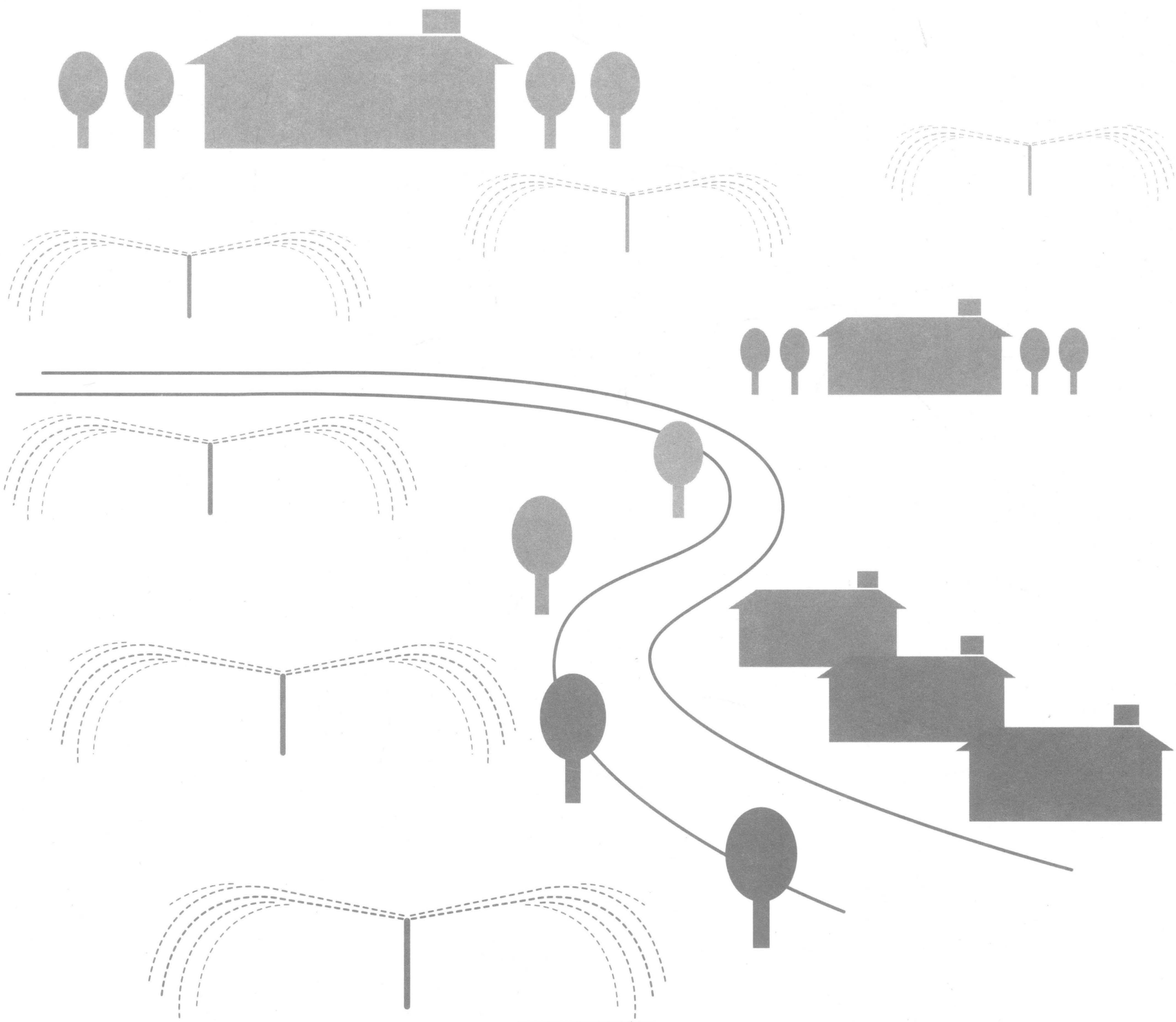
Bulletin 860

Reuse of Reclaimed Wastewater through Irrigation

for Ohio Communities



THE OHIO STATE UNIVERSITY
EXTENSION

Reuse of reclaimed wastewater

Authors

Karen Mancl, Associate Professor
Food, Agricultural and Biological Engineering
The Ohio State University

Don Rector, Environmental Engineer
Division of Surface Water
Ohio Environmental Protection Agency

This project is supported, in part, by the Ohio Small Communities Environmental Infrastructure Group.

1/97—3M—Lesher

Issued in furtherance of Cooperative Extension work, Acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture, Keith L. Smith, Director, Ohio State University Extension.

Contents

Part 1: Siting

Part 2: Design

Part 3: Management

References

Appendix A

Appendix B

Appendix C

Tables and figures

Part 1 Siting

Ohio's streams and lakes are highly valued for water supply, aquatic life, and recreation. As a result, the discharge of treated wastewater is coming under ever greater control. Treatment plants are expected to meet lower discharge requirements for carbonaceous biochemical oxygen demand ($CBOD_5$), total suspended solids (TSS), and nutrients. In addition, new requirements are being added to permits. For some Ohio communities, wastewater reuse through irrigation of treated wastewater is becoming an attractive option. Irrigating treated wastewater recycles nutrients and reduces the demand for potable water for irrigation of crops, turf, or timber.

This bulletin is for engineers and system designers that work with communities as consultants and regulators. Details on the siting, design, and management of surface irrigation systems for treated domestic and commercial wastewater are included. Subsurface absorption of wastewater is an option for individual or community wastewater systems. However, subsurface absorption systems are designed differently than surface irrigation systems and are not discussed in this manual.

Community considerations

Discharge requirements

Strict discharge requirements for a nearby stream may be one compelling reason to consider irrigation. Meeting discharge limits may require a complex treatment process, high electrical or chemical costs, or careful and specialized plant operation. A community may choose wastewater reuse through irrigation during the most critical times of the year, or even forego discharge altogether, rather than construct or upgrade a treatment plant to meet strict discharge requirements. Irrigation of treated wastewater may be more affordable than extensive wastewater treatment.

Less sludge

Wastewater for irrigation requires lower levels of treatment than for stream discharge, which yields another benefit—*less sludge.* Lagoon systems are often used to renovate wastewater before reuse. Lagoon systems have low labor requirements and no routine sludge handling requirements.

Expediency and cost effectiveness

Being a long distance from a receiving stream may motivate a community to consider irrigation. Because excavating and laying long sewer lines can be the most expensive aspect of a wastewater treatment system, irrigating wastewater on nearby land may be more affordable.

Nutrient value

Water and nutrients are needed in and around communities. When tied to irrigation, the nitrogen and phosphorus present in wastewater are considered valuable nutrients rather than contaminants. Because treated wastewater can be irrigated on turf, timber, and field crops, a number of irrigation sites can be considered, such as golf courses, parks, plant nurseries, and farm fields. Large communities can benefit from reusing even a portion of their wastewater both through savings in potable water demand for irrigation and reduced wastewater treatment costs.

Limitations

Available land

Locating enough suitable land may make irrigating treated wastewater difficult for some communities. Adverse soil conditions, topography, and land use can increase the land area needed to irrigate wastewater to ensure the protection of public health and the environment.

Three land ownership arrangements are typical of irrigation systems: 1) the wastewater treatment authority purchases and manages the land used for irrigation; 2) the wastewater treatment authority purchases the land and leases it to farmers; 3) the wastewater treatment authority contracts with land owners to provide irrigation as a long-term management plan.

Soil permeability

Very low soil permeabilities dramatically affect the amount of land needed for a wastewater reuse system. Soil surveys developed for each of Ohio's counties provide an estimate of the soil permeabilities at a potential reuse site. If more detail is needed, field evaluations can be conducted by certified soil scientists.

Soil water

Excess soil water limits the amount of additional water that can be applied through wastewater irrigation. Subsurface drainage systems are needed to remove excess soil water from agricultural fields in Ohio. A subsurface drainage system may also help minimize runoff and erosion, wet conditions in the plant root zone, or unfavorable field working conditions in the spring and autumn.

A useful tool for evaluating the impact of subsurface drainage systems is the computer model DRAINMOD. This model estimates the drainage system design requirements necessary to obtain the optimal irrigation frequency for the proposed site. The model simultaneously provides information on irrigation and storm events that produce runoff, allowing the designer to put runoff control measures in place.

Operators

Over the years, operator training and experience has been directed toward mechanical treatment plants with stream discharge. Operating a wastewater treatment/irrigation system requires specialized operator skills.

Winter conditions

Provisions for adverse conditions can sometimes add to the cost and complexity of a treatment/irrigation system. A variety of options need to be considered for winter conditions, including storage through winter months, protection from freezing and draindown for winter operation, or treatment for permitted stream discharge during the winter months.

System components

Irrigation system components, such as irrigation pipe, emitters, and pumps, are an added expense to a wastewater treatment system. These added costs need to be accounted for when measuring cost savings that result from reduced treatment requirements for irrigated wastewater.

Selecting a site

Almost any area in the state of Ohio can be considered for reuse of renovated wastewater. Irrigation sites fall into three categories:

- **Unrestricted access sites**—parks, golf courses, lawns, highway medians, and playing fields
- **Restricted access sites**—fenced or isolated woodlands or meadows
- **Agricultural sites**—areas where nonhuman food crops are grown

Although site characteristics make some areas more suitable for irrigation than others, provisions can be made to allow irrigation in areas that are less than ideal. Table 1 presents the characteristics of an ideal site, as well as strategies for overcoming site limitations.

When selecting a site for irrigation, keep cost trade-offs in mind. Land cost is an obvious factor to consider. Cost to transport the wastewater to the site may present some important trade-offs. Pumping treated wastewater to an upland site is more costly than gravity flow to a lowland site. The cost of a stream crossing to reach a possible site may outweigh the higher land costs nearby. Restricted access and remote sites have lower treatment requirements, resulting in lower treatment costs.

Table 1. Site characteristics for wastewater reuse site

Site characteristic	*Ideal*	*Provisions if not ideal*
Soil permeability	Greater than 0.2 inches/hour	More acres are needed for irrigation
Slope	Less than 15 percent for cultivated fields Less than 20 percent for turf or pasture Less than 40 percent for timber	Runoff control measures (consult with Natural Resources Conservation Service)
Surface water	Not applied to wetlands, streams, or waterways	
Floodplains	More than 10-year flood return period	Storage or alternate application site during flood event
Depth to groundwater	1 foot to soil mottling or other evidence of groundwater	Storage or alternate management strategy during high groundwater periods Drainage systems may also be an option
Depth to bedrock		
Agricultural and restricted access	More than 2 feet	If site is filled, fill material must be in place for at least 4 years before reevaluation for suitability
Unrestricted access	More than 1 foot	

Pretreatment objectives

The major considerations of treatment are to reduce odor, protect public health, and allow for proper operation of the irrigation equipment.

