K = 0.2), the other fittings are a strainer (K = 2.2), an union (K = 0.2), a foot valve (K = 1.7), and an entrance loss (K = 0.5).

$V := \dfrac{Q}{\dfrac{\pi \cdot D^2 \cdot 448.9}{4 \cdot 144}}$ $\quad V = 2.144$ ft/sec

$K := 0.2 + 9.3 + 2.2 + 0.2 + 1.7 + 0.5 \quad K = 14.1$

$PL_{minor} := \dfrac{K \cdot V^2}{2 \cdot 32.2}$ $\quad PL_{minor} = 1.006$ ft $\quad PL_{minor} := \dfrac{PL_{minor}}{2.31}$

$PL_{minor} = 0.436$ psi

where

L is the length of the suction pipe, ft
Q is the flow rate of the pump, gpm
C is the Hazen-Williams pipe roughness factor
PLminor is the headloss caused by the fittings, ft or psi
hf is the friction loss in the suction pipe, ft or psi
V is the velocity in the pipe, ft/sec

Step 21. Calculate the total dynamic head and specify pump.

The total dynamic head is the pressure or head the pump must supply to the system. The elevation difference between the spray field and the pump needs to be included. The total dynamic head is:

$SL := 20$ ft $\quad SL := \dfrac{SL}{2.31}$ $\quad SL = 8.658$ psi

$hf = 0.072$ psi $\quad PL_{minor} = 0.436$ psi

$P_{pump\_outlet} = 40.476$ psi

$TDH := P_{pump\_outlet} + SL + hf + PL_{minor}$ $\quad TDH = 49.642$ psi

$TDH := TDH \cdot 2.31$ $\quad TDH = 114.672$ ft

Let $TDH := 115$ ft

One will need to select a pump that will pump 32 gpm at a total dynamic head of 115 ft. There are other parameters to check in the selection of the pump such as the net positive suction head. The following terms are used above.

where

TDH is the total dynamic head which the pump will supply, ft
SL is the elevation difference between the pump and the spray field, ft
$P_{\text{pump outlet}}$ is the pressure at the outlet of the pump, ft or psi
PL_{minor} is the headloss caused by the fittings, ft or psi
hf is the friction headloss in the pipe, ft or psi

Calculated Values

$Q = 32$	Design flow rate, gallons/day
$\text{Vol} = 960$	Volume of dosing tank, gallons
$T_n = 87.67$	The estimated pounds of total nitrogen being applied as a constituent of the wastewater effluent, lb/yr
$\text{Area}_n = 2.546 \times 10^4$	The minimum area of the spray field assuming nitrogen is the land-limiting factor, ft^2
$\text{Area}_{\text{hyd}} = 1.54 \times 10^4$	The minimum area of the spray field assuming the intake rate of the soil or the hydraulic loading rate is the land-limiting factor, ft^2
$\text{Area} = 2.546 \times 10^4$	The design area for the spray field, ft^2
$\text{Nosb} = 30$	Number of spray blocks of size S_l x S_m
$Q_{\text{spr}} = 4$	Design flow rate of the selectedsprinkler head, gpm
$\text{App\_rate} = 0.428$	The application rate for the selected sprinkler head operated at the selected pressure, inches/hr

