

A Guide to Planning and Designing Effluent Irrigation Disposal Systems in Missouri

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PREFACE

Most municipalities discharge treated waste water into streams, often with the effect of degrading overall water quality. The Clean Water Commission, recognizing this problem, has passed a regulation prohibiting this practice in certain areas of Missouri. Costs of advanced waste treatment systems are quite high, thus focusing much attention on returning these waste water effluents to the land through normally less expensive irrigation systems. This approach has considerable merit: present irrigation systems are designed to handle large volumes of water; the soil-plant complex is an effective renovation media, capable of utilizing both water and the effluent nutrients; and finally, re-using these potential pollutants and water may provide economic return through crops and livestock.

The Clean Water Commission has the responsibility and authority to correct and/or prevent "pollution" of "waters of the state." These terms are defined in the law and discussed briefly in the first section. With these facts in mind, staff engineers of the Clean Water Commission held a series of meetings with staff members of the University of Missouri-Columbia College of Agriculture, School of Forestry, and College of Engineering; Missouri Geological Survey; Soil Conservation Service; Missouri Division of Health; Missouri Department of Conservation; Missouri Water Resources Research Center; U.S. Forest Service; USDA Agricultural Research Service; USDA-ASCS; Ft. Leonard Wood; and other interested individuals to develop guidelines for disposing of sewage effluent through irrigation systems. This report is a result of their combined efforts.

Research data and field experience from many sources have been used to develop this guide for planning, design, construction, and management of alternative systems for effluent disposal.

The information and design guidelines herein are intended primarily for the use of government agency personnel, municipal and industrial planners, University staff members, and professional engineers concerned with sewage effluent disposal.

Although there is much yet to be learned about effluent disposal, this represents an effort to collect all available information and present it in a useable form.

2. Infiltration Rates

Sound system design depends on the knowledge of the rate at which water enters and moves through the soil. The infiltration characteristics of dry soils may be described by an initially high infiltration rate, that decreases as effluent water continues to be applied. After continued application of effluent, the soil becomes wet and infiltration approaches a constant value. This constant value is referred to as the basic intake rate, or the conductivity of the moist soil in question.

An on-site evaluation must be used to estimate water conductivity of soils that are made wet. Ranges of conductivities for different kinds of soil are explained in two references. They are the U.S.D.A. Soil Conservation Service hydrologic soil grouping (83) and the University of Missouri Extension Division Circular 823 "Soils of Missouri" (67). The hydrologic grouping is based upon data reported by Musgrave (46). Soils listed in Circular 823 can be related to the hydrologic groupings through descriptive permeability classes that are assigned to each soil series. Table 3 lists the estimated moist conductivities.

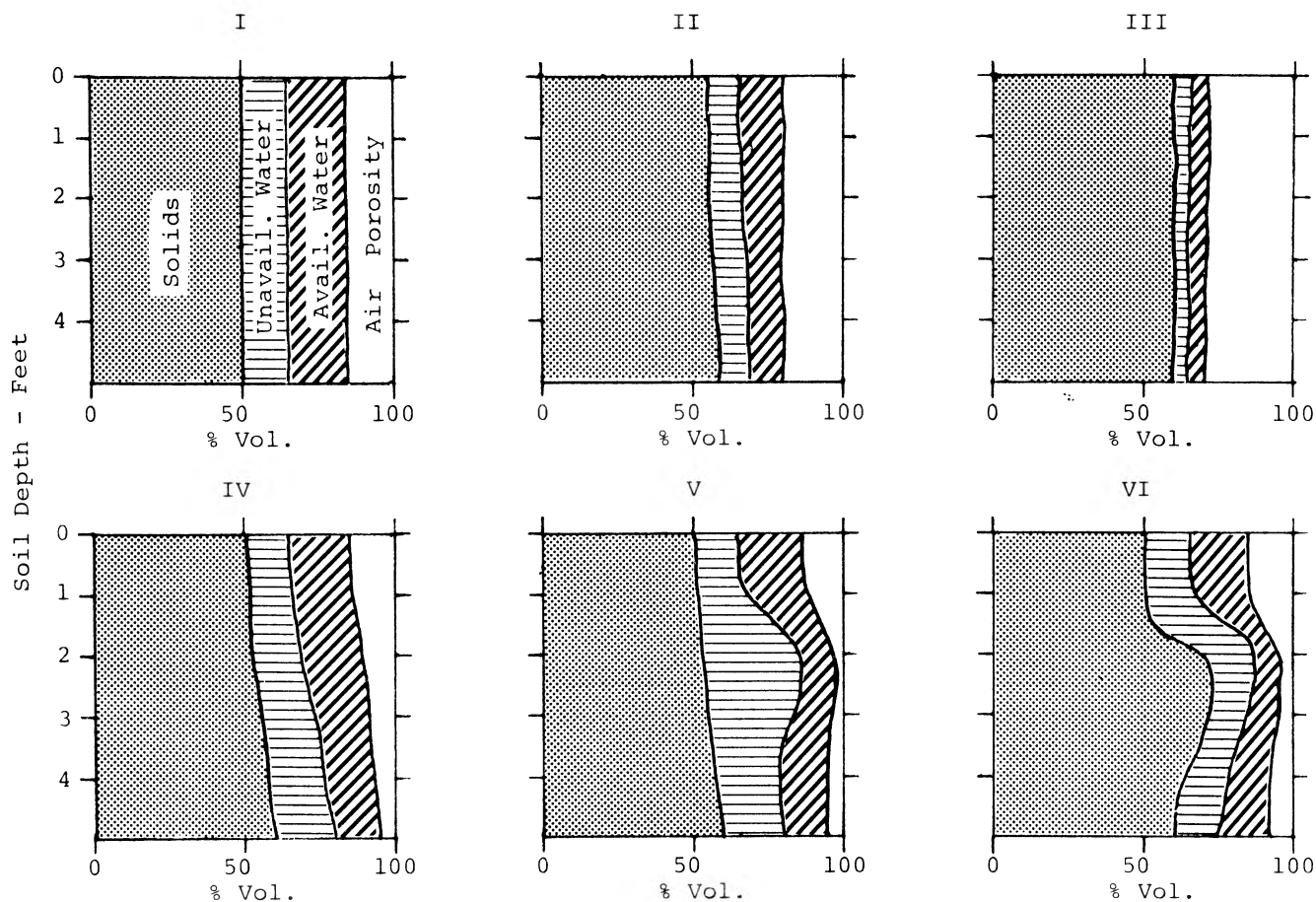
Figure 1 shows six kinds of soil volume profiles and relates them to water conductivities. The estimated conductivities are for summer temperatures and a grass cover to insure initial entry of water into the soil.

TABLE 3

ESTIMATED SUMMER CONDUCTIVITIES FOR WATER BY MOIST SOILS
AND
MAXIMUM AMOUNTS OF WATER TO PASS THROUGH SOILS

Soil Permeability Class from Cir. 823 "Soils of Mo."	Hydrologic Group Symbol (S.C.S.)	Estimated Summer Conductivity inches/hr.	Maximum Amounts of Water* inches/yr.
Very Slow	D	less than .016	less than 18
Slow	C	.016 - .04	18 - 44
Moderate	B	.04 - .10	44 - 68
Rapid	A	.10 & greater	68

* Annual amounts are reduced to one-eighth of that which would be possible if summer conductivities could be maintained for 365 days. Half of the reduction is to provide for needed periods of drying and half is to account for reduced conductivities associated with low temperatures.



SIX KINDS OF SOIL VOLUME PROFILES AND ESTIMATED
SUMMER CONDUCTIVITIES FOR MOIST SOILS

FIGURE 1.

- I. Well aggregated silty soils and limestone-derived soils without pans. Conductivity, values scattered about 0.1 inches per hour.
- II. Soils with large amounts of coarse fragments or sand and some silt or clay in aggregates. Conductivity, 0.25 inches per hour.
- III. Well sorted (uniform grain sized) coarse sandy soils. Conductivity, approximately 1.6 inches per hour.
- IV. A soil having a developed surface soil-subsoil profile and the normal expected depth increased in density. (No pans.) Conductivity decreases with increasing depth to approximately .016 inches per hour at 5 feet depth.
- V. A soil with a claypan layer. The moist claypan restricts profile conductivity to less than .01 inches per hour.
- VI. A soil with a fragipan layer. The fragipan layer restricts profile conductivity to less than .016 inches per hour.

AUTHORS

Mark Peterson, Dept. of Agricultural Engineering, UMC, Senior Author
Ted Forester, Missouri Clean Water Commission, Editor
Paul Gwin, Agricultural Editors Office, UMC, Editor
Clarence Scrivner, Dept. of Agronomy, UMC
George Garner, Dept. of Agricultural Chemistry, UMC
James Brown, Dept. of Agronomy, UMC
Ed Lightfoot, Missouri Clean Water Commission
Robert Blanchar, Dept. of Agronomy, UMC
Richard Guthrie, Soil Conservation Service
George Smith, Water Resources Research Center
Jack Slusher, School of Forestry, UMC
Carl Settergren, School of Forestry, UMC
William Lobenstein, Dept. of Horticulture, UMC
Coy McNabb, Dept. of Agricultural Economics, UMC
Phillip Coombs, Soil Conservation Service
C. M. Woodruff, Dept. of Agronomy, UMC
Charles F. Cromwell, Jr., Dept. of Agricultural Engineering, UMC

CONTRIBUTORS

Dennis Sievers, Dept. of Agricultural Engineering, UMC
Edward J. Constien, Dept. of Agricultural Engineering, UMC
Bonnard Moseley, School of Veterinary Medicine, UMC
Christian Johannsen, Dept. of Agronomy, UMC
Darrell King, Dept. of Civil Engineering, UMC
Steve Decker, Missouri Clean Water Commission
Wayne Decker, Dept. of Atmospheric Science, UMC
Dale Fuller, Missouri Geological Survey
Alva Preston, Jr., Dept. of Agronomy, UMC
John Doll, Dept. of Agronomy, UMC
William H. Pfander, Dept. of Animal Husbandry, UMC
Thomas Dean, Missouri Geological Survey
Gene Cox, School of Forestry, UMC

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PART I.

The Missouri Clean Water Law

In 1972 the Missouri General Assembly passed legislation creating the Missouri Clean Water Commission. This was not the first legislation aimed at protecting waters of the state. In 1957, a Water Pollution Board was created and it functioned until April, 1972, when it was replaced by the newer regulatory agency. The job of the Clean Water Commission is to:

. . . develop comprehensive programs for the prevention, control, and abatement of new or existing pollution of the waters of the state.*

“Waters of the State” are defined in the state statute as:

. . . all rivers, streams, lakes, and other bodies of surface, and sub-surface water . . . not . . . confined and retained completely upon the property of a . . . person . . .*

When the Missouri General Assembly passed legislation creating the commission, it also defined water pollution and adopted a state water policy.

What is Water Pollution?

Water Pollution is defined in the law as follows:

. . . such contamination, or other alteration of the physical, chemical or biological properties, of any waters of the state, including change in temperature, taste, color, turbidity, or odor of the waters, or such discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state as will or is reasonably certain to create a nuisance or render such waters harmful, detrimental or injurious to public health, safety or welfare, or to domestic, industrial, agricultural recreational, or other legitimate beneficial uses, or to wild animals, birds, fish or other aquatic life.*

State Water Policy

The water policy declares that waters of the state may not be used as a means of disposing of any type of waste:

. . . it is hereby declared to be the public policy of this state to conserve the waters of the state and to protect, maintain and improve the quality thereof for public water supplies, for the propagation of wildlife, fish and aquatic life, and for domestic, agricultural, industrial, recreational and other legitimate beneficial uses.*

Composition of the Commission

The six-member commission is bipartisan. It is appointed by the Governor, subject to approval of the Senate. All members must be representative of the public and must have an interest in and knowledge about the effects and control of water contaminants. No more than two may represent agricultural, municipal, industrial or mining interests. The Commission elects its own chairman and vice chairman annually. Members of the Commission serve without pay but are reimbursed for necessary travel and other expenses incurred in performance of their duties. An Executive Secretary is appointed by the Commission to serve as its administrative agent. The term of office for Commission members is four years, but there is no limitation on the number of terms an appointed member may serve.

*Chapter 204, Missouri Revised Statutes, 1969 and Supplements.

What the Commission Does

The Commission is obligated to develop programs for the prevention, control, and abatement of new or existing pollution of the water of the state. This may include establishing water quality standards for the streams; issuing orders prohibiting discharge of certain water contaminants; issuing permits for approved waste treatment systems; and administering loans and grants from federal government or elsewhere.

The law tends to speak in broad objectives and leaves specific regulations up to the Commission. The 1972 statutes instruct the Commission to adopt regulations aimed at preventing water pollution from each source or potential sources of pollution.

All municipalities and industries must secure a permit from the Commission prior to the construction or operation of a waste treatment system. An annual fee of \$25.00 is required for such a permit.

The law spells out the procedures to be followed prior to establishment of new regulations or water quality standards. Public hearings are required so that all viewpoints may be expressed.

Water quality standards, have been established for all streams in the state. These vary depending on the type of stream and its use.

Included as measures of water quality are pH, dissolved oxygen, temperature, toxic substances, bacteria, taste and odor producing substances, turbidity, color, oil and grease, solids of any kind, radioactive materials, and fluorides. Tolerance for each has been established.

Anyone causing the water quality in a stream to deviate from established standards is subject to enforcement. A copy of the standards adopted by the board for each stream may be obtained upon request to the Commission.

PART II.

Basic Concepts

Effluent from a municipal waste treatment plant can be returned to the land on which a crop is grown and thus reduce the amount of potential pollutants entering a stream. If the distribution system is well designed and well managed, wastes introduced into either surface or sub-surface water would not have an adverse effect on water quality. Land on which effluent is applied in a controlled manner and from which crops are removed has been designated a soil-plant filter.

Overland flow systems are designed specifically for treatment by passing the effluent through a soil-plant-filter with subsequent runoff. These systems must produce a discharge quality amenable to the particular receiving waters. This system should be considered only on impervious soils, such as heavy clay soils. It appears to be best suited to northern Missouri.

Designing and managing a soil-plant-filter to effectively remove nutrients from effluent is the key to these systems. Crops are to be grown that are suitable for removing the quantities of nutrients applied through the disposal systems. The crops will then be removed for livestock feed or other uses.

An important distinction needs to be made between *effluent irrigation disposal* systems and conventional *agricultural irrigation*. Effluent irrigation disposal is the disposal of the maximum amount of effluent which can be renovated by the soil-plant-filter without detrimental effects to surface or ground waters, soils, or crops. Agricultural irrigation is the application of water or effluent for maximum economic return from the cropping system.

A system using effluent for agricultural irrigation will require more storage volume, will be applied to greater acreage, and will usually be operated only in the summer months. Agricultural irrigation with effluent would probably be applied with more portable irrigation systems, usually by a farmer-owner. For effluent irrigation disposal systems, larger volumes will be applied to less land with more permanent systems, over a larger portion of the year. Land and equipment will usually be owned and managed by municipalities.

PRELIMINARY CONSIDERATIONS

Land disposal installations are normally used where the waste contains pollutants which can be removed successfully through organic decomposition and the adsorptive, physical, and chemical reactions in the soil and vegetation. Preliminary considerations of a site for ground disposal should be the compatibility of the waste with the organic and earth materials and the percolation rates and exchange capacity of the soils. The ground disposal of waste water will eventually recharge the groundwater or reemerge into streams; therefore, the quality, direction and rate of movement, and use of the groundwater are prime considerations in evaluating a proposed site.

Good surface drainage is essential to provide good vegetative growth conditions for removal of nutrients. The major factors in design of ground disposal fields are topography, soils, vegetation, geology, hydrology, weather, agricultural practice, adjacent land use, and equipment selection and installation.

DESIGN REPORT

A design report shall be submitted to the Missouri Clean Water Commission by the design engineer. It shall include any pertinent information about the location, geology, topography, hydrology, soils, areas for future expansion and adjacent land use. For details, refer to Addendum No. 2, A Guide for Design of Sewage Works, available from the Missouri Clean Water Commission, P. O. Box 154, Jefferson City, Mo. 65101 (48). A construction permit and, later, an operating permit required by the Board, will then be issued if the design report is approved.

PART III.

Design Guidelines

A. SYSTEM OBJECTIVES

Two approaches with differing objectives regarding water are considered: (1) Irrigation to dispose of effluent and (2) irrigation to increase agricultural production, using sewage effluent.

- (1) Effluent irrigation disposal is the disposal of the maximum amount of effluent which can be renovated by the soil-plant-filter without detrimental effects to the surface or ground water and to the soils or crops. The ability of the soil and underlying geological formations to accept, renovate, and transmit water may determine the amount of effluent that can be applied. However, in many cases, the amount of application will be determined by the capability of the crop to remove potential pollutant materials. Near maximum crop production is essential for maximum evapotranspiration and nutrient removal.
- (2) Agricultural irrigation - the application of water or effluent for maximum return from the cropping program.

The amounts of water to be added under this approach are greatly influenced by rainfall patterns. The probability of agricultural irrigation demand has been estimated by Hashemi and Decker (27) and by Woodruff (104). Average annual amounts of irrigation demand are of the magnitude of 6 inches for soils with available water storage capacity of 6 inches in the rooting zone, but amounts will vary between 1 and 10 inches because of weather. Low available water storage capacities (3 inches within the rooting zone) would require 3 more inches by irrigation water.

Most of the water is needed during June, July, August and September by growing plants. These calculations of the need for supplemental irrigation assume the system is managed in such a way that essentially no effluent passes through the root zone.

B. EVALUATION OF EFFLUENT TO BE APPLIED

Representative samples are essential to properly evaluate the effluent. Where the discharge is from a sewage treatment plant, 24 hour samples proportioned to the rate of flow will be needed to obtain a representative sample. In cases where the effluent is stored for several days or longer, a single sample of the effluent will suffice.

Analyses which will be of major importance will be for *total suspended solid (TSS), a volatile suspended solid (VSS), sodium, calcium, magnesium, electrical conductivity (EC), nitrogen, phosphorous, metal ions and fluoride*. The *sodium absorption ratio (SAR)* should be calculated from sodium, calcium, and magnesium determination. Appendix A indicates representative analyses of municipal sewage effluent in Missouri. Phenols, cyanide, sulfite and organic nitrogen may be important, depending on the degree of industrialization found in the sewage district. Refer to Tables B-1 and B-2 in Appendix B for more information on industrial effluents (8). A high TSS could lead to soil clogging if VSS is low, indicative of a biodegradable resistant material. If VSS approaches TSS, then, little soil clogging should be expected, provided

the rate of application is restricted to allow for the bio-degradable waste to be consumed. SAR values and EC readings are guides to soil characteristics and vegetative growth.

Use nitrogen and phosphorous analyses to evaluate vegetative nutrient needs and the removal efficiency of the plants when they are harvested. The other analyses mentioned are of concern because of potential toxicity of the substances to plants and animals.

An effective sewer use ordinance may be needed to prevent the discharge of industrial wastes that are not amenable to renovation by secondary treatment and disposal on a soil-plant-filter.

It is anticipated that all effluents arising from human sources will be disinfected before being applied by irrigation. Where chlorine is used as the disinfectant a chlorine demand test should be made at least once a month. Chlorine demand test values on stored effluent should be less than for direct discharge of secondary effluent. To maximize the bactericidal action, rate of chlorination versus contact time must be determined for each system designed. Ozonization and ultraviolet disinfection have the advantage of leaving no unwanted end products and should be considered for effluent irrigation systems.

Table C-1 (Appendix C) lists the recommended analyses to be performed on effluent as guides in planning the effluent irrigation system.

Quantitative tests should be performed individually when the concentration from the spectrographic qualitative trace appears to exceed the value given in Table C-2.

C. EVALUATION OF POTENTIAL DISPOSAL SITES

The following factors should be considered when evaluating potential effluent disposal sites: location, geology, hydrology, topography, soils, areas for further expansion and adjacent land use. Sound field evaluation depends on qualified, experienced people in each of these areas.

Location: The optimum location for effluent disposal is close enough to the effluent source to minimize pumping costs, pipe costs, and distance to travel for supervision, and yet be located in an agricultural area that is relatively sparsely populated, and likely to remain as such for a reasonable time.

Geology: Effluent disposal sites should be located in stable geological formations that are not subject to collapse or to immediate inducement of effluent to ground water caverns or aquifers. Where geologic conditions may permit rapid movement of the effluent or renovated water into ground water aquifers, additional design considerations are needed to protect these aquifers.

Hydrology: The hydrologic capabilities of a site must be considered in conjunction with the site's renovative ability. While surface soils may have high infiltration capacities the amount one can apply will be affected extensively by underlying soil properties. Subsurface formations must have the capacity to transmit the water and renovated effluent that has moved through the root zone. When vertical movement through the soil profile is restricted by soil layers with low permeabilities, tile drainage or lateral movement through the soil may permit continued applications.

Rainfall patterns, including intensities and probabilities, will influence performance of the effluent disposal system and must be considered.

Topography: Site topography must be adaptable to the agricultural operations to be performed, the erosion control measures installed, and the satisfactory operation of the effluent disposal system. Application rates must be compatible with crop cover, the available slopes, soil texture, and infiltration characteristics. Topography limitations for surface irrigation generally are more severe since excessive leveling may be required. Leveling is costly, and it may expose undesirable soils. Land so steep it can't be irrigated without severe erosion should not be irrigated.

Soils: Application rates and amounts selected must fit the soils on the disposal area. Clay soils have high exchange capacities and excellent renovative capabilities. However, application rates may be restricted by their low permeabilities. Sandy soils have high infiltration rates and low exchange capacities; thus lower application rates may be needed for these soils to allow more effective renovation. Soil maps may be helpful in selecting sites for more detailed evaluations.

Areas for Future Expansion: Additional area near the disposal site is desirable for future expansion. This generally reduces cost.

Adjacent Land Use: Although well designed and operated effluent disposal sites are generally relatively trouble-free, it is advantageous to locate the disposal area in a sparsely populated area, such as that used for agriculture. Areas where housing or other building development is anticipated should be avoided.

D. MONITORING OF RENOVATED WATER

Prior to the start of any effluent irrigation project, it is recommended that all water wells in the area be sampled for contamination indicators. This would protect the owner of the irrigation system if an already contaminated well was later shown to be contaminated. These wells may later be used for monitoring.

Monitoring of renovated water is essential in all cases. The frequency may vary however, and will be less for agricultural irrigation than for effluent irrigation disposal systems. Monitoring may be accomplished by sampling below the plant root zone or near the surface of the aquifer being recharged. This may be done by sampling the drainage water, vacuum lysimeter or wells.

Vacuum lysimeters, developed at the Pennsylvania State University, (See Appendix D) or commercially available soil water samplers, allow sampling of the soil water in locations such as the root zone. Such samples are generally representative of the renovated water quality. Vacuum lysimeters will break suction below 15 to 20 feet and, thus, are limited to depths shallower than 20 feet. For greater depths, a small submersible pump, operated by a portable generator or regular electric service can be useful. Pumps are available that will fit inside a 3 inch diameter casing.

Deep monitoring wells may also be required. The location, depth, and construction must be in accordance with the requirements of the Missouri Geological Survey and Missouri Clean Water Commission. Renovated water analysis will be specified by the Clean Water Commission for the particular effluent being applied.

At present, there are no state or federal standards for the quality of water entering the groundwater from effluent disposal systems. In the absence of these standards, groundwater quality objectives have been developed. See Appendix E. If groundwater recharge standards are developed, effluent irrigation disposal systems will have to comply accordingly.

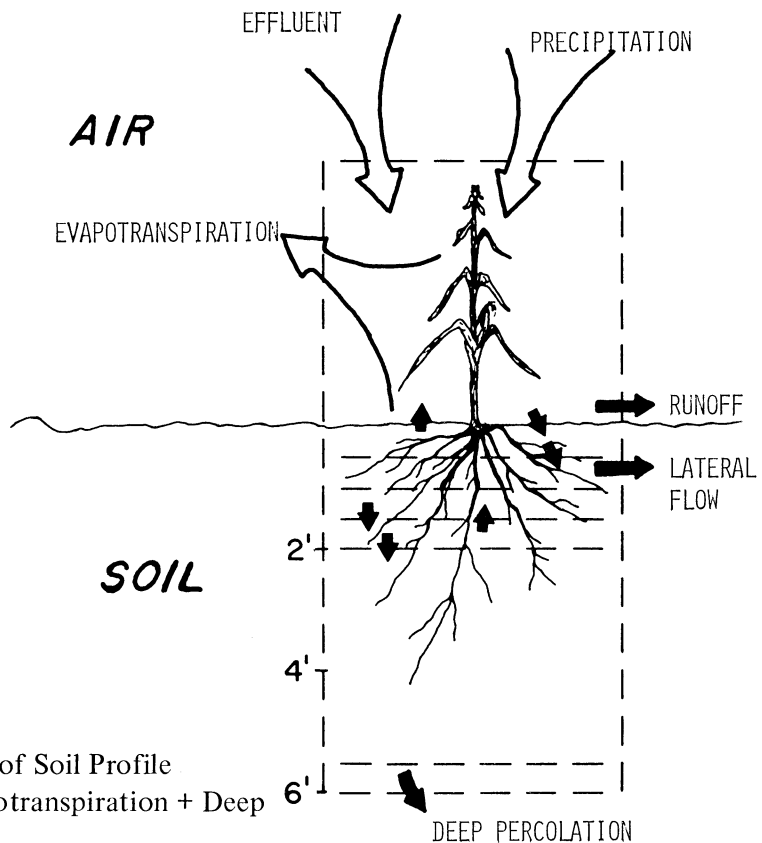
Surface water leaving the site of overland flow systems should be monitored at regular intervals. This monitoring should be done as directed by the Clean Water Commission. Any surface water leaving the disposal area will be subject to applicable effluent and water quality standards. These analyses will include total N, NH₃-N, B.O.D., C.O.D., Fecal Coliform, Total and Ortho phosphorous, pH, and electrical conductivity.

E. EFFLUENT DISPOSAL IN RELATION TO SOIL CHARACTERISTICS

1. Water Balance

A determination of annual effluent disposal quantities is vastly complicated by the variable rainfall patterns in Missouri. On impermeable soils, where seepage through the soil profile is negligible, no effluent could be applied during the wettest years without causing runoff. This is complicated by the increase in effluent quantities during wet years due to infiltration into city sewer lines in rainy periods, increased rainfall on lagoons, and the reduced evapotranspiration due to cool and cloudy weather. These factors are offset, to some degree, by the greatly increased dilution of runoff in water courses, and by the cool and cloudy weather.