Stabilization

Wastewater must be stabilized before irrigation to eliminate its objectionable odor. Therefore, the wastewater must be aerobic with some reduction in oxygen demand. In this way, objectionable odors will not be carried off the irrigation site as the wastewater is sprayed in the air or create odors as it lies on the ground before infiltrating into the soil.

Disinfection

Disinfection of wastewater prior to irrigation is an important consideration. While disinfection is essential for public access irrigation sites, such as parks or golf courses, it should also be considered for more remote sites. Disinfection will help protect the operators, farmers, or people who accidentally enter the site and are exposed to the treated wastewater.

Pretreatment technologies

Screening and settling

Screening or settling the wastewater to remove debris and grit help prevent clogging and wear of the irrigation equipment. Suspended solids in the wastewater should be *less than ⅓ the sprinkler nozzle diameter*. Oil and grease can also clog pipes and nozzles. Primary treatment to remove settleable solids, oil, and grease should be considered for communities with significant industrial or commercial waste flows.

Biological treatment

Biological treatment stabilizes and aerates wastewater. Treatment is needed to achieve a *$CBOD_5$ content of less than 25 mg/l for unrestricted access sites. For agricultural and restricted access sites, a $CBOD_5$ content of less than 40 mg/l is sufficient.*

Facultative and aerated lagoons are often used to provide biological treatment for irrigation systems. Lagoons provide much of the needed storage to maximize flexibility in managing the irrigation system. In areas where a large level area is not available for a lagoon, fixed film systems may be an option. Trickling filters and sand filters provide adequate treatment with low energy and minimal labor requirements.

Some communities currently using a mechanical treatment system before stream discharge may wish to switch to wastewater reuse. Activated sludge, extended aeration, or oxidation ditch systems already in operation can continue to be used to renovate wastewater prior to reuse. Additional storage may need to be added to existing treatment facilities to take advantage of wastewater reuse.

Disinfection

Disinfection is an important feature in wastewater reuse systems with unrestricted access. Tablet chlorinators are often used to disinfect wastewater. Another popular option is injecting liquid sodium hypochlorite into the wastewater. However, other chlorination systems or ultraviolet light can also be used if already available. Disinfection can occur prior to holding ponds, tanks, or application.

Screens

Leaves that fall into holding tanks can clog irrigation systems. Placing screens over holding tanks is one approach for keeping leaves out. Bar screens at the inlet of the irrigation system should also be installed to collect debris.

Part 2 Design

Land requirements

In Ohio, most systems will only apply wastewater from April through November. During the remaining four months of the year, treated wastewater can be either stored or discharged under NPDES permit.

Land area needs are determined by calculating a water and nutrient balance for a site. A water balance is a design tool that balances the water losses from the site through evapotranspiration, drainage, and rainfall runoff with the water inputs from rainfall and wastewater irrigation. Estimates of the total land area needed to assimilate hydraulic loads are presented in Figures 1 and 2 and can be consulted as a quick check to determine project feasibility.

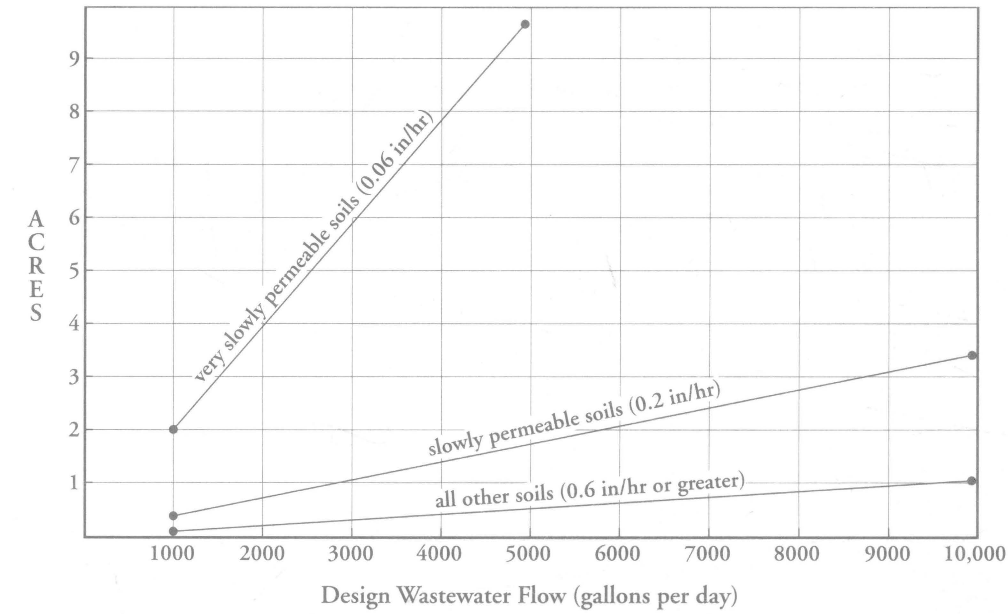


Figure 1. Minimum acreage needed for very small irrigation systems

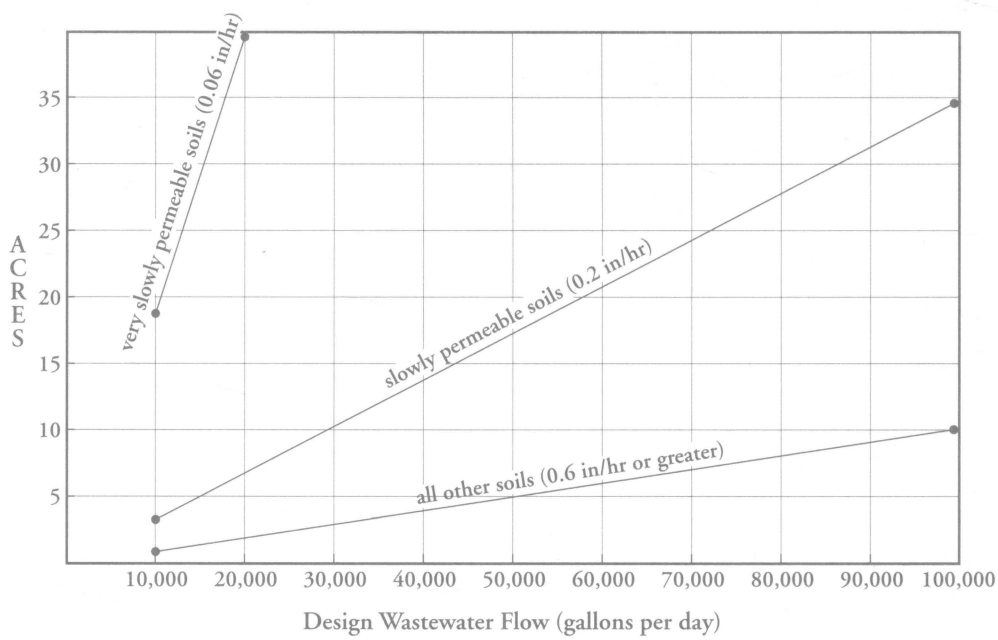


Figure 2. Minimum acreage needed for small- to medium-sized irrigation systems

Step 1

Estimate monthly evaporation for the proposed site. Appendix A lists the average monthly evaporation throughout Ohio.

Example

A small community in Franklin County, Ohio, treats 0.025 mgd of wastewater at a small oxidation ditch treatment plant before stream discharge at 25 mg/l $CBOD_5$ and 25 mg/l TSS. Upon renewal of their stream discharge (NPDES) permit, they now must treat their wastewater to meet new 30-day requirements of 10 mg/l $CBOD_5$, 12 mg/l TSS, and 1 mg/l ammonia in summer and 3 mg/l ammonia in winter. They now must also dechlorinate before discharge.

Rather than change the plant, the community is considering wastewater reuse and winter wastewater storage as an alternative to stream discharge.

Month	Evaporation (inches/month)
Jan	0.7
Feb	0.9
Mar	1.8
Apr	2.8
May	4.1
Jun	4.6
Jul	4.8
Aug	4.1
Sep	2.9
Oct	2.2
Nov	1.2
Dec	0.8

Since 1984, Union City, Ohio, has irrigated wastewater from its 0.4 mgd aerated lagoon systems onto 125 acres of crop fields surrounding its plant. The agricultural land is owned by the village, but is leased to farmers who grow corn, soybeans, and wheat. Wastewater is distributed throughout the field through solid-set sprinklers. The operators recently replaced all of the automatic valves in the field with a central, manually controlled valve station to increase their management flexibility and reduce costs.

Step 2

a) Determine the limiting soil infiltration rate for the proposed site. County soil surveys published by the Natural Resources Conservation Service (NRCS) report soil permeabilities in inches per hour for the top 60 inches of the soil profile.

b) For the proposed irrigation site identify the lowest soil permeability within the top 60 inches.

c) Convert the soil permeability in inches per hour to soil infiltration in inches per month. From 4 to 6 percent of the permeability is reflected in the infiltration rate of most soils. This factor is up to 10 percent for highly permeable soils.

Example

The soil survey indicates that the lowest percolation rate in the top 60 inches of soil in the neighboring crop field is 0.2 inches/hour. Therefore, the corresponding soil infiltration rate is 6 inches/month.

Soil permeability (inches/hour)	***Conversion*** for infiltration	***Conversion*** (hours/month)	***Limiting soil infiltration rate*** (inches/month)
0.06	0.04	720	2
0.2	0.04	720	6
0.6	0.05	720	21
2.0	0.06	720	86
6.0	0.06	720	259
20.0	0.1	720	1440

Step 3

Estimate monthly precipitation with a 5-year return period for the proposed site to account for wetter than average years. Appendix B lists the monthly precipitation with a 5-year return period for 10 climatic divisions throughout Ohio.