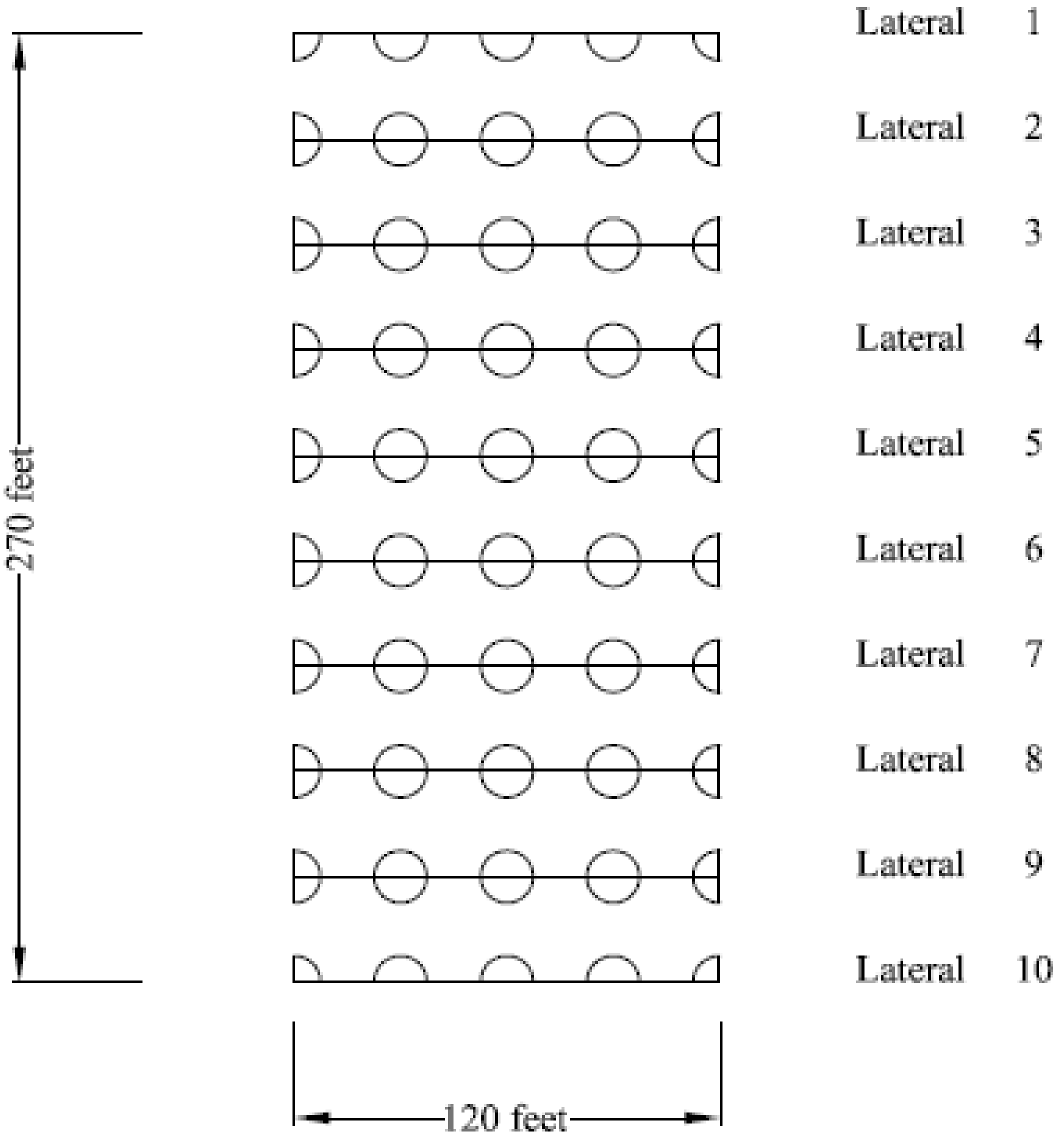


Figure 2.1. Preliminary layout of the sprinkler system (not to scale).