The following equation may be a guide in determining effluent application amounts. It may be used on a mean annual basis, the wettest year in 10 basis, or a monthly basis.



$$\begin{aligned} \text{Water Into Soil Profile} &= \text{Water Out of Soil Profile} \\ \text{Rainfall} + \text{Effluent} - \text{Runoff} &= \text{Evapotranspiration} + \text{Deep} \\ \text{Percolation} + \text{Lateral Flow} & \end{aligned}$$

The irrigation requirements for a grass meadow may be calculated from the precipitation and evaporation records. Using a strategy for irrigation which allows a daily application for replenishing the soil water to field capacity, the demand for irrigation has been computed for the summer months of May through August, based on lysimeter studies of actual moisture use (17). Actual evapotranspiration was found to closely approximate .75 of the measured pan evaporation. For the four-month period May 1-August 31, the likelihood of disposing of varying amounts of water are as indicated in Table 1.

TABLE 1. PROBABILITY OF DISPOSING OF GIVEN AMOUNTS OF WATER BY IRRIGATING A MEADOW, May 1 - August 31

Probability	Irrigation Deficit, Inches		
	Northwest Missouri	Central Missouri	Southeast Missouri
1 year out of 20	24.6	20	18.2
4 years out of 20	22.2	18	16.4
10 years out of 20	21.4	16	14.6
15 years out of 20	17.2	14	12.7
19 years out of 20	14.8	12	10.9

These irrigation deficits were calculated on a continuous irrigation basis, applying water daily to bring the soil moisture content up to field capacity and allowing no time for drying periods or harvest. Light, daily applications are possible with solid set systems. Mechanically moved systems, such as center pivot sprinkler systems, are unable to travel on some soils when they are totally saturated. Thus, the soil must be allowed to dry (and drain) some before operation. Annual irrigation deficits were also calculated for management schemes in which the soil was allowed to dry until it had capacity for .5 inch, 1.2 inches, and 1.7 inches of additional water. For these management schemes, multiply the total irrigation deficit by .82, .65, and .55, respectively, to obtain the amount of water that can be disposed of.

The irrigation deficits shown in Table 1 were calculated on a continuous wetting basis. Alternate wetting and drying cycles are necessary for crop harvest and to maintain good conditions for crop growth and nutrient removal. Multiply the irrigation deficit by an appropriate fraction to account for these drying periods. For example, if the grass is harvested every 40 days, and the last 12 days are allowed for drying and harvest, multiply the irrigation deficit by 28/40, or 0.7.

Until more refined data is available, the data for northwest, central, and southeast Missouri represent three climatic zones approximated by two diagonal (northeast-southwest) lines that divide the state into thirds. Interpolate as needed.

The greatest amount of water may be applied in July and August. In the following table the amounts used by the meadow for each of the summer months are shown.

The seasonal moisture demands in other areas of the state are similar.

TABLE 2. MONTHLY IRRIGATION DEFICITS IN CENTRAL MISSOURI

	<u>Water required on indicated frequency of years</u>			
	<u>May</u>	<u>June</u>	<u>July</u>	<u>August</u>
Three out of Four Years	2.4 in.	3.0 in.	3.7 in.	3.4 in.
Two out of Four Years	3.0	3.9	4.6	4.0
One out of Four Years	3.4	4.4	5.5	5.0

The irrigation deficit values in Tables 1 and 2 were based on the assumption that there will be no lateral flow or deep percolation. (This approximates claypan or fragipan soil conditions.) Thus, the total amount of effluent that can be applied may be estimated:

Total amount of effluent = irrigation deficit + deep percolation + lateral flow.

As lateral flow will generally be small unless a tile system is installed, the total annual application equals the irrigation deficit (multiplied by the appropriate factors), plus the planned deep percolation amount. Select a planned deep percolation amount that can be passed through the soil under consideration (see the section on infiltration rates), and will meet the groundwater quality objectives (Appendix K).

2. Infiltration Rates

Sound system design depends on knowledge of the rate at which water enters and moves through the soil. The infiltration characteristics of most soils may be described by an initially high infiltration rate that decreases as effluent continues to be applied. After some time the infiltration rate of the soil appears to approach a constant value. This constant value is referred to as the basic intake rate, or the permeability of the soil.

Fine-textured soils hold more moisture than coarse soils. These fine-textured soils take up water much less readily, however, except initially, when the intake rate may be high, especially if the surface is cracked or crumbly. Applying water at a rate faster than the soil can take it often results in soil compaction and puddling, erosion, and runoff. This reduces the intake rate of the soil for the next irrigation. These problems are less troublesome in Missouri than in the arid west because there is usually a crop cover during irrigation season. However, selection and design of the distribution system is very important.

Some irrigation systems, such as center pivot sprinkler systems, are designed and managed to apply water at a rate exceeding the *basic* intake rate of the soil. They normally apply 1 inch of water or less, and thus operate near the high *initial* intake rate of the intake rates of the soil. Solid set systems are often designed on the basis of *basic intake rates* of the soil under consideration. Surface irrigation systems have the advantage that the flow-rate can easily be adjusted for soils with low intake rates. The careful evaluation of soils, cropping practices, topography, and intended management is crucial to proper system selection and design. In all cases, the design application rate should not exceed the intake rate of the soil. Reduce design application rates for sloping land. See Appendix E, Table E-1. These designs are based on a field investigation, recommendations of agencies involved, the sprinkler system manufacturer, and the designer's experience on similar soils. The following information may be used to supplement the field investigation.

Ranges of permeabilities for different kinds of soil are explained in two references. They are the U.S.D.A. Soil Conservation Service hydrologic soil grouping (54) and the University of Missouri Extension Circular 823, "Soils of Missouri" (75). The hydrologic grouping is based upon data reported by Musgrave (50). Soils listed in Circular 823 can be related to the hydrologic groupings through descriptive permeability classes that are assigned to each soil series. Figure 1 and Table 3 give estimated permeabilities and show the relationship to hydrologic groups.

Figure 1 shows six kinds of soil profiles based on total volume. The air porosity is that amount of the soil volume that is filled with air when the soil water content is at field capacity, and is therefore related to soil permeability under wet conditions (76).

The permeabilities listed for these profiles would be expected for normal summer temperatures and a grass cover to help insure initial entry of the water into the soil. A soil description such as found in soil survey reports will be useful in determining the design

TABLE 3. ESTIMATED PERMEABILITIES FOR SOIL PERMEABILITY CLASSES*

Permeability Class Name	Permeability inches/Hr.	Hydrologic Group Symbol**
Very slow	Less than .05	D
Slow	.05 - .15	C
Moderate	.15 - .30	B
Rapid	.30 and greater	A

*Soils of Missouri, Circular 823 (75)

**Musgrave, SCS (46,54)

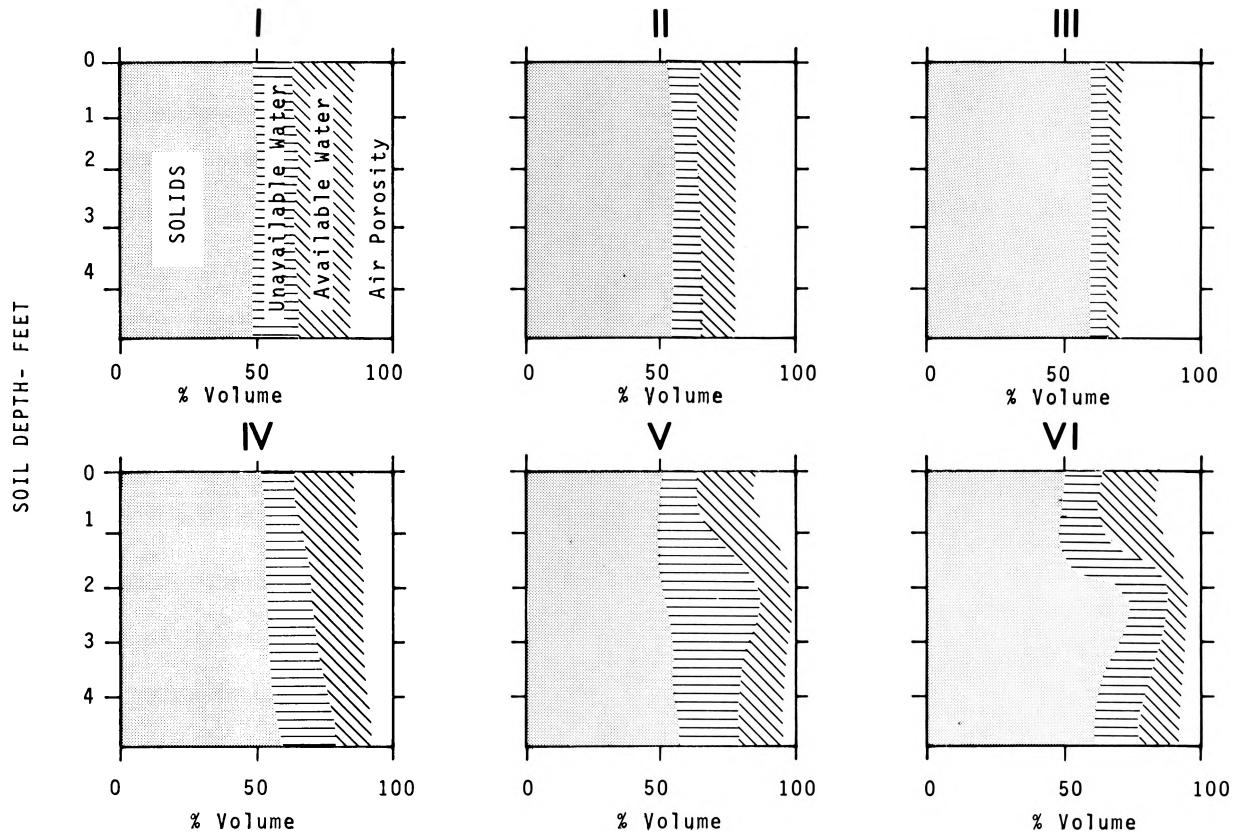


FIGURE 1. Soil Volume Profiles and Summer Intake Rates

- I. Well aggregated silty soils and limestone-derived soils without pans. Permeability, values scattered but average about 0.5 inches per hour.
- II. Soils with large amounts of coarse fragments or sand and some silt or clay in aggregates. Permeability, 0.8 inches per hour.
- III. Well sorted (uniform grain sized) coarse sandy soils. Permeability, approximately 5.0 inches per hour.
- IV. A soil having a developed profile with a normal expected depth increase in density. (No pans)
- V. A soil with a claypan layer. The moist claypan restricts profile permeability to less than .03 inches per hour.
- VI. A soil with a fragipan layer. The fragipan layer restricts profile permeability to less than .05 inches per hour.

application rate for a particular soil.

“Evaluating Missouri Soils,” University of Missouri Extension Circular 915, (74) is helpful when making the on-site inspection needed for a sound site evaluation.

If a system is to be operated primarily for effluent irrigation, operations will cover more months than needed for agricultural irrigations and therefore additional factors must be

considered. Permeability, for example, is related to viscosity of water and reductions of 1/3 to 1/2 of the conductivity were observed as being associated with 15 degree decreases in temperature. Daily application rates, therefore, must be reduced to account for cooler temperatures.

It has also been shown that infiltration and permeability rates for some effluents are somewhat lower than those for other surface waters. Vanderholm and Beer (94) estimate as much as a 50 percent reduction in infiltration rates from using animal waste effluents for irrigation compared to clear water.

Clogging is not expected to occur from applying secondary waste water to soil at two inches per week. However, a discussion of the consequences is included to give understanding of treatment capacity of soils. Although clogging can result from biochemical reactions, loading of inorganic and organic materials (both particulate and dissolved), or excessive hydraulic loading and geometry of the soil surface and profile, the most significant cause is the activity of microorganisms. The conversion of dissolved organic matter into biological sludge plus the failure of microorganisms to decompose filtered organic particulate matter can similarly clog soils and, thus, greatly restrict infiltration rate.

Clogging usually occurs in the top few inches of soil and is more a function of the organic mat than the coarseness of the soil. The perpetuation of anaerobic conditions in the soil surface layer will lead to clogging. Anaerobic conditions result in a slowed rate of biological activity and, thus, a tendency for sludge accumulation, production of ferrous sulfide and/or accumulation of polysaccharides. The anaerobic conditions could be brought about by either too high a BOD or hydraulic loading, but usually it is hydraulic overloading which leads to inability of the soil to accept the water application rate and ponding results. Alternate drying and wetting periods allow for drying out and re-establishment of aerobic conditions in the soil. If ponding persists clogging problems will increase.

Tiling of some soils might be necessary to maintain permeability. This technique would intercept the renovated water and prevent its joining the groundwater. Water draining from the tiles should be monitored for quality.

3. Renovative Capabilities

Soil-plant filters have been very effective in reducing viruses, pathogenic bacteria, BOD, and organic loads, as well as many chemical constituents (77). The renovative ability of soils is related to their exchange capacity, texture, and structure. Sandy soils have lower renovative capabilities, due to their low exchange capacity and the rapid movement of the effluent through the profile.

The first point that must be made when discussing land disposal in terms of public health is to state, repeat, and underscore the role of pretreatment in the system. No designer of land treatment facilities proposes the application to the soil of fluid wastes that contain disease bearing organisms or debilitating substances that are not destroyed by pretreatment, or will not be removed by land treatment.

The major source of pathogenic organisms in waste water is the sanitary wastes of man. All modern land disposal facilities properly designed to handle sanitary wastes employ primary, secondary, and chlorination treatment prior to application. This insures that nearly all solid and suspended material is removed, that a great deal of the dissolved organic material has been consumed, and that chlorination has disinfected the waste water to comply with state and/or local public health standards.

All this treatment is accomplished before the waste water is applied to the ground. The levels of pathogenic organisms in this waste water are not only extremely negligible but are at the same level as effluent currently dumped into the local watercourse which is likely to be the downstream community's source of drinking water.

Most pathogenic bacteria are already destroyed by secondary pretreatment and disinfection before wastes are applied to the land, but tests conducted on effluent after land disposal indicate a nearly complete removal of these organisms (88). The distances required to produce this purification vary depending upon the nature of the waste water and the character of the soil.

The removal of BOD and suspended solids in spray irrigation may be expected to be very effective, approaching 99 percent. This is primarily due to the high filtering effectiveness of the soil mantle and maintenance of aerobic conditions by alternating wet and dry periods.

The efficiencies of BOD, nitrogen and phosphorus removals in Table 4, (20) are based on values obtained in the last 15-20 years in comparable experimental systems under a variety of environmental conditions. They are confirmed by other studies. Efficiency of nitrogen removal may be increased and maintained for many years by additions of organic carbon. A high carbon-nitrogen ratio will accumulate nitrogen in the soil, reducing leaching. Increased organic matter will also maintain or improve soil structure, increase the potential for plant uptake and aid aeration and water flow processes.

TABLE 4. ESTIMATED EFFECTIVENESS OF LAND DISPOSAL SYSTEMS

	<u>Spray Irrigation</u>
BOD	99
SS	99+
N	80-90
P	99
Heavy Metals	99
Organic Comp.	99
Viruses	99+
Bacteria	99
Total Dissolved Solids	
Cations	0-75
Anions	0-50
<u>Spray Irrigation Condition</u>	
Soil:	Silt loam 5' deep C/N 15
Climate:	Great Lakes 2" in 8 hours once a week
Continuous Vegetation	

These values were determined for the soils and conditions specified. For soils of less depth and different texture on Carbon/Nitrogen ratio, adjust these figures accordingly to fit the conditions of the individual site. This also assumes the soil's ability to remove certain partially mobile elements has not been saturated.

The important point to note is that no other form of advanced waste water treatment appears to be so effective in removing such a wide range of pollutants. When effluent disposal on the land is compared to more conventional methods of tertiary treatment, it becomes apparent that the comparison must be made between one general, highly effective method and a battery of specific removal processes.

The effluent disposal work conducted at Pennsylvania State University is a documented example of the renovative capabilities of spray disposal (59). This system was installed on a soil texture ranging from a silt loam to silty clay loam with slopes averaging about 4 percent. Secondary effluent (see Table 5) was applied at rates of 0, 1, and 2 inches per week.

TABLE 5. EFFLUENT COMPOSITION*

Substance	Concentration, mg/l
BOD	7.2
pH	7.2
Alkalinity	113.0
Chloride	36.0
Nitrate as N	2.2
Apparent ABS	2.4
Orthophosphate as P	7.7
Potassium	14.1
Calcium	32.6
Magnesium	18.7
Sodium	47.0

*Pennsylvania State University Waste Water Renovation Project (59)

The concentration of nitrate nitrogen was reduced by 68 to 82 percent, and phosphorus by 99 percent. Other constituents were also decreased appreciably. Deep wells in these areas indicated ABS concentrations less than 0.08 ppm, phosphorus less than 0.33 ppm, nitrate less than 0.7 ppm, and chloride less than 5.93 ppm. These figures (the highest measured), indicate that a very significant amount of biological and chemical treatment takes place before wastewaters reach the groundwater.

Cropland was evaluated as a treatment system by nutrient removal efficiency. This is the ratio of the weight of nutrient removed in harvested crop to the weight of the same nutrient applied in the wastewater. Nutrient removal efficiencies for alfalfa hay and corn silage for 1965 are presented in Table 6.

TABLE 6. NUTRIENT REMOVAL EFFICIENCY FOR TWO RATES OF WEEKLY APPLICATION

Nutrient	Alfalfa Hay		Corn Silage	
	1 in.	2 in.	1 in.	2 in.
Nitrogen	*	-	102%	103%
Phosphorus	64%	39%	39%	22%
Potassium	189%	119%	62%	40%

*Not calculated because legumes utilize a variable quantity of nitrogen from the atmosphere.

The Pennsylvania State studies indicate that in 1965 three cuttings of reed canarygrass removed 6.13 tons of dry matter, at a mean concentration of 2.93 percent. This amounts to 359 pounds of nitrogen. In addition to nutrients removed by crops, most soils fix large amounts of phosphorus.

Note: In addition to the nutrient removal abilities of crops, yields are usually increased (1, 13) by irrigation with effluent unless the quality of the wastewater is not suitable for the crops being raised (14).

The amount of an element entering the groundwater may be estimated, assuming steady state conditions. Elements can generally be classed as mobile, partially mobile, or immobile in soil systems (3). Table 7 indicates the mobility of various elements.

TABLE 7. PERCOLATION CHARACTERISTICS OF VARIOUS CONSTITUENTS (3)

Group 1. Nitrate, Chloride, Sodium, and Sulfate are considered to be mobile. The approximate amounts reaching groundwater may be calculated as follows:

Amount in groundwater = amount added - crop removal.

Note: These nutrients are subject to leaching into the groundwater even though the amount of rainfall plus effluent applied is less than the potential evapotranspiration.

Group 2. Calcium, Magnesium, Potassium, and Boron are partially mobile. The fraction reaching groundwater would be expected to become greater with continued application of these elements. For Calcium and Magnesium this time period would be shorter than for Potassium and Boron. After considerable time, when the soils capacity to fix that element is saturated, the amount reaching groundwater may be estimated using the same consideration as used for Group 1. Soil tests may be used to determine the constituent concentration with depth, and to follow these concentration changes with time.

Group 3. Aluminum, Arsenic, Chromium, Copper, Iron, Lead, Manganese, Molybdenum, Phosphorus, and Zinc form insoluble compounds in soil and are relatively immobile. However, many of these constituents become mobile as organic chelates under anaerobic or strongly reducing conditions. Unless extremely large amounts are added to soil it is the opinion of many researchers that the level of these substances in groundwater would not be increased.

Consequently, care should be taken to see that when elements in Group 1 and 2 are applied to a soil-plant-filter, the rates of application do not greatly exceed the amounts taken off through the cropping system or absorbed by the soil.

Each site should be evaluated individually to determine its renovative capabilities.

The soil mantle of proposed infiltration disposal sites should have the following conditions:

(1) an infiltration capacity sufficiently high to minimize ponding and runoff during the period of disposal, and yet retain water long enough to allow interaction with plants and microbes, (2) a high capacity to fix and store effluent constituents for use by microbes and plants, (3) permeability sufficient to allow vertical drainage of renovated effluent and maintain aerobic conditions, and (4) a mantle covering all bedrock thick enough to insure sufficient renovation of the water before it recharges the groundwater.

A general classification scheme for evaluating soils for the renovation of effluent is given below:

- a. *Soils with a high capacity to accept sewage effluent—*
 1. *Natural drainage – good.*
 2. *Texture – sandy loams, loams, silt loams, and well structured clay loams, silty clay loams, and clays.*
 3. *Permeability – moderate to high surface infiltration (0.6 to 2.0 in/hr); subsurface horizons at least moderately permeable (greater than 0.15 in/hr).*
 4. *Topography – nearly level to gently rolling.*
 5. *System management considerations—*
 - a. *Sprinkler or surface disposal systems.*
 - b. *Applied to agronomic crops during the growing season and to forest or pasture when appropriate.*
 - c. *Effluent storage needed only during peak precipitation periods.*
- b. *Soils with a moderate capacity to accept sewage effluent –*
 1. *Natural drainage – good.*
 2. *Texture – some very fine sands and sands if sufficiently deep; poorly structured fine textured soils using overland flow.*
 3. *Permeability – low to moderate surface infiltration with moderate internal permeability; some soils with impermeable layers.*
 4. *Topography – nearly level, gently rolling, or moderate slopes.*
 5. *System management considerations—*
 - a. *Sprinkler or surface effluent disposal systems.*
 - b. *Soils cropped where possible, greater use of pastures on steeper slopes.*
 - c. *Overland flow may be appropriate where soils are nearly level with low infiltration and permeability rates.*
 - d. *Some soils with impermeable layers correctable with tile drainage.*
 - e. *Sandy soils must have sufficient depth for adequate interaction with effluent.*
- c. *Soils with low capacity to accept sewage effluent—*
 1. *Natural drainage – poor.*
 2. *Texture and permeability – moderate infiltration and permeability to depth of impermeable layers; lateral permeability adequate to prevent anaerobic conditions from perched water tables.*
 3. *Topography – gently rolling to moderate slopes.*
 4. *System management considerations –*
 - a. *Disposal area includes areas receiving water from lateral flow; sprinkler irrigation on ridge tops or at proper intervals on long slopes.*
 - b. *Perched or shallow water tables effectively lowered with drainage wells.*
 - c. *Steeper slopes primarily pasture and forest vegetation; occasional row crop on gentle slopes; crop variety tolerant of wetter soils.*
- d. *Soils requiring special design considerations, if used for sewage effluent disposal:*
 1. *Drainage, texture, and permeability:*
 - a. *Poorly drained soils not correctable with tile drainage.*
 - b. *Fine textured soils with low infiltration and permeability not suitable for overland flow.*
 - c. *Most coarse textured soils with infiltration rates greater than 2.0 inches/hour.*

2. *Topography—*
 - a. *Upland soils with high water tables or perched water tables not correctable with tiling or drainage wells.*
 - b. *Bottomland or flood plain soils subject to frequent flooding and high water tables.*
 - c. *Permeable soils with a shallow layer over bedrock.*
 - d. *Soils with frequent sinkholes or where water enters directly into the ground water.*
 - e. *Soils too steep and infiltration too slow where runoff is commonly expected.*

F. EFFLUENT DISPOSAL IN RELATION TO PLANT CHARACTERISTICS

1. *Crops Most Adaptable to Effluent Disposal*

Row crops grown for cash income or livestock feed generally do not adapt to effluent disposal as well as forages, especially certain grasses. Crops such as corn, soybeans, and grain sorghum require relatively dry conditions in the spring to prepare the land and do the planting. These crops do not create a full canopy until June or July, thus providing less protection for the soil from puddling and crusting. In addition to having lower evapotranspiration rates in June and early July than forages, yields of these crops are reduced by excessively wet conditions.

The use of reed canarygrass for effluent disposal is elaborated on due to its adaptability to soil-plant-filter effluent disposal systems. Reed canarygrass is not a popular grass in Missouri because its use has not been promoted. Due to its ability to remove large amounts of the major elements under proper management, it is suggested that this forage grass be given strong consideration. Recommendations on other grasses will be given as their nutrient removal capacities are evaluated.

Reed canarygrass is a tall, cool season perennial with a rhizomatous root system. It will grow in a very wet, marshy area and reportedly has withstood flooding for as long as 49 days without permanent injury. It is unexcelled for wet areas and adapts well to effluent disposal.

In pure stands, reed canarygrass will respond to extremely high rates of nitrogen. This grass has a very high production potential under high nutrient and moisture conditions. It will probably make more summer growth under these conditions than any other cool season grass in Missouri.

Reed canarygrass is one of the earliest grasses to begin spring growth. It can be made into hay or chopped for silage, but must be harvested before it becomes coarse and stemmy. If the crop is harvested without grazing, the first growth should be mowed when the first heads begin to appear. Reed canarygrass is also excellent for establishing a dense sod to control erosion in critical areas.

Reed canarygrass may be established in the same manner as other cool season grasses. When seed is 80 percent or better in germination, a seeding rate of five to eight pounds per acre is adequate. Many times seed is extremely low in germination and low in vitality. This is the greatest cause of seeding failures. It may be fall-seeded during August or seeded very early in the spring.

For more information, see UMC Guide 4649, "Reed Canarygrass, Ryegrass, and Garrison Creeping Foxtail," (97) UMC Guide 4650 "Establishing Forages," (96) or call your area agronomy extension specialist.

Another grass which may be used as a supplement to reed canarygrass is tall fescue. This grass, however, does not adapt to wet conditions or high fertility rates as well as reed canarygrass. See UMC Guide 4646, "Tall Fescue" (98) for more information.

2. Nutrient Removal Capabilities of Various Crops

Table 8 gives average amounts of nutrients removed through cropping: (66, 104).

TABLE 8. PLANT FOOD CONTENT OF CROPS

Crop	Yield	Part of Crop	N lb.	P ₂ O ₅ lb.	K ₂ O lb.	Ca lb.
Corn	80 bu.	Grain	64	29	16	1
	1120 lbs.	Cobs	4	1	11	1
	2.5 T.	Stalks	47	10	89	27
		TOTAL	115	40	116	29
Cotton	1500 lbs.	Lint & Seed	40	20	15	2
	1500 lbs.	Other	26	7	26	28
		TOTAL	66	27	41	30
Milo	70 bu.	Grain	61	23	15	1
	2 T.	Stalks	20	10	62	23
		TOTAL	81	33	77	24
*Soybeans	30 bu.	Beans	109	22	32	5
	1.5 T.	Stalks	19	3	19	50
		TOTAL	128	25	51	55
*Alfalfa	4 T.	All	196	44	189	118
*Clover, Red	2 T.	All	77	18	79	51
*Clover, Sweet	3 T.	All	158	36	113	82
*Lespedeza	2 T.	All	92	18	51	41
*Soybeans	2 T.	All	94	20	52	44
Bluegrass	2 T.	All	52	25	80	16
Orchard Grass	2.5 T.	All	65	21	115	14
Red Top	2 T.	All	46	18	82	16
Timothy	2.5 T.	All	53	16	95	18
**Reed Canarygrass	6.1 T.	All	359	82	360	
***Fescue	5 T.	All	275	60	325	

*Legume crop. Approximately 70% of the N in inoculated legumes is fixed from the air. Data in these tables obtained from Morrison, N.P.F.I., and other sources.