Example

Month	Evaporation (inches/month)	Precipitation (inches/month)
Jan	0.7	4.0
Feb	0.9	3.3
Mar	1.8	4.4
Apr	2.8	4.6
May	4.1	5.2
Jun	4.6	5.0
Jul	4.8	5.2
Aug	4.1	4.5
Sep	2.9	3.9
Oct	2.2	3.6
Nov	1.2	4.0
Dec	0.8	3.7

Indian Springs Golf Course near Mechanicsburg, Ohio, has reused treated wastewater from the clubhouse and restaurant on a portion of its driving range since 1991. Following treatment and disinfection through a package aerobic treatment plant, the wastewater is stored in one of five concrete tanks. Early each morning, the wastewater is distributed on the driving range through pop-up irrigation sprinklers.

Step 4

Calculate the design wastewater hydraulic load in inches per month for each month. For design purposes, assume that the ground is frozen from December through March resulting in no wastewater infiltration. This type of slow rate land treatment system is limited to application rates of less than 4 inches per week. Also calculate total annual hydraulic load.

(Evaporation + infiltration) – precipitation = hydraulic load

Example

Month	*Evaporation* inches/month *(Step 1)*	*Maximum infiltration* (inches/month) *(Step 2)*	*Precipitation* (inches/month) *(Step 3)*	*Design hydraulic load* (inches/month) *(Step 4)*
Jan	0.7	0	4.0	0
Feb	0.9	0	3.3	0
Mar	1.8	0	4.4	0
Apr	2.8	6	4.6	4.2
May	4.1	6	5.2	4.9
Jun	4.6	6	5.0	5.6
Jul	4.8	6	5.2	5.6
Aug	4.1	6	4.5	5.6
Sep	2.9	6	3.9	5.0
Oct	2.2	6	3.6	4.6
Nov	1.2	6	4.0	3.2
Dec	0.8	0	3.7	0
Total hydraulic load				38.7

Step 5

Determine the size of the application area.

$$\text{Acres needed} = \frac{\text{Daily wastewater flow (mgd)} \times 365 \text{ (days/year)} \times 36.8 \text{ (acre inch/m gal)}}{\text{Total hydraulic load (inches/year)}}$$

Example

$$\frac{0.025 \text{ mgd} \times 365 \text{ days/year} \times 36.8 \text{ acre-inches/m gal}}{38.7 \text{ inches/year}} = 8.7 \text{ acres}$$

Wastewater from the 28 homes in the community of Wilson, Ohio, has been treated and stored in two one-acre facultative lagoons since 1990. During the summer months the treated wastewater is distributed by gravity though a flood irrigation system into three acres of woodlot.

Step 6

a) All plants use nitrogen (N) to sustain themselves and grow. To encourage plant growth, farmers apply manure or fertilizer to supply necessary amounts of nitrogen. The amount of nitrogen needed to reach a desired crop yield varies with the crop grown. Table 2, for example, lists the nitrogen needs of corn. The nitrogen needs of other crops are listed in the *Ohio Agronomy Guide, 13th Edition,* Bulletin 472, available from local Ohio State University Extension offices.

A nitrogen balance for the irrigation site should be developed to insure that groundwater contamination will not result. The objective is to keep nitrate levels below 10 mg/l in the groundwater beneath the site.

Nitrogen applied – nitrogen used by crop = nitrogen available for leaching

Water applied + precipitation - water evaporated = water available for dilution

All of the nitrate and ammonia in the wastewater is available for plant uptake and any excess can leach into groundwater. Organic nitrogen in the wastewater becomes a part of the soil organic matter and is mineralized at a rate of less than 5 percent per year.

Table 2. Annual nitrogen application (expressed as lb N/acre/year) recommended for corn

	Yield goal *(bushels/acre)*		
	120	*150*	*180*
Previous crop	***Annual application*** *(lb N/acre)*		
Forage legume	60	110	150
Grass crop	65	170	200
Soybeans	85	190	200
Continuous corn or other crops	115	200	200

b) Calculate:

Nitrogen available for leaching (lb/acre) =
(Inorganic N content (mg/l) x annual wastewater (inch) x 0.226) + N fertilizer (lb/acre) – N crop needs (lb/acre)
of wastewater application

c) Calculate:

Water available for dilution (inches) =
Wastewater applied (inch) + annual precipitation (inch) – annual evaporation (inch)

d) Calculate:

$$\text{Nitrate content of water leaching from site (mg/l)} = \frac{\text{available N (lb/acre)}}{\text{dilution water (inch)}} \times 4.42$$

This calculation is a conservative approach in that the nitrate leaching from the site can be further diluted in the groundwater. It also does not take into account denitrification losses. Consider working with a hydrogeologist to conduct a more comprehensive analysis if designing a large system, applying high nitrogen content wastewater, or working in problem areas with elevated groundwater nitrate levels.

Example

(30 mg/l x 38.7 acre-inches x 0.226) + 0 lb/acre – 200 lb/acre = 62 lb/acre available for leaching

38.7 inches applied + 38 inches precipitation – 32 inches evaporation = 44.7 inches water available for dilution

$$\frac{\text{62 lb/acre}}{\text{44.7 inches}} \times 4.42 = 6.1 \text{ mg/l}$$

Conclusion

Annual application of 38.7 acre-inches of treated wastewater per year will not pose a problem in elevating the nitrate levels in the infiltration water above 10 mg/l. Fertilizer and /or manure application to the site may need to be adjusted and agreed upon to account for nitrogen applied through reused wastewater.

Minimizing public health concerns

Avoiding direct contact between people and disease-causing organisms in wastewater is the goal in reducing health concerns. Several approaches can be used to avoid direct contact. Reliable disinfection to reduce the number of bacteria and other pathogens is one approach. In addition to testing for fecal coliform bacteria, quick tests for chlorine residual can increase confidence in the disinfection system. Restricting irrigation to times of the day or year when people are not present is another way to avoid direct contact. Irrigation only at night or when a facility is closed can be incorporated into the management plan. Establishing buffer areas between the irrigation site and the edge of the field is another approach to avoid contact. Fencing or signs may be needed to help define the buffer area. Figure 3 presents some sample signs. Table 3 lists the fecal coliform limits and buffer area requirements for each category of reuse.

Most domestic wastewater contains low levels of metals. Table 4 lists suggested limits for metals in wastewater for irrigation.

Table 4. Limits for metals in treated wastewater for irrigation

Aluminum	5.0 mg/l
Arsenic	0.10
Beryllium	0.10
Boron	0.75
Cadmium	0.01
Chromium	0.1
Cobalt	0.05
Copper	0.2
Fluoride	1.0
Iron	5.0
Lead	1.5
Lithium	2.5
Manganese	0.2
Molybdenum	0.01
Nickel	0.2
Selenium	0.02
Vanadium	0.1
Zinc	2.0

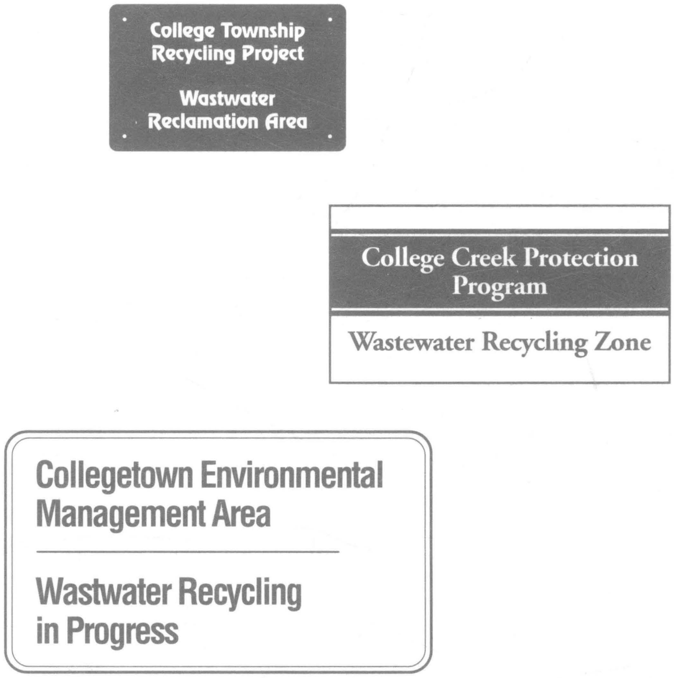


Figure 3. Sample signs for wastewater reuse sites

Table 3. Fecal coliform limits (MPN/100 ml—30 day average) for wastewater reuse

Public access buffer area	*Unrestricted access sites*	*Restricted access sites*	*Agricultural sites*
None	23 night application	23	23
75 feet	—	23	23
100 feet	—	200	1000
200 feet	—	1000	no disinfection necessary
300 feet	—	—	no disinfection necessary

Additional buffer areas need to be observed for fixed features, such as:
- Private water well .... 100 feet
- Community water well .... 300 feet
- Sink hole .... 100 feet
- Drainage way .... 50 feet
- Surface water .... 50 feet
- Road right-of-way .... 100 feet without windbreak using spray irrigation
  .... 10 feet with windbreak or with flood irrigation
- Property line .... 50 feet

Provisions for severe weather

Freezing temperatures and heavy rains can present problems for irrigation systems. Fortunately, a number of strategies are available to mitigate problems caused by severe weather. When developing storage systems, consider the wettest year with a 5-year return frequency.

Irrigation is not recommended when:

- the ground is frozen
- the air temperature is less than 35° F
- wind velocity exceeds 20 mph for urban sites and 25 mph for agricultural sites using spray irrigation
- soil is bare unless erosion control measures are in place
- snow or water is standing on the ground surface
- groundwater is within 1 foot of the surface
- agricultural or horticultural practices are planned
- equipment receives routine maintenance

In general, wastewater storage provisions for at least 130 days of design average flow will be needed for periods when irrigation is not recommended.

If system operation calls for irrigation after October 31 and before May 1, provisions should be made for protection from freezing. All irrigation lines should be drained, buried, or insulated.

In some areas of Ohio, permits can be obtained for stream discharge during winter and times of high stream flow. These controlled discharge permits are often less stringent than year-round discharge permits, because wastewater is reused during summer low-flow periods when the environmental impact on the receiving stream would be greatest. If discharge is acceptable, storage needs can be significantly reduced.