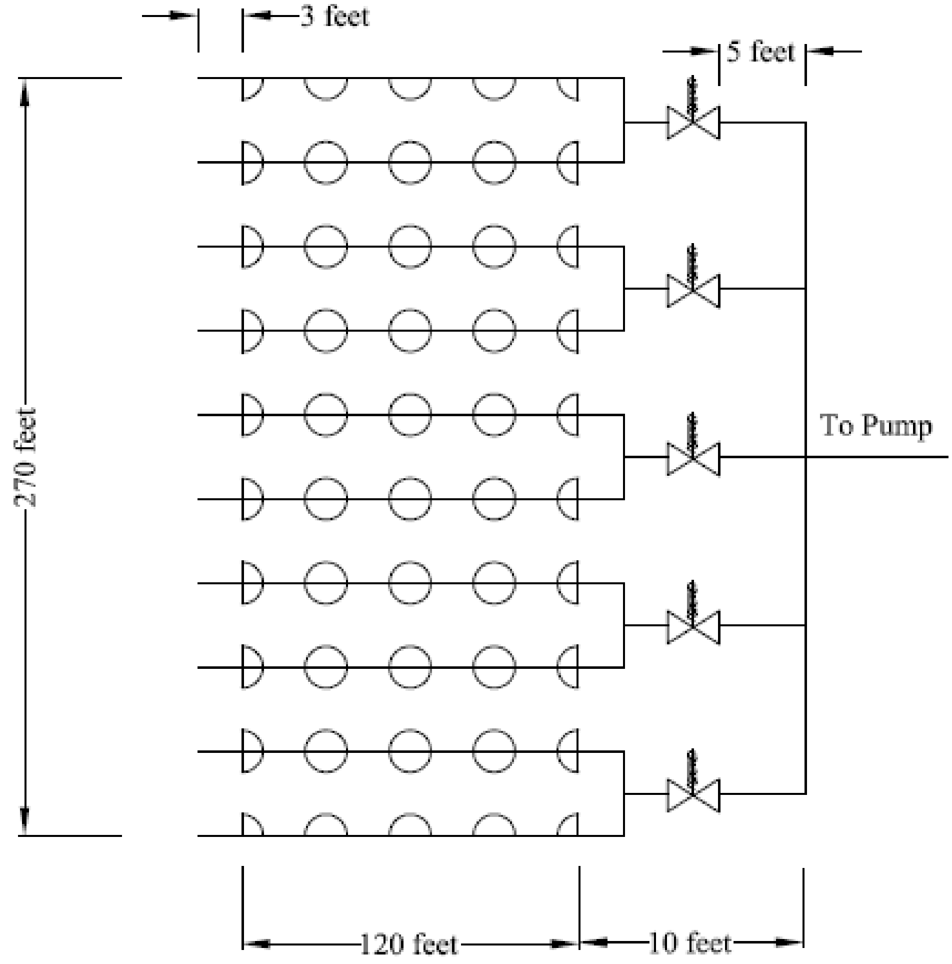


Figure 2.2. Layout of the sets for the spray field (not to scale).

Appendix C

A Case Against Using A Single Sprinkler To Distribute Effluent

Determining Nitrogen Distribution In Irrigated Area

The nutrient distribution is proportional to the effluent (or water) distribution. If the effluent contains 31 mg/l of total nitrogen and 10 inches of effluent were applied to a field, the nitrogen application would be 70 lb/acre of total nitrogen applied to the spray field. If 20 inches of effluent were applied, the nitrogen application would be 140 lb/acre. Therefore, if one can determine the distribution of effluent on the spray field, then one can also determine the distribution of nutrients. The nutrient of primary concern for an OSSF is nitrogen, especially nitrate.

Christiansen's Uniformity Coefficient: The coefficient of uniformity is used as a measure of uniformity of water application across a field. The coefficient of uniformity is commonly determined using the Christiansen Uniformity Coefficient (UCC). This coefficient is determined by measuring the distribution of water over a typical overlapped sprinkler pattern (Figure 3). The area enclosed by four adjacent sprinkler heads is divided into 20 or more equal areas, and the depth of water on each area is measured during a typical irrigation. The equation for calculating the UCC is as follows:

$$UCC = \left(1 - \frac{\sum_{i=1}^{n} \left| X_i - \overline{X} \right|}{n \times \overline{X}} \right) \times 100$$

where

UCC is Christiansen's Uniformity Coefficient, percent
X_i is the $i^{\underline{th}}$ single observation depth measured, inches
$\overline{X}$ is the mean of all of the individual observations, inches
n is the total number of observations.