**Reed Canarygrass normally will remove 40-45 lbs. of nitrogen per ton of dry matter from healthy, mature plants, and 60 lb. of nitrogen per ton when harvested in the black-green, fast growth stage. Paris, Texas and Ames, Iowa report nitrogen cropping removals of 361 and 400 lb. per season respectively. Reed canarygrass normally will remove 40 lb. of K₂O per ton of dry matter, but will remove up to 80 lb./ton if that much is available. Phosphorus removal is normally between 12 and 15 lb./ton of dry matter.

***Fescue will remove 45-75 lbs. of nitrogen per ton of dry matter, with the highest amount when the crop is harvested shortly after heading, while the stems are still green. Potash removal will normally average 65 lbs. per ton, but may increase to 80-120 lbs./ton if that much is available.

3. Crop Toxicities

Crop toxicities are most likely to occur when large quantities of effluent are being disposed of on the soil-plant-filter. Each situation is unique and must be evaluated accordingly, for the following reasons:

- a. Both the composition and volume of effluent will probably vary with time.
- b. The irrigated field area may be uniform or variable with respect to soil properties. In either event, the net effect of the effluent upon plant growth will be determined in large measure by the reaction of effluent components with the soil constituents at a specific site.
- c. Plant species (and in some cases varieties within species) vary in their nutrient requirements, tolerances to toxic conditions, and reaction to environmental conditions.

The three major areas of concern: (1) the effluent, (2) the soil, and (3) the plants interact. Therefore, the best decision might differ between two nearby situations. In any event each source of effluent must be considered separately in reference to its potential use.

Certain elements may be toxic to plants under certain conditions. Chemical toxicity levels are found in Appendix F.

4. Salinity and Alkalinity

Soluble salts, which occur normally in all soils, provide many of the nutrient elements essential for plant growth. An excess of soluble salt can delay or reduce seed germination, decrease vegetative growth, produce leaf symptoms of injury, or cause plants to die.

Adequate drainage of the soil is essential so that excess soluble salts can be removed by leaching with renovated water or rainfall. No Missouri soils have natural restrictions on crop production due to either total salts or high sodium content. But build-up of soluble salts, especially those high in sodium, will cause soil structure changes which may decrease permeability.

In general, profiles with layers or horizons of very low permeability will require very careful management to prevent sodium problems and the eventual build-up of high levels of total salts.

Total salt content is generally measured by two related readings: electrical conductivity and total dissolved salts. Electrical conductivity is a measurement of the ability of water to conduct electrical current. Since the amount of salts dissolved in water affects its ability to conduct electricity, the electrical conductivity can be used as an index of the overall content of ions or salts in solution.

Conductivity is expressed in mhos/centimeter. (Conductivity in mhos is the reciprocal of resistance in ohms.) As the mho is a large unit, millimhos/cm. ($EC \times 10^3$), or micromhos/cm. ($EC \times 10^6$), is normally used. One mho = 1000 millimhos = 1,000,000 micromhos.

Experience in irrigation with salty water in western states has led to development of water quality criteria combining both the salinity and the sodium alkalinity hazard. Relating these criteria to Missouri conditions, electrical conductivity of water is divided into four categories, 100-250, 250-750, 750-2250, and that above 2250 micromhos/cm. These four categories represent classes 1, 2, 3, and 4 (low, medium, high, and very high) salinity hazards. The reason for considerable range within each of these groups is that conditions of natural precipitation and internal drainage of the soil may modify the effect of a given kind of water on the salt buildup in the soil.

Total dissolved salts, expressed in *parts per million*, or *mg/liter*, indicates the weight in milligrams of dried salt from 1 liter of the irrigation water and thus gives a weight factor in

evaluating the salt hazard. A close correlation exists between electrical conductivity and dissolved salts:

p.p.m. = 0.64 x (EC x 10⁶) for water qualities in the range of 100-5,000 μmhos/cm.

tons/acre feet = 0.00136 x p.p.m.

EC x 10⁶ = 1.5 (p.p.m.)

1 p.p.m. = 0.227 lb./acre-inch

1000 p.p.m. = 1.36 tons/acre-foot

Total salt hazard is separate from the alkali or sodium hazard; this must be kept in mind in discussing and evaluating irrigation waters.

“Alkali” Soil Conditions

Water high in sodium tends to form alkali (sodium) soils, often termed black alkali, or slick spot soils. Alkali soils are low in soluble salts and, generally, highly alkaline in reaction (pH above 8.5), but are characterized principally by their poor physical condition. When a high-sodium irrigation water is applied to a soil, some of the sodium is adsorbed by (sticks to) the clay. It displaces an equivalent amount of other ions, principally calcium. Soils that contain about 15 percent or more of adsorbed sodium tend to swell and disperse when wet. This reduces their permeability to air and water, and drainage is impeded. As it dries, the soil becomes hard and breaks into large, tough clods instead of into friable granules.

Sodium or alkali hazard is also divided into four categories—*low*, *medium*, *high*, and *very high*. The water quality criterion used in making the divisions is the sodium-adsorption ratio, a mathematical expression which denotes the tendency of water to impart sodium to the clay complex of the soil. The accumulation of the sodium ion in the clay minerals is a major cause of the destruction of the structural units of the soil.

The sodium-adsorption ratio (SAR) is defined as:

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

where the concentrations of the three soluble cations are given in *milliequivalents per liter*. Divide the concentration of sodium in p.p.m. by 22.99, of calcium by 20.04, and magnesium by 12.15 to obtain milliequivalents per liter. The SAR of an irrigation water indicates the approximate equilibrium exchangeable-sodium-percentage of a soil with the water.

Soils that contain both excess soluble salts (salinity) and excess adsorbed sodium (alkali) are often termed *saline-alkali* soils. Wherever excess salts are present, these soils usually appear similar to saline soils. Leaching out the excess soluble salts changes the soil properties markedly and the soils appear similar to alkali soils. As a result of leaching, they become strongly alkaline; the particles disperse and the soil becomes unfavorable for the entry and movement of water and gases and for tillage.

The diagram (Fig. 2), developed from the U.S. Salinity Laboratory, may be used as a guideline.

The significance and interpretation of the quality ratings on the diagram are summarized below. The effluent applied will be diluted by rainfall, so use the chart accordingly.

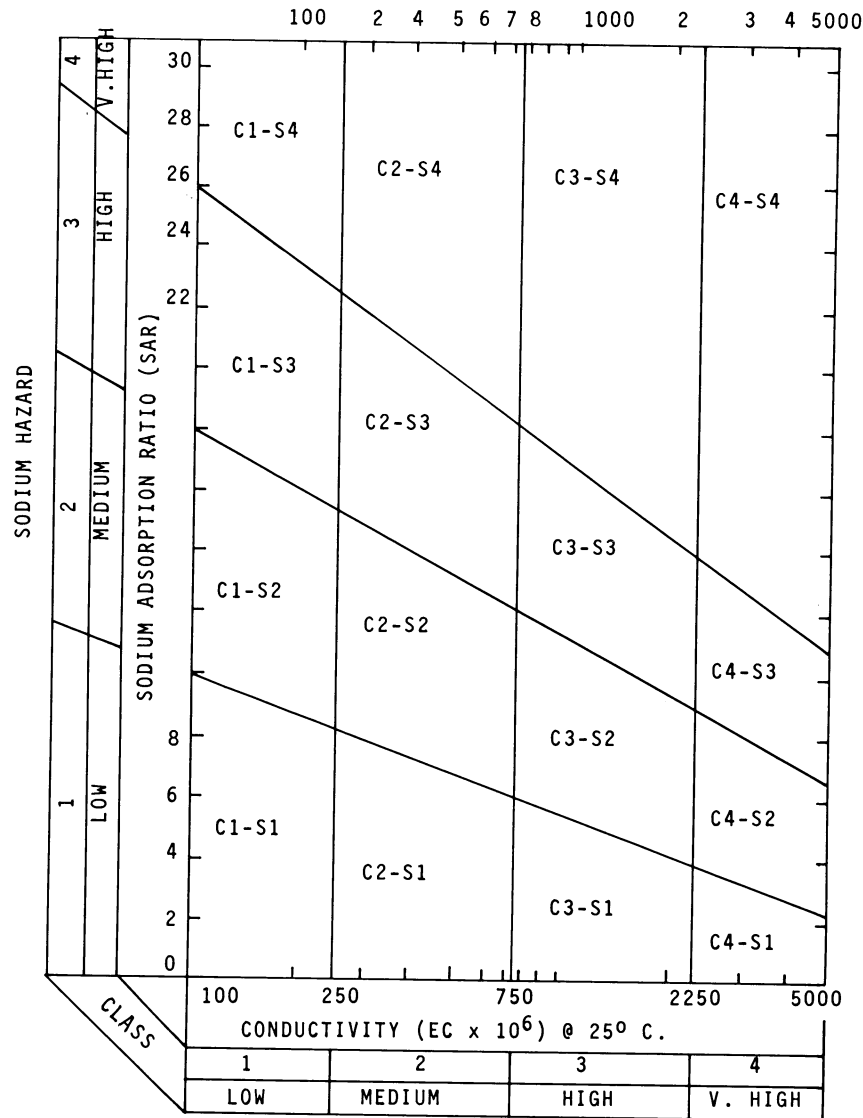


Figure 2. Classification of Water Quality for Irrigation (73)

Management of Salinity

Low-salinity water (C_1) can be used for irrigation with most crops on most soils with little likelihood that a salinity problem will develop. Some leaching is required, but this occurs under normal irrigation practices, except in soils of extremely low permeability.

Medium-salinity water (C_2) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most instances without special practices for salinity control.

High-salinity water (C_3) cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required, and plants with good salt tolerance should be selected.

Very high salinity water (C_4) is not suitable for irrigation under ordinary conditions but may be used occasionally under very special circumstances. The soils must be permeable,

drainage must be adequate, and irrigation water must be applied in excess to provide considerable leaching. Very salt-tolerant crops should be selected.

Management of Sodium or Alkalinity

Low-sodium water (S_1) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium-sensitive crops, such as stone-fruit trees and avocados may accumulate injurious concentrations of sodium.

Medium-sodium water (S_2) will present an appreciable sodium hazard in fine-textured soils of high cation-exchange-capacity, especially under low-leaching conditions, unless gypsum is present in the soil. This water may be used on coarse-textured or organic soils that have good permeability.

High-sodium water (S_3) may produce harmful levels of exchangeable sodium in most soils and will require special management—good drainage, high leaching, and additions of organic matter. Gypsiferous soils may not develop harmful levels of exchangeable sodium from such waters. Chemical amendments may be required for replacement of exchangeable sodium, except that amendments may not be feasible with waters of very high salinity.

Very high sodium water (S_4) is generally unsatisfactory for effluent disposal on land except at low and perhaps medium salinity where the solution of calcium from the soil or use of gypsum or other amendments may make the use of these waters feasible.

Lunin (ASTM STP 416 (1967)) stated that the use of saline water for irrigation of acid soils may increase soluble levels of Al and Mn to toxic levels. Due to concentration as a result of evapotranspiration, Bernstein (ASTM STP 416 (1967)) stated that the permissible EC of irrigation water should not exceed 4000 micromhos-cm., conforming to the information in the SAR-EC chart.

Control of Salinity

Plant roots take in water but absorb very little salt from the soil solution. Similarly, water but no salt is lost by evaporation from the soil surface. Both processes result in a concentration of salts in the soil water. If effluent or rainfall is small enough that leaching is ineffectual, or if internal drainage is inadequate, the soil will become saline if saline irrigation water is used and the growth of crops will be inhibited or prevented. *Leaching* is a means of flushing excess salts through the soil profile into the groundwater or to surface streams by lateral flow to surface seeps or by artificial collection of underdrainage.

Use the following procedure to determine if leaching is sufficient to eliminate salinity problems:

- (1) From Tables 9, 10, and 11, determine the allowable electrical conductivity of the saturated soil extract for the crop under consideration. Interpolation between the high and low figures may be necessary.

EXAMPLE: Assume the grass is reed canarygrass. From Table 9, reed canarygrass lies about 1/4 of the distance between 4,000 micromhos/cm. and 12,000 micromhos/cm. Interpolating, we find that reed canarygrass can tolerate a saturated soil extract conductivity of 6,000 micromhos/cm.

- (2) Estimate the total amount of water that has infiltrated into the soil: Effluent + rainfall - runoff.

EXAMPLE: Assume the system will be installed in southwest Missouri, and 15 inches of effluent will be applied each year. From Appendix G, mean annual rainfall = 39.2 inches. From Appendix H, mean annual runoff = 10.5 inches, assuming average soil conditions. Total water infiltrated = 15'' + 39.2'' - 10.5'' = 43.7 inches.

- (3) Estimate the amount of water leaching through the soil profile: Total water infiltrated - mean total annual evapotranspiration.

EXAMPLE: From Woodruff (104), mean total amount evapotranspiration may be estimated to be 38 inches. Leaching amount = 43.7'' - 38.0'' = 5.7 inches.

- (4) Estimate the actual leaching percentage: 100 x annual leaching amount ÷ total water infiltrated into the soil.

EXAMPLE: Actual leaching percentage = $\frac{100 (5.7'')}{43.7'')} = 13\%$.

- (5) Determine the mean conductivity of applied water:

$$\frac{(\text{inches of effluent applied}) (\text{effluent conductivity})}{\text{Total water infiltrated}}$$

Note: This assumed rainfall conductivity is insignificant. Assume the effluent conductivity is 1000 micromhos/cm.

EXAMPLE: mean conductivity of applied water = $\frac{15'' (1000)}{43.7''} = 343$ micromhos/cm.

- (6) Determine the required leaching percentage, from Figure 3.

EXAMPLE: Find the mean conductivity of the applied water on the horizontal scale: 343 micromhos/cm. Draw a vertical dotted line from this point to the allowable saturated soil extract conductivity, 6,000 micromhos/cm. In this case, 4,000 and 8,000 micromhos/cm. Draw a line horizontally to the left, and read the required leaching percentage, 6%.

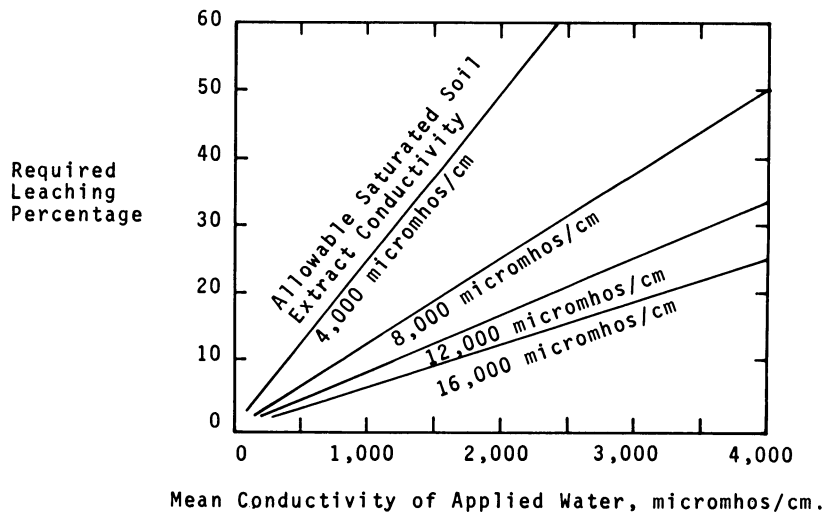


Figure 3. Required Leaching Percentage

TABLE 9. THE SALT TOLERANCE OF FORAGE CROPS (AS INDICATED BY THE ELECTRICAL CONDUCTIVITY OF SATURATED SOIL EXTRACT)

High Tolerance 18,000 micromhos/cm	Medium Tolerance 12,000 micromhos/cm	Low Tolerance 4,000 micromhos/cm
Saltgrass	White sweetclover	White Dutch clover
Bermuda grass	Yellow sweetclover	Meadow foxtail
Canada wildrye	Perennial ryegrass	Alsike clover
Western wheatgrass	Sudan grass	Red clover
Barley (hay)	Hubam clover	Ladino clover
Birdsfoot trefoil	Alfalfa (Calif. common)	
	Tall fescue	
	Rye (hay)	
	Wheat (hay)	
	Oats (hay)	
	Orchardgrass	
	Meadow fescue	
	Reed canary	
	Smooth brome	
12,000 micromhos/cm	4,000 micromhos/cm	2,000 micromhos/cm

TABLE 10. THE SALT TOLERANCE OF FIELD CROPS (AS INDICATED BY THE ELECTRICAL CONDUCTIVITY OF SATURATED SOIL EXTRACT) (47)

High Tolerance 18,000 micromhos/cm	Medium Tolerance 10,000 micromhos/cm	Low Tolerance 4,000 micromhos/cm
Barley (grain)	Rye (grain)	Field beans
Sugar beet	Wheat (grain)	
Rape	Oats (grain)	
Cotton	Rice	
	Sorghum (grain)	
	Corn (field)	
	Flax	
	Sunflower	
	Castor beans	
10,000 micromhos/cm	6,000 micromhos/cm	

TABLE 11. YIELD REDUCTIONS OF FORAGES DUE TO SALINITY (AS INDICATED BY THE ELECTRICAL CONDUCTIVITY OF THE SATURATED SOIL EXTRACT*)

Crop	Yield Reduction of Forages		
	10%	25%	50%
	--Electrical Conductivity, micromhos/cm--		
Bermuda grass	13	16	18
Tall fescue	7	10	15
Barley hay	8	11	14
Birdsfoot trefoil	4	8	11
Alfalfa	3	5	8
Orchardgrass	2	5	8
Clovers	2	3	4

*From: Water quality criteria - Report of National Technical Advisory Committee to Secretary of the Interior - 1968; Bernstein, L. 1964. USDA Agri. Info. Bulletin 283. (95)

(7) Compare the required leaching percentage with the actual leaching percentage.

EXAMPLE: The required leaching percentage, 6%, is less than the actual leaching percentage, and thus no problems are expected with salinity buildup in the soil.

NOTE: These salts leached through the soil profile will pass on into the groundwater, unless intercepted by a tile system.

Control of Exchangeable Sodium (Alkali) in Soil

Waters high in sodium affect soils differently than saline low-sodium waters and may require special management practices. Sodium in the water tends to be fixed or adsorbed by the soil in an exchangeable form. As the proportion of exchangeable sodium (alkali) increases, adverse physical and chemical conditions develop in the soil that limit or prevent the growth of plants.

Reclamation involves the replacement of the exchangeable sodium by calcium or magnesium and the removal of the sodium by leaching. It is often possible to prevent the formation of harmful levels of exchangeable sodium by the addition of calcium, usually in the form of gypsum, to the water or to the soil.

The sodium status of the water is expressed in terms of sodium-adsorption-ratio (SAR). Gypsum adds calcium to the soil, replacing sodium on the soil particles. Thus, sodium can leach on through the soil profile. Use Figure 4 as a guide (100) to determine the quantity of gypsum to reduce the soluble sodium content of the water to a level that will not produce adverse soil conditions. For instance, if the SAR of the irrigation water is 22 and the conductivity is 1,000, the gypsum required to reduce the SAR to 8 would be 0.29 tons per acre-foot of water. The selection of the value 8 for the SAR of the irrigation water after treatment with gypsum is arbitrary but is in a range that should be satisfactory.

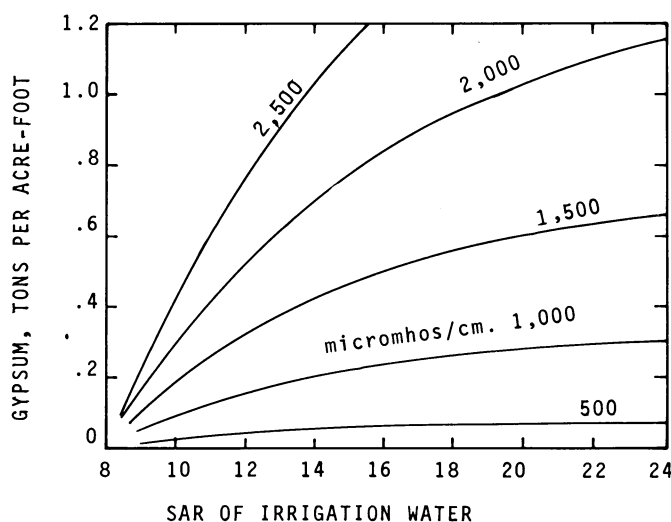


Figure 4. Gypsum Requirement. (Graphical estimate of the quantity of gypsum to be added to an irrigation water to reduce the sodium-adsorption-ratio (SAR) to S, for waters having conductivity values indicated on curves.)

Flooding, incorporating organic residues, deep plowing or sub-soiling, and growing fibrous-rooted crops also assist alkali reclamation. In nature, reclamation is accomplished by the action of rainfall and flood waters acting over extremely long periods of time.

A high concentration of the bicarbonate ion also increases the SAR of the water. The bicarbonate ion will combine chemically with the calcium and magnesium ions, producing insoluble calcium carbonate and magnesium carbonate. These compounds will precipitate out and leave a higher concentration of the sodium ions. This reaction will not go to completion with lower concentrations of bicarbonate. Tolerance levels of bicarbonates are figured as follows: (47)

Use the formula for residual sodium carbonate:

$$\text{RSC milliequivalents per liter} = (\text{CO}_3^- + \text{HCO}_3^-)\text{meq./l.} - (\text{Ca}^{++} + \text{Mg}^{++})\text{meq./l.}$$

Compare the results with the following to determine the suitability of the water for irrigation.

<u>Safe</u>	<u>Marginal</u>	<u>Unsafe</u>
0 - 1.25	1.25 - 1.5	2.5 meq./l or above

5. Effects on Livestock

Animal-plant-soil environmental interactions have many complexities. An assumption is made that beef cattle* will be the principal recipients of the forage, usually as harvested forage, sometimes as pasture. A further assumption is that the system will be managed to maximize disposal of the effluent on minimum acreage with the cattle gains being of lesser importance.

Factors to be considered are:

- a. Source of drinking water for the cattle in relation to effluent dispersal, i.e., ponds, shallow wells, etc.
- b. Nutritional adequacy of forage produced
- c. Toxicity due to effluent residue on plants or to accumulation of elements or compounds found in the effluent
- d. Parasitic burden associated with cattle grazing irrigated pastures

Drinking Water for Cattle

For pasture systems, management of the irrigation system and topography of the land in relationship to the source of cattle drinking water must be considered. The chemical composition and concentration of the water in the pool may be different than the effluent applied due to evaporation and filtration. When possible, effluent run-off should be kept out of ponds unless it passes through 100 to 200 feet of vegetation that has not received effluent directly. Shallow wells may reflect a gradual change in composition with time, when large amounts of effluent are being applied. Table I-1, Appendix I, gives values beyond which the supply should be rejected for livestock use.

It should be understood that the levels given in the table in Appendix I are generally safe limits. Higher levels may be tolerated, depending upon the amount of the element found in the ration and volume of water consumed. In determining toxicity levels, one should be concerned with the weight of substance per unit of body weight consumed per unit of time. Therefore, toxicity data from water sources are not plentiful.

*To our knowledge, there are no recorded cases where the contaminants have passed from effluent irrigation water to the liquid milk supply. However, lactating dairy cows should not be used since Public Health Regulations for liquid milk suppliers are stringent. Current knowledge does not preclude the possible passage of effluent-borne contaminants to the liquid milk supply, and thus the risk is not warranted.

Sewage effluent has been suspected as a cause of disease outbreaks in man and animals. However, few if any outbreaks have been proved to be caused by effluent from a properly designed and working sewage plant.

As early as 1940 Crawford and Frank reported on a trial where incoming sewage, sludge, and effluent from a disposal plant were fed to swine and cattle for a six-month period. Sewage entering this system contained not only the usual contamination from human sources but also contaminated material from animals used in experimentation at Beltsville, Md. At that time the Animal Disease Station was working with tuberculosis, brucellosis of cattle and swine, infectious anemia of horses, equine encephalomyelitis, mastitis of cattle, hog cholera, swine erysipelas, vesicular stomatitis and other bacterial and viral diseases.

On the basis of the tests made, it was concluded that virulent bacteria were not present in sufficient concentration in the sludge and effluent of this sewage treatment plant to cause disease in susceptible animals.

Effluent from a disposal plant contains large numbers of non-pathogenic bacteria. Due to competition, these large numbers of bacteria make it very difficult, if not impossible, for pathogenic bacteria to survive.

Nutritional Adequacy of Forage Produced

This issue is raised to alert the person or municipality who might lease the soil-plant filter area for grazing. The cattle may not grow well because they do not receive proper supplementation. Dependent upon the soil nutrient, the plant species, and quality of the effluent (level of plant nutrients and trace elements) the forage may need to be supplemented with energy-rich feedstuff, protein, and mineral supplements if young cattle in particular are to make economic gains. If effluent water is used to maximize forage yields, it is expected that the supplemental feeding will correspond to that normally used in a given region of the State. However, where the maximum amount of effluent is applied, feedstuff analysis of the resulting vegetation should be made. Protein level, calcium-phosphorus ratio, magnesium, potassium, cobalt, iodine and molybdenum-copper ratio would be expected to be most critical. This list would apply to both pasture and hay.

NOTE: Experience in Paris, Texas (24) with nutrient-rich cannery wastes, indicated the nitrogen and phosphorus content of effluent-irrigated hay was double that of normal hay. Cattle showed a definite preference for the effluent-irrigated hay.

Toxicity Due to Effluent Residue on Plants or to Accumulation of Elements or Compounds Found in the Effluent

Elements in municipal effluents that are most likely to be concentrated in forages, are selenium, fluoride, molybdenum, arsenic, and possibly, lead. Table I-2 in Appendix I, "Dietary Levels Where Toxicities Might Occur" is based primarily upon Underwood's "Trace Elements in Human and Animal Nutrition," 3rd Edition. Should a toxicity develop in cattle due to a certain element, it may be possible to reverse or prevent further toxicities by proper mineral supplementation.