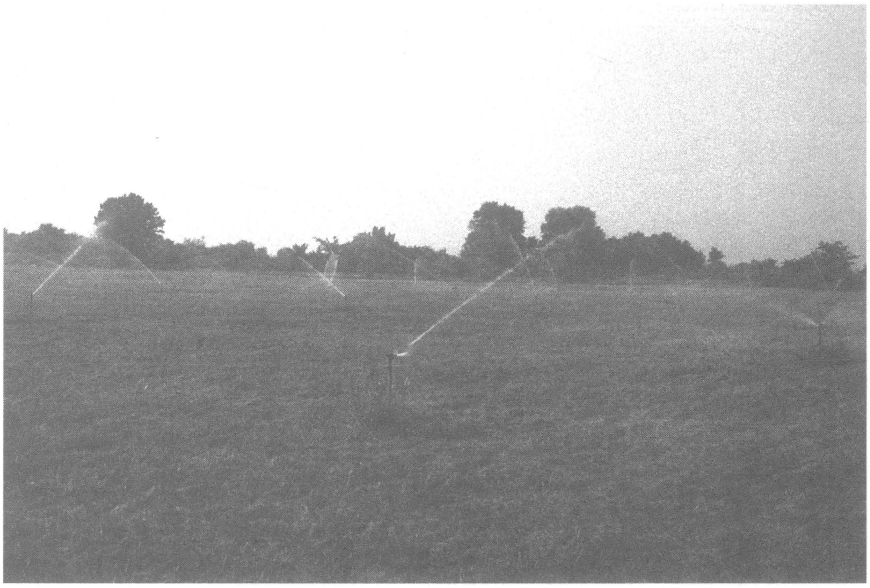
Water storage

Two types of storage needs must be addressed when developing a wastewater reuse system. One type provides operational storage, and the other is used for storage during poor weather conditions.

A minimum amount of operational storage is needed to give the operator flexibility to adjust, maintain, and service the irrigation system. All wastewater reuse systems need to provide a small amount of operational storage, which should be calculated as follows:

Operational storage = daily design flow x 4

Unless discharge to a receiving stream is possible, most systems will need to store wastewater through the winter months. One approach to determine anticipated storage needs is to set up a monthly chart covering one year. The chart will show the required storage needed in terms of design flow.



First installed in 1973, the wastewater reuse system at Deer Creek State Park is the oldest operating system in Ohio. Wastewater from the lodge, campgrounds, and all other park facilities is treated and stored in one aerated and one storage lagoon. Solid-set irrigation sprinklers distribute the wastewater to an isolated 12-acre field adjacent to the lagoons.

Step 7

Tabulate the design hydraulic load for each month for the application site.

Example

Month	(1) Design hydraulic load (inches/month)	(2) Application area (acres)	(1 x 2) Water applied (acre inches)
Jan	0	0	0
Feb	0	0	0
Mar	0	0	0
Apr	4.2	8.7	36.5
May	4.9	8.7	42.6
Jun	5.6	8.7	48.7
Jul	5.6	8.7	48.7
Aug	5.6	8.7	48.7
Sep	5.0	8.7	43.5
Oct	4.6	8.7	40.0
Nov	3.2	8.7	27.8
Dec	0	0	0

Step 8

Convert the anticipated wastewater volume each month to acre-inches.

Example

Convert 0.025 mgd to acre-inches per month.

Month	(1) Wastewater volume (m gal/month)	(2) Conversion (acres-inches/m gal)	(1 x 2) Wastewater volume (acre-inches/month)
Jan	0.775	36.8	28.5
Feb	0.7	36.8	25.8
Mar	0.775	36.8	28.5
Apr	0.75	36.8	27.6
May	0.775	36.8	28.5
Jun	0.75	36.8	27.6
Jul	0.775	36.8	28.5
Aug	0.775	36.8	28.5
Sep	0.75	36.8	27.6
Oct	0.775	36.8	28.5
Nov	0.75	36.8	27.6
Dec	0.775	36.8	28.5

Step 9

Begin developing a water balance table starting with an empty reservoir. All calculations will be in acre-inches.

Example

	Wastewater volume	Water applied	Change in storage	Accumulated in storage
Nov	27.6	27.8	0	0
Dec	28.5	0	28.5	28.5
Jan	28.5	0	28.5	57.0
Feb	25.8	0	25.8	82.8
Mar	28.5	0	28.5	***111.3***
Apr	27.6	36.5	–8.9	102.4
May	28.5	42.6	–14.1	88.3
Jun	27.6	48.7	–21.1	67.2
Jul	28.5	48.7	–20.2	47.0
Aug	28.5	48.7	–20.2	26.8
Sep	27.6	43.5	–15.9	10.9
Oct	28.5	40.0	–11.5	0

Identify the required minimum storage volume using the maximum accumulated volume. Remember, this is the actual wastewater that must be stored. If an open storage system is selected, additional storage must be provided for average annual rainfall minus average annual evaporation, which in Ohio ranges from 6 to 12 inches (Figure 4). Finally, a freeboard of 3 feet is recommended for reservoirs of from 15 to 50 acre/feet. A freeboard of 2 feet is recommended for smaller reservoirs.

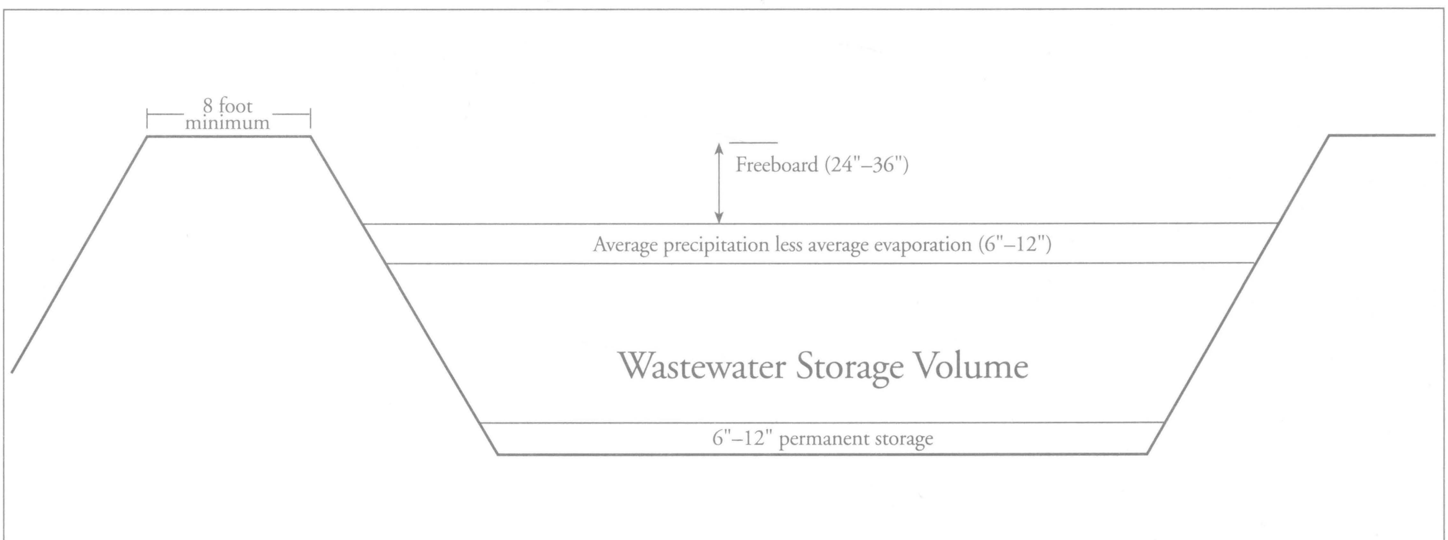


Figure 4. Recommended volumes for wastewater storage basins

Evaluation of a site for wastewater reuse

When considering a potential site, keep in mind the prevention of runoff. Site evaluations should begin with a topographic map of the proposed site. An aerial photograph is also useful. Shade in areas where wastewater application may have some restrictions. Maps and reports documenting restrictive features are available through the Natural Resources Conservation Service (NRCS) and the Ohio Department of Natural Resources (ODNR). Restrictive features of a site include areas with:

	Source of information
• 10-year flood frequency	Flood insurance maps
• All streams, waterways, wetlands, springs, ponds, and lakes	NRCS county soil survey
• Greater than 15 percent slope	NRCS county soil survey
• Less than 1 foot to seasonal water table	NRCS county soil survey
• Less than 2 feet to bedrock	NRCS county soil survey
• 100 feet from dwellings, roads, and other structures	aerial photo or site visit
• 100 feet from an operating or abandoned well	Site visit or ODNR well logs
• Subsurface drainage systems and storm sewer	Site visit or drainage district

Next outline the area being considered for wastewater application. Indicate throughout:

- current and intended land use
- reuse category (unrestricted, restricted, or agricultural)
- buffer areas
- existing or proposed fencing
- intended site modifications (earth moving, fill, windbreaks, or drainage)

Finally, test the soil on the proposed site to insure it was not contaminated by previous activities. Collect a composite soil sample from every 10 acres of application area to determine background levels in mg/kg of:

- aluminum
- arsenic
- beryllium
- boron
- cadmium
- chromium
- cobalt
- copper
- fluoride
- lead
- lithium
- molybdenum
- nickel
- selenium
- vanadium
- zinc
- phosphorus (as bray P_1)
- potassium
- sodium

For systems over 150,000 gpd, information on the groundwater in the area is important. The depth to groundwater aquifers in the area can be obtained from the county groundwater map published by ODNR. The direction of groundwater flow beneath the site can be determined by a hydrogeologist.

Part 3 Management

Irrigation systems

Distributing treated wastewater evenly over a field is the purpose of the irrigation system. A variety of system types and components are available. A detailed design of the necessary pumps, pipes, valves, and emitters must be developed by an irrigation professional. Because irrigation systems are not commonplace in Ohio, finding the right professional may be a challenge.

The society for engineering in agricultural, food, and biological systems (ASAE) in St. Joseph, Michigan, maintains a list of its members that specialize in irrigation systems. The Irrigation Association offers training and certifications for irrigation designers, contractors, and water auditors and also provides a list of certified irrigation system designers. Companies that sell irrigation systems may also provide design services. See the references in this bulletin for the addresses and phone numbers of the ASAE and the Irrigation Association.

Sprinkler systems

Irrigation systems fall into three categories; sprinkler, surface, and drip. Sprinkler systems are the most common. They work on slopes with up to 30 percent grade and are not limited by wastewater quality. All types of crops can be irrigated using sprinkler systems. Solid set sprinkler systems are most often used in wastewater reuse systems; center pivot, traveling gun, and traveling lateral systems also have applications.

Some limitations to the use of sprinkler systems are the purchase, placement costs, and field space for the equipment. Uncultivated tracks must be maintained for traveling systems. Field operations must maneuver around solid set systems. Another limitation of sprinkler systems is spray drift. Setbacks must be included in the field layout to minimize spray drift onto roads and dwellings.