The recommended minimum acceptable UCC for land application of industrial and municipal wastewater is 85 percent (Borrelli, 1990). Keller and Bliesner (1990) recommend a minimum UCC of 85 percent for delicate, shallow-rooted crops when the concern is adequate moisture for crop production. Based on the distribution pattern from a single sprinkler and a sprinkler spacing (s_l and s_m) of 0.5 the wetted diameter, a UCC of 85 is achievable except when the distribution pattern is a "donut" shape (Pair et al., 1983). A donut shape is an indication of the sprinkler head being operated at a pressure lower than recommended.

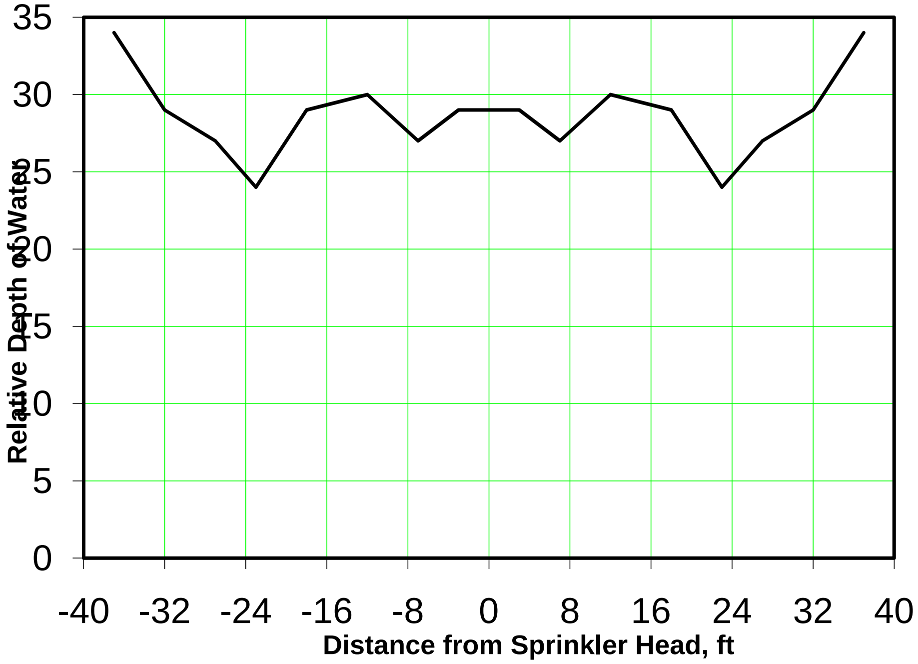


Figure A.1. Sprinkler pattern where overlap of the spray pattern is provided.

Linear Distribution of Water: Karmeli et al. (1978) assessed the spatial variability of water distribution for sprinklers. With very little loss of accuracy, they found that the distribution pattern over a spray field could be modeled linearly. They developed relationships between UCC and dimensionalized depths of water. The relationships are:

$$E_a = \left[100 - \left(100 - UCC\right) \times 2\right]$$

$$Y_{\max} = \left[\left(200 - E_a\right)/100\right]$$

$$Y_{\min} = \left[E_a / 100\right]$$

where

E_a is the water application efficiency in percent
UCC is the Christiansen Uniformity Coefficient in percent
Y_{max} is the actual depth applied divided by the average depth applied
(field average) on that part of the spray field receiving the most water
Y_{min} is the actual depth applied divided by average depth applied
(field average) on that part of the spray field receiving the least amount of water.

The above relationships assume that the depth of application varies linearly with the fraction of area for the spray field and that the depth of application is equal to the depth of water needed to bring the soil moisture up to field capacity.