Parasitic Burden Associated with Cattle Grazing Irrigated Pastures (95)

Under warm humid conditions certain helminth infections - ascariasis, farcioliasis, cysticercosis, and tape worm infection may be transmitted through surface irrigation water and plants infected with ova or intermediate forms of the organism. Chlorination and sewage

treatment are only partially effective in destroying the ova and parasitic worms. *Ascaris* ova have been reported to survive for 2 years in irrigated soil. Cattle grazing irrigated pasture would be less likely to be infected with helminths or pathogenic bacteria if a two-week interval existed between last application and grazing (95). Production of hay from soil plant filters would not carry as great a risk since the soil would need to dry out in order to cure the hay. Cattle grazing intermittently irrigated pastures where maximum effluent is disposed should be treated routinely with an anti-helminth drug. This would minimize the transfer of parasites from animal to animal via the soil-plant-water system. Such transfer is likely to happen even when there are no helminth in the effluent.

Due to the problems in protecting the animals' drinking water supply near effluent-irrigated land and the parasitic burden associated with grazing this land, it is recommended that the forage be harvested and fed to the livestock.

6. Disposal in Woodland

The use of woodlands as an area for waste disposal and as a means of nutrient removal has not been studied intensively. Several projects are currently under way and much of the limited information available comes from these waste-treatment projects. The Pennsylvania studies (59) are recent and give clues to what may be expected under certain conditions. The many variables involved demand that careful evaluation of the disposal site, sewage composition, treatment methods, etc., be made before any project is begun. A program of monitoring of the site conditions will also be necessary to prevent site deterioration before it progresses to an advanced state. Some knowledge of the factors involved will aid in avoiding many mistakes, such as the poor selection of sites, species, etc., and will serve as a guide in decision making.

Considerations in Site Selection

Vegetation influences a site and, conversely, the nature of the site also influences the vegetation. Shallow soils, for instance, may restrict the roots of trees and prevent their characteristic removal of soil moisture and nutrients from areas below the root zones of other types of plants. Hardpans and claypans may also reduce the tolerance of many species to increased applications of water. Soil and other site conditions may limit tree species selection for any given area.

Trees will normally bring nutrients and water from greater soil depths than will other types of vegetation. Most kinds of vegetation use large amounts of water but trees use the highest amounts (45). Because of its humus layer, and other characteristics, the forest floor also is usually more porous, allowing better water infiltration than is found on non-forested soils.

Much more than the soil of a site must be considered. The interrelationships of many variables will determine the performance of the trees. In addition to the soil type, balances between micro-organisms, nutrients, aerobic conditions, amounts of solar energy available and many other factors determine how successful vegetation is in producing the desired effluent renovation.

With irrigation, one of the major considerations will be the prevention of over-saturation of the soil. This results in a deficiency of oxygen and an accumulation of carbon dioxide. Such conditions usually result in reduced growth or killing of roots. If a soil's air space is too small, unsatisfactory aeration may develop from the respiration of roots and soil organisms. Irrigation that is too frequent on clay soils will lead to oxygen depletion in the lower root zone due to saturation of soil pores with water.

Some tree species are capable of growing in saturated soils. Most of these are swamp species, such as baldcypress, water tupelo and some species of *Salix*, *Alnus* and *Betula*. Other species have the capacity to adapt their juvenile root systems to a variety of conditions and can be established on dry or wet sites. Red maple and box elder are two such species. However, no species can remain covered with water indefinitely.

Controlled, uniform distribution of the effluent will be necessary to keep balance in the forest system. Pennsylvania State researchers were able to obtain satisfactory distribution at temperatures down to -12° F on woodland. Irrigation was done between April and November. After 8 years of operation, during which approximately 40 feet of waste water had been applied, they concluded the renovation capacity of the biosystems was still satisfactory.

Removal of Moisture by Trees

Little is known about the evapotranspiration of trees under continuous optimum moisture supply. A number of hydrologic studies indicate that losses of water by evaporation and transpiration on well-drained forested slopes are generally not less than 15 inches a year and may be twice that much on sites where rainfall is plentiful during the growing season. It has been estimated that forest cover along reservoirs and shorelines may use 1 to 6 inches more water annually than upland forest cover. In the South, forests are estimated to lose up to 0.30 inches of water each day. (34)

Evapotranspiration rates in an oak-hickory woodland in Boone County, Mo. varied from a minimum of 0.06 inches per day to a maximum of 0.26 inches per day. Higher rates would be expected if the soil was moist continuously. (29)

In the Pennsylvania studies, water losses within the biologically active zone were estimated at 1 inch per week during the growing season. (82) Any water naturally or artificially applied to the land surface in excess of those water requirements was potentially available for ground-water recharge. Recharge amounted to 90 percent of the effluent applied at the 2-inches per week rate. During the non-growing season, and the beginning and end of the growing season, the potential for recharge is greater because both evaporation and transpiration are reduced. However, biologic activity is also at a minimum and breakthrough of pollutants is most likely to occur when wastewaters are applied during winter months.

Whether transpiration is greater for broadleaf trees or conifers has not been determined. Studies indicate other factors may influence transpiration rates, including:

- Depth of rooting.
- Rate of development of the root system during the growing season.
- Time spring growth begins and length of the growing season.
- Root relation with soil micro-organisms.

Removal of Nutrients by Trees

Accumulation of data on nutrient removal from soil by trees is complicated by the length of time involved in forest cropping, the complexity of measurement involved, and the fact that trees use smaller amounts of soil nutrients than most other agricultural plants.

Trees do recover elements from the deep soil layers which would otherwise be lost in drainage water. These nutrients are returned to the soil surface in the annual leaf fall. The oven-dry weight of the forest floor leaf accumulation varies greatly, but Auten (1933) reported hardwood forest accumulations of 8 tons per acre in the Central United States. Chandler (5) quotes a figure of 2700 pounds per acre as an average weight of freshly fallen litter. Tree leaves

are by far the largest single source of forest soil organic matter and their annual contribution of mineral elements to the soil greatly exceeds that of all other tree parts combined. In well-managed forest stands, the removal of timber eliminates but a small fraction of soil nutrients because more than 95 percent of nitrogen and ash constituents are in the foliage and young branches that remain on the ground. Increased utilization would reduce the percentage somewhat but indications are that removal of annual crops is a much more efficient method of nutrient removal than periodic tree harvesting. (80)

Tree species appear to differ greatly in the relative and absolute amounts of nutrient elements absorbed from the soil. For instance, hickory trees appear to absorb larger amounts of the rare-earth elements than many other midwestern species. Nutrient consumption of forest trees varies with age, with consensus being that nutrient needs increase up to an age of 20-35 years and then decrease. As a general rule, deciduous trees absorb larger amounts of most mineral nutrients than do conifers. The absorption pattern for nitrogen is an exception.

Sopper (81) indicates that increasing concentrations of nitrate-nitrogen in forested areas receiving continued irrigation with sewage effluent could become a major problem and a deterrent to long-term use of forested areas for disposal sites. However, this is not an insurmountable obstacle.

One possible way to reduce nitrate concentration is through denitrification. Conditions favoring denitrification can be established by altering the sequence of irrigation applications to create short periods of soil saturation and promoting the anaerobic evolution of nitrogen gas. In this connection, only the forest tree species which tolerate short periods of inundation will survive this treatment. This must be kept in mind in the selection of tree species which might be planted on a potential irrigation site.

European studies indicate a *net* average annual uptake of nitrogen of about 6 to 10 pounds per acre; phosphorus 0.1 to 0.6 pounds per acre; potassium 1 to 5 pounds per acre; calcium 1 to 8 pounds per acre; magnesium 1 to 5 pounds per acre. Larger quantities are taken up but returned in leaf fall, etc.

The Penn State studies concluded that the forest as a "living filter" was highly efficient in removing phosphorous. (59) Phosphorous is readily fixed by the soil so most of it is held in an unavailable form. However, they anticipated no problem with phosphorous accumulation.

Toxicity to Trees

Because sewage effluents often have abnormally high amounts of some of the trace elements, the effluent disposal system manager must be concerned with the toxicity of elements to plant material.

Some work has been done on toxicity in seedling trees but very little is known about element buildup in mature stands of trees. Many interactions are involved, including tree species, pH, organic matter, water content, microorganisms, and the relations between the elements themselves. However, certain elements are thought to be more toxic than others to many species of trees.

Lutz and Chandler state that under anaerobic conditions sulfates are readily reduced to sulfides, including hydrogen sulfide, which is toxic to trees. Chlorine has also been reported to contribute to tree decline.

Chandler lists selenium, boron, and arsenic as toxic, with boron perhaps the most likely to do damage. Under some conditions, boron may be toxic in amounts as little as 0.4 or 0.5 parts per million. (6)

Also toxic are greater quantities of chlorine, copper, and sodium. Abundant nitrogen seems to reduce chlorine injury in some trees. Some soils have the ability to fix large amounts of copper in insoluble combinations. Some copper toxicity has been reported

7. Turf Disposal

Turf & Soil Considerations:

Good turf management techniques dictate that usage of effluent or any other irrigation waters for recreational turfs *must be limited* to those amounts required for best economic return and that are appropriate to optimum soil-plant relationships.

On recreational turfs, especially those that are exposed to constant traffic, maintaining desirable soil structure necessary to support viable grass is already a major problem. Under these conditions, application of maximum amounts of water under the effluent disposal concept can cause soil compaction and oxygen depletion detrimental to turf survival.

The majority of reports of successful turf irrigation on golf courses, etc. have been from areas that are short of irrigation water. Effluent irrigation supplies have permitted turf establishment which otherwise might not have been possible (33, 44, 85, 86). In more humid areas, it may be desirable to view sewage effluent as a potential source of supplemental irrigation water. Recreational turfs should not be viewed as a primary means for disposal of maximum amounts of effluent water.

Specialized areas such as golf greens receive extensive physical modification to provide superior water and air entry and movement. However, these constitute a relatively minor acreage as potential soil filters. Greens area will seldom involve more than 1 to 1 1/2 acres of a nine-hole golf course which may have 50 to 60 acres of irrigable turf. A major consideration of golf courses, parks, and play fields should be determined by the limitations of the native soil.

Significant quantities of sodium and other elements that could aggravate existing soil structure can have critical effects upon many turf soils. Effluent quality must receive thorough attention if waste water is contemplated as a source of irrigation water. This is especially true in municipalities where considerable chemical softening of waters is practiced.

Reports of relatively short-term tolerance to waters containing high total mineral salts, and high electrical conductivity values can be misleading. For example, analyses reported by Davis (12) and Madison (42) indicate that Kentucky bluegrass, fescues, and other species apparently tolerate 10 ppm boron in irrigation water. However, levels of boron in water much above 0.5 ppm are reported detrimental to deciduous trees and shrubs in the landscape (55). Boron tolerance in turf species is attributed to its accumulation in leaf tips which are subsequently removed by mowing. In long-term considerations, recycling back into the soil via clippings could result in ultimate accumulation to levels toxic even to turf species. Deal and Engel (14) report 7.5 pounds per acre boron toxic to Kentucky bluegrass. Mobility, soil retention, and toxicity levels of mineral elements and salts must receive careful attention in considering use of effluent waters on parks and recreational areas.

According to Merz (44), total dissolved solids in effluent water used for recreational purposes should be less than 3,000 ppm. Madison (41) reports turf species capable of tolerating normal levels of chlorine used in terminal treatment of effluents, being tolerant of 100 milliequivalents of chlorine, or more.

In addition, the fertilizer values claimed for effluent irrigation (33) need to be examined more carefully. The application of nitrogen and other plant nutrients in waste waters would

tend to be out-of-phase with natural growth cycles and desirable management practices of turf species predominant in Missouri areas.

Supplying moisture and nutrients to warm season turf species in summer months through effluent disposal has been quite successful. In addition, these warm season grasses are most commonly utilized in areas from which successful effluent irrigation has been reported. For the cool-season grasses more common to their areas, tolerance and resistance to the most damaging fungal diseases can be drastically reduced by growth stimulation during the summer period. To be used successfully, effluent waters will need to be monitored continually for soluble nutrients, especially nitrogen, as well as boron, sodium, and other troublesome constituents. Adjustment of routine fertilization practices will be necessary to avoid excessive growth stimulation that can be detrimental to the health of cool-season turf. Problems may be expected if nitrate plus ammonium levels approach 20 to 25 ppm during the summer months.

Special Considerations:

Careful planning and design are essential for sound reclaimed water-turf systems that will be accepted by the general public. Many public relation problems may be prevented if the effluent is properly treated in the sewage treatment plant. A well oxidized effluent is most desirable, to reduce odor and organic matter accumulation on the turf and soil.

Irrigation waters used on any facility open to the public should meet U.S. Public Health Standards for bacterial quality of potable water. One might question how many golfers put their tees in their mouths before and after teeing off, but the possibility of spreading any disease or creating negative public reaction is too great to not meet these standards. Chlorination of the renovated effluent is the most common method of controlling pathogenic organisms. Concentration of chlorine and length of contact time are both important. Generally it is more desirable to maintain lower amounts of chlorine and longer storage periods. This reduces pipe corrosion and interference with grass growth.

Sewage effluent should not be sprayed on domestic water wells or reservoirs or on drinking facilities on the recreational facility. Special measures must be taken to protect these facilities.

To protect the general public, the irrigation system valves should be designed so that unauthorized persons cannot open them. Valves, sprinkler heads, and reservoirs should be appropriately labeled to warn the public that the water is unsafe for drinking.

No cross-connections should be permitted between any pipeline used for sewage effluent and a pipeline used for domestic supply. Lines carrying other than domestic water should be clearly marked and painted or otherwise identified to minimize possibility of cross-connection.

Management Considerations:

Reclaimed water should be analyzed periodically at the pump intake to detect significant trends in certain elements which might be potentially detrimental to turf growth. Particular industrial processes may introduce specific mineral elements in harmful amounts, so a water quality analysis should be determined.

On the basis of the analysis, develop a fertility program to complement the nutrients added through the reclaimed water. Ignoring this factor may create problems due to excess nitrogen etc.

Spray reclaimed water during times of the day which will minimize contact with the public and allow the maximum time to dry. Late evening or night watering may provide least public

contact, but may not be desirable because of slow drying and summer fungal diseases. Late night or very early morning watering may be preferable.

In conclusion, with careful attendance to the above problems, using reclaimed water for turf irrigation has considerable potential; without thorough consideration, it can be an expensive lesson. Remember that a concurrent public relations program is essential to the success of this concept.

G. METHODS OF APPLICATION

Three types of system have merit for effluent disposal: sprinkler systems, surface systems, and overland flow systems. Tile interceptor systems should be considered when impermeable subsurface layers are encountered.

1. *Sprinkler Systems.*

Sprinkler systems allow waste disposal on rolling and irregular land that would be impractical to surface irrigate. Although initial and operating costs are generally higher for sprinklers, labor requirements are generally reduced, and some systems may be automated. Sprinkler systems also offer the best uniformity of any system. For all sprinkler systems, select sprinklers and spacings that will not cause runoff on the particular soil type, topography, crop, and time of application. A significant factor to consider in designing sprinkler effluent disposal systems is the production of very small air borne particles, called aerosol, and drift of these particles caused by wind. Aerosol may be reduced by using smaller, low angle impact sprinklers or uninterrupted spray nozzles, operated at lower than normal pressures. Some systems have a wind meter connected to the controls, so that the system will stop operating if the wind speed exceeds some value, i.e. 15 miles per hour.

Effluent that is high in sulphur content may cause brass sprinklers to become inoperative. Plastic sprinklers have given some relief to this problem; some manufacturers are using an acetal co-polymer material (plastic) as a construction material for greater chemical resistance.

Several manufacturers make a special corrosion resistant gun sprinkler for handling waste from pulp and paper plants. Generally, treated secondary sewage effluent is fairly clean and should not cause many problems to sprinklers and guns, other than normal wear and failure. Control valves and similar accessories may require epoxy coating for longer life.

Impact drive sprinklers are perhaps less likely to cause trouble than the gear or cam drive type in handling sewage effluent. From an engineering standpoint, probably the most vulnerable component is the sprinklers. Parts that fail first are drive mechanisms, bearings and seals. After a period of use, large gun type sprinklers can be rebuilt while smaller sprinklers are usually discarded.

An adequate suction strainer for the pump intake should be used where small sprinkler nozzles are used. This is especially true for 1/4-inch and smaller nozzles. All-steel pumps are less susceptible to corrosion than the pumps with brass impellers.

2. *Surface Systems.*

Surface irrigation systems rely on gravity to distribute the effluent down the row or border, prior to infiltrating into the soil. Consequently, surface disposal systems require land that

has gentle, uniform slopes or has been graded to obtain uniform distribution. Some runoff will occur if the lower part of the row or border is to receive a medium application. As this is generally unacceptable from a pollution abatement standpoint, tailwater pits and automatic return pumps may be needed to catch runoff and return it to the mainline. Gated pipe is the most popular method of distribution to the field.

3. *Overland Flow Systems.*

An exception to the design-for-no-runoff approach is the overland flow system. This system utilizes a single line of sprinklers to supply effluent to the high end of a heavily grassed area. The wastewater is renovated as it passes through the grass filter. Several studies of filtration have indicated substantial capability to renovate wastewaters. Wilson (101) reports on an English study in which suspended solids were reduced 73 percent, BOD values were reduced 59 percent, and coliform counts were reduced by 97 per cent. This was for tertiary treatments of sewage effluent, with loadings up to 2.76 acre-feet per day. Wilson also reported on a study at Pima, Ariz. utilizing grass filtration to renovate oxidation pond effluent. He concluded: (1) partial treatment occurred through grass filtration, but runoff was unsuitable for discharge into streams because of high hydraulic loading (greater than 1.4 acre-feet per acre per day), (2) grass height and density should be great enough to ensure operation of grass as a filter, and (3) Bermuda grass demonstrated its ability to endure prolonged flooded conditions.

Perhaps the most comprehensive study of a spray runoff system was done at the Campbell Soup Company at Paris, Texas (24, 36, 37). A total of 133 inches of water was applied to the experimental watersheds during the 12 month study. The disposal area, severely eroded clay soil, was terraced and smoothed. Single lateral sprinkler lines were installed below each terrace. Of the total amount applied, 18 percent was lost through evapotranspiration. Runoff accounted for 61 per cent and deep soil percolation accounted for 21 per cent. Runoff increased to a maximum of 80 per cent during periods of heavy rainfall. Table 12 gives the mean characteristics of the wastewater and concentration change:

TABLE 12. EFFLUENT CHANGES THROUGH OVERLAND FLOW SYSTEM

Chemical Parameter	Mean Value	Concentration Change %
pH	7.2	-----
Electrical Conductivity (umhos/cm)	449	+9.6
Chloride (mg/l)	44.1	+6.6
Total Suspended Solids (mg/l)	472	-93.5
Volatile Suspended Solids (mg/l)	218	-96.3
Total Phosphorus (mg/l)	7.4	-42.5
Nitrate Nitrogen (mg/l)	0.20	-----
Kjeldahl Nitrogen (mg/l)	17.0	-84.7
Chemical Oxygen Demand (mg/l)	806	-91.7
Total Organic Carbon (mg/l)	250	-90.8
Biological Oxygen Demand (mg/l)	572	-98.4

This system achieved mass removals of 92 to 99 per cent of the volatile solids and oxygen-demanding substance, 86 to 93 per cent removal of nitrogen, and 50 to 60 per cent removal of phosphorus. Soil textural class and system age had little effect on treatment efficiencies. Increasing the land area and reducing the loading frequency increased treatment

efficiencies. Phosphorus removal was increased from 40 per cent to 88 per cent by changing from a one per day to three per week spraying schedule. An increase in salinity was noted in the soil. Crop removal is considered essential to maintain treatment efficiency.

The Paris study indicates that slopes between 2 and 6 per cent, and slope lengths of about 175 feet are optimum. That system was designed on application rates of 0.5" per day in the summer and 0.25" per day in the winter. Although Paris, Tex., has a similar rainfall pattern to that of central Missouri, its climate is warmer. Reed canarygrass responded well to the saturated conditions of the disposal area.

Overland flow systems are being studied. Present experience and knowledge appear to be inadequate to recommend renovation of municipal sewage effluent by this method except on a trial basis.

H. INTERCEPTOR TILE SYSTEMS

Many soil types in Missouri have layers or strata that restrict vertical drainage. Usually there is some slope to these layers. Frequently the restricting layer outcrops on side slopes. If such fields are used as disposal areas for sewage plants or livestock lagoons, a perched water table may form. This is a common occurrence in wet seasons and shows up most often as a hillside seep. Applications of effluent during wet seasons will aggravate this problem. Direct runoff from seepy areas is not desirable where polluted water is being applied. In addition, these wet spots are difficult to manage for crop harvest and other cropping practices.

The best cure for wet areas is an interceptor drain. Short lengths of concrete or clay drain tile with "leaky joints" or perforated plastic drainage tubing can provide a gravity outlet for the water. Interceptor lines should be laid at or just above the layer that restricts vertical drainage. They should be laid with a very slight slope toward the outlet pipe. They should be placed up slope far enough to be well below plow depth and frost depths when back filled. The outlet pipe should also be buried well below plow and frost depths, and should not be perforated because it may carry water under pressure in the lower part of the field.

The direction of movement of the water along the restrictive layer should always be determined. This usually can be done with a soil auger to locate the restrictive layer, and an engineer's level to find relative elevations. The interceptor tile will function most efficiently when it is installed across the direction of subsurface water movement. Because of the lack of field experience on tiling certain soils, tile drains may be spaced at 80 or 100-foot intervals. If this spacing is inadequate, another tile line may be installed halfway between two lines, effectively reducing the spacing by half.

I. OVERALL SYSTEM DESIGN CHECKLIST

Use the following procedure-checklist to analyze a particular system and develop a sound, well-designed system:

1. *Effluent Quantity and Quality*

Determine present effluent production and calculate total expected annual quantity. Next determine the expected effluent production for the latter years of the life of the system.

Determine the effluent quality according to Part IIIB, "Evaluation of Effluent to be Applied."

2. *Water Balance*

From Table 1, Part IIIE1, determine the annual irrigation deficit for the proposed location in the state, for a frequency that is acceptable for the site under consideration. Although the Missouri Clean Water Commission will make the final determination for each case, a reasonable frequency might be 15 years out of 20 years, or 19 years out of 20 years. Multiply this by a factor to account for the system operation, and a factor to account for drying periods. For example, a solid set system installed in central Missouri and operated 28 days out of 40 days for each cutting of hay would be able to dispose of 12 inches $\times 1.0 \times \frac{28}{40} = 8.4$ inches,

19 years out of 20 years. Now add a planned deep percolation (or lateral flow) amount. For example, add 20 inches. Check this planned deep percolation amount against the permeability of the soil under consideration. A soil with a saturated permeability of .3 inch per hour could pass 20 inches of water in $20/.3 = 66.6$ hours, which it could easily do in the summer. The proposed annual application is thus 8.4 inches + 20 inches = 28.4 inches.

3. *Preliminary Site Information*

Check all potential sources of information for the on-site investigation and system design. U.S. Geological Survey topographic maps and geological information from the Missouri Geological Survey are very useful. In addition, Section IIIE of this publication, University of Missouri Extension Circulars 823 and 915 (74, 75), and soils information available through the Soil Conservation Service, will be helpful to estimate infiltration rates of the soils under consideration.

4. *Field Investigation*

Conduct a thorough on-site field investigation of soils, topography, geology, and the hydrological aspects of the proposed site. Experienced specialists in each of these areas are necessary for an accurate field evaluation. Evaluate the soils and hydrologic and geologic conditions of the site in accordance with Section IIIE3.

The most accurate means of determining infiltration characteristics is to run multiple infiltration tests on the soils under consideration, using equipment and application rates similar to the proposed system (sprinkler, surface, etc). However, this may not be feasible in all cases. Determine if it is feasible to apply the proposed total annual application to the soils and subsurface materials under consideration. (For example, a claypan or fragipan soil could be unable to accept the additional planned deep percolation amount unless a tile drainage system is installed.)

5. *Effluent Renovation by Soils and Cropping System*

Determine the amounts of nitrogen, phosphorus, and potassium in the proposed total annual application. (1 ppm = 0.227 lb./acre-inch). Refer to Table 8 and determine if the crops to be grown will remove this amount of N, P, and K in one year. Adjust accordingly.

A second consideration is that plant nutrients supplied through the effluent should not be applied faster than a soil can absorb them. For example, approximately 40 to 50 days are required for a forage crop to grow enough to be harvested. Reed canarygrass, starting growth about April 1, may be harvested May 20, July 1, August 10, September 20. With four

cuttings, yields may be expected to reach 5 to 8 tons of dry matter per year. Allowing twelve days for drying and for harvest, this leaves 28 days for effluent disposal per period.

Assuming 300 pounds of nitrogen can be removed by the crop, this would amount to 75 pounds for each of four cuttings, three pounds per day, or 21 pounds per week. The actual amount applied can be calculated from the nitrogen concentration in the effluent and the effluent application rate. Soils with an available moisture storage capacity of 4 inches in the root zone will retain the effluent long enough to remove nitrogen from the effluent if the effluent is applied at no more than one 2-inch application per week. This also assumes the 2 inches of effluent has no more than 21 pounds of nitrogen mentioned above (104).

Although no standards have been set for groundwater quality in Missouri, the Clean Water Commission has set the Drinking Water Standards of the U.S. Public Health Service as objectives. See Appendix J. Thus effluent renovation should be adequate to meet these criteria.

Although little specific data is available, evaluate the soil's ability to reduce BOD and certain other constituents by examining Table 4, "Estimated Effectiveness of Land Disposal Systems," and the soil classification scheme under Section III.E3, "Renovative Capabilities of Soil." Reduce the proposed total annual application if necessary.

Refer to Table 7; calculate the amount of chlorides, sodium, and sulfates in an acre-inch of effluent. Multiply these values by the number of acre-inches in the proposed total annual application to estimate the amount of each of these mobile elements that will reach the groundwater. Do the same for calcium, magnesium, potassium, and boron, the elements listed as partially mobile. If these estimated amounts of chemical constituents reaching the groundwater do not meet the groundwater quality objectives, reduce the proposed total annual application or prescribed additional pretreatment.

Evaluate potential chemical toxicity problems by checking the effluent analysis against Appendix F, "Chemical Toxicity Levels for Plants," and Table C-2 in Appendix C, "Trace Element Tolerances for Irrigation Water." If these toxicity levels are exceeded for the cropping system under consideration, reduce the proposed total annual application amount, change cropping systems, or install effluent pre-treatment to eliminate the toxicity problem.

Evaluate alkalinity and salinity hazards by checking Figure 2, "Water Quality for Irrigation" for the electrical conductivity and sodium-absorption ratio of the effluent. Check to see that leaching is sufficient, and adopt special management practices as needed. The proposed total annual application amount may have to be reduced.