Surface systems

Surface systems rely on surface grade and channels to help distribute the wastewater. Gated pipes discharge the wastewater at one end of a field and gently sloping furrows carry the wastewater throughout the field. Row crops and plant nurseries on level terrain are well suited for surface irrigation. Surface irrigation systems require less equipment than sprinkler systems and are not subject to spray drift problems. However, surface irrigation systems do not uniformly distribute the wastewater; the heaviest applications occur near the discharge points.

Drip systems

Drip irrigation systems use low-rate emitters to deliver wastewater slowly to the plant. Wastewater must be very low in solids, and disinfection may be required to reduce biofilms that can clog emitters. Drip systems can be used on any slope and are well suited to permanent planting, such as landscaping. The equipment and installation costs for drip systems may be high, but they do not create spray drift problems and, if buried, do not interfere with agricultural operations.

Combined systems

Some operations may wish to combine irrigation system types. Some of the wastewater may be reused for the landscaping around buildings through a drip irrigation system. Turf and field crop areas may be irrigated with sprinklers. The areas close to roads may rely on surface irrigation to minimize spray drift (Figure 5).

Zone operation

Irrigation systems are often designed to operate in zones across the field area. Zone operation has several advantages. Pumping capacity can be lower, which results in energy savings. Zone operation also allows wastewater and air to infiltrate the soil.

Control valves

Control valves are needed throughout the system to accommodate field management and system maintenance. While it is tempting to consider the use of automatic valves, extensive use is not recommended. Operators need to attend to irrigation operations to monitor weather conditions, check for system clogging, and observe ponding and possible runoff. Automatic valves not only give the illusion that the system is completely automatic, they can make it difficult for the operator to make necessary adjustments. Consider valves that are manual on with an automatic shut-off. In this way the operator can check field conditions before irrigation. If automatic valves are used, they should be controlled from a central location and be easy to override with manual controls.

System protection

Irrigation systems are exposed to the elements and are subject to damage and degradation.

Plastic components

Some plastic components are sensitive to ultraviolet light. Be sure to keep plastic pipe and other light-sensitive plastic components buried or covered.

Freezing

Freezing can also damage pipes and system components. Make sure all sections of the irrigation system can be easily drained when not in use. If irrigation is being considered throughout the winter months, the system should drain after each application.

Rodents and nesting material

Rodents and their nesting material can also infest irrigation systems when not in service. Rodents crawl into open pipes and empty tanks. Include animal guards on the ends of all exposed pipe. Be sure to cover the ends of pipes whenever a section of the system is disconnected. Old coffee cans work well for temporary covers on open pipes. Check exposed pipes for evidence of animal damage.

Leaves and other debris

Leaves and other debris can clog sprinklers and emitters. It may be necessary to place screening over holding tanks to keep leaves out of the irrigation system. Landscape plantings near holding basins may need to be modified to reduce clogging.

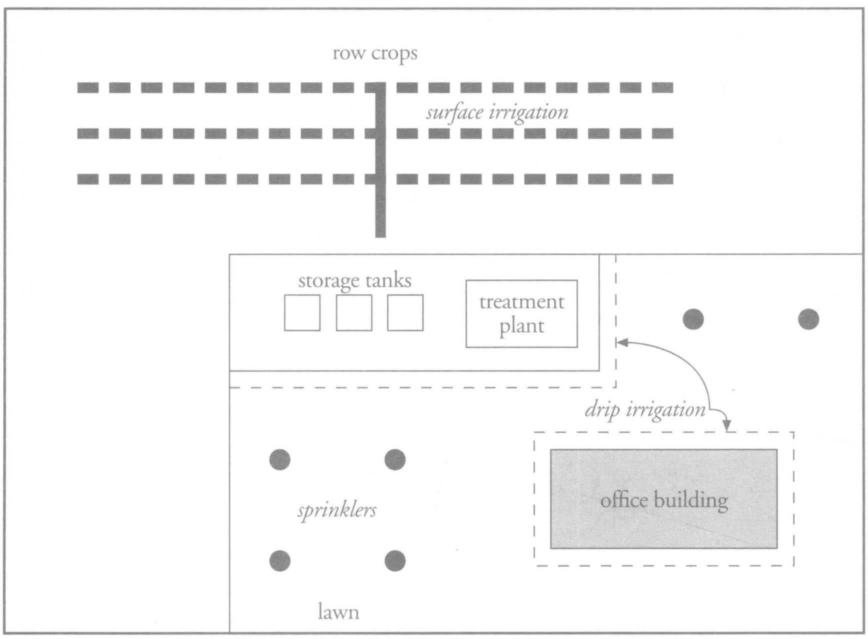


Figure 5. Sample irrigation system plan

Operation

Crop management

Crop management must also be considered when developing an irrigation plan. Irrigation may need to be suspended to allow time for planting, cultivation, mowing, and harvest. While it is difficult to predict exactly what day agricultural operations will occur, the irrigation plan must include time allowances for "down time."

Crop variety

Incorporating a variety of crops into a wastewater reuse system can help minimize conflicts between the need to manage a crop and the need to disperse wastewater over the site. Combining plots with turf, woodlot, and a variety of agricultural crops is strongly recommended because it gives an operator maximum flexibility.

Develop a simple field map with acreage, crop, and any irrigation restrictions. An example field map is shown in Figure 6.

Because revenue can be generated from crops grown on wastewater reuse sites, crop management sometimes distracts the operator from the first priority of the site, reuse of wastewater. Be careful not to get caught up with managing the crop to maximize yields. To insure adequate wastewater reuse to protect the environment, water and nutrient application rates are conservative. Plant growth may at times be limited due to poor drainage or wastewater application may reduce the time available for cultivation. The crop may at times be limited in water or nutrients.

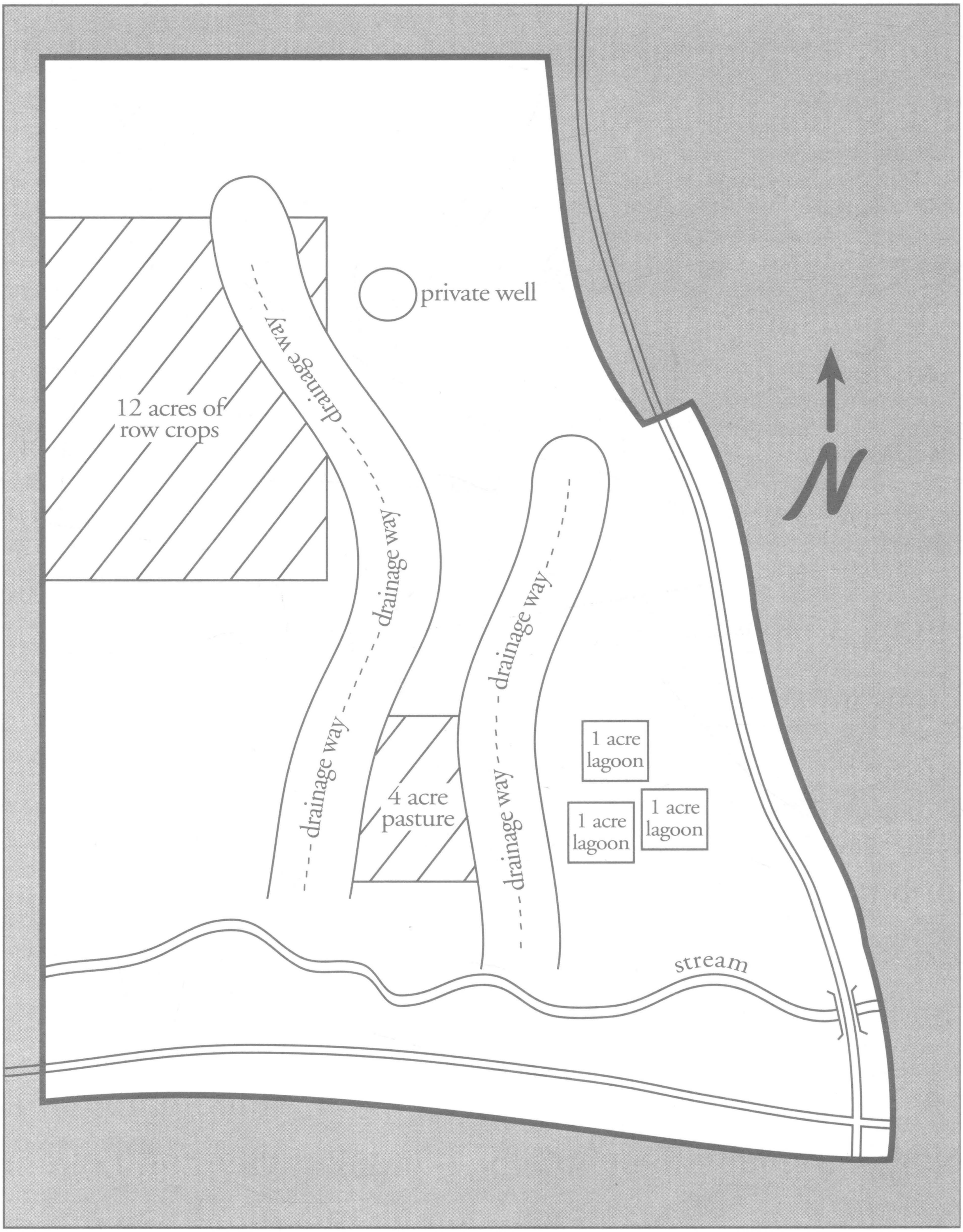


Figure 6. Field map for wastewater reuse system

Monitoring

Monitoring approaches for irrigation systems are different than for systems that discharge to streams. The objective of an irrigation site monitoring program is to provide for early detection of problems. In most cases, simple adjustments can be made to the operation to avoid polluting ground or surface water. As a minimum, monitoring should occur at four spots in the system: 1) the treatment plant effluent, 2) storage, 3) irrigation system, 4) soil (and in some cases the vegetation and groundwater). The frequency of monitoring depends on public access to the irrigation site and the system size (Tables 5 and 6).

Treatment plant effluent

The treatment plant effluent should be monitored to ensure that minimum treatment levels are achieved before it is discharged to the storage facility. The effluent should be monitored for $CBOD_5$ and total coliform bacteria. Treatment systems using chlorine for disinfection may choose to monitor chlorine residual as an early warning for problems in the disinfection system. Total metal analysis is necessary for treatment plants receiving industrial wastewater. The wastewater flow must be monitored.