An estimate can be made as to the depth of water applied to all parts of the field. A linear non-dimensional distribution curve for depth can be developed if the fraction of area receiving the various depths is arranged from smallest to highest. The equation is:

$$Y = \left[Y_{\min} + \left(Y_{\max} - Y_{\min} \right) \times \left(X \right) \right]$$

where Y is the dimensionless depth or actual depth divided by the average depth applied (field average)

X is the fraction of area having a dimensionless depth of Y or less

Y_{max} is the actual depth applied divided by the average depth applied (field average) on that part of the spray field receiving the most water

Y_{min} is the actual depth applied divided by average depth applied (field average) on that part of the spray field receiving the least amount of water.

The value of X will vary from 0.0 to 1.0 with X = 0.5 occurring at Y =1 (an example is shown in Figure 8). Using the above equations, the distribution of water over a field can be estimated by knowing the UCC of the sprinkler system. The UCC must be measured or estimated. Because the distribution of water is critical to the proper distribution of wastewater constituents, a UCC of at least 85 percent is preferred for the spray field of the OSSF.

When the depth of water applied is less than the depth needed to bring the spray field to field capacity, the value for E_a will increase. However, the distribution of water over the spray field remains the same and UCC does not change except due to shifts in wind. Regardless, water is applied deeper than average on some parts of the spray field and less than average on other. For a given irrigation system, the same parts of the spray field are over-irrigated or under-irrigated for each irrigation. This also means that nutrients or other land-limiting constituents will also be applied at greater and lesser amounts than average.

Example for Using the Coefficient of Uniformity: The following example is provided to demonstrate the need for a properly designed sprinkler irrigation system. Too often, current practice is to provide no overlap of sprinklers. Thus the distribution pattern is that provided by a single sprinkler. For this example, it is assumed that the distribution pattern is triangular or a truncated cone in three dimension.

Volume of wastewater per day: 300 gpd
Total nitrogen content in wastewater: 30 mg/l
Maximum application rate for surface irrigation of treated effluent: 0.041 gal/ft^2/day (TAC 285.90, 2001)
Vegetation: Pioneer succession vegetation
Nitrogen uptake of vegetation: 223 lb/yr
Land limiting factor: nitrogen

Christiansen Uniformity Coefficient: 85 percent
Wetted diameter of sprinkler head: 20 ft

Calculations: Proposed Method

C_n = 30 mg/l Q = 300 gpd N_y = 223 lb/yr

$$T_n = \frac{(C_n)(Q)(8.34)(365)}{1000000};$$ T_n = 27.40 lb/yr

$$Area_n = \frac{(43560)(T_n)}{N_y};$$ $Area_n$ = 5,352 ft^2

$$Volume = \frac{Q}{7.48} \times 365;$$ Volume = 14,639 ft^3

$$Depth\_Applied = \frac{Volume}{Area_n} \times 12;$$ Depth_Applied = 32.76 inches/yr

Assume UCC = 85

$$E_a = [100 - (100 - UCC) \times 2]$$ E_a = 70

$$Y_{\max} = [(200 - E_a)/100]$$ Y_{max} = 1.30

$$Y_{\min} = [E_a/100]$$ Y_{min} = 0.70

Thus, 50 percent of the irrigated area has an average annual application of 1.15 time the depth applied per year, that is, this portion of the field was over-irrigated (Figure 8).