6. *Effects on Livestock*

If the effluent disposal area is to be pastured, evaluate each of the following factors: source of livestock drinking water, nutritional adequacy of forage, toxicities due to effluent residues on forage consumed, and parasitic problems. See Section III.F5

If the crop is to be harvested and removed from the effluent disposal area, the primary consideration is evaluating the potential toxicity of the effluent residue on the plants.

Refer to Table I-2, Appendix I. Calculate estimated intake of nutrients by livestock, and compare with toxicity levels. If toxicity problems are apparent, either reduce the total annual application, supplement the effluent with other water, reduce intake by diluting forage with other forage, or offset by mineral supplementation if this is possible.

7. *Method of Application*

Choose an effluent disposal system that will accomplish the desired renovation. In addition, the method of application chosen must fit the available soils, topography, cropping system,

geology, and groundwater regime. A crucial element in system selection and design is the soil intake rate. Select a system design application rate less than the infiltration rate of the soil, for the total annual application and management scheme to be used. See Section IIIG, "Methods of Application," and Section IIJJ, "Equipment."

8. *System Capacity*

If effluent disposal is the primary objective, the system capacity should be designed to dispose of the maximum amount of effluent during the periods of greatest evapotranspiration in the summer. Refer to Irrigation System Nomograph, Appendix K, and determine the system capacity for the acreage needed for .25 inches per day. (Multiply this system capacity by 2 to be able to apply .5 inches per day.)

If agricultural irrigation is the primary object, select a net peak rate for the crop under consideration, from Table K-1 in Appendix K, and an application efficiency. Determine system capacity from the System Capacity Nomograph. Most sprinkler systems will have an application efficiency of 75 to 80 percent if properly designed for the soil and cropping system being irrigated. A surface irrigation system with a tailwater return would have a similar efficiency. Solid set sprinkler systems and center pivot sprinkler systems can be operated 24 hours per day, assuming no breakdowns. Traveling guns, gated pipe, towline sprinkler systems, and other sprinkler systems will operate fewer hours per day; management will influence the number of hours.

Irrigation system characteristics also are important in determining system capacity. For example, center pivot sprinkler systems rely on traction and the ability to travel over the land to operate. Sound engineering design of traction components and alternate wetting and drying periods are thus essential. Center pivot and traveling gun sprinkler systems can apply water at a rate higher than the infiltration rate of some soils, and thus runoff will occur if these systems are operated continuously over a small acreage of land.

9. *Storage Needed*

Storage reservoirs provide the useful function of reducing concentrated loads of toxic substances, in addition to providing flexibility in applying quantities of effluent. Provide adequate storage for winter months in which effluent may not be applied, plus enough extra volume to allow for a wet spring and early summer. Investigate the feasibility of storing from a wet year for possible application the following year. Use the information on monthly irrigation deficits in various locations in Missouri, Table 2, Section IIIE1.

10. *Monitoring System*

Test the water quality of all wells in the area prior to starting the effluent disposal system for future reference. Design a monitoring system compatible with the specific site conditions as recommended in Section III D. Consult with the Clean Water Commission and the Missouri Geological Survey for more specific information.

11. *System Management*

All sprinkler and surface irrigation systems should be managed to eliminate runoff. Drying periods are desirable to maintain soil structure, facilitate crop harvest, and foster aerobic conditions to break down organic materials and kill bacteria. However, aerobic conditions can generally be maintained for applications of 2 inches per week or less. The amount per application

should be reduced on sandy soils to reduce leaching of nutrients. More than one application per week may be appropriate under these conditions.

A dense sod makes it possible to move machinery on the field shortly after a rain or irrigation but wet soil will delay hay drying. Hay conditioners will cut drying time in half. An annual yield of 5 to 8 tons of hay in three or four cuttings can be expected with the first cutting in the early part of May.

Chopping the forage as green chop or for silage has the advantage that less time is required in the field than for baling operations. Grass cut for silage may need to be wilted to a moisture content in the range of 70-80 percent. Hay is usually baled at about 15 percent unless drying facilities are available. Grass that is cut in the morning may be put up as silage late the same day or the following day. Grass intended for hay normally can be baled the second or third day after cutting and conditioning.

An alternative cropping system is to use a combination of corn and rye or wheat. This has the advantage of greater economic return than reed canarygrass or fescue. The nutrient and water removal capabilities of this system would not be expected to differ greatly from the grasses. If maximum nutrient removal is desired, remove the entire corn plant as silage. If maximum water usage is desired, harvest the corn for grain.

In either of these schemes, plant rye or wheat as soon as the corn is harvested. This should generally be before the middle of October in central or southern Missouri. This would probably require stalk shredding, disking, and drilling. Consider aerial seeding if the corn is not harvested by the middle of October. The purpose of the wheat or rye is for moisture removal. In the spring, plant the corn in the wheat, and mow the wheat 10 days to 2 weeks later, in order to kill the wheat. Plan this system so that the wheat is at the joint stage when mowed, and thus will be killed. This allows the wheat to take out the maximum amount of moisture. The wheat is mowed, and not removed from the field. The amount of nutrients in the wheat at this stage is not great, and a harvester would inflict damage on the stand of corn.

A key factor in managing any cropping system is to monitor the fertilizer needs of the crop through soil tests and plant tissue analysis. This is essential to insure that toxicities or nutrient deficiencies are not developing or existing. A cropping system's ability to remove particular nutrients is greatest if it is not restricted by other nutrient deficiencies.

For management of the soil-plant filter, the tests listed below are essential. Other analyses are useful in specific cases.

pH	TSS	TN	Boron
EC	TVS	NO ₃ -N	Cyanide
SAR	TP	NH ₃ -N	Fluoride

Potassium

Trace Element Spectrographic Analysis (Qual.)

For more information, see UMC Guide 9130, "Using Field Soil and Tissue Tests," (10) UMC Guide 9131, "Sampling Plant Tissue and Soil for Analysis," (68) UMC Guide 9100, "Computerized Interpretations of Soil Tests - A Guide for Liming and Fertilizing Missouri Soils," (9) and "Plant Tissue Soil Analysis Manual" (67).

12. Winter Operation of Effluent Disposal Systems

The operation of irrigation systems in the winter can be divided into two aspects. The first is conditions under which the system will operate without damage to the system. The second

is conditions under which the soil plant filter will provide renovation of the applied wastewater.

Freezing weather operation requires some special considerations in designing systems. The system must be designed and managed so that no effluent will freeze in the pipe or on the sprinklers. Any portion of the system subjected to freezing conditions should be installed so that it will drain quickly when shut off. A minimum grade of two percent on pipelines with adequate drains is desirable for quick draining in freezing weather.

Although conventional sprinklers have been used satisfactorily under freezing conditions, sprinkler heads designed for frost protection are best. Pennsylvania State researchers have developed a non-rotating sprinkler specifically for freezing conditions.

Operation of surface effluent disposal systems during freezing conditions would probably cause many problems, such as ice buildup on drop structures, gates. An ice buildup near the gated pipe may also affect the distribution pattern.

Winter application of effluent is likely to be more successful on wooded areas or permanent pastures. Frost formation in forest areas is primarily porous honeycomb or granular frost. Whereas the frost formed in cultivated fields is largely the very dense and impermeable concrete frost. Frost generally forms at least three weeks earlier and extends to a greater depth in cultivated areas compared to forest areas.

Some renovation of the wastewater is provided by the soil and is independent of the crop cover. Removal of some of the more mobile compounds such as nitrates, depends upon an active root system, and is greatly reduced in the winter months. The growth of the plants will depend in part on the temperature and available light.

If renovation due to plants is needed to provide an acceptable effluent from the soil plant filter, storage capacity for the winter months should be provided. If the system is to be operated during winter, nutrient removal for those nutrients not removed by the soil-plant filter may be required.

J. EQUIPMENT

1. Pipe and Piping Systems

When selecting the proper pipe material for an effluent disposal system a number of factors should be considered. These are:

1. Portable or stationary above ground or buried.
2. Corrosiveness of the effluent.
3. Pressure at which system will be operated.
4. Volume of water to be transported.
5. Economics.

In the choice of materials, one should remember that nutrients in the effluent may cause corrosion or electro-chemical deterioration. This deterioration will occur for 6 to 12 months each year when irrigating liquid wastes. The chemical strength of the wastes, especially agricultural and certain cannery or industrial wastes, is many times that of typical agricultural irrigation water.

Irrigation pipe may be classified in two categories: metallic and non-metallic. Metallic pipe consists of aluminum alloys and bare, galvanized or coated steel pipe. The non-metallic materials are asbestos cement pipe and extruded plastic pipe. Asbestos-cement and plastic pipe are considerably more resistant to chemical deterioration than either aluminum or steel pipe. Refer to Table 13 for characteristics of common pipe materials.

With most permanent systems, galvanized risers are used. Threaded outlet riser fittings are available for asbestos cement, solvent weld, and ring-tite pipe. Fittings are also available to inter-

TABLE 13. CHARACTERISTICS OF PIPE MATERIALS (78)

MATERIAL	ADVANTAGES	DISADVANTAGES	COUPLINGS	COMMENTS
Plastic	Low weight Easy to handle Installation is not difficult; pipe comes in long joints. Especially adaptable to permanent underground systems. Quite resistant to chemical deterioration.	Low mechanical strength; must therefore have thicker walls to contain pressure. Not suited to portable systems. Some plastics deteriorate in sunlight and high temperature. Pipe should not be laid on rocks; special backfill material may be needed.	Ring gasket is easy to install, allows for expansion, but requires thrust blocks. Solvent weld is more difficult to install, and forms a rigid connec- tion difficult to repair. Does not require thrust blocks in as many locations.	Polyvinylchloride, PVC and polyethylene, PE, are the most common plastic for irrigation pipe.
Asbestos-cement	Chemically resistant to most wastewaters; but subject to deterioration by strong acids. Adaptable to permanent underground systems.	Pipe is heavy and more difficult to install than plastic pipe. Not suited to portable systems because of weight.	Bell and gasket, with little end restraint. Concrete thrust blocks are needed, tees, ells, and end plugs to offset end thrust.	By adding asbestos fibers to a cement slurry, the tensile strength is in- creased to withstand high pressures.
Steel	Will generally withstand the maximum pressure of these materials. Adaptable to permanent systems.	Heavy, difficult to in- stall. Subject to chemical corrosion, and thus should be coated in- ternally and externally if used.	Welded or threaded couplings; difficult to install.	Schedule wall thickness pipe is used for well casing and small diameter threaded and couples permanent lines. Thin wall seam welded pipe is used for some perma- nent main lines
Aluminum	Light weight, easy to handle. Especially adapted to port- able, above-ground systems. High mechanical strength, easy to connect pipes.	Bare aluminum tubing is subject to corrosion by poor water quality. (Alclad aluminum pipe is more chemically resistant.) Not adapted to underground installation without coat- ing.	Portable pipe has bell and gasket, with fasteners for high pressures.	Available as extruded or roll formed, seam welded pipe.

connect asbestos cement, solvent weld, and ring-tite pipe and to connect either of these to steel pipe. Hydrants may also be installed in the line to connect portable aluminum laterals to underground main or supply lines. A flex or swing-joint is needed to connect the riser to the lateral line to reduce problems caused by freezing or physical damage. Risers should be of sufficient height to prevent interference of the nozzle stream by vegetation.

There are a number of different types of piping materials available to the irrigation industry. Due to their varying properties, several types may be combined to obtain the most economic system. Sufficient check and relief valves should be installed to protect the pipeline from hydraulic problems.

2. Solid Set Sprinkler Systems

Solid set sprinkler systems consist of enough pipe and sprinklers to cover the entire disposal area. As effluent disposal systems will be operated for several months during the year, solid set sprinklers are advantageous because of their low labor and maintenance requirements. This type of system will comprise the majority of municipally owned and operated systems.

The standard solid-set system is one in which the entire acreage to be irrigated is covered with pipe and sprinklers. However, as shown in Figure 5, during normal irrigation only a small portion (.05 to .20) of the acreage is irrigated at any one time. This allows the main, supply line, and pump and power unit to be smaller than if the entire acreage were irrigated at one time. Solid set systems can be cycled automatically to apply light, frequent applications of effluent. These light applications are less likely to produce runoff than heavier applications. In addition they allow time for the crop roots to remove nutrients before leaching occurs.

Permanent, Underground Systems

Two types of solid set systems are commonly used: permanent, underground systems, and above-ground systems. Permanent underground systems are well suited to most effluent disposal operations. The pipelines do not interfere with crop harvest and other cultural practice.

As the permanent system will not be moved, it is practical and economically desirable to use several sizes of pipe. Therefore, in designing a permanent system the designer starts at the last sprinkler on the lateral and designs back toward the main line, increasing the pipe size as the main line is approached. Friction loss in laterals and mains must be considered in permanent systems. The total sprinkler pressure variation in permanent systems, including elevation, should not exceed 20 percent between the sprinkler having the highest pressure and the sprinkler having the lowest pressure.

Sprinkler spacing is also important, because it is not economical to change spacing once a system has been installed. Excellent design is a must because these systems will be used for 25 or more years. Refer to Tables E-1, L-2, and L-3 in the Appendix to select sprinkler and lateral spacings. Reduce application rates to fit slopes, soils, and topography. Sprinkler and lateral spacings of 60 feet by 80 feet have been popular for grass and other croplands; 40 feet by 60 feet has been more popular for undertree sprinkler systems in woodlands. Refer to Table 3, Appendix L for the application rate for a particular spacing and sprinkler flow-rate.

In designing a permanent system, either the area or the lateral design system may be used. With the area system the design is such that an area of the field will be irrigated at one time. This normally means more than one lateral. The lateral design system is one in which individual

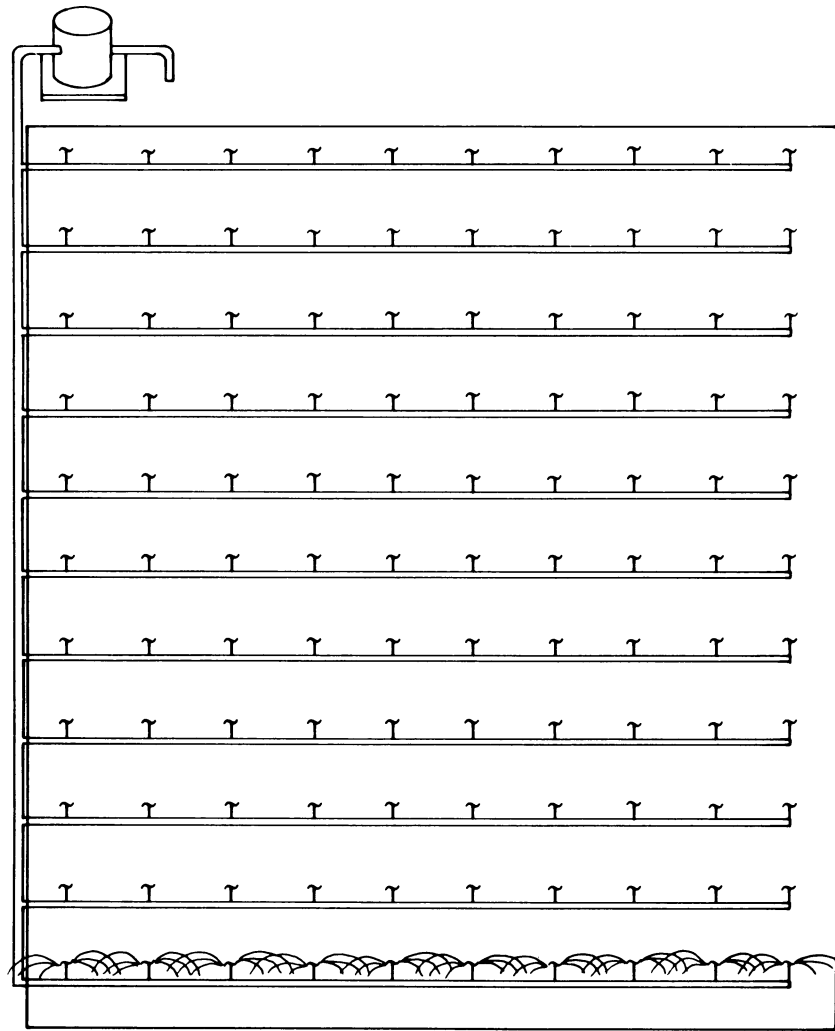


Figure 5. Solid-Set Sprinkler System, (only a portion of the system is operating at one time)

laterals are controlled by valves, and may be operated as desired. Normally, two or more laterals are operated simultaneously, but in widely separated areas of the field. Figures 6 and 7 show examples of designs using the area and the lateral design system. On rolling terrain, the pipe sizes would be adjusted for maximum uniformity of pressure. Some designers specify a mainline to the high point in the field, and then use smaller pipe sizes to control the pressure.

To keep permanent systems as inexpensive as possible, most are designed for application rates of approximately 0.2 inch per hour. As the application rate is increased, system costs increase rapidly. The labor required to operate a permanent system is opening and closing valves and minor maintenance, such as unstopping a plugged sprinkler nozzle and general supervision. Depending upon the system design, this will vary from 1/60 to 1/10 hour per acre per irrigation. Where permanent systems are used for row crops, narrow alleyways or rows may be left out where the laterals are located. This will create some minor inconvenience in cropping, and in controlling weeds. One approach is to remove the risers before preparing land, place a plug in the riser outlet and use a flag to mark the location of the riser outlet. After the land is

prepared, the risers are replaced. This will be time-consuming on a large acreage, but is satisfactory on a small acreage. This may also be done for most harvest operations.

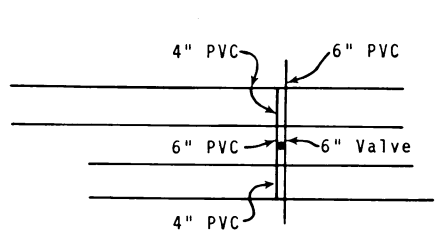
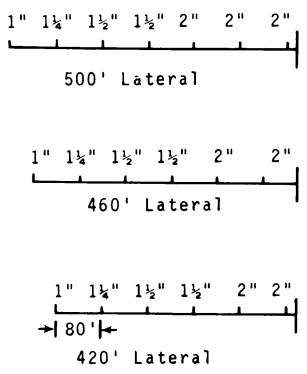
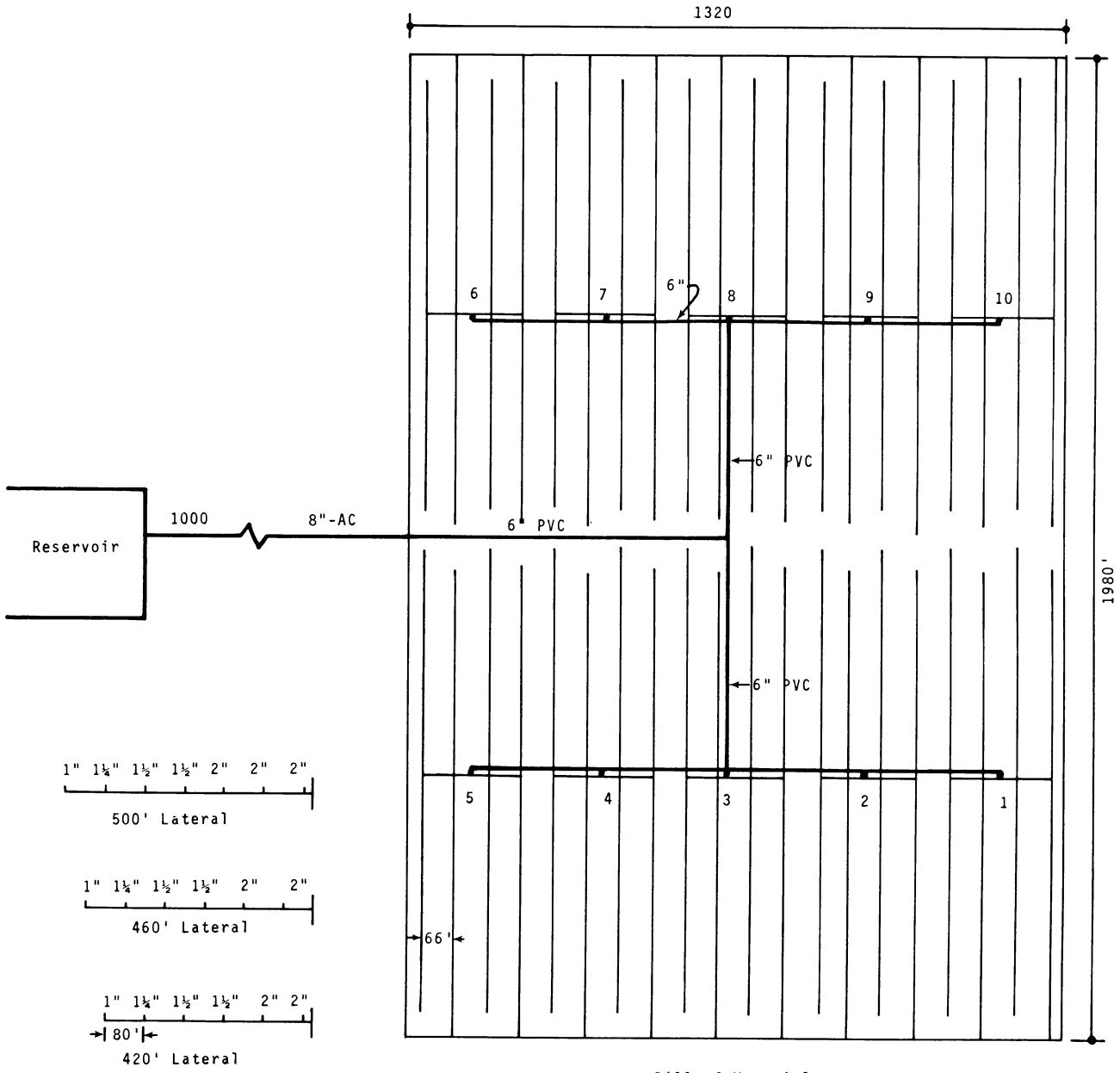
Above-Ground Solid Set Systems

Above-ground aluminum pipe systems can be used to good advantage in woodlands and other areas where underground installation is difficult. Install sprinklers in risers tall enough to spray effluent over the crop cover. The design of an above-ground solid set system is different from that of a permanent underground system. With the above-ground system it is not practical to use more than a couple of sizes of pipe in the lateral or main line.

An automated version of the above-ground solid-set system is the sequencing valve system. With this system, two variations are available. With one system a small one-inch valve is used with each sprinkler. Figure 8 gives an example of this system. Either 1¼ inch or 1½ inch laterals are used. When the system is started, the first sprinkler on each lateral starts to operate. After a specified operating time, these sprinklers stop; and the second sprinkler on each lateral starts to operate. This sequence continues until every sprinkler has operated. It is not necessary to have equal numbers of sprinklers on each lateral. The operation of this system is controlled by a timer which is connected to the pump and power unit. Either an electric motor or internal combustion engine may be used, but the automation is simplified with an electric motor system. Operating time per sprinkler can vary from approximately 15 minutes to 10 hours. The increased mechanical complexity of these systems makes them less desirable for effluent disposal.

The other variation of the sequencing valve system sequences the lateral line rather than individual sprinklers. This system uses hydraulic or electric valves.

The major advantages of the solid-set and permanent systems are their adaptability to any crop, soil type, terrain, and shape and size of field; low operational labor requirements; low application rate, and 24 hours per day operation. The major disadvantage is the relatively high initial cost compared with other systems. However, as effluent disposal systems will generally be operated many hours per year, the low labor requirement of these systems makes them very desirable. A major advantage of the low application rates is the ability to apply effluent on most soils under saturated conditions with no runoff, something generally not possible with systems such as the traveling gun and center pivot sprinkler.



Bill of Materials

1,000' - 8"-AC	12,800' - 1 1/2" PVC
4,440' - 6"-PVC	6,400' - 1 1/4" PVC
1,320' - 4"-PVC	6,400' - 1" PVC
12,000' - 2"-PVC	10 - 6" Gate Valves

510 Risers and Sprinklers (9.2 GPM at 60 PSI)
 Pump and Power Unit (525 GPM at 85 PSI)

Figure 6. Permanent Solid-Set System Using Area Design

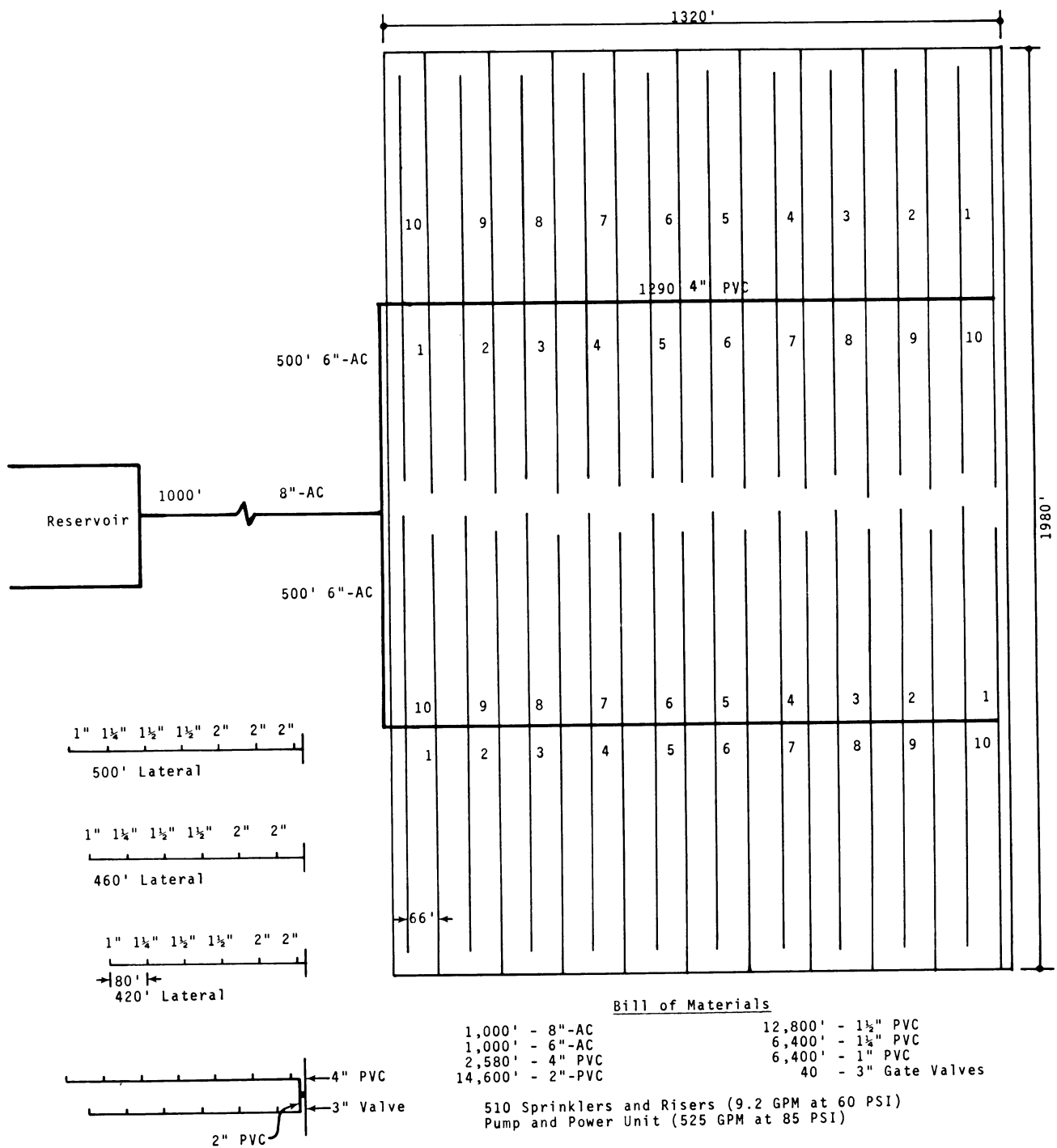


Figure 7. Permanent Solid Set System Using Lateral Design. (Two laterals will be operated from each valve. The 4 sets of laterals marked 1 will be operated simultaneously, then those marked 2 will be operated, etc. through 10.)