Storage system

The storage system requires only limited monitoring. A weekly record of storage volume will help in managing the system to avoid future problems. A simple, easy to read staff gauge with cross-arms is an excellent way to measure liquid levels. Red markings at the top of the gauge give an easy indication that water levels are too high.

Irrigation system

For the irrigation system, precipitation and water applied by the system need to be monitored. Simple rain gauges placed in and near the application site can capture both precipitation and irrigation water.

Table 5 . Small system monitoring (less than 150,000 gpd)

	Unrestricted access sites	*Restricted access sites*	*Agricultural sites*
Treatment plant			
$CBOD_5$	Weekly	Weekly	Weekly
Total coliform (when irrigating)	Weekly	Weekly	Monthly
Flow	Daily	Daily	Daily
Storage			
Volume	Weekly	Weekly	Weekly
Irrigation system			
Precipitation	Inches/day	Inches/day	Inches/day
Wind speed	Application day	Application day	Application day
Wind direction	Application day	Application day	Application day
Air temperature	Application day	Application day	Application day
Irrigation	Inches/day	Inches/day	Inches/day
Soil			
Depth to water table	1 per month	1 per month	1 per month
Soil temperature	1 per month	1 per month	1 per month
Heavy metals	1 per year	1 per year	1 per year
Phosphorus	1 per year	1 per year	1 per year

Soil

The soil within the irrigation site is one of the integrators of all the material being applied. Soil samples can be analyzed at the Ohio State University Research/Extension Analytical Laboratory (REAL) in Wooster, Ohio. Establish one benchmark site per 10 acres, and collect a soil sample before irrigation begins and each year at the beginning of the application season. For systems over 150,000 gpd, samples should be collected twice a year.

By testing a sample of soil from the same spot each year any possible accumulations of minerals and metals can be monitored. This will act as an early warning for possible surface or ground water contamination. If levels begin to get high, simple adjustments can be made in irrigation scheduling to avoid problems.

Vegetation

The vegetation is a biological integrator of all of the material being applied. Both information on yield and plant tissue nutrient levels can act as an early warning system for problems. Plant tissue samples can also be analyzed at the REAL. Plant tissue tests can reveal nutrient imbalances and the need to add soil amendments such as lime, potassium, or phosphorus.

Groundwater

Groundwater should be monitored up-gradient and down-gradient of large irrigation systems. Monitoring wells should be sampled at the beginning and end of the irrigation season for indicators of wastewater contamination.

Monitoring programs

Monitoring programs for systems greater than 500,000 gpd would be similar, but need to be developed individually to meet local conditions and wastewater characteristics.

While much of the monitoring occurs during the irrigation period, some monitoring must continue year-round. Records of wastewater flow and storage volumes, for example,

Table 6 . Large system monitoring (150,000 to 500,000 gpd)

	Unrestricted access sites	*Restricted access sites*	*Agricultural sites*
Treatment plant			
$CBOD_5$	2 per week	2 per week	2 per week
Total coliform (when irrigating)	2 per week	2 per week	2 per week
Flow	Daily	Daily	Daily
Total inorganic Nitrogen	Monthly	Monthly	Monthly
Storage			
Volume	2 per week	2 per week	2 per week
Irrigation system			
Precipitation	Inches/day	Inches/day	Inches/day
Wind speed	Application day	Application day	Application day
Wind direction	Application day	Application day	Application day
Air temperature	Application day	Application day	Application day
Irrigation	Inches/day	Inches/day	Inches/day
Soil			
Depth to water table	1 per week	1 per week	1 per month
Soil temperature	1 per month	1 per month	1 per month
Heavy metals	2 per year	2 per year	2 per year
Phosphorus	2 per year	2 per year	2 per year
Groundwater			
Fecal coliform	2 per year	2 per year	2 per year
Chloride	2 per year	2 per year	2 per year
Nitrate	2 per year	2 per year	2 per year

need to be recorded throughout the year. Depending on the pretreatment system used, the effluent may also need to be monitored throughout the year.

Regulation and issuance of permits

One advantage of using an irrigation system is that it requires few permits. The Ohio Environmental Protection Agency (OEPA) issues a Permit to Install (PTI) before a treatment plant and irrigation system can be constructed. The agency staff reviews the plans to insure the system is adequately designed. An operation and maintenance plan needs to be submitted with the permit application. This plan will likely require revision after the first irrigation season. Plans for intermittent operation should be described to insure that the soil remains aerobic.

Monitoring requirements and effluent limitations are specified in a PTI. Monitoring results must be submitted regularly to OEPA. If the irrigation area has or will be served with subsurface drains, a discharge permit (NPDES permit) will also be required. Any discharge from the drainage system must be sampled.

Early contact with the district OEPA office is highly recommended. By obtaining the necessary application forms early and discussing the desire to reuse wastewater, the planning process can be streamlined.

References

ASAE. 2950 Niles Rd., St. Joseph, Michigan 49085 Phone: (616) 429-0300.

Evans, David R., et al. 1989. *Water Reuse. Manual of Practice SM-3.* Water Environment Federation, Alexandria, VA.

Great Lakes-Upper Mississippi River Board of State Public Health and Environmental Managers. 1990. *Recommended Standards for Wastewater Facilities.*

Irrigation Association. 8260 Willow Oaks Corporate Dr. Suite 120 Fairfax, VA 22031. Phone: (703) 573-3551. Fax: (703) 573-1913.

Jensen, M. E. editor, 1980. *Design and Operation of Farm Irrigation Systems.* ASAE Monograph No. 3. American Society of Agricultural Engineers, St. Joseph, MI.

Ohio Agronomy Guide, 13th Edition. Bulletin 472. Ohio State University Extension.

Reed, S. C., et al. 1990. *Natural Systems for Wastewater Treatment. Manual of Practice FD-16.* Water Environment Federation, Alexandria, VA.

Skaggs, R. W. DRAINMOD. Dept. of Biological and Agricultural Engineering. Box 7625. North Carolina State University, Raleigh, NC 27695-7625. [DRAINMOD requires detailed and properly prepared input data files for soils, long-term climate records, and crop records. Files for major Ohio regions may be obtained through Larry Brown, Dept. of Food, Agricultural and Biological Engineering. 590 Woody Hayes Dr., The Ohio State University, Columbus, OH 43210-1057 or brown.59@osu.edu]

U.S. EPA. 1992. *Guidelines for Water Reuse. EPA/625/R-92/004.* Center for Environmental Research Information. Cincinnati,OH.

U.S. EPA. 1981. *Process Design Manual: Land Treatment of Municipal Wastewater. EPA 625/1-81-013.* Center for Environmental Research Information, Cincinnati, OH.

Appendix A

Monthly evaporation data for Ohio counties

County	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Adams	0.8	1.0	2.0	3.0	4.1	4.5	4.6	4.2	3.2	2.3	1.4	0.9
Allen	0.7	0.9	1.6	2.8	4.3	5.0	5.0	4.4	3.2	2.3	1.2	0.7
Ashland	0.7	0.8	1.6	2.7	4.0	4.7	4.7	4.1	2.9	2.2	1.3	0.8
Ashtabula	0.7	0.8	1.4	2.6	3.7	4.4	4.5	4.0	2.9	2.3	1.3	0.8
Athens	0.8	1.0	1.9	2.9	3.9	4.3	4.3	4.0	2.9	2.1	1.3	0.9
Auglaize	0.7	0.9	1.7	2.8	4.3	5.1	5.1	4.5	3.3	2.3	1.2	0.7
Belmont	0.8	0.9	1.8	2.9	3.9	4.4	4.6	4.0	2.9	2.2	1.3	0.8
Brown	0.8	1.0	2.0	3.0	4.1	4.7	4.7	4.3	3.3	2.4	1.4	0.9
Butler	0.8	1.0	1.9	3.2	4.4	5.2	5.2	4.8	3.5	2.5	1.4	0.9
Carroll	0.7	0.8	1.6	2.7	3.8	4.4	4.6	4.1	2.9	2.2	1.3	0.8
Champaign	0.7	0.9	1.8	2.9	4.3	5.0	5.0	4.5	3.3	2.3	1.3	0.8
Clark	0.8	0.9	1.8	2.9	4.3	5.1	5.1	4.5	3.3	2.3	1.3	0.8
Clermont	0.7	1.0	1.9	3.1	4.2	4.9	4.9	4.6	3.4	2.5	1.4	0.9
Clinton	0.8	0.9	1.9	3.0	4.2	4.8	4.9	4.4	3.3	2.4	1.3	0.9
Columbiana	0.7	0.8	1.6	2.7	3.8	4.3	4.5	4.0	2.9	2.2	1.3	0.8
Coshocton	0.7	0.9	1.7	2.8	3.9	4.5	4.7	4.1	2.9	2.2	1.3	0.8
Crawford	0.7	0.8	1.6	2.7	4.1	4.7	4.8	4.1	2.9	2.1	1.2	0.7
Cuyahoga	0.7	0.8	1.5	2.7	4.0	4.7	4.7	4.1	2.9	2.2	1.3	0.8
Darke	0.8	0.9	1.8	3.0	4.4	5.3	5.2	4.7	3.4	2.4	1.3	0.8
Defiance	0.6	0.8	1.5	2.7	4.2	4.9	5.0	4.3	3.0	2.2	1.1	0.6
Delaware	0.7	0.9	1.7	2.7	4.1	4.7	4.8	4.2	2.9	2.1	1.1	0.7
Erie	0.6	0.8	1.5	2.7	4.1	4.7	4.8	4.1	2.9	2.1	1.2	0.8
Fairfield	0.8	0.9	1.8	2.8	4.0	4.5	4.6	4.0	2.9	2.1	1.2	0.8
Fayette	0.8	0.9	1.8	2.9	4.1	4.7	4.8	4.3	3.1	2.3	1.3	0.8
Franklin	0.7	0.9	1.8	2.8	4.1	4.6	4.8	4.1	2.9	2.2	1.2	0.8
Fulton	0.6	0.8	1.5	2.6	4.2	4.8	4.9	4.2	2.9	2.1	1.0	0.6
Gallia	0.9	1.0	2.0	3.0	3.9	4.2	4.2	3.8	2.9	2.1	1.3	0.9
Geauga	0.7	0.8	1.5	2.6	3.8	4.5	4.5	4.0	2.9	2.2	1.3	0.8
Greene	0.8	0.9	1.8	3.0	4.3	5.0	5.0	4.6	3.3	2.4	1.3	0.9
Guernsey	0.8	0.9	1.8	2.8	3.9	4.5	4.7	4.1	2.9	2.2	1.3	0.8
Hamilton	0.8	1.0	1.9	3.2	4.4	5.1	5.1	4.7	3.5	2.5	1.4	0.9
Hancock	0.6	0.8	1.6	2.6	4.1	4.7	4.8	4.2	3.0	2.1	1.1	0.7
Hardin	0.7	0.8	1.7	2.7	4.2	4.8	4.9	4.3	3.0	2.2	1.2	0.7
Harrison	0.8	0.9	1.7	2.8	3.9	4.5	4.7	4.1	2.9	2.2	1.3	0.8
Henry	0.6	0.8	1.5	2.7	4.2	4.8	4.9	4.2	3.0	2.2	1.1	0.6
Highland	0.8	1.0	1.9	3.0	4.1	4.6	4.7	4.3	3.2	2.3	1.3	0.8
Hocking	0.8	0.9	1.9	2.8	4.0	4.4	4.4	3.9	2.9	2.1	1.3	0.8
Holmes	0.7	0.8	1.6	2.7	3.8	4.4	4.5	4.0	2.9	2.2	1.3	0.8
Huron	0.7	0.8	1.6	2.7	4.1	4.7	4.8	4.1	2.9	2.1	1.2	0.8
Jackson	0.9	1.0	2.0	3.0	4.0	4.3	4.3	3.9	3.0	2.2	1.3	0.9
Jefferson	0.8	0.9	1.7	2.8	3.9	4.5	4.7	4.1	2.9	2.2	1.3	0.8
Knox	0.7	0.9	1.7	2.7	3.9	4.5	4.6	4.1	2.9	2.2	1.2	0.8
Lake	0.7	0.8	1.5	2.7	3.9	4.6	4.7	4.1	2.9	2.3	1.3	0.8
Lawrence	0.9	1.1	2.0	3.0	3.9	4.3	4.2	3.8	3.0	2.2	1.4	0.9