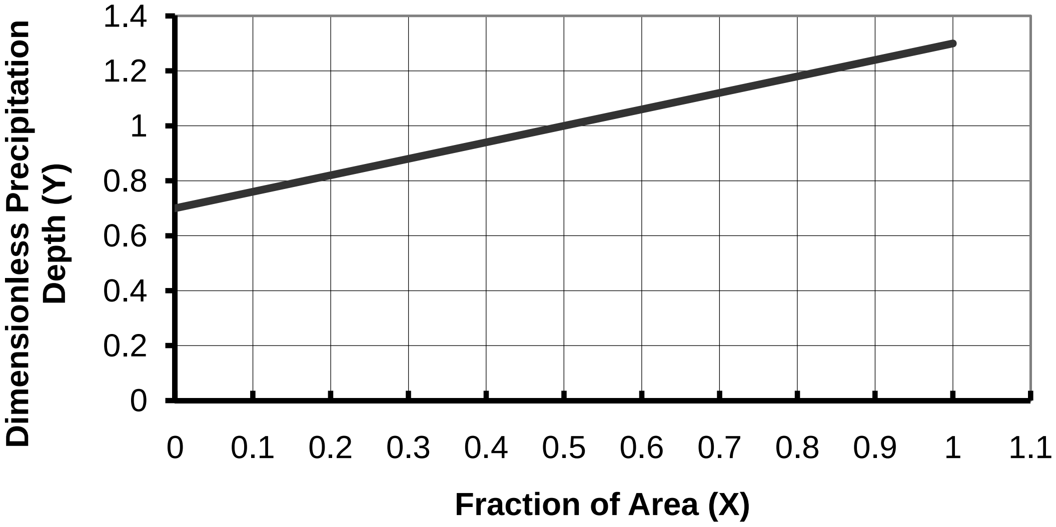


Figure A.2. Estimated linear distribution of water on field irrigated with wastewater effluent.

The volume of water applied to the 50 percent of the irrigated area that was over irrigated was

$$\text{Volume}_{50} = 14{,}639\times1.15\times0.5 = 8417 \text{ ft}^3$$

Amount of nitrogen applied: $N_{applied} = 27.4\times0.5\times1.15 = 15.76$ lb/yr

Amount of nitrogen used by the selected vegetation:

$$N_{used} = \frac{5352}{2\times43560}\times223; \qquad N_{used} = 13.75 \text{ lb/yr}$$

Amount of nitrogen leached is: $N_{leached} = 15.76 - 13.75 = 2.01$ lb/yr

Calculations: Current TAC 285 Method

$C_n = 30$ mg/l $\qquad$ Q = 300 gpd $\quad N_y = 223$ lb/acre/yr

$$T_n = \frac{(C_n)(Q)(8.34)(365)}{1000000} \qquad T_n = 27.40 \text{ lb/yr}$$

$$Volume = \frac{Q}{7.48}\times365 \qquad \text{Volume} = 14{,}639 \text{ ft}^3$$

$$Area = \frac{Q}{MAR} = \frac{300}{0.041} = 7317 \text{ ft}^2$$

$Depth\_Applied = \frac{Volume}{Area} \times 12$;   Depth_Applied = 24.01 inches/yr

To estimate the fate of the nitrogen within this system, it was necessary to select a typical sprinkler system and its appropriate shape of water distribution. In this case, a 40 ft wetted diameter sprinkler was used and the water distribution pattern form an individual sprinkler is assumed to be a typical truncated cone-shaped pattern. The area affected by this sprinkler was sub-divided into 24 equal concentric parts in order to estimate the amount of nitrogen being applied beneath the sprinkler. With the truncated cone pattern, the average depth of water applied to each of the 24 sub-areas was determined (Table 7). Based on that incremental depth of water applied, the annual amount of nitrogen applied was determined. Lastly, the amount of deficit or excess nitrogen applied to the site was determined by subtracting the amount of plant uptake nitrogen (0.268 lb N) from the incremental nitrogen applied. The following data were selected or determined for a single sprinkler head considering the assumptions stated for this example case study.