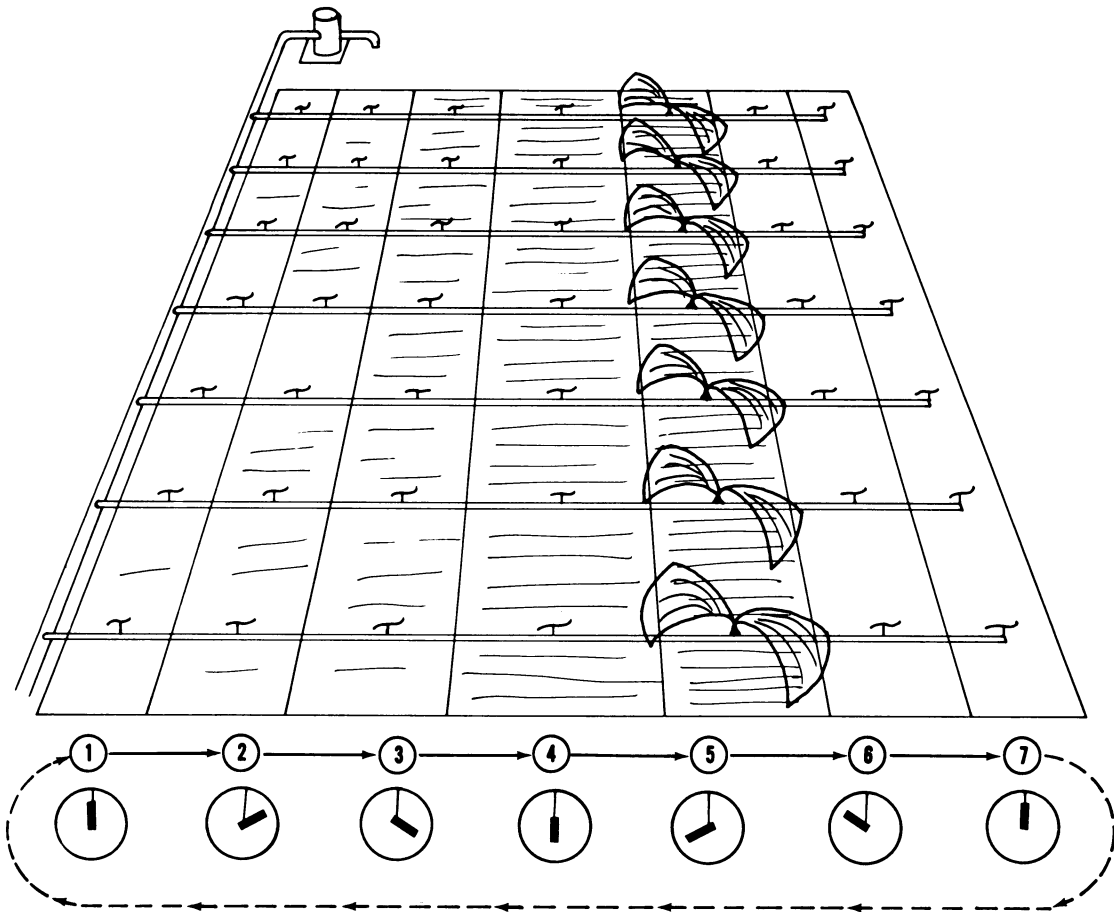


Figure 8. Sequencing Valve Solid-Set System. (This is an automatic system, with the operation being controlled by a time clock.)

3. Center Pivot Sprinkler Systems

In addition to the solid set sprinkler system, consider the center pivot sprinkler system has special merit for effluent disposal. These systems generally have a lower initial cost per acre, but higher labor and maintenance cost than solid set systems. Center pivot systems are low enough in cost for many farmers to consider them for irrigating various crops with sewage effluent.

The center pivot sprinkler system consists of main pipeline suspended above the crop by towers. The pipe has sprinklers along its length, and rotates around the pivot location in a circle. The sprinklers on the mainline near the pivot point move over the field slower and cover less area than those on the outer end. The outer 1/4 of the sprinkler system covers 1/2 of the area. (See Figure 9.) Consequently, the sprinklers on the outer end have a higher capacity, and apply water at a faster rate to obtain a uniform depth of application throughout the field. The moving principle gives more uniform distribution patterns than stationary systems because the wind effects are greatly reduced.

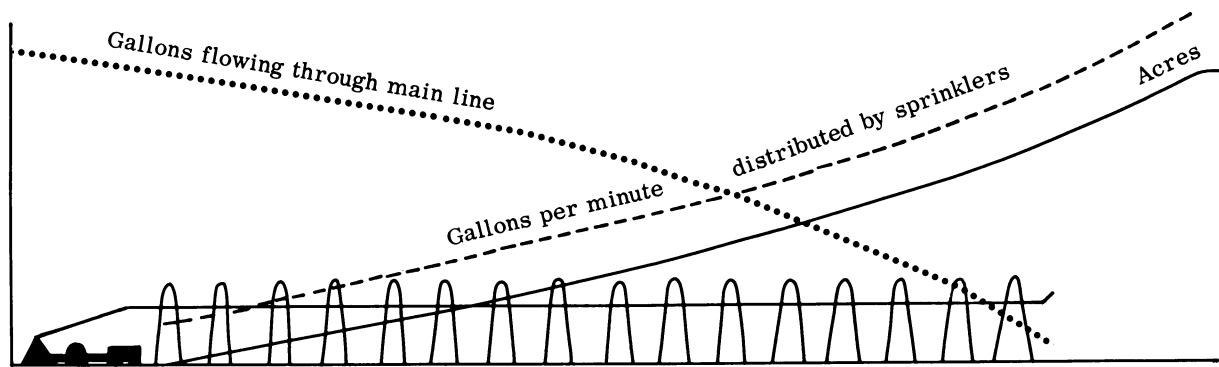


Figure 9. Gallons Per Minute and Acres, Center Pivot System

(More gallons of water must flow through the main line near the pivot, but fewer gallons are distributed in this area because fewer acres are being irrigated.)

Sprinkler Combinations

Many types of sprinkler combinations are being used for center pivot systems. One method is to select the large sprinklers for the system, the largest being on the outer end of the system. These large sprinklers require the highest operating pressure (80-85 psi at the pivot and 70 psi at the end gun), but produce the greatest wetted diameter. Thus, application rates are lower than with any other sprinkler configuration for a given length system and a given flow rate.

Another sprinkler configuration utilizes the same size of small sprinkler throughout the system, but spaces them closer together at the outer end. However, as the effective wetted diameter is decreased, application rates are significantly increased. A third sprinkler configuration now in use consists of small fogger nozzles which spray downward from the main line. Obviously this system would accentuate the above features: low operating pressure, very fine droplet size, small wetted diameter, but high application rates.

A variation of this system is presently being used for some wastewater disposal systems in Washington: spray nozzles are mounted to spray behind the system, decreasing traction problems and allowing operation during freezing temperatures. Perhaps the most important advantage of the small nozzle is reduced aerosol. It is apparent, however, that a combination of sprinkler sizes, application rates, droplet sizes, length of mainline, and type of management must be considered for each application.

Application Rates

Application rates (or rainfall intensity) are highest on the far end of the pivot system. See Figure 10).

Because each succeeding sprinkler head on the system must move farther and faster than the one before it, more water must be applied per foot of system length toward the far end. As this flow rate in gallons per minute per foot of system length increases faster than the wetted diameter of the larger sprinklers on the far end, application rates are greatest on the far end.

Runoff, erosion, and traction problems result when the water is applied at a rate exceeding the infiltration rate of the soil. Since the water comes down with greater force on the outer part of the circle than in the inner part of the circle, the outer area of the soil can become less penetrable as the season progresses.

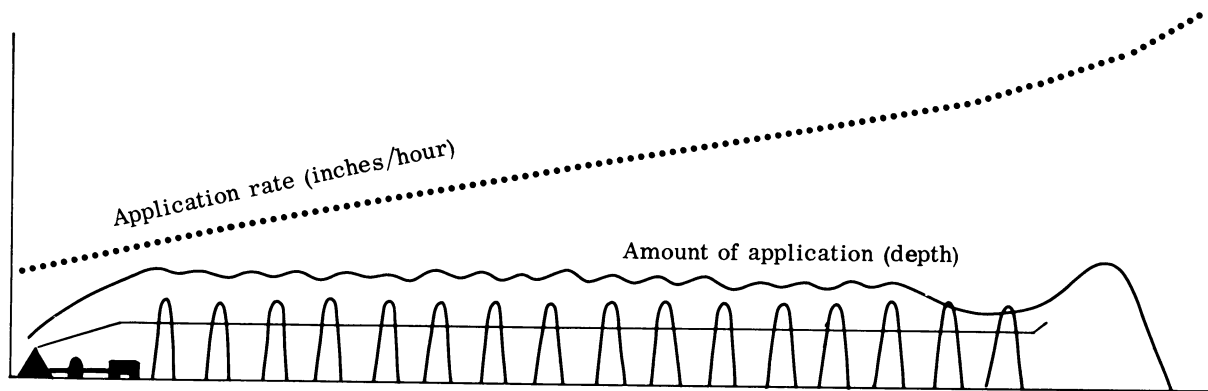


Figure 10. Application Rate and Depth, Center Pivot System

Limiting the length of the main line is one way to decrease this application rate. A 1280-foot system can irrigate 130 to 135 acres in a 160 acre square field. Seven to 17 towers would be needed to support such a system. A 1280-foot system that will cover 135 acres out of a square 160 field set for a 1000 gallons per minute capacity will have an application rate of approximately 1¼ inches per hour, using the large sprinkler combination.

The ability of soils to absorb *light* applications of water (1/3 to 1 inch) at a rate higher than their normal intake rates when saturated allows these systems to be used on these soils. Decreasing the flow rate of these systems also reduces application rates.

Correct Operating Pressure

Most fields can withstand relatively high application rates if the water can be applied throughout the season without destroying the soil structure or clogging the soil surface. High water pressure at the sprinkler nozzle is the best tool for maintaining soil structure under sprinkler irrigation. The correct pressure has two main functions: first, pressure increases the range and coverage of water droplets. Extra range and coverage allows more time for the water to soak into the soil.

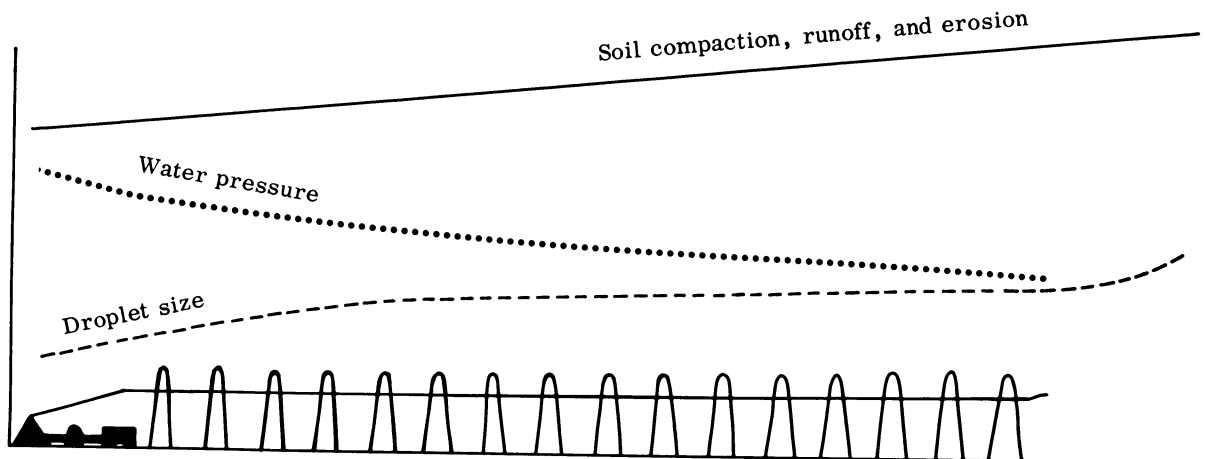


Figure 11. Pressure and Droplet Size, Center Pivot System

(Water pressure is necessary to produce small droplets which will not seal the soil surface. Water pressure drops along the main line of the system.)

The second function of water pressure is to reduce droplet size. A small water droplet has less momentum than a large droplet as it impacts on a soil particle. The result is to maintain a higher infiltration rate. Small droplets cause considerably less puddling and runoff than large droplets. Note the increase in droplet size toward the outer end of the system in Figure 11. Evaporation from small droplets is much less than might be expected—puddling, runoff, and erosion are usually more severe problems. Good results have been obtained from high pressure: 80 to 85 pounds per square inch at the pivot, and at least 70 psi at the end gun. This must be tied to sprinkler configuration.

Pipe Size

Pipe size is another factor to consider. Friction loss is greatest in small diameter pipes. Many companies are changing from the standard 6 inch diameter pipe to 6-5/8, 7 and 8 inch pipe. This results in lower operating costs, and higher operating pressures farther out on the pivot system.

Rotation Speed

The outside tower of a 1280-foot pivot system must travel about 1½ miles in one revolution. Increasing the speed of rotation results in a lighter application of water. Since changing the output of the pumping unit is difficult, the depth of application is most easily changed by adjusting travel speed. Faster speeds and lighter applications have special merit on heavier soils with low intake rates and waterlogging problem. Many systems have a speed range of 6 to 80 hours per revolution. This allows flexibility in managing the system.

Presently there are water-drive, electric-drive, oil-drive, and air-drive units on the market. The electric, oil, air, and some water drives are generally reversible. This is important if the field has obstacles which cannot be covered. Some companies indicate that their equipment can operate on slopes up to 20 percent. If hilly ground is to be irrigated, the system should have the flexibility, strength, and constant speed characteristics for those operating conditions. Systems are also available with steel wheels, rubber tires, and legs that walk.

Field Preparation

Field preparation is very important for center pivot systems. Pot holes should be drained or filled to avoid the system becoming stuck. Small ditches to be crossed may be filled, or small bridges constructed. Some designers have considered installing tracks or towers, or circular asphalt runways for the towers.

Center pivot systems can be moved from one pivot location to another, thus decreasing the cost per acre. This is generally not desirable for effluent disposal, however, because of labor requirements and the relatively large amount of effluent to be spread each year. See Table M-1, Appendix M, for labor requirements of this system.

Summary

Center pivot systems offer some real advantage for effluent disposal in Missouri. If properly designed and applied to each situation, these advantages include low labor requirements, relatively low costs compared with solid set systems, and excellent distribution uniformity. The new perma-lube and galvanizing features of some systems are positive measures to reduce maintenance and increase the life of these systems.

4. Traveling Gun Sprinkler Systems

Traveling gun sprinklers are quite popular for agricultural irrigation in Missouri, and can be used for effluent disposal. However, they probably, will be owned and managed by farmers because of their lower initial cost, higher labor requirements, and maintenance requirements compared with the solid set sprinkler system.

The traveling gun sprinkler system consists of a single large sprinkler mounted on a four-wheel trailer, pulled across the field by a cable winch. The cable winch is powered by an auxiliary engine, a water turbine, or water cylinder. Water is supplied to the unit through a high pressure, flexible irrigation hose.

This system generally requires from 15 to 20 hours of labor per application on 100 acres. This involves loading and moving aluminum pipe, installing earth anchors, and unreeling cable and flexible hose. Effluent disposal systems would probably be designed with underground mainline pipe, reducing this labor requirement to an hour or less per set. (10 hours labor to apply an application of effluent to 100 acres). Much of this work can be done from a tractor seat.

The diagram below indicates a typical field layout (63). As the self-propelled unit passes adjacent to the water supply outlet the hose forms an elongated "U" behind the unit. As the self-propelled unit proceeds along its travel path the hose is extended full length in the opposite direction from its original layout. The utilization in this way allows for continuous movement of twice the length of the hose, or 1,320 feet. Thus, one pass through a 40 acre field can be attained without stopping. A hose reel is usually used to move the hose from one setting to another.

Select a sprinkler with adequate capacity for the purpose intended. The application rate of this sprinkler should not be greater than that of the soil's intake capabilities based on available information and field observations. These traveling units range in capacity from 50 to 1500 gallons per minute. The most popular size has a capacity of 500 to 600 gpm. The application rate in inches per hour depends only on the size of sprinkler and operating pressure. Travel speed is varied to apply different depths of water. Sprinkler trajectory angle, type of nozzle, and lane spacing should all be matched to local conditions.

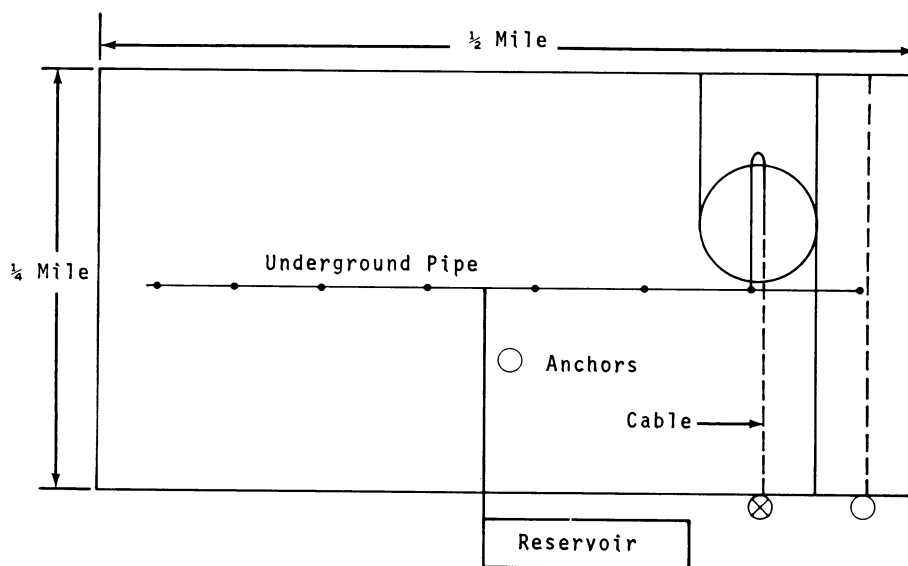


Figure 12. System Layout for a Traveling Gun Sprinkler System

The traveling gun sprinkler system adapts to a wide range of irrigation and disposal situations, with a labor requirement that is acceptable for most farming enterprises. Fields with rolling topography, odd shapes, shallow soils, and sandy soils can be readily irrigated. For municipal sewage disposal system, the life of the system and its components, labor requirements, and operating costs should be carefully evaluated. Because of labor requirements, these systems are generally more adapted to a farmer-owner than a city owned and managed operation.

5. Other Sprinkler Systems

Hand-carry Portable Sprinkler Systems

Hand-carry sprinkler systems consist of a main line laid out from the effluent source to the field, and one or more laterals with sprinklers to irrigate a portion of the field. Laterals are moved by hand. They have high labor requirements, and thus are not in common use. Their ability to irrigate small acreages, adaptability to diverse topography, and the availability of used systems offer advantages for a farmer who wants to irrigate a small acreage with effluent. A version of this system uses hand-moved gun sprinklers. This reduces labor somewhat, but has a poor distribution pattern.

Towline Sprinkler System (End-Tow Lateral)

The towline system saves labor by enabling the towline to be towed from one set to another by a tractor. These systems generally have a lower initial cost and operating cost than traveling sprinkler systems. Underground mainline pipe may be used, the mainline pipe may be disconnected for each move, or the mainline may be laid in a shallow V-ditch. The latter enables the operator to cross the mainline pipe, and is quite popular. A short (10-15') flexible hose is used to connect the lateral to the main line. Towline systems are often designed for laterals spaced 60 feet apart, with sprinklers spaced 40 feet apart on the lateral.

Side-Roll Lateral Sprinkler Systems

To decrease the amount and intensity of labor required, the lateral sprinkler line has been placed on wheels. The pipe is the axle with the wheels usually spaced 30 feet apart and the sprinklers midway between. Wheels are available in different diameters with the larger wheel used for the maximum clearance.

The operation of the side-roll lateral is similar to that of the hand-move system. The lateral line is moved between sets by rolling the wheels. The move is usually powered by a small internal combustion engine located at one end or in the middle of the mainline. After completing the field, the system is rolled back to the start.

6. Gated Pipe and Other Surface Systems

Surface effluent disposal systems here will refer to surface irrigation systems designed for percolation into the soil profile rather than renovation of effluent by passing it through a grassed area. The grass filter concept was discussed in the section on the overland flow system. The reason for this approach is that the surface effluent disposal systems are generally less adapted to providing the light, uniform application of effluent into a grass cover needed for an efficient overland flow system.

Consequently, for these systems, either of two schemes will be proposed:

(1) A municipally-owned and operated system in which effluent disposal is the primary purpose. To utilize the available land most fully, a tailwater (runoff) pit and automatic return pumping unit shall be installed. This enables the system operator to apply a fairly uniform application the entire length of run, without runoff.

(2) A system operated for irrigation of crops (probably owned by a farmer). The latter system would generally apply 4 to 8 inches per year. With careful management, a system such as this can be operated with insignificant runoff.

Three types of surface irrigation are suited to disposal of effluent: *border irrigation*, *furrow irrigation*, and *contour levees*.

Because the pressure is needed only to pump water into the pipe on the ground, these are low pressure systems, with corresponding low operating cost and horsepower requirements.

Effluent can be supplied to the disposal field for the first two systems with gated pipe, usually aluminum or plastic. Semirigid plastic gated pipe is less subject to corrosion than aluminum. Gated pipe is usually 6" to 10" in diameter, with adjustable spigots or gates installed every 30 to 80 inches.

Border Irrigation

Border irrigation consists of low parallel soil ridges constructed in the direction of the maximum slope of the field. The ridges or borders, are spaced from 30 feet to 100 feet apart. Forages, pasture, and other close growing crops can be irrigated with a border system on slopes up to 3 percent.

Uniform water distribution depends on a sheet of water passing down through the border, with a depth of from 3 to 5 inches. Consequently, the fall between berms should not exceed 0.2 foot. Because of this limitation, border irrigation requires an even, gently sloping field, either naturally or through land grading. Berms may be constructed with a border maker, a road maintainer, or a rear blade behind a tractor.

Lengths of run for border irrigation should not exceed 1320 feet, and should be less for slopes exceeding 0.5 percent to reduce erosion and improve uniformity of distribution.

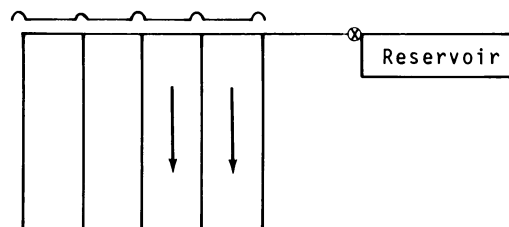


Figure 13. Border Irrigation Layout, Top View

Furrow Irrigation

Irrigation with furrows provides relatively uniform distribution of waste waters for row crops. Furrow irrigation is generally not recommended on fields steeper than 1 percent. Often some land grading is required for good water distribution.

The row crop may be planted on ridges, or the furrows may be constructed with disc or middlebuster furrow openers. Furrow flow rates should not exceed the carrying capacity of the furrow nor cause erosion. See UMC Guide 1641, "Land Grading for Irrigation, Design and Construction," for recommended lengths of run, slopes, and furrow flow rates.

Contour Levee Effluent Disposal

Contour levee irrigation requires a gently sloping field, either naturally or through land grading. Small ridges or contour levees are constructed through the field on a vertical interval of not more than 0.3 feet. Land grading facilitates straight borders, constructed perpendicular to the general land slope. This eliminates the need for winding contour levees on non-graded fields and subsequent harvest complications. Contour levees constructed on fields with a slope greater than 0.6 percent generally result in an excessive number of ridges, spaced close together.

A contour levee system is shown in Figure 14. Small drop structures are used to let the water from one ridge down to the next.

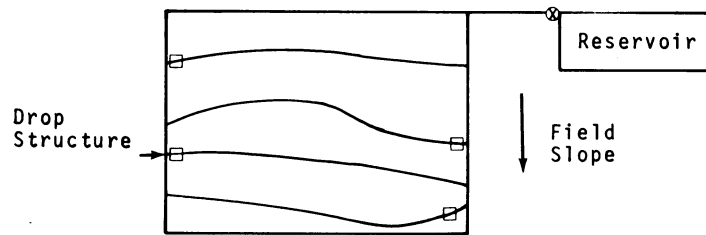


Figure 14. Contour Levee System Layout

Surface Effluent Disposal System Automation

The technology now exists for automation of surface effluent disposal systems. Using a combination of underground pipe, a "solid set" pipe system, and electric or pneumatic valves, labor requirements can be reduced to occasional checking and calibration. Times and float switches located at strategic locations complete the equipment list.

Contour levee systems can be semi-automated by installing drop structures that can be tripped by an electrical signal. A float and timer combination can actuate the drop structure.

PART IV.

Effluent Disposal Systems: Cost and Return Analysis

Economic studies have been made on effluent disposal (46). To determine comparative costs of various systems on a particular site, both annual ownership and operating costs must be obtained. Refer to UMC Guide 1690-1693, "Irrigation Cost and Return Analysis," for a step-by-step procedure. Estimates of the useful life of system components are helpful when selecting the optimum system to fit local conditions. UMC Guide 1691, "Irrigation Cost and Return Analysis: Annual Ownership Costs," (65) provides a table indicating the expected life of irrigation equipment under normal agricultural irrigation.