County	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Licking	0.8	0.9	1.8	2.8	4.0	4.5	4.7	4.1	2.9	2.1	1.2	0.8
Logan	0.7	0.9	1.7	2.8	4.2	4.9	5.0	4.4	3.2	2.3	1.2	0.8
Lorain	0.7	0.8	1.5	2.7	4.0	4.7	4.8	4.1	2.9	2.2	1.3	0.8
Lucas	0.6	0.8	1.5	2.6	4.1	4.6	4.8	4.1	2.9	2.1	1.1	0.6
Madison	0.8	0.9	1.8	2.8	4.2	4.8	4.9	4.3	3.1	2.2	1.3	0.8
Mahoning	0.7	0.8	1.5	2.6	3.6	4.2	4.3	3.8	2.8	2.2	1.3	0.7
Marion	0.7	0.8	1.7	2.7	4.1	4.7	4.8	4.1	2.9	2.1	1.1	0.7
Medina	0.7	0.8	1.5	2.7	3.9	4.6	4.6	4.1	2.9	2.2	1.3	0.8
Meigs	0.9	1.0	2.0	3.0	3.9	4.2	4.2	3.8	2.9	2.1	1.3	0.9
Mercer	0.7	0.9	1.7	2.9	4.4	5.2	5.2	4.6	3.3	2.3	1.2	0.7
Miami	0.8	0.9	1.8	3.0	4.4	5.2	5.2	4.7	3.4	2.4	1.3	0.8
Monroe	0.8	1.0	1.8	2.9	3.9	4.3	4.4	3.9	2.9	2.2	1.3	0.8
Montgomery	0.8	1.0	1.8	3.0	4.4	5.2	5.2	4.7	3.5	2.5	1.3	0.9
Morgan	0.8	0.9	1.9	2.9	3.9	4.4	4.4	3.9	2.9	2.1	1.3	0.8
Morrow	0.7	0.9	1.7	2.7	4.0	4.7	4.7	4.1	2.9	2.1	1.2	0.7
Muskingum	0.8	0.9	1.8	2.8	4.0	4.5	4.8	4.1	2.9	2.2	1.3	0.8
Noble	0.8	0.9	1.8	2.9	3.9	4.4	4.5	4.0	2.9	2.2	1.3	0.8
Ottawa	0.6	0.8	1.5	2.6	4.1	4.7	4.8	4.1	2.9	2.1	1.1	0.7
Paulding	0.6	0.8	1.6	2.8	4.3	5.0	5.1	4.4	3.1	2.2	1.1	0.6
Perry	0.8	0.9	1.8	2.8	4.0	4.4	4.5	4.0	2.9	2.1	1.3	0.8
Pickaway	0.8	0.9	1.8	2.8	4.0	4.6	4.7	4.1	3.0	2.2	1.3	0.8
Pike	0.8	1.0	1.9	3.0	4.0	4.4	4.5	4.1	3.0	2.3	1.3	0.9
Portage	0.7	0.8	1.5	2.6	3.6	4.2	4.3	3.8	2.8	2.2	1.3	0.7
Preble	0.8	0.9	1.8	3.1	4.4	5.2	5.2	4.7	3.5	2.5	1.3	0.9
Putnam	0.6	0.8	1.6	2.7	4.2	4.9	5.0	4.3	3.1	2.2	1.1	0.7
Richland	0.7	0.8	1.6	2.7	4.0	4.7	4.7	4.1	2.9	2.2	1.2	0.8
Ross	0.8	0.9	1.9	2.9	4.0	4.5	4.6	4.1	3.0	2.2	1.3	0.8
Sandusky	0.6	0.8	1.5	2.6	4.1	4.7	4.8	4.1	2.9	2.1	1.1	0.7
Scioto	0.8	1.0	2.0	3.0	4.0	4.4	4.4	4.1	3.1	2.3	1.4	0.9
Seneca	0.6	0.8	1.6	2.6	4.1	4.7	4.8	4.1	2.9	2.1	1.1	0.7
Shelby	0.7	0.9	1.7	2.9	4.3	5.2	5.1	4.6	3.3	2.4	1.3	0.8
Stark	0.7	0.8	1.5	2.6	3.7	4.3	4.4	4.0	2.9	2.3	1.3	0.7
Summit	0.7	0.8	1.5	2.6	3.7	4.4	4.4	4.0	2.9	2.2	1.3	0.7
Trumbull	0.6	0.8	1.4	2.5	3.5	4.2	4.2	3.7	2.7	2.2	1.2	0.7
Tuscarawas	0.7	0.9	1.6	2.8	3.8	4.4	4.6	4.1	2.9	2.2	1.3	0.8
Union	0.7	0.9	1.7	2.8	4.1	4.8	4.9	4.3	2.9	2.2	1.2	0.8
Van Wert	0.7	0.8	1.6	2.8	4.3	5.1	5.1	4.5	3.2	2.3	1.2	0.7
Vinton	0.8	1.0	1.9	2.9	4.0	4.3	4.4	3.9	2.9	2.1	1.3	0.9
Warren	0.8	1.0	1.9	3.0	4.3	5.1	5.0	4.6	3.5	2.5	1.4	0.9
Washington	0.8	1.0	1.9	2.9	3.9	4.3	4.3	3.9	2.9	2.1	1.3	0.9
Wayne	0.7	0.8	1.5	2.7	3.8	4.4	4.5	4.0	2.9	2.2	1.3	0.8
Williams	0.6	0.8	1.5	2.7	4.2	4.9	5.0	4.3	3.0	2.1	1.1	0.6
Wood	0.6	0.8	1.5	2.6	4.1	4.7	4.8	4.1	2.9	2.1	1.1	0.6
Wyandot	0.1	0.8	1.6	2.7	4.1	4.7	4.8	4.1	2.9	2.1	1.1	0.7

Appendix B

Monthly rainfall with 5 year return period by Ohio climatic division

Division	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
1	3.3	2.7	3.8	4.1	4.4	5.0	4.3	4.0	3.8	3.8	3.3	3.3
2	3.4	2.6	3.9	3.9	4.3	4.7	4.3	4.2	4.0	3.3	3.5	3.3
3	3.6	3.1	4.1	4.0	4.5	4.6	4.7	4.1	4.3	4.2	3.7	3.5
4	4.0	3.1	4.6	4.4	5.0	5.3	4.6	4.5	4.1	3.5	3.8	3.4
5	4.0	3.3	4.4	4.6	5.2	5.0	5.2	4.5	3.9	3.6	4.0	3.7
6	3.9	3.1	4.3	4.2	4.9	5.2	5.2	4.6	4.1	3.7	3.7	3.5
7	3.8	3.1	4.6	4.2	4.9	5.0	5.4	4.5	4.0	4.0	3.5	3.5
8	4.5	3.9	5.4	4.9	5.5	4.9	5.0	4.4	4.4	3.8	4.5	4.0
9	4.6	3.8	5.5	5.1	5.1	4.9	5.6	5.0	4.1	3.6	4.2	4.2
10	4.0	3.6	5.0	4.5	5.1	5.3	5.1	4.8	4.3	3.6	3.6	3.8