Wetted Diameter of Sprinkler: 40 ft
Area Covered by Sprinkler: 1256.6 ft^2
Average Depth of Water: 24.01 in.
Volume of water per year: 2514 ft^3
Total Nitrogen Applied 4.71 lb/yr
Nitrogen per Inch of Water: 0.196 lb/ac-in of water applied over the 1256.6 ft^2
Crop Nitrogen Use: 6.433 lb/yr

Based on the above analysis, this individual sprinkler head had excess water applied on 7 of the 24 incremental sub-areas, or 29.2 percent of the area beneath this sprinkler received excess water. This excess water resulted in excess nitrogen being applied at a rate of 0.782 lb over this incremental area or an equivalent of 93 lb/ac/yr. Note that this excess nitrogen applied only occurred on the area receiving the excess water. From the 7317 ft^2 of irrigated area required by the design, the number of sprinklers required to cover the total area was 5.8 sprinklers. Since the total excess nitrogen applied per sprinkler was 0.782 lb, these sprinklers applied a total of 4.55 lb of excess nitrogen to the site, which will be prone to be leached below the root zone of the crop. This 4.55 lb of nitrogen represents 16.6 percent of the nitrogen applied compared to only 7.3 percent of excess nitrogen applied with the proposed design method. Another fact to note is that the effluent was applied at approximately 46 percent of the rate of evapotranspiration on 37 percent more land than is required by the proposed method of designing a sprinkler system where 63 percent of the crop water use is provided.

Table C.1. Estimated annual nitrogen distribution over the area covered by a single sprinkler head

Number of Area	Average Depth of Water Applied for incremental area, in.	Incremental Nitrogen Applied, lb	Deficit (-) or Excess Nitrogen Applied, lb
1	0.76	0.0062	-0.2618
2	2.29	0.0187	-0.2493
3	3.86	0.0315	-0.2365
4	5.46	0.0446	-0.2235
5	7.11	0.0581	-0.2100
6	8.79	0.0718	-0.1963
7	10.53	0.0860	-0.1820
8	12.31	0.1005	-0.1675
9	14.15	0.1156	-0.1525
10	16.05	0.1311	-0.1370
11	18.01	0.1471	-0.1210
12	20.05	0.1637	-0.1043
13	22.18	0.1811	-0.0869
14	24.40	0.1993	-0.0688
15	26.72	0.2182	-0.0498
16	29.18	0.2383	-0.0297
17	31.78	0.2595	-0.0085
18	34.57	0.2823	0.0143
19	37.58	0.3069	0.0389
20	40.88	0.3339	0.0658
21	44.59	0.3642	0.0961
22	48.89	0.3993	0.1312
23	54.27	0.4432	0.1752
24	64.67	0.5281	0.2601
Total		4.731	0.782*

*Sum of positive values in the column

If the western part of the state is considered, where the maximum application rate as prescribed in TAC 285.90 increases to 0.115 gal/ft^2/day, the area required would decrease to 2609 ft^2 for the same effluent quantity of 300 gpd. When using a sprinkler system designed with no overlap, there would be approximately 16 lb of nitrogen leached below the root zone or 59 percent of the nitrogen applied. The area receiving excess nitrogen would increase from 29.2 percent of the area to 71 percent of the irrigated area. In this case, 51 percent of the crop water use was provided with the proposed method, whereas 105 percent was provided by the TAC 285.90 method. For the proposed method of sizing a spray field, the percent of the applied nitrogen leaching below the root zone would remain at 7.3 percent for any location in the state.

The quantity of nitrogen that could potentially reach the groundwater from a single OSSF may appear to be quite small, but there are two other factors that need to be considered. First is the total number of OSSF's installed in the state and the subsequent total mass of nitrogen that could reach our water resources. The second component that needs to be considered is the number of home clusters that exist, especially those that surround the many lakes that the population uses for recreation. If the mass of nitrogen can be reduced from 7 to 52 percent by adopting this proposed method of designing surface application systems for OSSFs, both our fresh water drinking supplies and our recreational lakes will be maintained at a much higher quality.

These examples considered are using the truncated cone shaped water distribution pattern only, and the results will change when another distribution pattern is considered or if overlap of the sprinklers is designed into the system. In addition, no surface application system should be designed on only one parameter when there are numerous factors to consider, each affecting the outcome of the other. A sound design will always consider both a water balance and a nutrient balance on the system.