Adjust this information to fit local conditions as needed. For example, some centrifugal pumps designed specifically for continuous industrial use will last longer than some less expensive pumps designed for agricultural irrigation. Annual hours of pumping and quality of maintenance affect the life of power units and pumps. Life of a gear head or belt drive depends on quality of the materials, amount of use, and normal deterioration.

Aluminum pipe has been known to last less than 5 years when installed in a non-draining disposal system for sewage effluent. Expected life of center pivot systems depends, in part, on sturdiness of system components, thickness of parts, and type of protective coating (if applied). Some companies guarantee all galvanized parts for ten years.

Five different effluent disposal systems were compared on the basis of ownership costs and operating costs (64). Each system was designed to apply 24 inches of effluent per year on a selected total acreage to that system. A pumping rate was selected for each system that allowed for winter storage, rainy periods, and maintenance time. The effluent source was assumed to be 2000 feet from the edge of the disposal area. Table 14 gives a summary of this analysis.

Information in Table 15 does not include cost of primary and secondary treatment. The authors further observed that an economy of scale is highly dependent on the soil, cost of land, distance to the disposal area, and several other factors.

The cost and return worksheet on the following page is useful in estimating income and costs. To determine the added economic value of the fertilizer nutrients in the effluent, use the formula 1 p.p.m. = 0.227 per acre-inch of effluent. Multiply the pounds per acre-inch times the total annual application, and the price of that particular element.

TABLE 14. EFFLUENT DISPOSAL COST ANALYSIS OF FIVE SYSTEMS*

Type of System	System Size, Acres	Initial Cost Per Acre	Annual Ownership Cost Per Acre ²	Annual Operating Cost Per Acre-Inch ³
1. Solid Set Sprinkler System	100	\$1064	\$110.73	\$.50
2. Large Center Pivot Sprinkler System ⁴	135	\$ 220	\$ 28.11	\$.49
3. Small Center Pivot Sprinkler System ⁴	35	\$ 535	\$ 72.34	\$.58
4. Traveling Gun Sprinkler System	100	\$ 237	\$ 37.27	\$.72
5. Gated Pipe System with Tailwater Return	100	\$ 215	\$ 28.18	\$.48
Average		\$ 364.82	\$ 55.33	\$.55

*System comparisons based on applying 24 inches per year¹

¹These annual costs may be reduced by the net income from the crop irrigated by the effluent.

²Annual ownership costs were calculated on the assumed useful life of each system: solid set, 20 years; center pivot system, 14 years; traveling gun system, 10 years; traveling gun hose, 4 years; and gated pipe, 12 years.

³Operating costs include labor at \$3.00 per hour. The variability of labor costs affect installation and operating costs greatly. Labor requirements of various systems are given on Table N-1.

⁴The 135 acre and 35 acre center pivot system are the maximum sizes that can operate on 160 and 40 acre fields respectively.

TABLE 15. COSTS OF DISPOSAL SYSTEMS ACCORDING TO MUNICIPALITY POPULATION*

Number of Systems	Number of People in the Municipality	Cost Per Person, \$
7	< 2000	\$113-520
8	2001 - 8000	\$ 43-215
5	> 8000	\$112-235

*Williams and Works, a consulting firm in Michigan, collected this data from effluent disposal systems.

SAMPLE WORKSHEET FOR FESCUE OR REED CANARYGRASS HAY PRODUCTION

Size and Description of production: 40 Acres harvested as often as needed but usually about three times annually.

CAPITAL REQUIRED/ACRE			This project¹
Land/Acre-purchase cost			\$ <u>300</u>
	Range²	Average	
Seed bed preparation	\$ <u>6</u> to <u>16</u>	<u>8</u>	<u>10</u>
Seed & seeding	\$ <u>3</u> to <u>6</u>	<u>4</u>	<u>5</u>
Other	\$ <u> </u> to <u> </u>	<u> </u>	<u> </u>
Total/Acre	<u>9</u> to <u>22</u>	<u>12</u>	<u>315</u>
Total Capital Required for Project			\$ <u>12,600</u>

ANNUAL COSTS AND RETURNS

Gross Receipts/Acre

Yield, Tons/ Acre	<u>3</u> to <u>6</u>	<u>4 1/2</u>	<u>4 1/2</u>
Price/Ton	\$ <u>15</u> to <u>30</u>	<u>20</u>	<u>22</u>
Gross Receipts	\$ <u>45</u> to <u>180</u>	<u>90</u>	<u>99</u>

Harvesting Costs³

	<u>\$/acre/cutting</u>	<u>\$/ton/cutting</u>	<u>\$/bale/cutting</u>
Mow and Condition	3.00	1.50 ⁴	0.044
Rake	1.50	.75 ⁴	0.022
Bale	8.00	4.00	0.12
Haul and Store	10.20	5.10 ⁵	0.15
Field Chop	10.50	\$2.00	----
Field Chop, Haul, and Fill Silo	21.00	\$3.25	----

This project (three cuttings, chopped, hauled and put in silo): 21 X 3 = 63

Other costs/acre	<u> </u>	<u> </u>	<u> </u>
Gain	Range²	Average	This project
Net gain/Acre	\$ <u>15</u> to <u>90</u>	<u>30</u>	<u>36</u>
	Number of acres		<u>40</u>
	NET ANNUAL GAIN FOR PROJECT		\$ <u>1,440</u>

¹Select data that fits this particular project based on local costs.

²See UMC Guide #302, Farm Custom Rates in Missouri. (5)

³All harvest costs based on most commonly used custom rates

⁴Based on 2 ton per acre yield

⁵Based on 2 ton per acre yield and 34 bales per ton

PART V.

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Appendices

VI. APPENDIX A: REPRESENTATIVE ANALYSES OF MUNICIPAL SEWAGE EFFLUENT IN MISSOURI

The Clean Water Commission field unit collected the samples on November 11-12, 1971. Samples were composited and/or sub-sampled so that two samples per site resulted. One sample was analyzed in the Clean Water Commission Laboratory, Jefferson City, and the other by the Department of Agricultural Chemistry's Spectrographic Laboratory, University of Missouri-Columbia.

Spectrographic analysis was done by emission spectrograph without standards added. Emission line densities were compared for each element. Those which appeared in highest concentration were analyzed for by a quantitative procedure.

Table A1. Missouri Effluent Quality Survey
Mean Values of Effluent Quality and Results from the Big Piney Watershed

Parameter	Mean of 3				Cabool Lagoon	Cabool Lagoon	Cabool Lagoon	Houston			Licking Lagoon
	Mean of 90 Lagoons	Mean of 12 Trickling Filter Plants	Mean of 3 Activated Sludge Plants	Contact Stabilization Plants				Polishing Lagoon	Houston Plant		
O-PO ₄ as P mg/L	5.4	7.7	5.4	7.6	1.5	7.5	3.3	8.5	16.5	6.0	
T-PO ₄ as P mg/L	11.3	16.5	9.6	11	3.5	9.5	4.5	10.0	18.0	8.0	
NO ₃ -N mg/L	0.3	1.5	0.3	0.7	0.4	0.2	0.2	0.5	0.1	0.2	
NH ₃ -N mg/L	5.1	17.9	23.5	7.0	15	5.6	6.0	20	60	13	
BOD mg/L	44	46	44	25	82	70	28	24	65	20	
COD mg/L	123	93	98	50	220	110	190	60	170	95	
F ⁻ mg/L	< 0.1	0.1	0.5	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	
Cl ⁻ mg/L	69	135	157	256	290	200	184	146	156	108	
SO ₄ mg/L	60	90	81	64	< 10	< 10	11	28	45	< 10	
Fe ⁺⁺ mg/L					< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	
Na ⁺ mg/L	42	63	29	63	29	90	80	80	130	90	
K ⁺ mg/L	16.2	16.2	24.1	18.1	10	8	5	4.5	23	6.5	
Ca ⁺⁺ mg/L					170	144	144	172	272	166	
Mg ⁺⁺ mg/L					142	104	120	140	116	90	
B μg/L					20	60	110	260	350	200	
Pb μg/L					3	4	4	5	10	4	
Cr μg/L					3	3	2	3	890	1	
Conductance μmhos/cm	800	800	900	1200	700	600	700	850	1100	650	
SAR					0.40	1.39	1.19	1.10	1.63	1.40	

Lagoon Samples were grab samples, plant samples were 24-hour composite samples.
Analysis by Missouri Clean Water Commission Laboratory and University of Missouri, Department of Agricultural Chemistry Laboratory.

APPENDIX B: CHARACTERIZATION OF INDUSTRIAL WASTE WATERS

TABLE B1. SOME SIGNIFICANT CONSTITUENTS OF INDUSTRIAL WASTEWATERS (8)

Chemical	Industry
Acetic acid	Acetate rayon, pickle and beetroot manufacture.
Alkalis	Cotton and straw kiering, cotton manufacture, mercerizing, wool scouring, laundries.
Ammonia	Gas and coke manufacture, chemical manufacture.
Arsenic	Sheep-dipping, fell mongering.
Chlorine	Laundries, paper mills, textile bleaching.
Chromium	Plating, chrome tanning, aluminum anodizing.
Cadmium	Plating
Citric acid	Soft drinks and citrus fruit processing.
Copper	Plating, pickling, rayon manufacture.
Cyanides	Plating, metal cleaning, case-hardening, gas manufacture.
Fats, oils, grease	Wool scouring, laundries, textiles, oil refineries.
Fluorides	Gas and coke manufacture, chemical manufacture, fertilizer plants, transistor manufacture, metal refining, ceramic plants, glass etching.
Formalin	Manufacture of synthetic resins and penicillin.
Hydrocarbons	Petrochemical and rubber factories.
Hydrogen peroxide	Textile bleaching, rocket motor testing.
Lead	Battery manufacture, lead mining, paint manufacture, gasoline manufacture.
Mercaptans	Oil refining, pulp mills.
Mineral acids	Chemical manufacture, mines, iron and copper pickling, DDT manufacture, brewing, textiles, photoengraving, battery manufacture.
Nickel	Plating.
Nitro comp.	Explosives and chemical works.
Organic acids	Distilleries and fermentation plants.
Phenols	Gas and coke manufacture, synthetic resin manufacture, textiles, tanneries, tar, chemical and dye manufacture, sheep-dipping.
Silver	Plating, photography.
Starch	Food textile, wallpaper manufacture.
Sugars	Dairies, foods, sugar refining, preserves, wood process.
Sulfides	Textiles, tanneries, gas manufacture, rayon manufacture.
Sulfites	Wood process, viscose manufacture, bleaching.
Tannic acid	Tanning, sawmills.
Tartaric acid	Dyeing; wine, leather and chemical manufacture.
Zinc	Galvanizing, plating, viscose manufacture, rubber process.

TABLE B2. SUMMARY OF INDUSTRIAL WASTE: ITS ORIGIN, CHARACTER, AND TREATMENT (8)

Industries Producing Wastes	Origin of Major Wastes	Major Characteristics	Major Treatment and Disposal Methods
Food and drug: Canned goods	Trimming, culling, juices, and blanching of fruits and vegetables	High in suspended solids, colloidal and dissolved organic matter	Screening, lagooning, soil absorption or spray irrigation
Dairy products	Dilutions of whole milk, separated milk, buttermilk, and whey	High in dissolved organic solids, mainly protein, fat, and lactose	Biological treatment, aeration, trickling filtration, activated sludge
Brewed and distilled beverages	Steeping and pressing of grain, residue from distillation of alcohol, condensate from stillage evaporation	High in dissolved organic solids, containing nitrogen and fermented starches or their products	Recovery, concentration by centrifugation and evaporation, trickling filtration, use in feeds
Meat and poultry products	Stockyards, slaughtering of animals, tending of bones and fats, residue in condensates, grease and wash water, picking of chickens	High in dissolved and suspended organic matter, blood and other products and fats	Screening, settling and/or trickling filtration
Beet sugar	Transfer, screening and juicing waters, draining from lime sludge, condensates after evaporator, juice, extracted sugar	High in dissolved and suspended organic matter, containing sugar and protein	Reuse of water, coagulation and lagooning
Pharmaceutical products	Mycelium, spent filtrate, and wash water	High in suspended and dissolved organic matter, including vitamins	Evaporation and drying; feeds
Yeast	Residue from yeast filtration	High in solid (mainly organic) and BOD	Anaerobic digestion, trickling filtration
Pickles	Lime water, brine, alum and tumeric, syrup, seeds and pieces of cucumber	Variable pH, high suspended solids, color and organic matter	Good housekeeping, screening, equalization
Coffee	Pulping and fermenting of coffee bean	High BOD and suspended solids	Screening, settling, and trickling filtration
Fish	Rejects from centrifuge, pressed fish, evaporator and other wash water wastes	Very high BOD, total organic solids, and odor	Evaporation of total waste, large remainder to sea
Rice	Soaking, cooking, and washing of rice	High in BOD, total and suspended solids, (mainly starch)	Lime coagulation, digestion

Soft drinks	Bottle washing, floor and equipment cleaning, syrup storage-tank drains	High pH, suspended solids and BOD	Screening, plus discharge to municipal sewer
Apparel:			
Textiles	Cooking of fibers, desizing of fabric	Highly alkaline, colored, high BOD and temperature, high suspended solids	Neutralization, chemical precipitation, biological treatment, aeration and/or trickling filtration
Leather goods	Unhairing, cooking, delining and baking of hides	High total solids, hardness, salt, sulfides, chromium, pit precipitated lime and BOD	Equalization, sedimentation, and biological treatment
Laundry trades	Washing of fabrics	High turbidity, alkalinity, and organic solids	Screening, chemical precipitation, flotation, and adsorption
Chemicals:			
Acids	Dilute with water, many varied dilute acids	Low pH, low organic content	Upflow or straight neutralization, burning when some organic matter is present
Detergents	Washing and purifying soaps and detergents	High in BOD and saponified soaps	Flotation and skimming, precipitation with CaCl ₂
Cornstarch	Evaporator condensate, syrup from final washes, water from "bottling up" process	High BOD and dissolved organic matter, mainly starch and related material	Equalization, biological filtration
Explosives	Washing TNT and guncotton for purification, washing and pickling of cartridges	TNT, colored, acid, odorous, and contains organic acids and alcohol from powder and cotton, metal, acid, oils, and soaps	Flotation, chemical precipitation, biological treatment, aeration, chlorination of TNT, neutralization
Insecticides	Washing and purification products such as 2, 4D and DDT	High organic matter, benzene ring structure, toxic to bacterial and fish, acid	Dilution, storage activated carbon adsorption, alkaline chlorination
Phosphate and phosphorous	Washing, screening, floating rock, condenser bleed-off from phosphate reduction plant	Clays, slimes and tall oils, low pH, high suspended solids, phosphorus, silica and fluoride	Lagooning, mechanical clarification, coagulation and settling of refined waste
Formaldehyde	Residues from manufacturing synthetic resins, and from dyeing synthetic fibers	Normally has high BOD and HCHO, toxic to bacteria in high concentrations	Trickling filtration, adsorption on activated charcoal

TABLE B2 (Continued)

Industries Producing Wastes	Origin of Major Wastes	Major Characteristics	Major Treatment and Disposal Methods
Materials:			
Pulp and paper	Cooking, refining, washing of fibers, screening of paper pulp	High or low pH, colored; high suspended, colloidal, and dissolved solids, inorganic fillers	Settling, lagooning, biological treatment, aeration, recovery by-products
Photographic products	Spent solutions of developer and fixer	Alkaline, contains various organic and inorganic reducing agents	Recovery of silver, plus discharge of wastes into municipal sewer
Steel	Coking of coal, washing of blast-furnace flue gases, and picking of steel	Low pH, acids, cyanogen, phenol, ore, coke, limestone, alkali, oils, mill scale, and fine-suspended solids	Neutralization, recovery and reuse, chemical coagulation
Metal-plated	Stripping of oxides, cleaning and plating of metals	Acid, metals, toxic, low volume, mainly mineral matter	Alkaline chlorination of cyanide, reduction and precipitation of chromium and lime precipitation of other metals
Iron-foundry products	Washing of used sand by hydraulic discharge	High suspended solids, mainly sand; some clay and coal	Selective screening, drying of reclaimed sand
Oil	Drilling muds, salt, oil and some natural gases, acid sludges and miscellaneous oils from refining	High dissolved salts from field, high BOD, odor, phenol, and sulfur compound from refinery	Diversion, recovery, injection of salts, acidification and burning of alkaline sludges
Rubber	Washing of latex, coagulated rubber, exuded impurities from crude rubber	High BOD and odor, high suspended solids, variable pH, high chlorides	Aeration, chlorination, sulfonation, biological treatment
Glass	Polishing and cleaning of glass	Red color, alkaline nonsettleable suspended solids	Calcium chloride precipitation
Naval stores	Washing of stumps, drop solution, solvent recovery, and oil recovery water	Acid, high BOD	By-products recovery, equalization, recirculation and reuse, trickling filtration
Energy:			
Steam power	Cooling water, boiler blowdown coal drainage	Hot, high volume, high inorganic and dissolved solids	Cooling by aeration, storage of ashes, neutralization of excess acid wastes

Coal processing	Cleaning and classification of coal, leaching of sulfur	High suspended solids, mainly coal; low pH; high H_2SO_4 and $FeSO_4$	Settling, froth, drainage control, and scaling of mines
Nuclear power	Processing ores, laundering of contaminated clothes, research-lab wastes, processing of fuel, power-plant cooling waters	Radioactive elements, can be very acid and hot	Concentration and containing or dilution and dispersion

APPENDIX C: RECOMMENDED EFFLUENT ANALYSES FOR PLANNING SYSTEMS

TABLE C1. RECOMMENDED EFFLUENT ANALYSES TO MAKE WHEN PLANNING AND DESIGNING EFFLUENT IRRIGATION SYSTEMS

Total Solid	Sodium
Total Volatile Solid	Calcium
Total Suspended Solid	Magnesium
Volatile Suspended Solid	Potassium
B.O.D.	Iron
C.O.D.	Sulfate
pH	Chloride
Total N	Fluoride
NH ₃ -N	Boron
NO ₃ -N	Cyanide
Total P	Metal Analysis
Ortho-P	Chlorine Demand
Electrical Conductivity	Fecal Coliform
	Fecal Streps
	Spectrographic Qualitative Trace

TABLE C2. TRACE ELEMENT TOLERANCES FOR IRRIGATION WATER*

Element	*For continuous use - all soils	**For short term use - fine textured soils
	ppm	ppm
Aluminum	1.0	20.0
Arsenic	1.0	10.0
Beryllium	0.5	1.0
Boron	0.75	2.0
Cadmium	0.005	0.05
Chromium	5.0	20.0
Cobalt	0.2	10.0
Copper	0.2	5.0
Fluorine	***	***
Iron	***	***
Lead	5.0	20.0
Lithium	5.0	5.0
Manganese	2.0	20.0
Molybdenum	0.005	0.05
Nickel	0.5	2.0
Selenium	0.05	0.05
Tin	***	***
Tungsten	***	***
Vanadium	10.0	10.0
Zinc	5.0	10.0

*Water Quality Criteria - Report of National Technical Advisory Committee to Secretary of the Interior. 1968 (95)

*These tolerance levels were developed for western states, in which most or all of the crop water requirement is met by irrigation.

**Short term use refers to time periods as great as 20 years.

***No limits proposed.

APPENDIX D: VACUUM LYSIMETER, DESCRIPTION AND SPECIFICATIONS

A vacuum lysimeter consists of a porous ceramic cup (1-7/8 inches O.D. x 2-7/8 inches long) cemented into the lower end of a 1-7/8 inch O.D. plastic pipe. The pressure at which air will enter the moist porous cup is approximately one bar. The upper end of the plastic pipe is sealed with a 1-hole rubber stopper fitted with a short length of one-half inch diameter polyethylene tubing over which a short length of heavy-walled rubber tubing is fitted. In operation, a portable, hand-operated piston-pump is attached to the plastic pipe chamber. The chamber is evacuated to about 27 inches of mercury and is then closed by a screw clamp. The hydraulic gradient across the porous cup causes the water to flow into the chamber until the forces are balanced. To remove the sample, the screw clamp is opened, releasing the vacuum. Suction is applied through a suction flask to a length of polyethylene tubing inserted through the rubber tubing into the bottom of the chamber. The total volume of the sample is measured, and an appropriate subsample is used for chemical analysis. Vacuum lysimeter components are available as follows:

Porous cup: 3/32 inch wall thickness, Catalog No. 1910,
Soil Moisture Equipment Company
Box 30025
Santa Barbara, California 93015

Tubing for removing sample: 1/4 inch diameter x 1/16 inch wall thickness, polyethylene tubing, Catalog No. 9565-L77
A. H. Thomas Company
Vine Street at Third
P.O. Box 779
Philadelphia, Pennsylvania 19150

Stopper: two hole rubber, No. 10 size

Tubing for applying suction: 1/4 inch diameter x 1/8 inch wall thickness, black rubber tubing, Catalog No. 9545-R37,
A. H. Thomas Company

Clamps: Hoffman screw compression clamps, Catalog No. 2848B10,
A. H. Thomas Company

Tubing from ground surface to lysimeter: 1½ inch diameter PVC

Hand operated vacuum pump

APPENDIX E:

APPENDIX E: TABLE E-1. RECOMMENDED
DESIGN APPLICATION RATE REDUCTIONS FOR
VARIOUS SLOPES

Slope	Application Rate Reduction
0- 5 per cent grade*	0 per cent
6- 8 per cent grade	20 per cent
9-12 per cent grade	40 per cent
13-20 per cent grade	60 per cent
Over 20 per cent	75 per cent

*Grade = drop in feet per lineal feet.

*Reduce design application rate (inches/hours) for
sprinkler systems to correspond with the above values
to minimize runoff.

APPENDIX F: CHEMICAL TOXICITY LEVELS FOR PLANTS

Aluminum (A1)

Solubility of A1 in soils is determined by pH; as soil acidity falls below pH 5.0, A1 becomes progressively more active. A1 is an important natural constituent of soil.

TABLE F-2. TOXIC LEVELS OF ALUMINUM
IN SOLUTION CULTURE (7)

Crop	ppm Al (pH 4.5)
small grain	2
corn	1
timothy	2
bluegrass	1
redtop	14

The impact of A1 in sewage effluent upon plant growth would depend upon A1 concentration, pH, rate of application, species of plant and soil characteristics such as texture, organic matter content, and infiltration, and percolation rates which are dictated by profile characteristics.

Arsenic (As)

Arsenic normally does not accumulate in plants. Root growth is impeded as the As level of the soil increases to the point of complete death of root meristematic activity. In New Zealand, 3 to 7 ppm As in plant tissue was considered non-toxic to livestock. According to data presented by Chapman, (7) grasses generally are more tolerant of As than legumes. Vetch containing up to 16 ppm As showed no adverse symptoms.

Barium (BA)

Barium should not be toxic to plants unless the level of Ba in the soil exceeds the sum of Calcium and Magnesium.

Boron (B)

Boron tends to exist in the soil in the form of borate anion. Various borates at certain rates will sterilize the soil yet B is quite essential to plant growth. Species differ in their tolerances to B as illustrated by Chapman in Table F-2.

TABLE F-2. TOLERANCES OF DIFFERENT CROPS TO BORON

B sensitive	Semi-Tolerant	Tolerant
elm	small grain	sweet clover
blackberry	Ky. bluegrass	turnip
larkspur	corn	beet
cowpea	alfalfa	cotton
soybean		

Work at the University of Missouri Agricultural Experiment Station would cause us to place alfalfa with the tolerant group and cotton in the semi-tolerant.

Chapman reports that when irrigation water contains more than 0.75 ppm B toxic effect will occur on sensitive crops. Missouri work shows that an excess of 3 pounds of boron per acre per year will harm soybean plants, and that corn and grain sorghum will be damaged by 8 pounds of boron per acre per year, but alfalfa will tolerate up to 16 pounds. Repeated applications will build up in poorly drained soil thus the percolation capacity of the soil must be considered when evaluating the effect of B in irrigation water.

TABLE F-3. SOME REPRESENTATIVE PLANT LEVELS OF BORON (7)

Crop	Intermediate Levels	
	Normal ppm	concentrated ppm
barley	15-78	219
corn	5-72	72
cotton	187-305	522
oats	15-50	54
sunflower	12-150	---
sweet clover	58-665	602

Chlorine (Cl)

The form of chlorine involved in soil and water work is chloride (an anion). The chloride anion is soluble and does not readily react with soil constituents to form insoluble compounds.

Chapman reports that 1.4 to 3.4 ppm chlorides in orchard grass is a high level. Alfalfa and small grains seem fairly tolerant of chlorides per se.

The major effect that the chloride content of sewage effluent would have would be in increasing the salinity or conductivity of the soil solution to a level that plants might not tolerate (see the section on salinity).

Chromium (Cr)

Little of a useful nature in plant culture has been reported about chromium. In small grains and corn the material presented by Chapman would indicate that when chromium in the plant exceeds 4 ppm, toxicities might develop.

Cobalt (Co)

There is little available data to report on cobalt toxicity in plants.

Copper (Cu)

Chapman reports that corn, beans, and squash are sensitive to excess Cu while grapes are resistant. One hundred milligrams of exchangeable Cu per kilogram of soil may produce copper toxicities. Levels in the plant in excess of 20 ppm Cu could be indications of possible toxicity.

Field work in Missouri has shown that corn and alfalfa will tolerate single applications of copper as copper sulfate up to 20 lbs. copper per acre. The finer textured soils are capable of rendering copper quite unavailable to plants at rates up to 20 lbs. copper per acre.

Fluorine (F)

The fluoride anion is quite toxic in acid soils but if the soil pH is in excess of 6.5 the fluoride is rendered insoluble (probably as CaF_2). The following are representative plant values (Chapman):

TABLE F-4. REPRESENTATIVE PLANT CONCENTRATIONS OF FLUORINE

Crop	Normal	High	Toxic
	----- ppm F -----		
alfalfa	3-15	13-65	
buckwheat	10-100	100-500	500
corn		85-150	150

Iodine (I)

Chapman reports that amounts in excess of 5 lbs. KI (potassium iodide) per acre have injured plants. In nutrient solutions, I concentrations in excess of 0.5 to 1.0 ppm are toxic. Data on specific field crops are sparse.

Iron (Fe)

Iron is a normal constituent of soils. There are no reported field toxicities due to Fe. In most cases, Mn reaches toxic levels in soils before Fe. It has been observed in the Advance area of Missouri that excess Fe seems to induce Zn deficiency.

Lead (Pb)

Chapman found no references in the literature to lead toxicities in plants grown in soil. Lead seemed to be “fixed” by soil humus. Application of 5500 pounds of lead per acre resulted in a Pb level in barley of only 3 ppm with no toxicity. In Illinois work corn and soybeans were tolerate (see the section on salinity).

Lithium (Li)

Chapman reports that there are few references relating lithium toxicities through plant concentration and soil levels. Cotton seems quite tolerant of lithium while citrus is very sensitive.

Magnesium (Mg)

Excesses of magnesium appear only when magnesium is in great excess of calcium which rarely occurs.

Manganese (Mn)

Manganese toxicity most often results from acid, poorly drained conditions which cause reduction of Mn^{+2} which is soluble. Raising the soil pH above 5.5 will usually remove the toxic condition.

TABLE F-5. REPRESENTATIVE PLANT CONCENTRATIONS OF MANGANESE AT TWO SOIL APPLICATION RATES (7)

Crop	Normal	Excess
	----- ppm -----	
barley	-----	770
Lespedeza	70-130	400
oats	12-82	---

Molybdenum (Mo)

Toxic levels of molybdenum for plants are rarely observed but molybdenum levels in plants may be toxic to animals, especially to ruminants. Levels in alfalfa of 0.5 ppm Mo are normal.

Nickel (Ni)

Greater than 5 to 10 ppm exchangeable nickel in soils should cause one to suspect toxic conditions. Liming tends to offset high soil nickel levels.

TABLE F-6. REPRESENTATIVE PLANT LEVELS OF NICKEL FOR TWO SOIL APPLICATION RATES

Crop	Intermediate	High
	----- ppm Ni -----	
alfalfa	1-4	---
barley	---	4-6
corn	0.14	---
grasses	0.2-3	9-56
oats	7-51	32-340

Nitrogen (N)

There are probably no direct toxic effects of N nitrogen in plant metabolism. High or excess nitrogen levels may induce deficiencies of other nutrients or may weaken the resistance of the plant to insects and diseases. The companion ion with nitrogen may cause undesirable effects. In arable soils most nitrogen forms are converted to nitrate which (1) may leach, or (2) contribute to salinity problems. Excess quantities of high nitrogen organic materials may cause ammonia burn to growing plants.

Phosphorus (P)

Direct toxic effects of phosphorus in soils have not been observed. High soil phosphorus can induce deficiencies of copper, zinc, iron, and perhaps other nutrients.

Potassium (K)

Potassium may be toxic to plants by contributing to the salinity problem. High levels of potassium will induce magnesium deficiencies especially on sandy soils.

Selenium (Se)

Certain plant species are notorious Se accumulators. In the range country these plants should be removed or controlled because the selenium levels may be toxic to the animals.

Chapman (7) reports the following selenium concentrations to be high but not toxic for plant growth (ppm Se): Alfalfa 500, barley 450, corn 275, bromegrass 200, and oats 535.

Silver (Ag)

There are no reports of toxic levels of silver on plants. Chapman reported alfalfa to contain 1.3 ppm silver and grasses 0.1 to 0.4 ppm silver.

Sodium (Na)

It appears that sodium in effluent would cause soil physical problems before the level of sodium would be toxic to plants. Sodium disperses soil colloids which results in poor

TABLE F-7. TOLERANCES OF SPECIFIC CROPS TO SALT CONCENTRATIONS (PEARSON)

EXCHANGEABLE SODIUM PERCENTAGE (ESP) RANGE*	CROP
10-20	beans
20-40	clover, tall fescue, oats
40-60	wheat, cotton, alfalfa
60	tall wheatgrass

Refer to additional information in the section on salinity.

*ESP-100x meNA/cation exchange capacity

infiltration of water and poor root aeration. Soil dispersal problems occur according, to Chapman, when 10 to 20% of the soil cation exchange capacity is saturated with sodium whereas toxic levels of sodium for plant growth are found when 33% or more of the exchange capacity is saturated with sodium.

Strontium (Sr)

Chapman reports no excess or toxic levels of strontium; radioactivity of strontium is of more concern than toxicities due to strontium concentration. The following intermediate levels are reported in ppm strontium: alfalfa 100-1000, barley 3, birdsfoot trefoil 75-100, red clover 180-850, corn 9-26, meadow fescue 25-40, and orchard grass 20-25.

Sulfur (S)

Chapman reported one citation where 1 ton sulphur per acre reduced alfalfa yields. Toxic levels of $\text{SO}_4\text{-S}$ in alfalfa and barley tissue where reported in excess of 0.75 percent dry basis.

Sulfur will have an acidifying effect on the soil. The magnitude of the effect will depend on the form of sulfur as well as quantity applied.

Tin (Sn)

There are no reports of tin toxicities in the field. Less than 2 ppm tin in plant tissue seems normal.

Titanium (Ti)

There are no reports of titanium toxicities in the field.

Vanadium (V)

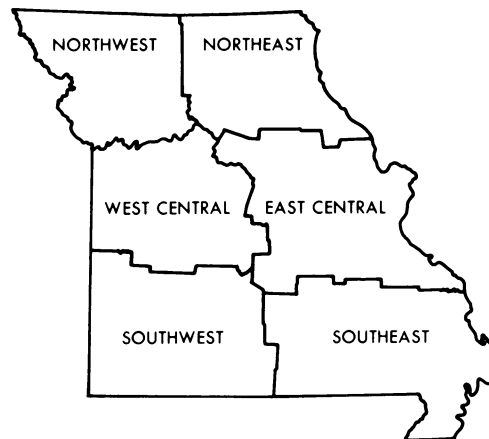
Ten ppm vanadium added to a sandy soil decreased growth of orange seedlings and 150 ppm V killed all plants. There are no reports of toxicities under normal field conditions. In nutrient solutions vanadium in excess of 0.5 ppm is toxic.

Zinc (Zn)

Chapman reports that single applications of 500 lbs. zinc and 700 lbs/zinc/acre as zinc sulfate were toxic to cowpeas and corn, respectively. 1 me Zn/100 g (one milliequivalent of zinc per 100 grams of soil) has been reported to be toxic to corn. Lime tends to decrease toxicity as may phosphate applications.

The effect of zinc application is persistent in Missouri claypan soils for up to 4 years at modest rates of 20 lbs/acre.

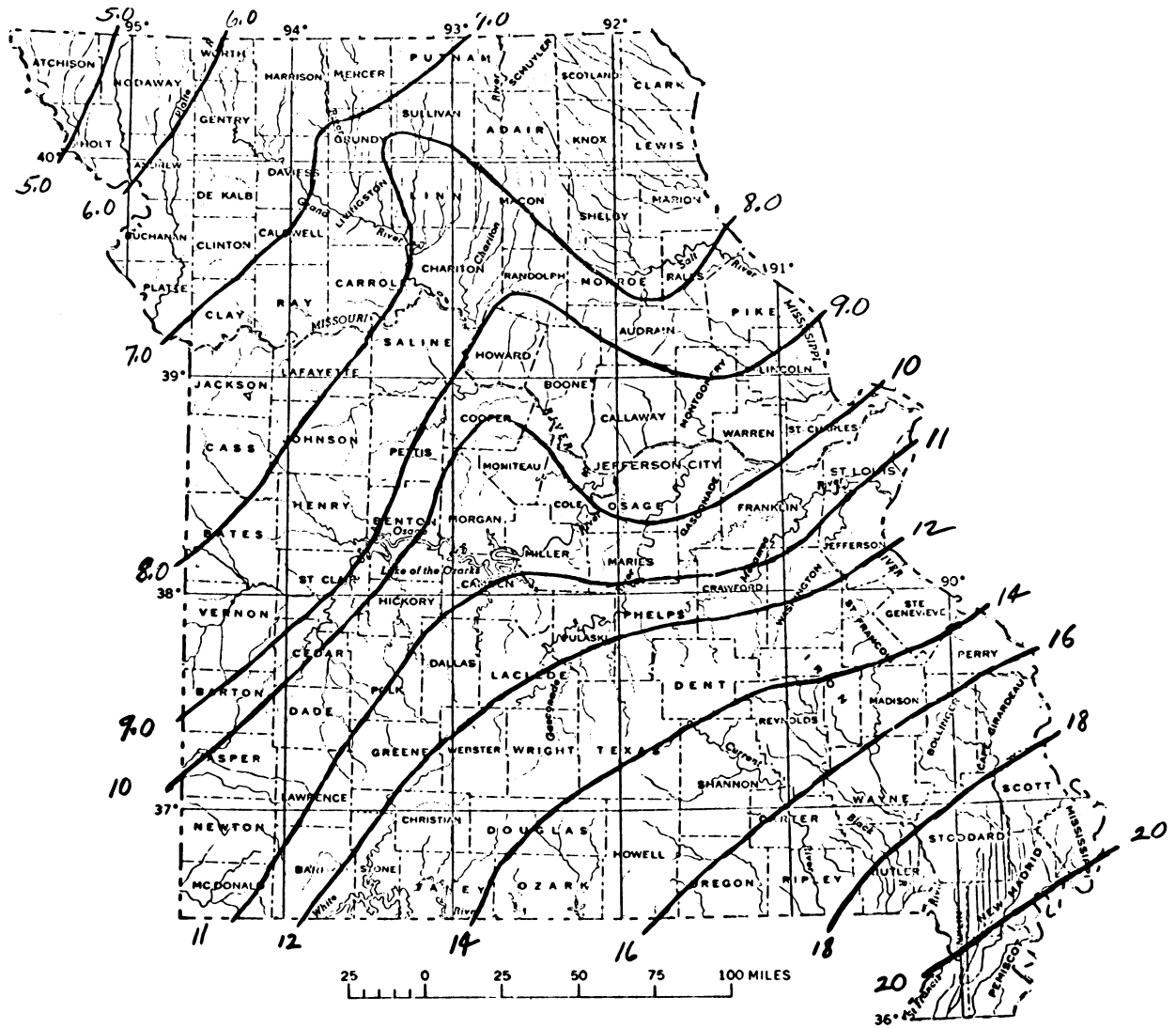
**APPENDIX G: RANGE OF MONTHLY
PRECIPITATION AMOUNTS**



**TOTAL PRECIPITATION WHICH HAS BEEN EXCEEDED 10, 25, 50, 75, AND 90 PERCENT
OF THE TIME, INCHES**

NORTHWEST													
	Total	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
10%	64.6	2.6	2.2	4.0	6.2	6.9	10.3	5.2	6.4	8.1	5.0	5.0	2.7
25%	46.7	1.7	1.7	3.1	4.7	5.0	7.4	4.0	5.0	5.9	3.6	2.9	1.7
50%	32.0	1.0	1.1	2.0	3.0	3.7	5.3	2.8	3.9	4.1	2.1	1.9	1.1
75%	19.9	.7	.4	1.3	2.4	2.4	3.2	1.8	2.4	2.0	1.6	.9	.7
90%	10.6	.2	.2	.4	1.6	1.4	2.1	1.0	1.4	.8	.8	.4	.3
WEST CENTRAL													
10%	72.3	3.6	3.0	5.6	7.0	8.9	9.1	5.1	7.1	8.6	6.0	5.5	2.8
25%	52.1	2.2	2.0	3.8	5.1	6.0	6.8	3.8	5.4	6.9	4.3	3.4	2.4
50%	35.2	1.3	1.4	2.6	3.6	4.0	4.9	2.7	3.2	4.1	3.0	2.5	1.9
75%	21.8	.9	.9	1.6	2.6	2.6	2.8	1.3	2.0	2.6	1.9	1.4	1.2
90%	13.9	.4	.3	.8	2.1	2.2	1.4	.8	1.4	1.4	1.4	.6	1.1
SOUTHWEST													
10%	79.8	4.3	3.6	6.5	8.2	8.8	9.8	6.0	7.9	9.0	6.3	5.5	3.9
25%	57.5	3.0	2.2	4.0	6.1	7.0	7.2	4.1	5.4	6.6	4.8	4.1	3.0
50%	39.2	2.0	1.7	2.9	4.3	4.7	5.1	2.9	3.3	3.8	3.2	2.9	2.4
75%	24.2	.9	1.2	2.1	3.1	3.0	3.1	1.4	2.0	2.0	2.1	1.9	1.4
90%	14.3	.5	.4	1.3	2.1	2.0	1.4	.9	1.2	.9	1.6	1.1	.9
NORTHEAST													
10%	67.8	3.0	2.2	4.6	6.2	6.8	9.0	5.4	7.2	9.1	5.9	5.4	3.0
25%	50.2	2.0	1.8	3.8	4.8	5.0	7.0	4.1	5.8	6.0	3.9	3.8	2.2
50%	33.9	1.2	1.3	2.6	3.1	3.6	5.0	2.8	3.8	3.7	2.4	2.4	2.0
75%	22.1	1.1	.7	1.7	2.4	2.4	3.1	1.4	2.4	2.4	1.8	1.4	1.3
90%	12.3	.3	.4	1.0	1.7	1.6	1.7	.4	1.5	1.4	1.0	.9	.4
EAST CENTRAL													
10%	70.4	4.0	3.1	6.2	7.0	8.5	8.4	5.2	6.2	7.4	5.5	5.0	3.9
25%	54.1	2.7	2.7	4.0	5.4	6.7	6.8	3.8	5.1	6.0	4.0	4.0	2.9
50%	37.2	1.7	1.9	2.9	3.7	4.7	4.4	2.8	3.6	3.7	2.9	2.8	2.1
75%	23.6	1.2	1.3	2.1	2.4	2.8	2.9	1.7	2.1	2.2	1.8	1.7	1.4
90%	13.9	.5	.6	1.4	1.6	1.7	1.3	1.2	1.4	1.2	1.4	1.0	.3
SOUTHEAST													
10%	84.7	7.3	5.6	8.4	8.0	9.0	8.1	5.4	7.1	7.1	7.0	6.3	5.4
25%	61.4	5.0	3.9	6.0	6.1	6.7	5.8	3.8	5.0	5.3	4.7	5.0	4.1
50%	39.9	3.0	2.7	3.9	4.2	4.2	3.2	2.7	3.4	3.4	3.0	3.0	3.2
75%	25.4	1.8	1.6	2.4	2.7	2.7	2.1	1.6	2.3	1.8	1.9	2.1	2.4
90%	16.2	1.2	1.1	1.6	2.1	1.4	1.2	1.4	1.1	1.2	.9	1.4	1.6

APPENDIX H: AVERAGE ANNUAL
 RUNOFF IN INCHES
 FOR MISSOURI



APPENDIX I: EFFECTS OF EFFLUENT DISPOSAL ON LIVESTOCK

TABLE I-1. WATER QUALITY CRITERIA FOR LIVESTOCK USE*

Hazardous trace elements	
(levels in excess of those shown are grounds for rejection of a supply)	Substances mg/l
	Arsenic----- 0.05
	Barium ----- 1.00
	Cadmium ----- 0.01
	Chromium ----- 0.05
	Cyanides ----- 0.2
	Lead ----- 0.05
	Selenium----- 0.01
	Silver ----- 0.05
	Mercury----- **
Other trace elements	
(levels shown should not be exceeded if alternate sources are available)	
	Manganese ----- 0.05
	Iron ----- 0.3
	Copper ----- 1.0
	Zinc ----- 5.0
	Fluoride ----- 0.7-1.2
	Nitrate -----45.0
	Cobalt-----**
	Aluminum -----**
	Beryllium -----**
	Boron -----**
	Molybdenum-----**
	Vanadium -----**
	Tin -----**

*Water Quality Criteria (95)

**No tolerances established

NOTE: Total dissolved inorganic solids 10,000 mg/L may be tolerated by beef cattle while for general farmstead use 500 mg/L is a more acceptable figure.

TABLE I-2. DIETARY LEVELS WHERE TOXICITIES IN CATTLE MIGHT OCCUR
(These values are based on total diet)

Iodine	in excess of 100 ppm
Copper	30 ppm with low molybdenum intakes (0.1-0.2 ppm)
Zinc	500 ppm
Selenium	5 ppm
Manganese	800 ppm
Cobalt	not given (intakes of .66 mg/kg body weight reduced growth)
Chromium	50 ppm
Fluoride	30 ppm
Molybdenum	20 ppm dependent upon copper intake
Nickel	no cattle data (700 ppm for small chickens)
Cadmium	40 ppm (zinc level usually low)
Lead	older cattle less susceptible (3 ppm for sheep)
Vanadium	less than 25 ppm
Mercury	1 ppm (our estimate) chemical form is critical
Boron	no figure available (20 ppm Boron normally in alfalfa)
NaCl	1.3% upper limit
Potassium	(500 gram/day per head varies with na, ca, mg content)
Iron	200 ppm
Broine	20 ppm
Rubidium	200 ppm
Tin	no figure available generally non-toxic

Note: Zn, Cd, Mn and Fe levels increased in leaves of forages where 20-30 Ton of sludge was applied.

APPENDIX J: GROUNDWATER QUALITY* EFFLUENT OBJECTIVES

Water Quality Standards have been adopted by the Clean Water Commission for all streams in Missouri. The uses of the stream water were established and limits were then placed on the appropriate parameters to protect these uses.

Water Quality Standards for groundwater have not been adopted by the Clean Water Commission, although the Clean Water Law gives the Commission the authority to do so.

Water supply is the major use of our groundwater and therefore efforts should be made to protect it for this use. Effluents have reappeared in springs resulting in odors and discoloration of the spring water. This must also be taken into consideration in future objectives.

The following information objective is presented to distinguish this from authoritative values that may be adopted by the Clean Water Commission at some future date.

One should follow the 1962 Drinking Water Standards (70) as published by the U.S. Public Health Service.

TABLE J-1. U. S. PUBLIC HEALTH SERVICE 1962 DRINKING WATER STANDARDS (70)
(SUBJECT TO CHANGE)

	Recommended Limits mg/1	Mandatory Limits mg/1	Proposed AWWA Water Quality Goals mg/1
Physical characteristics			
Turbidity units	5		0.1
Color units	15		3
Odor, threshold odor number	3		none
Taste			No objectionable
Chemical characteristics			
Alkyl benzene sulfonate (ABS)	0.50		0.20
Arsenic (As)	0.01	0.05	0.05
Barium (Ba)		1.00	1.00
Cadmium (Cd)			0.41
Carbon-chloroform extract (CCE)	0.20		0.4
Chloride (Cl)	250		see T. D. S.
Sulfate (SO ₄)	250		see T. D. S.
Total dissolved Solids	500		200
Chromium (Cr. hexavalent)		0.05	0.05
Copper (Cu)	1.00		0.2
Cyanide (CN)	0.01	0.2	0.01
Fluoride (F)	0.7-1.2	0.8-1.7	0.9
Iron (Fe)	0.30		0.05
Lead (Pb)		0.05	0.05
Manganese (Mn)	0.05		0.01
Nitrate (NO ₃)	45		45
Phenols	0.001		0.001
Selenium (Se)		0.01	0.01
Silver (Ag)		0.05	0.05
Zinc (Zn)	5		1.0
Hardness (as CaCO ₃)			80

*Quality of water after passing through the soil profile.

In addition, the following parameters apply:

Suspended solids	5	mg/l
B.O.D. ₅	5	mg/l
C.O.D.	20	mg/l

APPENDIX K: SYSTEM PUMPING RATE

The required pumping rate depends on the acreage to be irrigated, the number of hours per day the system can be operated, and the gross peak daily moisture required.

The peak daily moisture required depends on the crop, the climate and the prevailing weather conditions. Allowance should be made for evaporation and uneven distribution.

Table K-1 may be used to determine the system pumping capacity.

TABLE K-1
Peak Daily Moisture Requirement, Inches per Day (93)

Crop	Climate	Net Peak Rate	Irrigation Efficiency Percent		
			80	75	70
Alfalfa, cotton, pasture, field corn, sweet corn, soybeans, sugar beets, orchards, citrus	Humid	0.20	0.25	0.27	0.29
	Sub-Humid	0.25	0.31	0.33	0.36
Grain sorghum, small grains, potatoes, turf grasses, tomatoes, berries, nursery crops, truck crops	Humid	0.15	0.19	0.20	0.21
	Sub-Humid	0.20	0.25	0.27	0.29

Note: Use sub-humid peak rate on soils having less than 4 inches of available moisture in the root zone.

APPENDIX L: SYSTEM DESIGN TABLES

TABLE L-1. UNITS OF MEASUREMENT

One gallon	=	231 cubic inches 8.3 lbs. 3.78 liters
One cubic foot	=	7.5 gallons 62.4 lbs.
One acre	=	43,560 sq. ft.
One acre-foot	=	43,560 cu. ft. 325,848 gallons
One acre-inch	=	3,621 cu. ft. 27,154 gallons 133 tons
One acre-inch per hour	=	450 gal. per minute 1 cubic foot per second
One pound per square inch	=	2.31 ft. of head 2.04 inches of mercury
One ft. of head	=	0.433 psi
Atmosphere pressure	=	14.7 psi 33.9 ft. of head 29.92 inches of mercury

TABLE L-2. SPRINKLER SPACING GUIDES (79)

(Designs capable of maintaining a coefficient of uniformity at 85%)

Most systems should be designed for 5-10 mph winds.

For 0-5 mph Winds (calm conditions, night operation).

Triangular Spacing: Sprinkler spacing along the lateral should not exceed 75% of the effective wetted diameter, and between laterals, 72% of the effective diameter.

Square or Rectangular Spacing: Spacing between sprinklers and between laterals should not exceed 75% of the effective diameter.

For 5-10 mph Winds

Triangular Spacing: Sprinkler spacing along the lateral should not exceed 55% of the effective diameter, and between laterals, 50% of the effective diameter.

Square or Rectangular Spacing: Spacing between sprinklers and between laterals should not exceed 50% of the effective diameter.

TABLE L-3: SPRINKLER SYSTEM AVERAGE APPLICATION RATE, INCHES PER HOUR

Spacing Feet	Gallons per Minute from each Sprinkler																			
	1	2	3	4	5	6	8	10	12	15	18	20	25	30	40	50	100	200	500	1000
20 x 20	.24	.48	.72	.96	1.20	1.44	1.92													
20 x 30	.16	.32	.48	.64	.80	.96	1.28	1.60	1.93											
20 x 40	.12	.24	.36	.48	.60	.72	.96	1.20	1.45	1.81	2.17									
25 x 25	.15	.30	.46	.61	.77	.92	1.23	1.54	1.85	2.31										
30 x 30	.11	.21	.32	.43	.54	.64	.86	1.07	1.28	1.61	1.93	2.14								
30 x 40	.16	.24	.32	.40	.48	.64	.64	.80	.96	1.20	1.45	1.61	2.01	2.40						
30 x 50	.13	.19	.25	.32	.38	.51	.64	.76	.96	1.15	1.28	1.60	1.92							
30 x 60	.11	.16	.21	.27	.32	.43	.53	.64	.80	.96	1.07	1.54	1.61	2.14						
40 x 40	.12	.18	.24	.30	.36	.48	.48	.60	.72	.90	1.08	1.20	1.50	1.80	2.40					
40 x 50	.10	.14	.19	.24	.29	.38	.48	.58	.72	.86	.96	1.20	1.44	1.92						
40 x 60	.12	.16	.20	.24	.32	.40	.48	.60	.72	.80	1.00	1.20	1.60	2.00						
50 x 50	.12	.15	.19	.23	.31	.39	.46	.58	.69	.77	.96	1.15	1.54	1.92						
50 x 60	.10	.13	.16	.19	.26	.32	.39	.48	.58	.64	.80	.96	1.28	1.60						
50 x 70	.11	.14	.17	.22	.28	.33	.41	.49	.55	.69	.82	1.10	1.37							
60 x 60	.13	.16	.21	.27	.32	.40	.48	.53	.67	.80	1.07	1.34								
60 x 70	.11	.14	.18	.23	.27	.34	.41	.46	.57	.69	.92	1.15								
60 x 80	.10	.12	.16	.20	.24	.30	.36	.40	.50	.60	.80	1.00								
70 x 70	.10	.12	.16	.20	.24	.29	.35	.39	.49	.59	.79	.98	1.96							
70 x 80	.10	.14	.17	.21	.26	.31	.34	.43	.52	.69	.86	1.72								
70 x 90	.12	.15	.18	.23	.28	.30	.37	.46	.61	.76	1.52									
80 x 80	.12	.15	.18	.23	.27	.30	.38	.45	.60	.75	1.50									
80 x 100	.10	.12	.14	.18	.22	.24	.30	.36	.48	.60	1.20									
100 x 100	.10	.12	.14	.17	.19	.24	.29	.39	.48	.96	1.93									
100 x 120	.10	.12	.14	.16	.20	.24	.32	.40	.80	1.60										
150 x 150	.11	.13	.17	.21	.25	.31	.37	.46	.61	.76	1.52									
150 x 180	.11	.14	.18	.22	.27	.33	.41	.49	.55	.69	.82	1.10	1.37							
200 x 300	.10	.12	.14	.16	.20	.24	.32	.40	.80	1.60										
300 x 300	.11	.21	.53	1.07																
360 x 360	.15	.37	.74																	

The indicated diameters in this catalog are obtainable when operating without wind and with; 6" riser pipe for discharges up to 10 GPM, 9" riser pipe for discharges from 10 GPM to 26 GPM, 12" riser pipe for discharges from 26 GPM to 50 GPM and 18" riser pipe for discharges above 50 GPM. Total Depth of Application = Application Rate, in/hr. Hours of Operation

$$\text{Application Rate, inches/hr.} = \frac{96.3 \times \text{Sprinkler GPM}}{\text{Net area covered by sprinkler, ft.}}$$

NOTE: Design precipitation rates less than .2 inch per hour are not very uniform, and are better suited to frost protection than to effluent disposal.

APPENDIX M

TABLE M-1. LABOR REQUIREMENTS OF VARIOUS DISPOSAL SYSTEMS (65)

System	Hours Labor Per Acre Per Application
Traveling gun sprinkler	.25 ¹
Center pivot sprinkler	
135 acre size	.05 ²
35 acre size	.07 ³
Gated pipe	.60 ⁴
Solid set sprinkler	5

¹This assumes 4 man-hours of labor plus 1 hour of supervision per day for a sprinkler covering 20 acres per day (2 sets). A system with buried pipe and a hose reel requires approximately one hour of labor per set plus one half hour supervision per set.

²This requirement is without moving time. This is 2 hours per revolution for lubrication, adjustment, etc. plus 2 hours supervision per day. Moving requires 8 man-hours.

³This requirement is without moving time. This is one hour per revolution for lubrication, adjustments, etc. plus 1-1/2 hours per day supervision. Moving requires 5 man-hours.

⁴This requirement is for systems requiring some pipe moving, and no tailwater pits. A system utilizing a tailwater return pump and no pipe moving should require approximately .2 hours/acre/application.

⁵These systems can be completely automated. One hour of supervision per day is generally sufficient.

RELATED PUBLICATIONS*

AGRICULTURAL ECONOMICS

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