Ohio's Climatic Divisions

Appendix C

Monthly rainfall data for Ohio counties

County	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Adams	3.5	3.0	4.4	3.9	4.3	3.8	4.7	3.5	3.1	2.3	3.0	3.0
Allen	2.4	2.1	2.9	3.6	4.0	4.0	3.7	2.9	2.8	2.6	2.7	2.3
Ashland	2.6	2.0	3.1	3.4	3.9	3.9	4.0	2.9	2.7	2.1	2.6	2.3
Ashtabula	2.8	2.3	3.3	3.8	4.0	3.8	4.0	3.4	3.0	3.1	3.2	2.8
Athens	3.0	2.6	3.9	3.8	4.1	4.1	4.6	3.2	2.8	2.3	2.8	2.8
Auglaize	2.3	2.0	2.9	3.6	3.9	3.9	3.6	2.9	2.8	2.6	2.7	2.3
Belmont	3.0	2.7	3.9	3.8	4.2	4.2	4.6	3.3	2.9	2.3	2.8	2.8
Brown	3.4	3.0	4.2	4.0	4.2	4.1	4.2	3.1	2.9	2.3	3.2	2.9
Butler	3.1	2.8	4.0	3.8	4.0	3.8	4.0	2.9	2.7	2.2	3.0	2.7
Carroll	3.0	2.5	3.7	3.7	4.1	4.1	4.4	3.1	2.8	2.7	2.8	2.6
Champaign	2.8	2.2	3.3	3.9	4.1	4.1	3.9	3.0	2.8	2.3	2.7	2.4
Clark	2.8	2.3	3.4	3.9	4.1	4.1	4.0	3.0	2.8	2.3	2.8	2.5
Clermont	3.3	2.9	4.1	4.0	4.1	4.0	4.1	3.0	2.8	2.3	3.1	2.8
Clinton	3.4	3.1	4.4	4.2	4.4	4.2	4.4	3.2	3.0	2.4	3.3	3.0
Columbiana	2.9	2.4	3.6	3.6	4.0	4.0	4.3	3.0	2.8	2.7	2.7	2.5
Coshocton	2.9	2.3	3.5	3.9	4.3	4.3	4.5	3.2	3.0	2.3	2.8	2.5
Crawford	2.5	2.1	2.9	3.6	3.9	3.9	3.9	3.1	2.8	2.3	2.7	2.3
Cuyahoga	2.7	2.2	3.1	3.5	3.8	3.6	3.8	3.1	2.8	2.9	3.0	2.5
Darke	2.8	2.2	3.3	3.9	4.1	4.1	3.9	3.0	2.8	2.3	2.7	2.4
Defiance	2.2	1.8	2.7	3.5	3.7	3.7	3.5	2.7	2.6	2.4	2.5	2.2
Delaware	2.7	2.2	3.5	3.8	3.9	3.9	4.0	2.9	2.6	2.0	2.6	2.4
Erie	2.3	1.9	2.8	3.4	3.7	3.7	3.7	2.9	2.7	2.1	2.6	2.2
Fairfield	2.9	2.4	3.7	4.0	4.2	4.2	4.2	3.1	2.8	2.2	2.8	2.5
Fayette	2.9	2.4	3.7	4.0	4.2	4.2	4.2	3.1	2.8	2.2	2.8	2.5
Franklin	2.7	2.2	3.5	3.8	3.9	3.9	4.0	2.9	2.6	2.0	2.6	2.4
Fulton	2.2	1.8	2.7	3.5	3.7	3.7	3.5	2.7	2.6	2.4	2.5	2.2
Gallia	3.3	2.9	4.3	3.8	4.1	3.7	4.5	3.4	3.0	2.2	2.9	2.9
Geauga	2.9	2.4	3.4	4.0	4.2	4.0	4.2	3.4	3.1	3.2	3.4	2.8
Greene	3.1	2.8	4.0	3.8	4.0	3.8	4.0	2.9	2.7	2.2	3.0	2.7
Guernsey	2.9	2.6	3.8	3.7	4.1	4.1	4.5	3.2	2.8	2.3	2.8	2.7
Hamilton	3.2	2.8	4.0	3.8	4.0	3.9	4.0	3.0	2.8	2.2	3.0	2.8
Hancock	2.3	2.0	2.8	3.5	3.9	3.8	3.6	2.8	2.8	2.5	2.7	2.3
Hardin	2.4	2.1	3.2	3.5	3.7	3.7	3.6	2.7	2.6	2.2	2.5	2.3
Harrison	3.0	2.6	3.7	3.7	4.2	4.1	4.5	3.1	2.9	2.8	2.8	2.6
Henry	2.2	1.9	2.8	3.4	3.7	3.7	3.5	2.8	2.7	2.5	2.6	2.2
Highland	3.4	3.1	4.4	4.2	4.4	4.2	4.4	3.2	3.0	2.4	3.3	3.0
Hocking	2.9	2.6	3.8	3.7	4.0	4.0	4.4	3.2	2.8	2.2	2.8	2.6
Holmes	2.8	2.2	3.4	3.7	4.2	4.2	4.3	3.2	3.0	2.3	2.8	2.4
Huron	2.5	2.1	2.9	3.6	3.9	3.9	3.9	3.1	2.8	2.3	2.7	2.3
Jackson	3.4	3.0	4.3	3.8	4.2	3.7	4.5	3.5	3.1	2.2	2.9	2.9
Jefferson	3.0	2.4	3.6	3.7	4.0	4.0	4.4	3.1	2.8	2.7	2.8	2.5
Knox	2.8	2.2	3.4	3.7	4.2	4.2	4.3	3.2	3.0	2.3	2.8	2.4
Lake	2.8	2.3	3.2	3.7	4.0	3.8	4.0	3.3	3.0	3.1	3.2	2.6
Lawrence	3.4	3.0	4.3	3.9	4.2	3.8	4.5	3.5	3.1	2.3	3.0	3.0

County	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Licking	2.9	2.4	3.7	4.0	4.2	4.2	4.2	3.1	2.9	2.1	2.8	2.5
Logan	2.7	2.1	3.2	3.7	3.9	3.9	3.8	2.9	2.7	2.2	2.6	2.3
Lorain	2.4	1.9	2.8	3.5	3.8	3.8	3.7	2.9	2.7	2.2	2.6	2.2
Lucas	2.1	1.8	2.6	3.1	3.5	3.5	3.4	2.7	2.5	2.3	2.4	2.1
Madison	2.9	2.3	3.6	3.9	4.1	4.1	4.1	3.0	2.7	2.0	2.8	2.5
Mahoning	2.8	2.3	3.4	3.4	3.9	3.7	4.1	2.8	2.6	2.5	2.6	2.4
Marion	2.6	2.1	3.4	3.6	3.8	3.7	3.8	2.8	2.5	1.9	2.5	2.3
Medina	2.7	2.2	3.1	3.5	3.8	3.6	3.8	3.1	2.8	2.9	3.0	2.5
Meigs	3.3	2.9	4.2	3.8	4.1	3.6	4.4	3.4	3.0	2.2	2.8	2.8
Mercer	2.7	2.1	3.2	3.7	3.9	3.9	3.8	2.9	2.7	2.2	2.6	2.3
Miami	2.7	2.2	3.3	3.8	4.0	4.0	3.9	2.9	2.8	2.3	2.7	2.4
Monroe	3.1	2.7	4.0	3.9	4.3	4.3	4.7	3.4	2.9	2.4	2.9	2.9
Montgomery	3.1	2.7	3.9	3.8	3.9	3.8	3.9	2.9	2.7	2.1	2.9	2.7
Morgan	2.9	2.6	3.8	3.7	4.0	4.0	4.4	3.2	2.8	2.2	2.8	2.6
Morrow	2.7	2.2	3.5	3.8	3.9	3.9	4.0	2.9	2.6	2.0	2.6	2.4
Muskingum	2.9	2.6	3.7	3.6	4.0	4.0	4.4	3.1	2.7	2.2	2.7	2.6
Noble	3.0	2.6	3.9	3.8	4.1	4.1	4.6	3.2	2.8	2.3	2.8	2.8
Ottawa	2.2	1.8	2.6	3.2	3.5	3.5	3.4	2.8	2.5	2.1	2.4	2.0
Paulding	2.3	2.0	2.8	3.5	3.9	3.8	3.6	2.8	2.8	2.5	2.7	2.3
Perry	2.9	2.5	3.8	3.6	4.0	4.0	4.4	3.1	2.7	2.2	2.7	2.6
Pickaway	2.9	2.4	3.7	3.9	4.1	4.1	4.2	3.0	2.8	2.1	2.8	2.5
Pike	3.3	2.9	4.2	3.8	4.1	3.6	4.4	3.4	3.0	2.2	2.8	2.8
Portage	2.7	2.3	3.1	3.6	3.8	3.7	3.9	3.2	2.9	3.0	3.2	2.6
Preble	3.1	2.7	3.9	3.8	3.9	3.8	3.9	2.9	2.7	2.1	2.9	2.7
Putnam	2.3	2.0	2.8	3.5	3.9	3.8	3.6	2.8	2.8	2.5	2.7	2.3
Richland	2.7	2.2	3.3	3.6	4.0	4.0	4.2	3.1	2.9	2.3	2.7	2.4
Ross	3.2	2.8	4.1	3.7	4.0	3.5	4.3	3.3	2.9	2.1	2.8	2.8
Sandusky	2.2	1.8	2.6	3.3	3.7	3.7	3.6	2.9	2.6	2.0	2.5	2.1
Scioto	3.4	3.0	4.4	3.9	4.2	3.7	4.6	3.5	3.1	2.2	3.0	3.0
Seneca	2.4	1.9	2.9	3.5	3.8	3.8	3.8	3.0	2.7	2.2	2.7	2.3
Shelby	2.7	2.2	3.3	3.8	4.0	4.0	3.8	2.9	2.7	2.2	2.6	2.3
Stark 2.8	2.3	3.4	3.5	3.8	3.8	4.2	2.9	2.7	2.6	2.6	2.4	
Summit	2.7	2.2	3.1	3.6	3.9	3.6	3.8	3.1	2.9	3.0	3.1	2.5
Trumbull	2.6	2.2	3.0	3.5	3.8	3.6	3.7	3.1	2.8	2.8	3.0	2.4
Tuscarawas	3.0	2.4	3.6	3.7	4.0	4.0	4.4	3.1	2.8	2.7	2.8	2.5
Union	2.7	2.2	3.5	3.8	3.9	3.9	4.0	2.9	2.6	2.0	2.6	2.4
Van Wert	2.4	2.1	2.9	3.6	4.0	4.0	3.7	2.9	2.8	2.6	2.7	2.3
Vinton	2.9	2.6	3.8	3.7	4.1	4.1	4.5	3.2	2.8	2.3	2.8	2.7
Warren	3.4	3.0	4.2	4.0	4.2	4.1	4.2	3.1	2.9	2.3	3.2	2.9
Washington	3.0	2.6	3.9	3.8	4.1	4.1	4.6	3.2	2.8	2.3	2.8	2.8
Wayne	2.7	2.1	3.2	3.5	4.0	4.0	4.1	3.0	2.8	2.2	2.6	2.3
Williams	2.2	1.9	2.8	3.4	3.7	3.7	3.5	2.8	2.7	2.5	2.6	2.2
Wood	2.2	1.8	2.7	3.4	3.6	3.6	3.5	2.7	2.6	2.4	2.5	2.0
Wyandot	2.4	1.9	2.9	3.5	3.8	3.8	3.8	3.0	2.7	2.2	2.7	2.3

Notes:

Notes: