Order Number 1346717

Subsurface irrigation of turf: An examination of current methods

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The University of Arizona, 1991

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Subsurface Irrigation of Turf - An Examination of Current Methods

by

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A Thesis Submitted to the Faculty of the

SCHOOL OF RENEWABLE NATUREL RESOURCES

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF LANDSCAPE ARCHITECTURE

In the Graduate College

THE UNIVERSITY OF ARIZONA

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STATEMENT BY AUTHOR

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ACKNOWLEDGEMENT

As you consider the sentiments expressed in this acknowledgement, remember that limitations of the written or spoken word are great.

I can't come close to expressing the depth or intensity of feelings of gratitude that I feel towards you, mother, for believing that I could accomplish my goals. You never gave up and your steadfastness kept me from giving up many times. I would have not even started the process that lead to this accomplishment if it were not for you.

Professor Mike Deeter, thank you for assuring me that I could do it and somehow making me believe it. Your confidence in my abilities relieved my personal pressure and actually made the project fun!

A further expression of gratitude must be made to the other members of my graduate committee, Dr. Donovan Wilkin, Professor of Landscape Architecture and Dr. James Sell, Assistant Professor of Geography. Gentlemen, your suggestions, comments and critiques proved invaluable in keeping me on track during the rocky start and preparation of this study.

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ABSTRACT

This study examines literature on subsurface irrigation of turf using published and unpublished sources to determine its relevance for the designer of irrigation systems. It looks at two installed sites to determine current industry practices and then develops a model to assist the designer of these systems. Finally areas in need of further research and technical development are suggested.

Literature is not readily available to the designer and it is sometimes contradictory. Case studies show that subsurface irrigation is an effective method of irrigating turf, especially in arid parts of the world. A model to select tubing and emitter spacing is developed by summarizing existing literature and case studies.

Virtually all areas of design, installation and management need further research. Two primary areas that need further investigation are specific design issues and benefits to the end user such as cost, water savings and maintenance procedures.

INTRODUCTION

Scarcity of Potable Water

"It is virtually beyond the comprehension of today's American to realize it is possible that some day water may not flow from the tap as simply as it does now (Oklahoma Water Resources Board,

1973, p. 7)."

For too long, Americans have taken for granted that water is an inexhaustible commodity. It has only been in the last decade or so that they, as a whole, have begun to realize that the natural resources of the earth are not infinite. Finally attention is being focused on ways to conserve this finite supply of clean water.

Fresh water is derived from snow or rainfall runoff. So, it follows that these supplies are linked to the weather. Seasonal variations in precipitation make it difficult to estimate future supplies. If the use of present water supplies is limited to ensure future supplies, then some water must go unused. If too much available water is used, the risk of future shortages is high. "The problem facing the world today is that because of the variability of flow, some water can never be put to use (Leopold, 1974, p. 132)." Additionally, there is a spatial variability to the supply of water. Majopr world regions are characterised by water deficites, while other regions suffer from extreme over supply.

Table 1 shows that extremely small percentages of unfrozen fresh water, which could potentially be available for use by humans, are contained in lakes, rivers, ground water and the atmosphere.

WATER ON EARTH	
LOCATION	Percentage
SURFACE WATER	
Fresh Water Lakes	0.009
Saline lakes and inland seas	0.008
Average in stream channels	0.0001
SUBSURFACE WATER	
Water in unsaturated aerated zone (includes soil moisture)	0.005
Ground water within depth of 1/2 mile	0.30
Ground water, deep lying	0.31
OTHER WATER LOCATIONS	
Ice caps and glaciers	2.15
Atmosphere (at sea level)	0.001
World ocean	97.20
TOTALS (rounded)	100.00

Table 1. Sources of Water on Earth (Leopold, 1974, p. 120).

Ever increasing quantities of water are required for irrigation of newly developed farm lands to support a growing population. The United States receives an average of approximately 30 inches precipitation annually. Three quarters of this is returned to the atmosphere as evaporation and transpiration. The balance infiltrates to the water table or runs off to the oceans. There are approximately 7,500 gallons of water per day available for use by every person in the United States. Of this available water, 1500 gallons is actually used (Leopold, 1974, p. 133).

Since the distribution of irrigation water is normally uneven, its efficient use is not only desirable, but economically imperative. Unfortunately, many present methods of irrigation are not especially efficient. For this reason, a great deal of research is being conducted in methods of increasing irrigation efficiencies.

The United States has an abundant and generally dependable supply of fresh water. But major problems are associated with unequal distribution of precipitation. The western United States receives only one-third of the nation's average rainfall, yet uses enormous quantities of water, especially for irrigation. This inequitable distribution and location of water supplies, distant from where they are needed, has given rise to social, economic and legal problems, which will become more complicated and more critical in the coming decades. Each year, approximately six times the annual flow of the Mississippi river is used to irrigate the world's crops. By 1990, 250 million hectares of land were irrigated to produce crops. Each year farming accounts for approximately 70 percent of global water use (Postel 1990, p. 39).

Certainly water will cost much more in the future. And as the pressures resulting from increasing population and expanding technological and agricultural needs become more intense, the need to conserve and wisely use the nation's supplies of fresh water will increase.

Water Awareness in the Southwest

Throughout the Western United States, water is an important resource upon which are placed multiple demands. One major demand is agricultural use, another is industrial and a third, rapidly growing demand, is urban. In the low deserts of Arizona, urban growth has been tremendous. Aggravating this problem are the large areas of turf associated with major income sources such as tourism, golf and the resort industry (Kneebone, 1979). One area in which people have been most destructive to the Southwest's environment has to do with overusing the natural water supply. The results can be seen in water depletion and shortages, as well as destruction of the desert ecosystem. Rapid population growth and concentrated development in many areas are placing critical demands on the water supply (Paylore, 1976, p. 4).

The worst nightmare the green industry could have is now coming true in Santa Barbara, Ca., where lawn irrigation has been banned by the City Council because of a prolonged drought. In fact, golf courses were allowed to irrigate greens and tees only until a reclaimed water system could be installed. California's El Dorado County, Southwest of Lake Tahoe, instituted a moratorium on all new water connections and landscaping of new homes until the end of the drought. In effect all construction of new buildings in El Dorado County has been stopped (*Santa Barbara Bans Lawn Irrigation*, 1990, p. 124).

For several decades, water use in Arizona has exceeded its renewable supply (Steiner, 1985, p. 1). Groundwater supplies, which comprise the major water source in many areas, are being depleted at an alarming rate. In some of the arid parts of the western United States, water is being pumped that fell as rain during the Ice Age, at least 10,000 years ago (Leopold, 1974, p. 28). Figure 1 shows the effect of this groundwater mining on the water table. In forty years, the water table depletion in some areas has almost doubled. The direct effect of this lowering of the water table is an increase in the cost of the pumped water.

The supply of water available for landscape irrigation is limited and becoming more so each year. Some Southwestern states are now passing regulations on water use in landscaping (Hurst, 1990, p. 94). Arizona, recently adopted a comprehensive Groundwater Code. It establishes Active Management Areas that contain 80 percent of the population of the state. Its goal is to eliminate groundwater depletion by the year 2050. To accomplish this goal, all water users must participate in strict conservation measures (Steiner, 1985, p. 1).

Relevance of Turf to the Arid Southwest

A landscape style common to the Southwest contains large canopy trees to shade the residence, with turf to reduce reflected heat and provide a softer, more usable ground plane. As previously noted, this type of landscape must be supported by supplemental irrigation. Typically, the additional irrigation is supplied by a traditional spray irrigation system, an inefficient method of irrigation in hot, arid climates. Using high pressure sprinklers under hot windy conditions wastes large quantities of water due to distortion of the spray pattern and evaporation of the fine water droplets in the air (Solomon, 1990, p. 12).

So, why bother with turf and lushly planted landscapes? From a purely water conservation point of view, a minimalist approach to landscaping would seem appropriate. Aside from personal preferences, which are a matter of style and could probably be affected by education if necessary, there are some strong economic, and ecological, reasons for a more lush landscape style.

Research at the University of Arizona has shown that the total electrical usage for a residence can be reduced through the use of effective landscape planting practices. Total electrical usage for two-week long periods (one in August and one in October) was similar for turf and shade models, and 7 - 10% more for the model surrounded by only rock. Results indicated that cooling energy savings in October would be greater than increased water costs compared to the unirrigated rock model for all landscape treatments with vegetation (McPherson, 1988, p. 2).

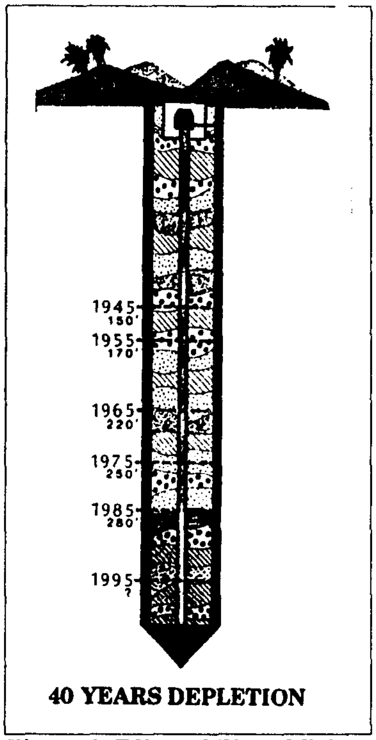

Figure 1. Effect of Water Mining on the Groundwater Table (Johnson, 1985, p. 5).

Commercial applications can also make a strong case for lush landscapes from a marketing point of view. In 1988, there were 191 golf facilities in Arizona. They provided an economic benefit to the state in the form of an annual revenue of $270 million and as annual payroll of $110 million paid to 8,000 employees and. These direct benefits do not include substantial, and possibly greater benefits from the tourism industry supported by destination resorts (Barkley, 1989, p. 9).

In Scottsdale, Arizona, the Princess Hotel makes the most of its water supply without sacrificing an atmosphere of glamour and luxury. In addition to trees, shrubs and drought tolerant ground covers, the landscape includes 85,000 square feet of lawn. Because of water restrictions in Arizona, the irrigation system will eventually be converted to tertiary effluent water (*Water-Thrifty Landscape Blends Turf and Desert*, 1988, p. 127).

Any method or technique that could increase the effectiveness of the limited water supply should be welcome. Government agencies, as already noted, will continue to legislate the amount of water available to the landscape (Hurst, 1990, p. 94). There will be less water available for turf irrigation in the future, so the "green industry" must take the lead and get its house in order. Subsurface drip irrigation of turf is one such method that potentially offers a substantial savings in water use.

IRRIGATION

Crop Irrigation

Historical and archaeological findings show that crop irrigation has played a major role in the development of ancient civilizations. The oldest civilizations with irrigation developed along the Nile, Tigris, Euphrates, Indus, and Yellow Rivers (Nakayama 1986, p. 1). Gravity irrigation began along the Nile about 6,000 B.C. These crude systems were based on overflow of flood waters into valley bottoms and delta lands. By 3,500 B.C., the practice of "bailing up," drawing water from wells using a counterbalanced pole and dumping it into irrigation canals, was in use (Irrigation History: From Buckets and Crossbeams to Computers, 1989, p. 94).

The ancient Chinese tried to use bamboo to transport water from streams to crop areas. They were unsuccessful because they couldn't solve the problem of leakage. Since 800 A.D., and continuing to the present, sophisticated irrigation practices have been carried on by Pueblo Indians in New Mexico, Colorado and Arizona. In 1847, Brigham Young and the Mormon settlement in Utah built irrigation systems in the American south west. The first federal irrigation project was begun in 1868, to irrigate land on the Mojave Indian reservation in Arizona. By 1948, more than 30 million acres of land were under public or private irrigation in the United States (Irrigation History: From Buckets and Crossbeams to Computers, 1989, p. 96).

A surge in irrigated crop lands has taken place since 1950. Today approximately 625 million hectares of cropland are under irrigation. And one third of the global harvest comes from the 17 percent of the world's cropland that is irrigated (Postel, 1990, p. 39).

Landscape Irrigation

While ancient civilizations were built on flood irrigation, it is not very practical. Efficient irrigation systems using pipes are more serviceable for larger systems. In 1897, "Farmer Skinner," as he is remembered, invented the first sprinkler irrigation system. He borrowed a drill from his local dentist, took a length of galvanized steel pipe, and made holes in the pipe at three-foot intervals. Resting the pipe six feet overhead in a Y-shaped piece of pipe set in the ground, Skinner attached a garden hose and turned on the faucet. The crude device worked (Irrigation History: From Buckets and Crossbeams to Computers, 1989, p. 100).

Prior to World War II and the shortage of strategic metals, copper and aluminum were used for irrigation piping. However, these metals were easily corroded by the minerals in the water. Although prone to corrosion, galvanized pipe was found to be acceptable in price and longevity and remained in use until the early 1980's.

Used in Europe as early as 1937, polyvinylchloride (PVC) was introduced to the American market in 1952 (Irrigation History: From Buckets and Crossbeams to Computers, 1989, p. 100). In the early 1960's, the American Society for Testing Materials (ASTM) set standards for PVC strength and sizes. Due to its long life, ease of installation and low cost, this material has become the standard for the irrigation industry.

The commercial irrigation industry, as we know it today, developed after World War II when the returning veterans moved to the suburbs in the early 1950's. Lightweight, corrosion resistant and low cost materials became available and speeded the growth of the modern commercial irrigation industry. So, despite its 8,000 year history, modern irrigation is only approximately forty years old.

Micro-Irrigation

Micro-irrigation has no universally accepted definition. It includes several characteristics, which may or may not all be present in any particular installation. However, its most widely accepted characteristic is that it delivers water to the plant at a slow rate. A more specific discussion of micro-irrigation can be found in the next section of this study.

Early experiments with subsurface irrigation began in the late 1800's (Nelson, 1971, p. 1). The first work in subsurface trickle irrigation in which water was applied to the root zone without raising the water table was conducted in the United States at Colorado State University in 1913 by E. B. House, who concluded that it was too expensive for practical use (Nakayama, 1986, p. 2). Various materials, including porous clay pipe, canvas hose, reclaimed rubber and plastic products were tested. By the 1980's modern materials had been developed to the point that subsurface, or drip irrigation, as it came to be known, was reasonably successful.

The observation of Simha Blass, an engineer who developed the first patented surface trickle irrigation emitter, has been quoted describing greater vigor of a large tree near a leaking faucet in an orchard (Netafim Irrigation Equipment & Drip Systems, 1986, p.1). From Israel the concept of surface trickle irrigation spread to Australia, North America and South Africa by the late 1960's and eventually throughout the world. In 1971, the first International Drip Irrigation Conference was held in Tel Aviv, Israel, where 24 papers on drip irrigation were presented (Nakayama, 1986, p. 2).

Early application of micro-irrigation to turf was generally unsuccessful, the most common problem being plugging of the pipe or tubing. Most experiments centered around the use of porous pipe of one kind or another. However, one of the major disadvantages of porous pipe was its propensity to plug. With porous pipe, the inside wall of the pipe is, by nature, rough in texture and thus more likely to trap particles suspended in the water. This method was generally not successful and subsurface irrigation has suffered in reputation since.

In the early 1960's, plastic pipe with a very smooth inner wall and individual emitters at various spacings was tried. The smooth inner wall allowed the suspended and dissolved particles in the water to flow through the pipe without adhering to the inner surface of the pipe. Reducing the points of emission, from essentially the entire inner surface of the pipe to one emitter every few feet, allowed them to be individually engineered to greatly reduce plugging. The use of smooth wall pipe in now becoming the industry standard.

Characteristics of Micro-Irrigation

Micro-irrigation is an umbrella term used to describe a family of irrigation methods. This technique of irrigation is also known as drip irrigation, trickle irrigation, micro-spray and sometimes subsurface irrigation. It has been defined as follows:

> "Trickle irrigation is the slow application of water on, above, or beneath the soil by surface trickle, subsurface trickle, bubbler, spray, mechanical-move, and pulse systems (Nakayama 1986, p. 1)."
>
> "Micro-irrigation is used to describe micro-spray, line source (porous pipes, etc.) and point source (drip) irrigation systems (Micro-Irrigation: Good Things Come in Small Packages 1989, p. 96)."
>
> "Drip irrigation is the frequent, slow application of water to the soil for the purpose of sustaining plant growth (*Drip Irrigation Systems* 1985, p. 1)."
>
> "Drip irrigation is the frequent, slow, application of water to the specific root zone area of the plant material (Shepersky 1984, p. 4)."
>
> "Drip irrigation is the slow application of water to plants, usually with plastic pipe lines and either emitters or drip irrigation tubing to deliver water to the desired location (Drip or Trickle Irrigation for Ornamentals, 1978, p. 1)."
>
> So, micro-irrigation can be said to have the following characteristics:
>
> A. Water is applied at a low flow rate.
>
> B. Water is applied over a long period of time.

C. Water is applied at frequent intervals.

D. Water is applied via a low-pressure delivery system.

E. Water is applied directly into the plant root zone.

For this study then, micro-irrigation is defined as the application of water directly to the plant root zone, at a slow rate, over a long period of time, at frequent intervals, under low pressure. The most significant difference, from a design point of view, between standard irrigation methods and micro-irrigation is that, with micro-irrigation systems, the water is applied at a slow rate. That is, water is applied at a rate no faster than the soil can absorb it. Micro-irrigation is really a "system" of delivery incorporating many methodologies. But low volume delivery is a trait common to all micro-systems.

Benefits and Disadvantages of Micro-Irrigation

The characteristics that set subsurface, or micro-irrigation apart from traditional spray irrigation systems provide certain advantages to the user, the turf and the designer. These characteristics and benefits can be described as follows:

A. Water is applied at a slow flow rate (gallons per hour vs. gallons per minute). Water is applied at a rate at which it can easily be absorbed by the soil. Sprinkler, or spray, irrigation systems normally apply water at a rate of 1 gallon per minute or greater for each sprinkler. That is, each sprinkler head in the circuit passes this quantity of water to the turf. Micro-irrigation systems, however, operate at much lower volumes, normally at rates of .5 to 2.0 gallons per hour. The following advantages are realized by applying water at low flow rates:

1. Soil erosion is easier to control with low flow rates because the puddling of surface water is eliminated. Thus, sloping terrain can be irrigated with less concern for runoff that could cause erosion.
2. With a decrease of puddling, evaporation from the soil surface is greatly reduced.
3. Precise control of water location and volume is possible.
4. A saturated soil condition is easier to avoid with lower flow rates. As water is applied, the wetted front moves through the soil by capillary action, reducing saturation.

B. <u>Water is applied over long periods of time (hours vs. minutes)</u>. Since the rate of application is less, longer run times are required in order to apply the amount of water needed by the plant. Normally, spray irrigation systems apply water for five minutes to thirty minutes per run cycle. Since micro-systems apply water at much lower flow rates, they typically run from thirty minutes to a day or longer per cycle. The following advantages are realized by applying water over long periods of time:

1. A more desirable soil moisture profile is maintained with frequent water applications of several hours, instead of weekly applications of short duration. Fluctuations between the soil saturation/wilting point are reduced.
2. Deeper watering is possible, allowing poor soils to be utilized more effectively. Applying the water over a long period of time, allows it to migrate deeper into the soil.
3. Salt accumulations can be more easily leached from the root zone area. They are pushed along the wetted front beyond the root zone.

C. Water is applied at frequent intervals (daily vs. weekly). Applying water at frequent intervals reduces the variation in soil moisture. Spray irrigation systems normally apply water between one and three times per week, allowing the soil to dry between waterings. Depending on seasonal requirements, micro-irrigation systems are generally run every day, even or odd numbered days or three times per calendar week. The following advantages are realized by applying water at frequent intervals:

1. Less plant stress is experienced due to reduced soil saturation/wilting point cycles.
2. Plant cooling can be achieved by watering plants on a daily basis and allowing evaporation from the soil surface to cool the foliage. Heat tolerance of cool season grasses and ground covers can be increased with this technique.

D. Water is applied directly to the plant root zone. Spray irrigation systems broadcast water in the form of small droplets through the air to the leaf surface of the turf. These droplets are highly susceptible to wind drift. Sufficient water must fall on the leaf surface before it can penetrate through the thatch material and begin soaking into the soil. Micro-irrigation systems can apply water below ground level, exactly where needed. The following advantages are realized by applying water directly to the plant root zone:

1. Wasteful evaporation is reduced.
2. Runoff and erosion are reduced.
3. Efficient herbicide, pesticide and fertilizer application is possible directly to the root zone through the use of in line chemical injection devices.

E. Water is applied under low pressure (15 to 50 psi vs. 30 to 150 psi). Traditional sprinkler irrigation requires high head pressures in order to eject the water stream from the spray head the required distance. Micro-irrigation allows the capillary action within the soil to move the water. So pressure is only required to force the water through the emitter. The following advantages are realized by applying water under low pressure:

1. Installation costs are reduced. Components such as pipes, valves, pumps etc. can be downsized due to low pressures and reduced flow rates.
2. Fewer components can be used because larger areas can be irrigated with the same size components.
3. Pumping costs can be reduced.

F. Other Characteristics of micro-irrigation:

1. Tolerance to water and soil salinity is increased through micro-leaching. Due to low water tension in the root zone, the turf takes up fewer salts.
2. Vandalism can be substantially reduced because the components are not visible.
3. There is no over spray on cars, buildings, windows or sidewalks, Liability is reduced, therefore insurance rates can also be reduced.
4. Maintenance costs can be reduced. Mowing, edging and fertilization times can be greatly reduced. Since no sprinkler heads are located above ground in the turf area, damage from mowing and the necessity of edging around heads is eliminated. Fertilizer, soil amendments and insecticides can be applied through the system rather than being applied to the surface of the soil.
5. Irrigation need not interfere with activities on the site, so scheduling is simplified. Since there is no above ground water spray, irrigation can take place any time, day or night, even during active use of the area.

PROBLEM STATEMENT

Realization of Potential Advantages

Although potentially great, the advantages of micro-irrigation systems have not been realized, nor has research conclusively determined that these advantages actually exist. Literature on the subject makes varying claims of potential water savings. In practice, water savings have more often been negligible. This may be due, at least in part, to inefficient design, poor system management and generally a piecemeal approach to the design and installation of these systems.

Subsurface irrigation of turf has its own specific set of design issues that must be identified and controlled. Material and component engineering have recently been developed to the point where there is now little reason not to utilize this method of turf irrigation. But it is not in wide use today. In fact it is seldom used, and only then after considerable effort on the part of the designer to overcome resistance of other professionals involved. Subsurface irrigation of turf, like any other irrigation system, will not serve the needs of every turf variety, land situation or end user objective.

In 1985, while at a landscape architectural firm in Phoenix, the author was charged with designing a state of the art irrigation system that would demonstrate modern water conservation methods of turf irrigation. Subsurface irrigation techniques were examined and it was determined that they offered a possible answer to the client's request. However, information on the subject was scattered and many times contradictory.

Design information was scattered among many sources and incomplete at best. Justification for the use of such a system was sketchy or nonexistent. It appeared to the author that subsurface irrigation of turf offered many advantages, but this was difficult to document for the client and city officials who would have to eventually approve the system.

With considerable guess work and difficulty, the project was designed. It was impossible, however, to receive the required city approvals. The city engineer refused to give the needed approvals on the grounds that it had not been demonstrated that the system was dependable and so could not be used in the city right-of-way, one of the requirements of the project. The lack of solid, unbiased research seems to be hampering the adoption of what could be a very useful, water efficient technique.

Need for Further Research

Many arguments can be made for further investigation into the subject of subsurface irrigation of turf. Water is scarce, especially in the Southwest. In periods of extreme scarcity many governing bodies have been considering water rationing. Some are beginning to consider turf and its attendant irrigation to be a luxury that can be eliminated. Literature is unconvincing, unscientific and suffers from a lack of consolidation. Subsurface irrigation shows great promise for alleviating water shortages, but it is not generally accepted by the industry. Presently, there is no place a designer can go for assistance. The experts in the field tend to be the few contractors who install these systems. Since there are no text books for subsurface irrigation of turf, the designers of these systems who are competent must have learned through trial and error.

Objectives

This paper serves four academic and personal goals. They are to:

1. Review existing literature using published and unpublished sources to determine its relevance for the designer of subsurface irrigation systems;
2. Examine selected installed sites to determine current industry practices.
3. Develop a model to assist the designer of subsurface irrigation systems for turf; and to
4. Determine the areas of greatest need for further research and technical development.

METHODOLOGY

The methods used in this paper to examine subsurface irrigation of turf include a review of current literature and an examination of two case studies. Each method provides an alternative source of information for determining the answers to the objectives being addressed by this paper.

Literature Review

Literature dealing with design issues of subsurface irrigation of turf is scattered among many sources and seldom directed toward assisting the designer of such a system. To simplify analysis, existing literature is divided into three general categories: academic studies, popular journal articles and technical literature.

This categorization is imprecise because some scientific studies and much of the manufacturer generated technical literature is presented in popular journals. Even though there is a crossover in the categories where the material can be found, this classification is appropriate because the writings for each of these categories are directed to very different audiences, and written for different purposes.

The academic studies reviewed include dissertations, theses, conference proceedings and extension publications. Popular journals articles are from industry journals that contain advertising and could be considered promotional in nature, although much technical information is included. The term "technical literature" is used loosely. As used here, it does not infer accuracy. It is meant only to include irrigation design manuals and published manufacturer's installation handbooks, which tend to be of a more technical nature.

Case Studies

Although there are studies dealing with many of the elements involved in such a design, critical issues such as cost comparisons with conventional irrigation systems, specific design techniques, installation procedures, fertilization and maintenance are difficult to uncover. It is hoped that an examination of installed projects will give some insight into the accuracy and applicability of present writings on the subject. For this reason, two case studies will be examined in this paper.

The sites chosen, a residence and a city park, represent very different scales, uses and management regimes. They are located in the greater Phoenix area and include a small privately owned residence and a city park. It is hoped that comparing two quite different sized projects will provide the model with greater applicability and give insight into advantages of the methodology in relation to the size of the project.

LITERATURE REVIEW

An examination of current literature yields few studies that deal specifically with micro-irrigation of turf. Information is dispersed and of little use to the designer. To simplify the study, this literature review is divided into three categories: academic studies, popular journal articles and technical literature. Categorization of the literature is difficult and no clear division is apparent. A topical segregation, such as emitter spacing or depth or potential water savings, is difficult because of the different purposes for which the material is written. Popular journal articles tend to be promotional in nature and broad in scope, while academic studies are more narrow in extent. The technical literature is product specific, but does contain some valuable information on general design principles.

Most of the academic studies deal with the application of micro-irrigation of agricultural crops (Nelson, 1971 and Minner, 1987) or with some other consideration of turf irrigation such as water requirements of turf (Gassmin, 1987; Kneebone, 1979; Morgan, 1987 and Ratledge, 1987). However several studies are directly applicable to the design of subsurface irrigation systems (Snyder et. al., 1974; Devitt & Miller, 1988 and Jorgenson & Solomon, 1990). Popular journal articles such as (Stroud, 1987) deal explicitly with the topic, but in a more informal or promotional manner. Technical literature includes irrigation design text books designed for the classroom, of which *Handbook of Landscape Architecture Construction* (Weinberg, 1988) is an excellent example, and manufacturer's installation handbooks such as *Leaky Pipe* by Entek.

Academic Studies

A study dealing most with the design issues of emitter spacing, tubing depth and the effect of soil type on water movement within the soil was done at the Agricultural Research Center in Fort Lauderdale, Florida (Snyder et. al., 1974). The study analyzed various 10 foot square plots of turf with seven different soil classifications. Emitters were spaced 20 inches apart on the tubing and the tubing was spaced 24 inches apart in the ground and laid at a depth of 4 inches. Observations were made on the width of the bands of turgid turf over the irrigation lines. Several conclusions were drawn from the study. From a design standpoint, emitter spacing should be no more than 24 inches and as shallow as practicable, within four inches of the surface if possible. Because of the sandy soil used in the study, the system should be operated at relatively high emission rates with 1.8 to 2.8 gph/emitters. Three additional factors discussed in the study are worth noting. First, it was suggested that because of the low operating pressures involved with this type of system, variations in land elevations will cause uneven water flow and thus uneven turf appearance. Second, a coarse textured layer of soil beneath a finer textured layer has the potential to improve lateral water movement and thus allow wider tubing spacings, reducing system cost. Finally, fertilizer and pesticide application through the subsurface irrigation system might cause localized concentrations of nutrients causing undesirable turf conditions. The observation was made that ". . . when one emitter fails, the turf served by that emitter suffers noticeably (Snyder et. al., 1974, p. 37)."

A second study directly applicable to micro-irrigation of turf in a landscape situation was done in 1988 (Devitt & Miller, 1988). The purpose of this study was to determine what effect water salinity, soil type and emitter spacing had on turf appearance. The effects of three different emitter spacings (24, 35.8, and 48 inches) were compared. The most common Southwest turf species, common bermuda grass (Cynodon dactylon) was used in the study. A saline water was used for irrigation (Devitt, 1988, p. 134). The results of the study showed that in the sandy soil, turf quality decreased as water salinity increased. In the clay soil, the most important factor in turf quality was emitter spacing, with the 24 inch spacing the maximum effective. There were several conclusions drawn from the study. First, the selection of a turf grass species, or subspecies that is salt tolerant is important to the overall success of a subsurface drip system when using saline water. Many of the bermuda hybrids in wide use today are very salt tolerant, and at the same time drought tolerant; common "midiron" being one of the more salt and drought tolerant varieties. For the sandy soil, a 24 inch spacing and 6 inch depth is suggested. For clay soil, a shorter spacing is recommended. The author discourages the use of subsurface irrigation in clay soils because emitter spacing would have to be greatly reduced, thus driving up installation costs by suggesting that "the appropriate drip line spacing interval will be a trade-off between desired level of turf response and the cost of materials and installation" (Devitt, 1988 p. 142). And, "The canopy temperature data suggest that the bermuda grass was being subjected to greater stress via the subsurface drip systems than by the surface irrigated controls (Devitt, 1988, p. 140)."

A third study (Gibeault & Meyer, 1988) examined the effect of sprinklers and subsurface irrigation under water stress conditions. Research was conducted on several warm season and cool season turf grass varieties, watering them at 100%, 80% and 60% of the turf evapotranspiration requirements, with no difference in turf quality found. It was shown that considerable water can be saved by watering at less than the evapotranspiration rate, while maintaining turf appearance. With the warm season species there was no significant difference in appearance when irrigated by spray or subsurface irrigation. However, the cool season species, performed significantly better when irrigated by sprinklers. It was noted that when the tubing was installed at the manufacturer recommended spacing of 23 inches and emitter spacing of 18 inches at a depth of 8 inches, the cool season grasses did worse than the turf irrigated with spray systems. It was acknowledged that the subsurface-irrigation system "was apparently too deep and/or too widely spaced to provide adequate amounts of water (Gibeault, 1988, p. 17)." It was also suggested that subsurface-irrigation offered no probability of saving water.

A fourth study (Rauschkolb, 1991) is being conducted by the Maricopa Agricultural Experiment Station, affiliated with the University of Arizona. It is presently involved in research that should provide important design data for designers. This study is evaluating tubing spacings of 12, 24 and 36 inches at depths of 4, 8 and 12 inches. Two soils are being used in the study, a sandy loam common to lawns and parks throughout Arizona and river bottom sand, of a quality commonly used in golf greens. The study is not complete, but preliminary studies indicate optimum tubing spacing and depth of 24 inches and 8 inches respectively. An initial conclusion is that emitter and tubing spacings should be reduced in high traffic conditions (Rauschkolb, 1991).

A fifth study, (Jorgenson & Solomon, 1990) is being conducted by the Center for Irrigation Technology at California State University in Fresno, California. It shows great potential benefit for the designer of subsurface irrigation systems. Begun in 1990, the study will last for three years. Its goals are to determine the viability of subsurface irrigation of turf, conduct product evaluations and identify management techniques particular to this type of irrigation. Seven different brand products are being evaluated, both point source emitters and continuous line source tubing. Irrigation tubing is installed at a depth of five inches. Three horizontal spacings are used - the manufacturer's recommendation, one third narrower and one third wider than recommended. Turf quality and the presence of pests are being evaluated. The soil used for the tests is Hanford Fine Sandy Loam, with a more broad based applicability to landscape situations than the sandy soil used in some other studies. The study has already yielded several observations. Turf on the edges of the plots was dryer than other areas, probably due to heating of the soil caused by the concrete near the edge of the plot. An automatic air vent/vacuum relief valve is recommended for each remote control valve to prevent water and solids from being drawn back into the tubing when the valve is turned off. Even though the grass was not washed by water from traditional sprinklers, the surface did not become dusty or dirty as expected. The quality ratings for the line source tubing remained high further into the summer season than those for the point source emitters. Table 2 is a summary of the emitter spacing, emitter depth and the flow rate used in the study.

DESIGN SUMMARY - JORGENSON AND SOLOMON			
Product	**Nominal Flow**	**Emitter/Tubing Spacing**	**Tubing Depth**
Drip-in subsurface irrigation	0.5 GPH	18"	5"
Netafim Ram	0.6 GPH	12"	5"
Agrifim Subflo	1.0 GPH	12"	5"
Agrifim Inline	1.0 GPH	15"	5"
Pepco Laser Tubing	1.0 GPH	12"	5"
CTA	2.1 GPM/100'	Continuous	5"
Irri-Namic	1.6 GPM/100'	Continuous	5"
Aquapore	0.5 GPM/100'	Continuous	5"
Range Point Source	**0.5 GPH/1.0 GPH**	**12"**	**5"**
Mean Point source	**.8 GPM**	**14"**	**5"**
Range Line Source	**0.5-2.1 GPM/ 100'**	**18"**	**5"**
Mean Line source	**1.4 GPM/100'**	**Continuous**	**5"**

Table 2. Design Summary, Jorgenson and Solomon (Jorgenson and Solomon. 1990, p. 2).

A sixth study (Krans and Johnson, 1974) evaluated the merits of subsurface irrigation of turf during periods of heat stress. Two soil types were used in the experiments: a mixture of sand, Lomite and natural soil, and an unamended sandy soil. Treatments included sprinkler irrigation and subsurface irrigation using a lysimeter to saturate the soil from below. Several findings of interest here were determined. Recovery from heat stress was significantly greater for the subsurface irrigated plots than for the sprinkler irrigated plots. There was significantly greater root mass with the subsurface irrigated plots than for the sprinkler irrigated plots. Soil moisture content tended to be more consistent over time for the subsurface irrigated plots. Moisture stress was more apparent on the sprinkler irrigated plots. A final conclusion was "Subirrigation appears to have potential for improving the maintenance of bentgrass during periods of prolonged stress" (Krans and Johnson 1974, p. 530).

Summary

Table 3 shows a comparison of the emitter spacing, tubing spacing and tubing depth of the academic studies. It shows a range of emitter spacing of 12 to 24 inches, a tubing spacing of 8 to 48 inches and a tubing depth of 4 to 8 inches.

DESIGN SUMMARY OF ACADEMIC STUDIES			
Source	Emitter Spacing	Tubing Spacing	Tubing Depth
Theory and Experimentation for Turf Irrigation from Multiple Subsurface Point Sources Snyder et. al., 1974	20"	24"	4"
Subsurface Drip Irrigation of Bermudagrass With Saline Water Devitt, 1988	24"	24" to 48"	6"
Irrigation and Water Conservation Gibeault, 1988	18"	23"	8"
Maricopa Agricultural Experiment Station, University of Arizona Rauschkolb, 1991	16"	24"	8"
Evaluating Subsurface Drip Irrigation for Turfgrass: an Intrum Report. Jorgensen, and Solomon, 1990	12" to 18"	8" to 13"	5"
Range	12" to 24"	8" to 48"	4" to 8"
Mean	18"	23"	6"

Table 3. Design Summary, Academic Studies.

It is possible to summarize the design recommendations from these studies. It should be realized that any summary, drawn from different sources, must be general in nature. These recommendations could not be used by a designer without applying them to the conditions particular to the site in question. But, by drawing recommendations from a spectrum of sources, a picture of the issues involved in the design of a subsurface irrigation system can be drawn. Design recommendations from the academic studies are summarized as follows:

A. Emitter spacing should be no more than 24 inches, preferably less.

B. Emitter spacing should be reduced in heavy, clay soils.

C. Emitter spacing should be increased in high traffic areas.

D. Tubing spacing should be no more than 24 inches.

E. Tubing depth should be no more than 6 inches.

F. Tubing should be placed closer to the edge of the turf when it comes into contact with concrete, preferably within 6 inches.

G. An automatic air vent/vacuum relief valve is recommended at each remote control valve.

H. As soil texture becomes more coarse, emission rates should increase to 1.8 to 2.8 gallons per hour.

I. A layer of coarse textured soil beneath a finer textured layer has the potential to improve lateral water movement.

J. Salt tolerant turf species is important to success.

K. A pressure compensating system should be used if there are elevation differences on the site or if the tubing is used in excessively long runs.

L. Emitter and tubing spacings should be reduced in high traffic conditions.

Several value judgements are made with respect to subsurface irrigation of turf in the academic studies. The studies each have a different approach to the topic and consider different variables important. So, even though the conclusions may differ, they are relevant under varying conditions found in the field. These valuations can be summarized as follows:

A. Considerable water can be saved by watering at less than the evapotranspiration rate.

B. Turf appearance does not become dusty or dirty as a result of subsurface irrigation.

C. Cool season grasses perform less well with subsurface irrigation than warm season grasses.

D. Cool season grasses require that the tubing be placed closer to the soil surface.

E. The visual quality may be higher with line source emission systems than point source emission systems.

F. Subsurface-irrigation may offer little or no water savings.

G. Recovery from heat stress is greater for subsurface irrigated turf.

H. There is significantly greater root mass with the subsurface irrigated turf.

I. Soil moisture content tends to be more consistent over time for subsurface irrigated turf.

J. Moisture stress is less apparent on subsurface irrigated turf.

K. Fertilizer and pesticide application through the subsurface irrigation system could cause localized concentrations of nutrients.

Popular Journal Articles

Many applications, including residential and commercial lawns, athletic fields and ornamental plantings are suggested by Stroud for low volume, low pressure irrigation systems (Stroud, 1987, p. 80). This article describes installation procedures and lists advantages and disadvantages of subsurface irrigation of turf. Among the advantages listed are reduced maintenance costs, elimination of over spray, water savings, energy savings, simplified chemical application, use of the site while it is being watered, reduced disease problems and short payback period. Disadvantages are higher initial cost, poor quality of turf immediately after system installation, high accuracy required at installation and problems with defective equipment. Stroud recommends the injection of 10% sulfuric or muriatic acid through the system to prevent root intrusion into the system. In describing installation of the tubing, she suggests 24 inch to 32 inch spacing for the emitter lines and 24 inch spacing of the emitters. Stroud infers that the 32 inch spacing was chosen to reduce installation costs. The article suggests that the amount of trenching required for this spacing causes the initial installation cost to be up to 20% higher than spray systems. Stroud also claims a water savings of 50 to 60% if the system is properly installed and conscientiously operated.

A second article, (Subsurface Irrigation: Made for the Challenge of Drought, 1988) goes into great detail about design, installation procedures and advantages of this type of system. It also claims a water saving potential of 25 to 40% for the system. One of the most important advantages discussed is that of reduced liability. The reduced potential of lawsuits from wet sidewalks and streets is noted (Subsurface Irrigation: Made for the Challenge of Drought, p. 72). Other advantages discussed are a reduction of splash-transmitted diseases, ease of fertilizer application, cost comparable to conventional systems and uniform water distribution on slopped areas. An important point the article makes is the necessity for good design and installation practices. Spacing between rows must be exact and consistent. It is also important that the designer be familiar with this type of system since design and installation of subsurface systems is not forgiving of error. This is one of the few articles that recommends an emitter line spacing of less than 24 in. This is also the only popular journal article that describes modern vibrating plow installation of the tubing. The article says that installation costs no more, and probably less than conventional irrigation systems. To reduce the chance of root intrusion into the system, a regular watering schedule is suggested. It is thought that a dry soil condition will promote "hunting" by the roots and they will seek out water within the system (Subsurface Irrigation: Made for the Challenge of Drought, p. 80). This is the only article to address the issue of coefficient of uniformity, a measure of the evenness that the irrigation system is applying the water to the turf. Traditional surface irrigation systems are not very even in their application of water. But because the emitters are placed within two feet of each other throughout the lawn an extremely high coefficient of uniformity is obtained with subsurface irrigation.

A third article, (Micro-Irrigation: Good Things Come in Small Packages, 1989), is a comprehensive article that discusses a wide range of drip irrigation issues. The thrust of the article is that the quality, reliability and dependability of the components have recently been developed to the state where drip irrigation components are as dependable as any other type of irrigation components. It discusses several components that would be included in a typical system. A filtration system should be included in any drip system. A pressure regulator should be used on all systems, regardless of elevation changes on the site. A chemical injector will allow fertilizers, herbicides and insecticides to be applied through the system. A tensiometer should be used to monitor soil moisture and can even take charge of the irrigation controller. The use of pressure compensating emitters greatly simplifies the design and cost of the system by eliminating flow differences between emitters of different elevations. When considering total cost of the system, initial cost, installation cost, operating cost and maintenance cost must be considered. Operating costs are considerably less than conventional irrigation systems. One manufacturer has developed an emitter constructed of a plastic with an herbicide molded into the emitter orifice. This emitter has been highly successful in reducing root intrusion into the emitter (Micro-Irrigation: Good Things Come in Small Packages, 1989, p. 104).

A fourth article, (Cloud, 1980) was especially forward looking, considering that it was written eleven years ago. It suggested that ". . . no previous development will have the impact of the new, subterranean, injected irrigation systems (Cloud, 1980, p.36)." The article discussed the concept of "pulse watering," periodically cycling the system on and off to increase lateral movement of the water in the soil. It notes that extreme accuracy is needed in installing the system. Among the advantages listed were the elimination of trimming around sprinkler heads, reduced liability, no over spray on buildings, elimination of evaporation, the option of watering while the site is being used. Of interest is a comment that

> "Compaction is also not a problem with this form if irrigation, since the water is injected at a relatively high pressure into the substructure. Tiny channels are created when the water escapes to the surface and these become air ducts straight to the root zone (Cloud, 1980. p. 37)."

Summary

Table 4 shows a comparison of the emitter spacing, tubing spacing and tubing depth of the popular journal articles. It shows a range of emitter spacing of 12 inches to 32 inches, a tubing spacing of 12 inches to 24 inches and a tubing depth of 4 inches to 6 inches. Two of the articles, (Micro-Irrigation: Good Things Come in Small Packages, 1989 and Cloud, 1989) are not included in the table as they make no specific recommendations as to emitter spacing, tubing spacing or tubing depth.

Again, this summary is general in nature and sometimes contradictory. These design recommendations have been tried in the field and worked for the specific sites involved.

DESIGN SUMMARY OF POPULAR JOURNAL ARTICLES				
Source	**% Water Savings**	**Emitter Spacing**	**Tubing Spacing**	**Tubing Depth**
Subsoil Irrigation Systems Stroud, T., 1987	**50%-60%**	**24 inches/ 32 inches**	**24"inches**	**4 inches/ 6 inches**
Subsurface Irrigation: Made for the challenge of drought ***Landscape & Irrigation***	**25%-40%**	**12 inches/ 18 inches**	**12 inches**	**None Given**
Range	**25%-60%**	**13 inches/ 32 inches**	**24 inches**	**4 inches/ 6 inches**

Table 4. Design Summary of Popular Journal Articles.

The recommendations from the popular journal articles are summarized as follows:

A. Water filtration is required with subsurface irrigation of turf.

B. A pressure regulator is needed to provide even flow at all parts within the system.

C. Tensiometers should be used to monitor soil moisture.

D. Chemical injectors can be used to apply chemicals through the system.

E. Pressure compensating emitters can be used simplify the design and improve performance.

F. The total cost of the system from design, installation, operation, maintenance to repair should be considered when evaluating subsurface irrigation of turf.

G. Pulse watering can be used to increase lateral water movement in the soil.

H. A solution of 10 per cent sulfuric or muriatic acid, when injected through the system, can prevent root intrusion.

I. The designer and installer must be familiar with this type of system because subsurface irrigation of turf is not forgiving of error.

J. Modern vibrating plow equipment should be used for installation of the emitter tubing.

K. Regular watering is recommended to reduce root intrusion into the emitters.

Popular journal articles tend to make more value judgements respect to subsurface irrigation of turf than the academic studies. These positive valuations can be summarized as follows, realizing that most of them may be undocumented.

A. Component quality has improved in recent years.

B. Operating costs are less with subsurface irrigation when compared to conventional irrigation.

C. Maintenance costs are reduced with subsurface irrigation.

D. Liability may reduced considerably with subsurface irrigation.

E. Scheduling is simplified because watering can take place while the site is in use.

F. Soil compaction is reduced with subsurface irrigation.

G. Energy saving, in the form of pumping costs, are great because of the low pressures used with subsurface irrigation.

H. Splash transmitted diseases are eliminated with subsurface irrigation.

I. Water savings of 50 per cent to 60 per cent are possible with subsurface irrigation.

J. Efficient installation procedures can keep costs comparable to conventional irrigation systems.

K. A better coefficient of uniformity can be achieved on sloped areas with subsurface irrigation.

There are also some negative comments or cautions about subsurface irrigation of turf. They are summarized as follows:

A. There are still problems with poor quality products.

B. Installation must be more exact with subsurface irrigation than with conventional irrigation systems.

C. Initial costs can be higher with subsurface irrigation of turf.

D. High trenching costs can cause installation costs to be up to 20 per cent higher for subsurface irrigation systems.

Technical Literature

Irrigation design manuals, published manufacturer's installation handbooks and unpublished manuals are included here. The great majority of design manuals deal exclusively with spray irrigation. Only those publications that are produced by manufacturers of components used in subsurface irrigation of turf, deal with the topic in any detail.

The long time industry standard design handbook, *Turf Irrigation Manual*, (Watkins, 1983) makes no mention of subsurface irrigation of turf. It was first published in 1959, before subsurface irrigation was widely used in this country, and, surprisingly, does not include reference to it in its latest edition.

A second publication, *Trickle Irrigation For Crop Production* (Nakayama, 1986), is a complete technical reference on the subject of subsurface irrigation. The text is broad and includes a discussion of design, operation and management principles. Each topic is covered thoroughly, with considerable mathematical justification when required. Of considerable interest to subsurface irrigation of turf are the sections on soil water distribution, soil salt distribution, emitter clogging, filtering systems, fertilization and irrigation scheduling. It is noted that due to recent advances in material and design, ". . . maintenance requirements of subsurface systems are similar to surface trickle systems (Nakayama, 1986, p. 12)." Among the potential advantages listed for trickle irrigation are (Nakayama, 1986, pp. 16-18):

A. Enhanced plant growth

B. Reduced salinity hazard to plants

C. Improved fertilizer and other chemical application

D. Decreased energy requirements.

Also listed are several potential disadvantages (Nakayama, 1986, pp. 18-19):

A. Higher maintenance requirements

B. Salt accumulation near plants

C. Restricted plant root development

D. High system costs

The system designer must consider many variables, more than with conventional systems, when designing a subsurface irrigation system. These design and installation suggestions are given below (Nakayama, 1986, pp. 19-20):

E. Lateral tubing should be run flat, downhill or along the contour for noncompensating emitters.

F. Lateral lines can be run regardless of slope if pressure compensating emitters are used.

G. System capacity must be designed to meet peak plant evapotranspiration (the worst possible case).

H. Filtration units must meet the water quality and flow capacity of the system.

I. Backflow prevention devices must be installed to protect the water supply from chemicals injected through the irrigation system.

J. Air, or vacuum relief valves should be installed to prevent debris from being drawn into the system.

Nakayama suggests that the primary goal of any trickle irrigation maintenance program should be to control emitter clogging, thus providing the required amount of water to the plant. He suggests the following maintenance requirements for trickle irrigation systems (Nakayama, 1986, pp. 20-21):

K. Filters should be cleaned and inspected regularly.

L. Automatic flushing devices should be used where the water is high in silt and clay.

M. Chemical injectors and time clocks should be checked weekly.

N. The entire system should be inspected for malfunctioning emitters and leaks at least monthly.

O. Chemical water treatment should be used when chemical or biological hazards are present.

P. Inject only chemicals that have been approved for trickle irrigation systems.

Q. Soil moisture should be checked regularly.

R. Maximum chemical injection efficiency is achieved by allowing the system to run long enough to establish flow equilibrium, or evenly wet the soil, before the chemicals are injected into the system (Nakayama, 1986, p. 236).

Apart from the maintenance points just mentioned, Nakayama also suggests several management techniques or considerations to insure the best subsurface irrigation system performance. They are as follows (Nakayama, 1986, p. 21):

A. Automation of the system can save labor, water and chemical expense, however it may increase maintenance problems.

B. Use field measurements and observations to assist in irrigation scheduling.

C. More frequent irrigation scheduling can benefit soil or water salinity problems.

D. Fertilizer applications should be more frequent during the early stages of plant growth

A third publication is *Handbook of Landscape Architectural Construction* (Weinberg, 1988). It is the most current, complete irrigation design text available. It deals with irrigation master planning, components, design process, contract documents, specifications, bidding and drip irrigation design for shrubs and trees. As complete as it is, it makes only one reference to subsurface irrigation of turf. "When used to irrigate turf, the turf surface is usable at all times, even during irrigation (Weinberg, 1988, p. 206)." This is a major omission of an otherwise complete text. Reference is made to modern vibrating plow installation of drip tubing for shrubs and trees.

A fourth publication that deals exclusively with drip irrigation of trees, shrubs and ground covers is *Landscape Drip irrigation Design Manual* (Shepersky, 1984). It does not mention subsurface irrigation of turf. However, it is of value for its guidance in the hydraulic design of drip systems in general.

A fifth publication, of particular value, is *Micro-irrigation Design Manual* (Boswell, 1986). It does not address subsurface irrigation of turf, but it covers all other aspects of design. Soil wetting patterns ar discussed and It is noted that "Water movement in soils will be affected by the condition of the topsoil, the permeability of the subsoil, layers of soil with varying properties and the presence of a plow pan (Boswell, 1986, p. 2-6)." Figure 2 illustrates the relative shapes of wetting patterns as they are affected by soil. The article notes that "In addition to soil type, the application rate will affect the shape of the wetted pattern . . . a higher application rate tends to produce a wider zone of saturation under the emitter, assisting in horizontal movement. Thus for increased lateral movement, light sandy soils require water applications at higher rates. Heavy clays and clay loams, on the other hand, often

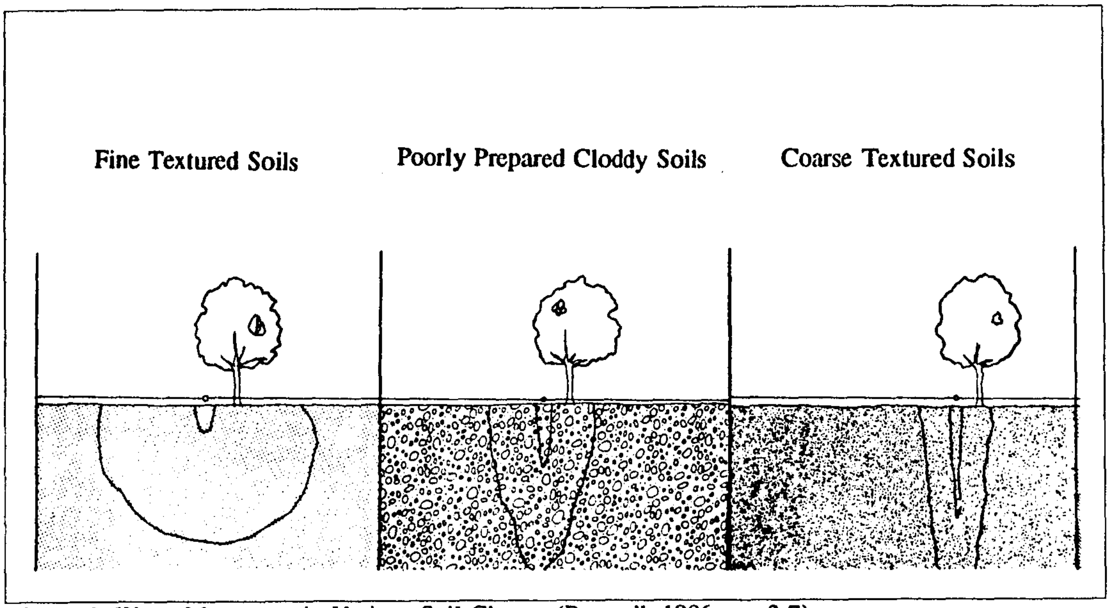

Figure 2. Water Movement in Various Soil Classes (Boswell, 1986, pp. 2-7).

benefit from a lower application rate (Boswell, 1986, p. 2-7/2-8)." Considerable treatment is given to chemical injection through the system. It is recommended that bacterial slime and algae be controlled with intermittent chlorination of 10 to 20 ppm for between 30 and 60 minutes (Boswell, 1986, p. 4-2/4-5). It is also suggested that chlorine treatment may be beneficial as a preventive to control biological growth in all parts of the system if used on a regular basis. Acid treatment of the system is also recommended to lower the Ph as a control mechanism to discourage microorganic growth and the precipitation of dissolved solids in the water. Phosphoric, hydrochloric and sulfuric acid are recommended. A procedure to adjust the Ph of the irrigation water is described (Boswell, 1986, p. 4-14). The author starongly recommends the application of fertilizer through the system. Among the advantages claimed are reduced fertilizer use, elimination of leaf burn and elimination of inhalation hazards. The three primary fertilizers, nitrogen, phosphorus and potassium, can easily be injected through the system (Boswell, 1986, p. 5-2/5-6). Several methods of injecting chemicals are described. Figure 3 shows three such chemical injection devices.

A sixth unpublished work by Netafim Irrigation, an Israeli company involved with drip irrigation since its inception, is a manual dealing with general subsurface irrigation design principles

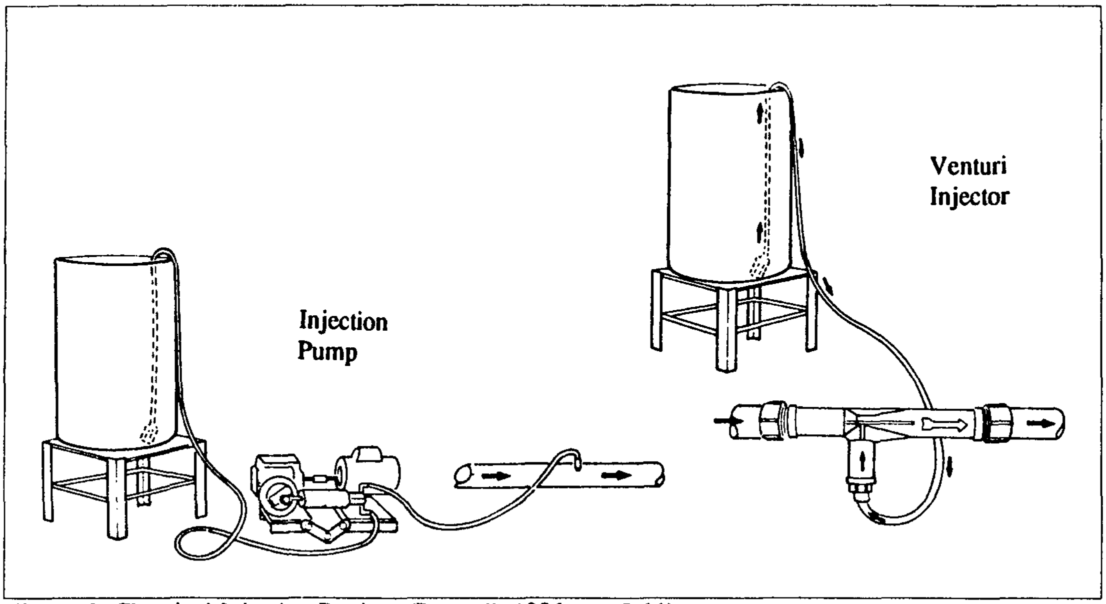

Figure 3. Chemical Injection Devices (Boswell, 1986, pp. 5-11).

(Netafim Irrigation Equipment & Drip Systems, 1986). Netafim produces an emitter tubing, called Ram tubing, used in agriculture applications and subsurface irrigation of turf. The emitter is built into the inside of the polyethylene tubing. The advantage of the emitter being built into the tubing is that a vibrating plow can be used to install the tubing without fear of damaging the emitter. Figure 4 shows a cut away section of Ram tubing with the emitter inside.

Among other advantages listed for subsurface irrigation of turf are (Netafim Irrigation Equipment & Drip Systems, 1986, p. 1):

A. Near 100 per cent coefficient of uniformity can be achieved.

B. Reduction or elimination of runoff on sloped sites is possible.

C. Narrow or irregularly shaped areas, such as those found in road medians and parking lot medians, can easily be irrigated.

D. Vandalism can be greatly reduced, if not eliminated.

E. Due to the low pressure nature of the systems, large expanses of turf can be irrigated at one time.

F. Modification of existing systems is simplified if the turf area is modified.

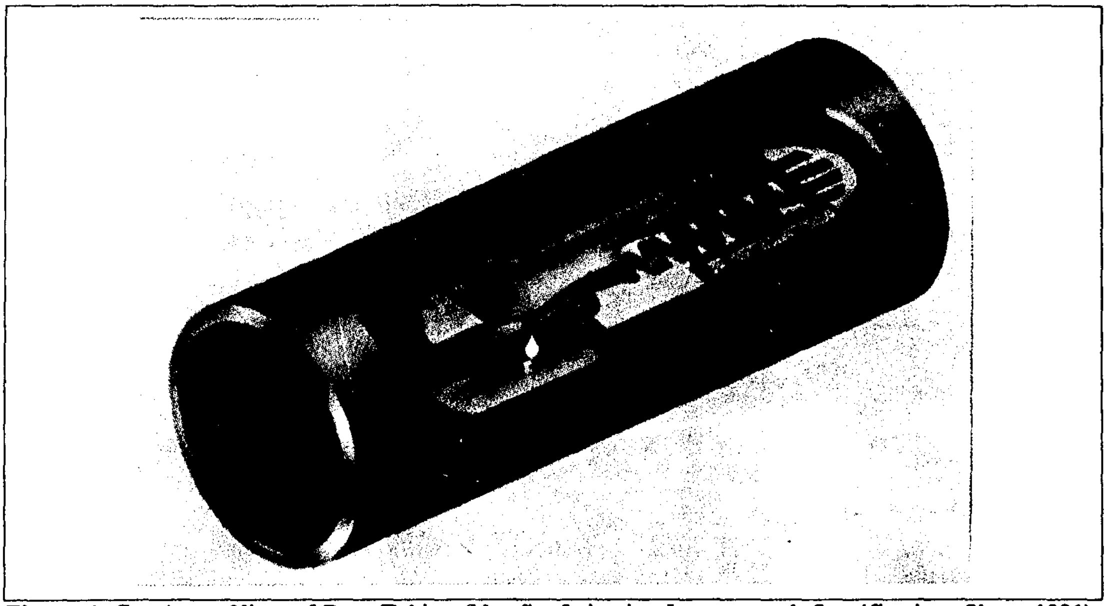

Figure 4. Cut Away View of Ram Tubing (Netafim Irrigation Incorporated, Specifications Sheet, 1991).

Subsurface irrigation of turf presents several hazards or areas of caution which are listed below (Netafim Irrigation Equipment & Drip Systems, 1986, p. 3):

A. Use only the highest quality materials and equipment.

B. Allow for regular flushing of drip lines.

C. Preventive maintenance is very important.

D. Because subsurface irrigation systems operate with low pressures, problems can go unnoticed.

Considerable attention is given to irrigation scheduling. It is recommended that watering be scheduled several times a week instead of a short watering every day. Several formulas and tables are given to help plan watering needs and scheduling. Once the soil moisture is brought to its optimum level for the turf, then only water that is lost through evapotranspiration need be replaced (Netafim Irrigation Equipment & Drip Systems, 1986, p. 13). Table 5 shows the evapotranspiration loss for different climate zones.

POTENTIAL EVAPOTRANSPIRATION LOSS BY CLIMATE				
Climate	Average High Temp. F.	Average Rel. Humidity %	P. E. T. Inches/Day	P. E. T. Inches/Wk.
Cool Humid	Below 70	Above 50	.10	0.70
Cool Dry	Below 70	Below 50	.15	1.05
Moderate Humid	70 - 85	Above 50	.17	1.19
Moderate Dry	70 - 85	Below 50	.20	1.40
Warm Humid	86 - 100	Above 50	.25	1.75
Warm Dry	86 - 100	Below 50	.28	1.96
Hot Humid	Above 100	Above 50	.32	2.24
Hot Dry	Above 100	Below 50	.36	2.52

Table 5. Potential Evapotranspiration Loss by Climate (Netafim Irrigation Equipment & Drip Systems, 1986, p. 13)

Once the evapotranspiration is established for a climate area, Table 6 and Table 7 can be used to determine the length of time the irrigation system must be run to supply that much water.

TIME REQUIRED TO APPLY ONE INCH OF WATER							
.6 GPH Emitter	Drip Line Spacing						
Emitter Spacing		12"	14"	16"	18"	20"	24"
12 Inches	Minutes	63	73	84	94	104	125
	Hours	1.0	1.2	1.4	1.6	1.7	2.1
18 Inches	Minutes	94	110	125	141	157	188
	Hours	1.6	1.8	2.1	2.4	2.6	3.1
24 Inches	Minutes	125	146	167	188	209	251
	Hours	2.1	2.4	2.8	3.1	3.5	4.2

Table 6. Time Required to Apply One Inch of Water with .6 GPH Emitters (Netafim Irrigation Equipment & Drip Systems, 1986, p. 15).

They give the length of time required to apply one inch of water. By multiplying the evapotranspiration rate from Table 5 by the number of minutes or hours from Tables 6 or 7, the run time for the system can be determined.

TIME REQUIRED TO APPLY ONE INCH OF WATER							
.9 GPH Emitter	Drip Line Spacing						
Emitter Spacing		12"	14"	16"	18"	20"	24"
12 Inches	Minutes	40	46	53	59	66	79
	Hours	0.7	.8	0.9	1.0	1.1	31.3
18 Inches	Minutes	59	69	79	89	99	119
	Hours	1.0	1.2	1.3	1.5	1.6	2.0
24 Inches	Minutes	79	92	106	119	132	158
	Hours	1.3	1.5	1.8	2.0	2.2	2.6

Table 7. Time Required to Apply One Inch of Water with .9 GPH Emitters (Netafim Irrigation Equipment & Drip Systems, 1986, p. 15).(Netafim Irrigation Equipment & Drip Systems, 1986, p.15)

Simple formulas to calculate water requirements are also given. Equation 1 can be used to determine the gross or total amount of water needed to maintain a certain area of turf. It shows the volume of water in gallons needed to replace the loss due to evapotranspiration.

$$V = .623 \times A \times Et.$$

Equation 1. (Netafim Irrigation Equipment & Drip Systems, 1986, p. 14)

V = Volume of water that needs to be applied, in gallons

.623 = Constant

A = Area in square feet to be irrigated

Et. = Evapotranspiration rate

Equation 2 shows the amount of water applied in inches per hour based on the flow of the emitter, the space between emitter lines and the space between emitters. It can also be used to calculate the time required to apply the needed water.

$$Q = \frac{1.6 \, x \, f}{d \, x \, e}$$

Equation 2. Netafim Irrigation Equipment & Drip Systems, 1986, p. 14)

Q = Quantity of water applied in inches per hour

1.6 = Constant

f = Emitter flow in gallons per hour

d = Space between drip lines in feet

e = Space between emitters on the drip lines in feet

Netafim also suggests a deep watering several times a week instead of a short watering every day (Netafim Irrigation Equipment & Drip Systems, 1986, p. 13). Netafim includes two construction details of emitter tubing installation. Figure 5 shows a recommended tubing depth of four inches to six inches and a typical connection to a PVC lateral pipe.

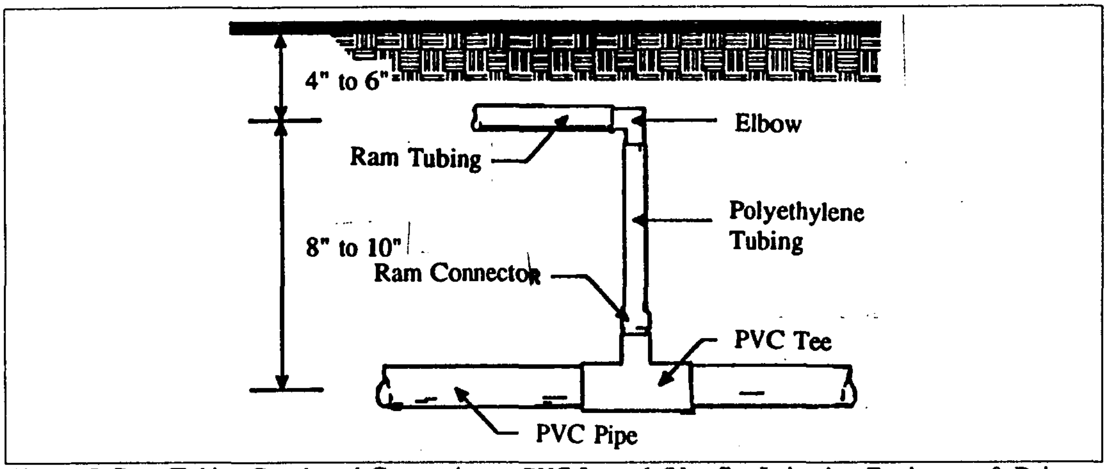

Figure 5. Ram Tubing Depth and Connection to PVC Lateral (Netafim Irrigation Equipment & Drip Systems, 1986, p. 6).

Figure 6 shows a Ram tubing layout for turf. It shows that the Ram tubing is run parallel and serviced by a PVC lateral pipe, or manifold, to which each Ram tube is connected. There is another PVC manifold, to which the outlet end of each Ram tube is connected.

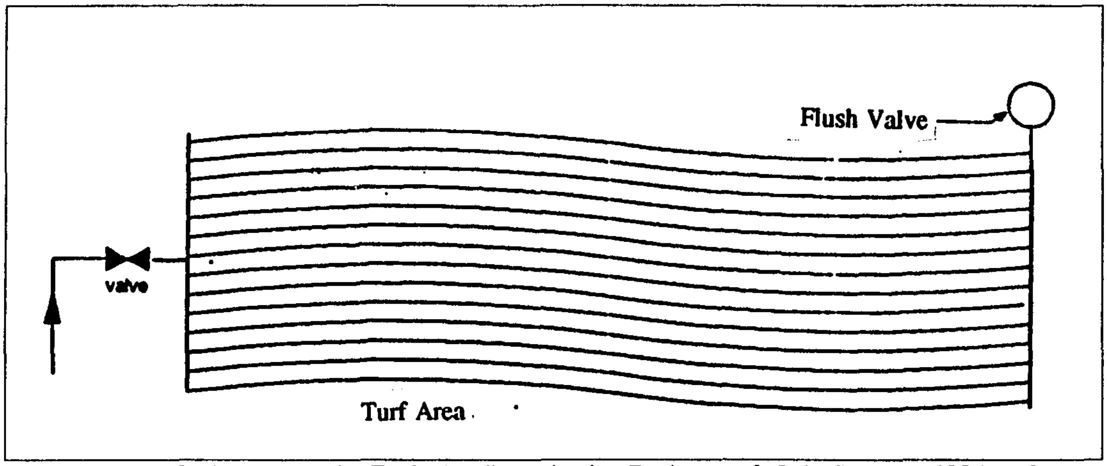

Figure 6. Ram Tubing Layout for Turf (Netafim Irrigation Equipment & Drip Systems, 1986, p. 8).

Netafim produces an line flushing valve, shown in Figure 7 that automatically flushes a predetermined quantity of water from the emitter tubing at the start and finish of each irrigation cycle. The automatic nature of the device is ideal for homeowner applications where maintenance may be erratic.

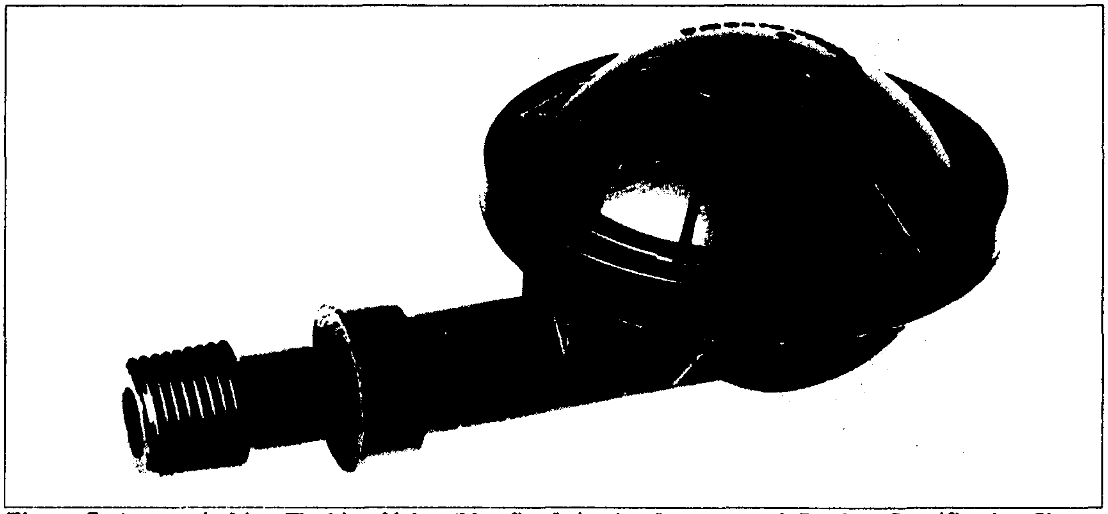

Figure 7. Automatic Line Flushing Valve (Netafim Irrigation Incorporated, Product Specification Sheet, 1990).

A seventh design manual that deals specifically with subsurface irrigation of turf, is from Intek Corporation (Leaky Pipe Subsurface Dispersal Systems, 1990). Intek produces porous pipe that emits water along its entire length. The manual is promotional in approach, but is a reasonably complete design manual. It deals with movement of water within the soil, saturation/wilting point cycles, cost comparisons, detailed installation procedures and includes simplistic installation plans. For a comparison of installation costs between conventional and subsurface irrigation systems, see Table 8.

LABOR REQUIREMENTS AND CAPITAL COSTS FOR INSTALLATION OF VARIOUS TYPES OF IRRIGATION SYSTEMS		
System Type	**Labor Hr/Ac**	**Capital $/Ac**
Surface	**0.15 to 1.00**	**120 to 500**
Sprinkler	**0.05 to 0.10**	**400 to 1200**
Moving	**0.20 to 0.70**	**200 to 400**
Subsurface	**0.14 to 0.16**	**250 to 1000**

Table 8. Comparison of Irrigation System Costs (*Leaky Pipe Subsurface Dispersal Systems*, 1990. p. 31)

Figure 8 shows a typical baseball field lay out. The manual provides simple plans for football and baseball fields and suggests that "The savings on water and maintenance should pay for the field in

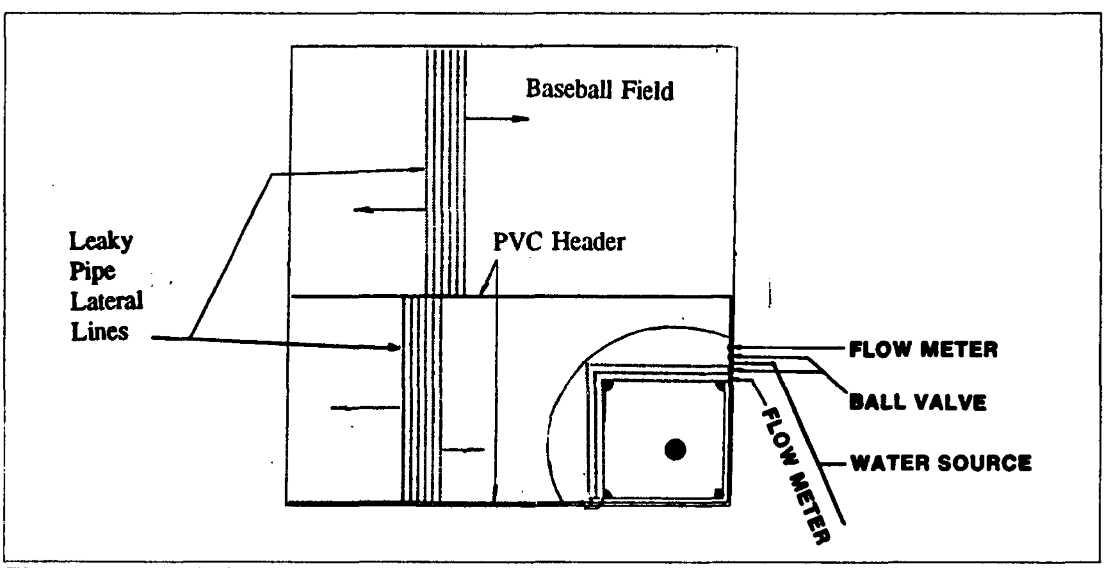

Figure 8. Baseball Field Layout (*Leaky Pipe Subsurface Dispersal Systems*, 1990, p. 34).

less than three years (Leaky Pipe Subsurface Dispersal Systems, 1990. p. 31)." This claim, however, is not substantiated, nor is the type of field being considered given.

Intek recommends emitter tubing spacing of two feet and tubing depth of between eight inches and twelve inches. The manual discusses the concept of "old soil" and "new soil".

> "In the process of laying or burying the Subsurface Delivery System, . . . at the point of installation, the old soil is disturbed or wounded. That portion becomes more permeable than the old soil until the disturbed soil settles down to again become old soil (*Leaky Pipe Subsurface Dispersal Systems*, 1990. p. 15)."

The eighth and ninth manuals examined are by Aquapore (Installation, Operation and Maintenance Instructions for Aquapore Subsurface Irrigation Systems, 1989 and Aquapore Installation Specifications and Construction Details, 1989). Aquapore also produces a type of porous pipe used in subsurface irrigation of turf. The manuals cover water movement within the soil, system components, installation methods, necessary equipment, turf water requirements and maintenance. Aquapore has written the most complete installation manuals available, that are designed for the general public. Figure 9 shows a typical Aquapore system component layout, from the water source to each irrigation zone.

The Manual covers irrigation components, soil preparation, installation methods, system layout, scheduling and maintenance. It recommends a tubing spacing of 12 to 36 inches and a depth of 4 inches. A typical emitter tubing layout is shown in Figure 10.

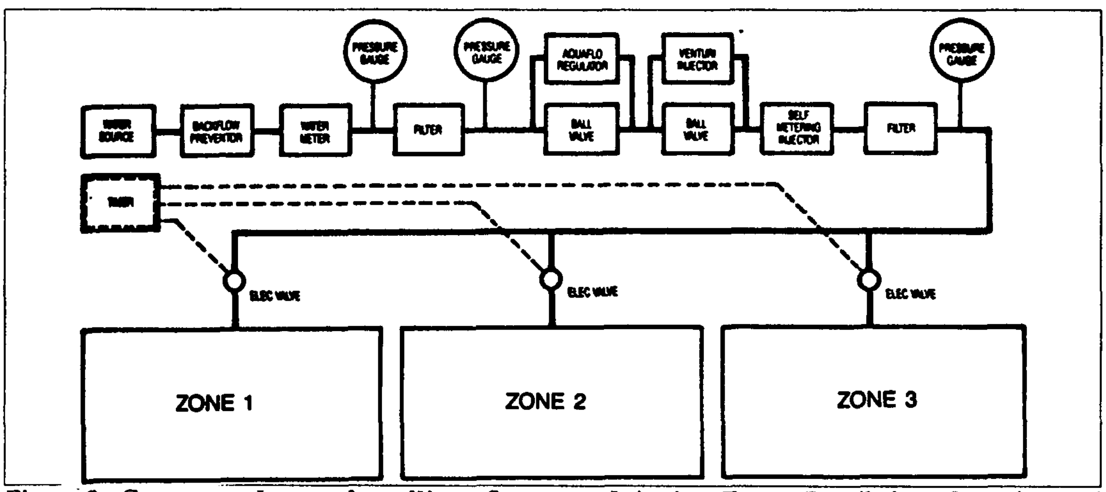

Figure 9. Component Layout from Water Source to Irrigation Zones (Installation, Operation and Maintenance Instructions for Aquapore Subsurface Irrigation Systems, 1989, p. 3-4).

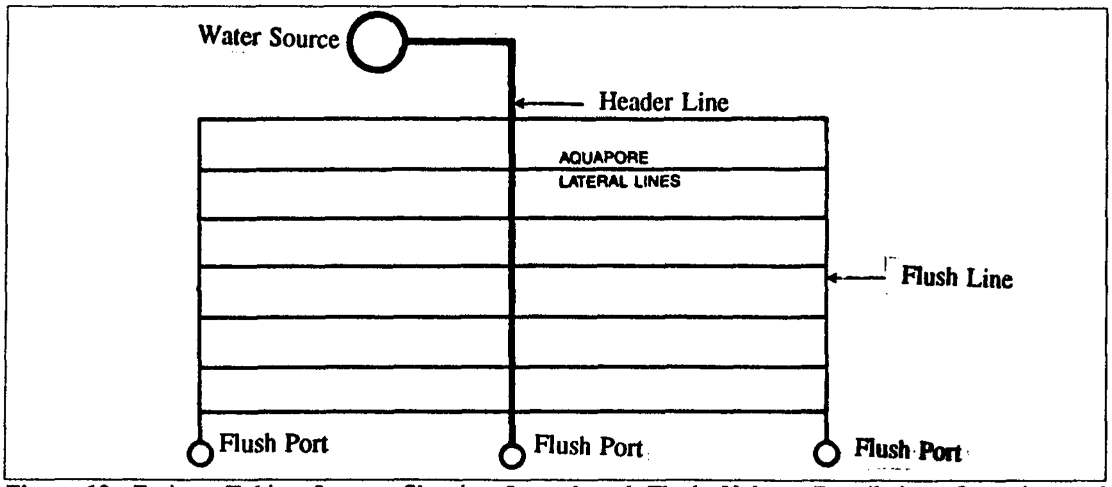

Figure 10. Emitter Tubing Layout Showing Lateral and Flush Valves (Installation, Operation and Maintenance Instructions for Aquapore Subsurface Irrigation Systems, 1989, p. 6-2).

It is suggested that an application rate of .5 GPM per 100 foot of pipe in loam soil and .75 GPM to 1.0 GPM per 100 foot of pipe in sandy soils is sufficient for most turf species (Installation, Operation and Maintenance Instructions for Aquapore Subsurface Irrigation Systems, 1989, p. 4-2). An entire chapter is devoted to soil preparation. The most important point made is that

> "The most ideal soil conditions for the installation of Aquapore are found when the soil has just recently been tilled and has a high moisture content without being too wet for the proper operation of the installation equipment. Rototilling is a must on all new installations (Installation, Operation and Maintenance Instructions for Aquapore Subsurface Irrigation Systems, 1989, p. 4-5)."

Considerable detail is also given as to layout of the emitter tubing. Specifically,

> "The first and last runs of Aquapore in each area or zone which parallel the edge should be laid only 6 inches from the edge of the zone. This is especially true when the zone is bordered by a cement sidewalk, driveway or other hard surface. These hard surfaces collect the heat from the sun and transfer the heat into the bordering lawn at a higher rate than normal, thus drying out that part of the lawn. At the bottom of a slope they can be 16 inches away from the driveway or sidewalk (Installation, Operation and Maintenance Instructions for Aquapore Subsurface Irrigation Systems, 1989, p. 4-6)."

In discussing trenching for the porous pipe, Aquapore considers conventional methods of trenching and vibrating plow methods. Aquapore provides a complete set of installation specifications and construction details. A filter/backflow/chemical injector assembly is shown in Figure 11.

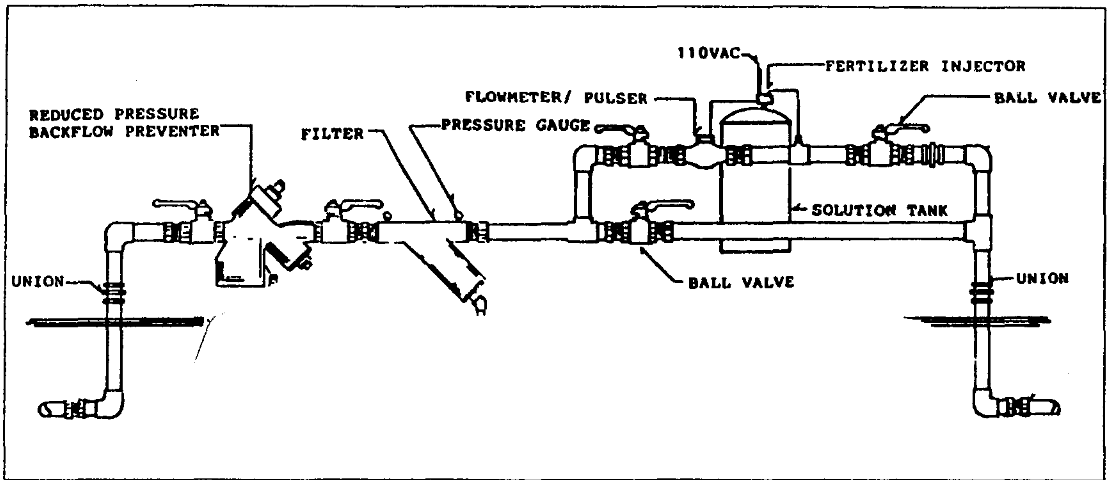

Figure 11. Valve Manifold Assembly (Aquapore-Installation Specifications and Construction Details, 1989, p. 7).

Aquapore also produces a "de-clogging" chemical specifically designed for subsurface irrigation systems. It contains phosphoric acid and is designed to dissolve iron, magnesium and calcium salts. If used regularly, it is claimed to inhibit slime deposits in the system. Aquapore has written a reasonably complete manual. Its primary drawback is that it is written specifically for an installation using porous pipe. Application to designs using point source emitters, such as Netafim, would have to be approached with caution.

Summary

Table 9 summarizes the tubing spacing and tubing depth recommendations from the technical literature. It shows a range for tubing spacing of 12 to 36 inches and a range for tubing depth of 4 to 12 inches. Only Intek and Aquapore are summarized in the table, as only they give depth or spacing recommendations.

TECHNICAL LITERATURE TUBING SPACING AND TUBING DEPTH SUMMARY		
Source	**Tubing Spacing**	**Tubing Depth**
Leaky Pipe Subsurface Dispersal Systems **Entek Corporation, 1990**	**24"**	**8"-12"**
Aquapore - Installation Specifications and Construction Details **Aquapore, 1989**	**12"-36"**	**4"**
Range	**12"-36"**	**4"-12"**

Table 9. Technical Literature Tubing Spacing and Depth Summary.

A general summary of the recommendations of the technical literature can be drawn. Again, it should be realized that the summary is drawn from many sources, but consistent, recurring recommendations should carry weight. Without reiterating all recommendations and suggestions from the technical literature, several important points can be emphasized here:

A. Emitter spacing should be reduced for coarse, sandy soils. Spacing can be increased for heavy, clay soils.

B. Pressure compensating emitters simplify the system design. Emitter lines can be run without regard for land contours.

C. Good filtration is important for satisfactory operation.

D. Backflow prevention devices are required because many chemicals can be run through the system.

E. Air relief valves will help keep the system free of debris by eliminating back suction when the system is turned off.

F. Automatic flush valves will simplify maintenance and help keep the system clean.

G. Chemical injectors can be used to supply many types of chemicals through the system.

H. Several scheduled waterings per week are preferable to daily waterings.

I. Coarse, sandy soils require higher emission rates from the emitters than heavy, clay soils.

J. Ideally, the soil should be uniform in texture throughout the site.

K. A vibrating plow can simplify installation.

Conclusions

Table 10 is a summary of water savings, emitter spacing, tubing spacing and tubing depth for all literature cited. As can be seen, there is considerable variability in the four categories shown.

ALL CITED LITERATURE DATA SUMMARY				
Source	**% Water Savings**	**Emitter Spacing**	**Tubing Spacing**	**Tubing Depth**
Academic Studies				
Irrigation and Water Conservation Gibeault, Meyer, 1988	**Not Mentioned**	**18"**	**23"**	**8"**
Subsurface Drip Irrigation of Bermudagrass With Saline Water Devitt, Miller, 1988	**Not Mentioned**	**24"**	**None**	**None**
Theory and Experimentation for Turf Irrigation from Multiple Subsurface Point Sources Snyder et. al. 1974	**Not Mentioned**	**20"**	**24"**	**4"**
Maricopa Agricultural Experiment Station, University of Arizona Rauschkolb, Roy S.	**Not Mentioned**	**None**	**24"**	**8"**
Popular Journal Articles				
Subsoil Irrigation Systems Stroud, T., 1987	**50%-60%**	**24"-32"**	**24"**	**4"-6"**
Subsurface Irrigation: Made for the Challenge of Drought ***Landscape & Irrigation***	**25%-40%**	**13"-18"**	**None**	**None**
Technical Literature				
Leaky Pipe Subsurface Dispersal Systems, **Entek Corporation, 1990**	**Not Mentioned**	**None**	**24"**	**12"**
Aquapore, Installation Specifications and Construction Details **Aquapore, 1989**	**Not Mentioned**	**None**	**12"-36"**	**4"**
Range	**25%-60%**	**13"-32"**	**12"-36"**	**4"-12"**
Mean	**44%**	**21"**	**24"**	**7"**

Table 10. All Cited Literature - Data Summary

Academic studies tended to deal with sandy soils that are not typically found in Southwest residential or commercial landscaping situations. These soils are used in golf course greens and funding may be more readily available for this type of study (Rauschkolb, 1990). These studies would not have wide application in residential and commercial landscape uses as far as system design, but may be helpful in specific situations. Emitter spacings of 20 inches to 24 inches were recommended along with tubing depths of 4 to 8 inches. An interesting concept introduced by Snyder (Snyder, 1974) is that a course textured layer of soil beneath a finer textured layer has the potential to improve lateral water movement.

Several potential disadvantages or problems were addressed. They included problems with slope conditions, fertilizer and pesticide application, poor performance in clay soils and emitter plugging. Appearance, not biomass is the controlling factor in landscape turf. So, academic studies that place a premium on turf growth (Krans, 1974; Devitt, 1988 and Rauschkolb, 1991) may not be as relevant as those that recognize turf appearance as more important (Jorgenson, 1990).

Popular journal articles claim a water savings of 25% to 60%. It could be expected that these might be inflated since they are written for a potentially consuming audience and could be promotional in nature. Only one article mentioned reduced liability potential with subsurface irrigation methods (Subsurface Irrigation: Made for the Challenge of Drought, 1988). This may turn out to be a very important consideration in the future economics of micro-irrigation of turf. Presently this advantage is not being realized and may be an educational issue (Ilercil, 1990). These articles suggested a wide range of emitter spacing, ranging from 13 to 32 inches. It is presumed that wide spacings are chosen to reduce installation costs.

Irrigation text books offer virtually no help to the subsurface irrigation designer. Technical literature, with two exceptions, also offers little help for the designer. It deals with subsurface irrigation only peripherally. When subsurface irrigation of turf is alluded to, it is only considered as a possibility.

Design issues are not addressed. Aquapore has written a design manual that deals specifically with subsurface irrigation of turf. It is acceptable as an overview of design principles, but lacks sufficient explanation for design flexibility. It also addresses only one method of subsurface irrigation turf, the use of porous pipe.

For design criteria to be more usable by the designer, they will need to be directly related to subsurface irrigation of turf and deal with both porus tubing and point source emission systems. Presently, all design parameters are not brought together in a logical form or in one location. Specific applications to subsurface irrigation of turf must be inferred and gathered from a multitude of sources.

CASE STUDIES IN MICRO-IRRIGATION OF TURF

The sites are chosen to represent a cross section of possible design scenarios for subsurface irrigation of turf. They also reflect different maintenance or management regimes. They are located in the greater Phoenix area and include a city park and a small privately owned residential site.

Both were new projects, as opposed to conversions of existing spray irrigation systems, and both were installed by the same irrigation contractor. Both projects were installed using drip tubing with point source emitters built into the tubing at selected intervals. To simplify installation, the contractor used a small tractor with an attachment capable of feeding emitter tubing through a vibrating plow blade. A metal plow blade designed to aid in installing the tubing is attached to the tractor as is shown in Figure 12.


Figure 12. Vibrating Plow Attachment.

Residential Site

Overview

The residential site is located in northwest Phoenix. It was installed in the summer of 1986 and has been in continual operation since. The design includes subsurface irrigation of the turf in the front and rear yards and conventional drip irrigation of the shrubs and trees. The front turf panel is approximately 700 sq. ft. and the rear panel is approximately 900 sq. ft. The owner contracted with Aqua Tech for design and installation of the system (Hercil, 1990). Figures 13 and 14 show the front and rear yards respectively.

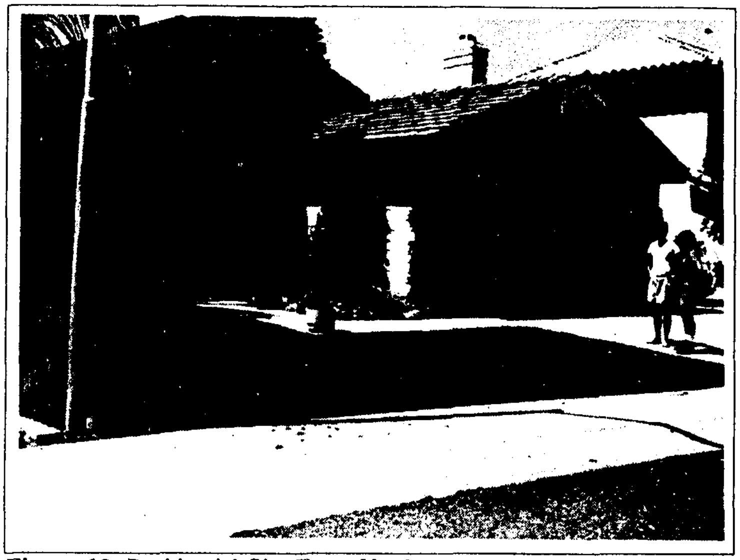
Figure 13. Residential Site Front Yard.

Design

The system was designed with an automatic controller for scheduling and includes an atmospheric backflow prevention device at the point of connection to the potable main line leading to the house. A valve manifold is located in the front yard to control the turf and shrubs in that area and a one inch PVC main line runs to a similar manifold in the rear yard to service the turf and shrubs in the rear. This part of the design is consistent with a traditional spray irrigation


Figure 14. Residential Site Rear Yard.

system. Figure 15 shows the valve manifold assembly in the rear yard.

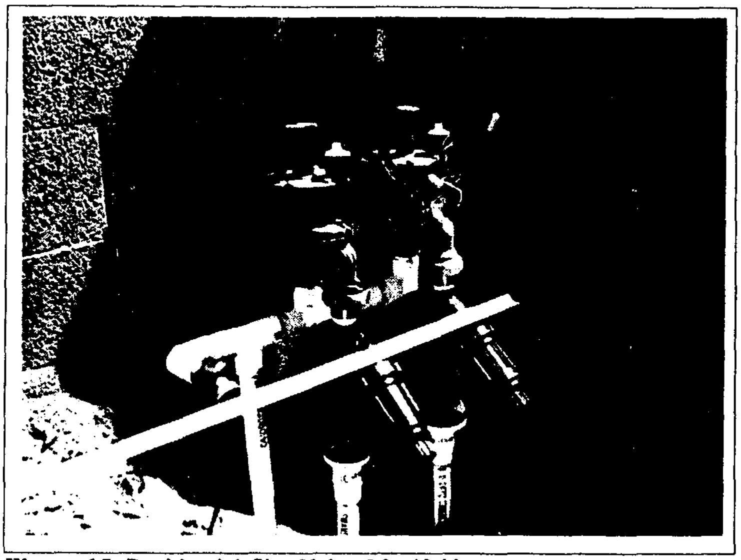

Figure 15. Residential Site Valve Manifold.

The manifolds consist of brass remote control valves with built in anti-siphon devices as additional protection for the system. Each valve is followed by a plastic screen filter to collect particulate matter before it passes to the emitter tubing. A pressure regulator then reduces the water pressure to the 30 PSI working pressure of the emitters. The emitter tubing is then attached to valve manifolds as shown.

A collector manifold, at the end of each tubing run, is used to equalize pressures within the lines and provide a single flush valve for cleaning the lines. The emitter tubing for this project is supplied from the factory with the emitters built in the tubing spaced one foot apart. The tubing is installed four inches deep, two feet apart, giving a two foot by one foot grid pattern for the emitters.

Along the edges of all turf panels that come in contact with concrete, such as sidewalks, pool decking or concrete walls the emitter tubing is installed 6 inches from the edge. This is done to compensate for the heat transferred to the soil by the concrete edges. This added heat promotes evaporation near the edges of the lawn, stressing this area (Ilercil, 1990).

Installation

The contractor, Aqua Tech of Phoenix, Arizona, has been installing subsurface irrigation systems for seven years. A vibrating plow, as shown in Figure 12, was used to install the emitter tubing. This attachment allows for installation of the emitter tubing at the spacing and depth desired to within a fraction of an inch (Ilercil, 1990). After installation of the tubing, the turf bed was raked to remove rocks and a root stimulating fertilizer was applied to the top of the soil. The system was turned on to wet the soil prior to laying a hybrid bermuda sod. Figure 16 shows the wetted pattern on the soil as the emitters begin to wet the surface. The project took three days to install.

Scheduling


Figure 16. Residential Site Soil Wetted Pattern.

The irrigation controller is scheduled to run the system for a total of five hours per week. The run time is divided into two cycles of 2 ½ hours each. With the emitter spacing used on this project, five hours of run time provides approximately 2 inches of water per week for the turf. Normal practice for spray irrigation systems in Phoenix in the summer is 2.25 in. per week. Thus, the turf is receiving .25 inches per week less, approximately 11% less, water than would be provided by a spray system.

Maintenance

The homeowner mows the lawn every seven to ten days during the growing season. The mower is set at a height of 1 3/4 to 2 inches depending on the appearance desired by the owner. The grass clippings are collected and removed during mowing.

Fertilizer is applied manually every other month during the growing season, approximately four times. Fertilization is done with a broadcast spreader using ammonium phosphate and applied at manufacturer's recommended rate. The fertilizer is then watered in with an oscillating sprinkler. The contractor recommends manual fertilizing to simplify maintenance procedures for residential home owners.

The irrigation system is flushed, using the previously described flush valves, twice a year in the spring and fall. The flush valves are opened and the system is turned on for several minutes until the water flows clean. In the four years of operation, there has been no noticeable plugging of the emitters.

Evaluation

An interview with the homeowner indicates very high satisfaction with the system. Aside from periodic line flushing and seasonal changes in the controller program, there has been virtually no maintenance. A visual examination of the turf shows very high color quality and an even density.

Governmental Site

Overview

The second case study is a six acre site located in Glendale, Arizona, at 5850 W. Glendale Avenue. It is part of the Sahuaro Ranch Park - Phase Four, a division of the Glendale city park system. The site is within the northwest corner of the Sahuaro Ranch park, bounded by 63rd Avenue on the west, Cheryl Drive and Brown Street on the north and east, and the remainder of the park on the south. Figure 17 shows the site layout.

The site is a retention basin for the park area. The soil is a loamy-clay, relatively uniform throughout. There is little slope on the site, except for a 30 foot to 50 foot wide strip around the edge. The maximum slope on these edges is the angle of repose for the soil, approximately 3:1. Some sloped areas are graded at 4:1 and 5:1. There is little rock in the soil, which simplified the use of the vibrating plow (Ilercil, 1990).

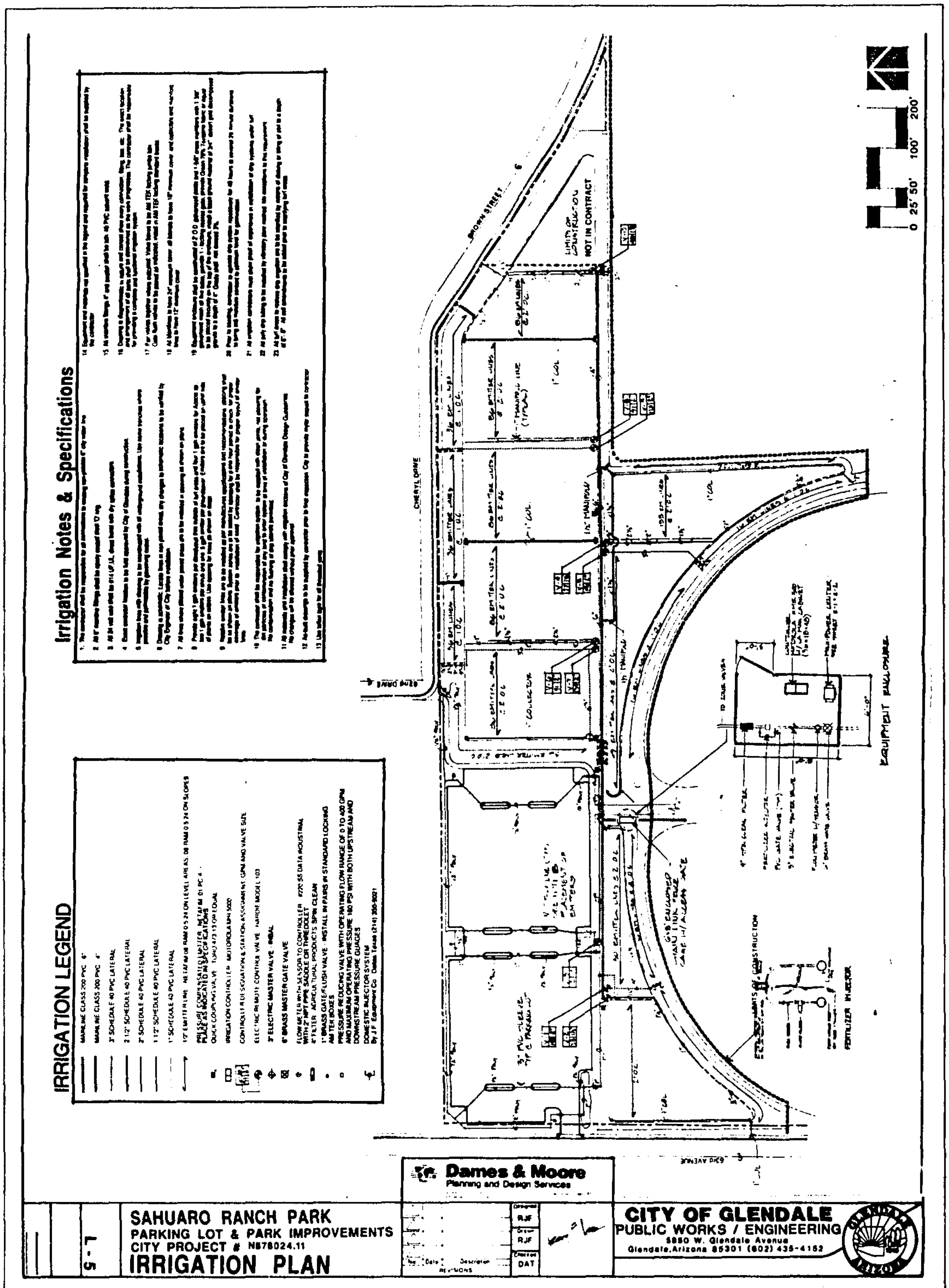

Figure 17. Governmental Site Layout.

Mr. Randall Spreitzer, the Glendale Parks Supervisor, was interviewed for this study and supplied considerable information about management of the system. The Glendale city park system has embarked on an informal testing program to evaluate various turf irrigation systems. They are now in the process of testing subsurface irrigation of turf on several of their city parks. Present tests have been successful and additional test projects are scheduled for the future (Spreitzer, 1990).

Design

The project was designed by Dames & Moore Planning and Design Services of Phoenix, Arizona. They were contracted by the City of Glendale to design the system and then observe construction.

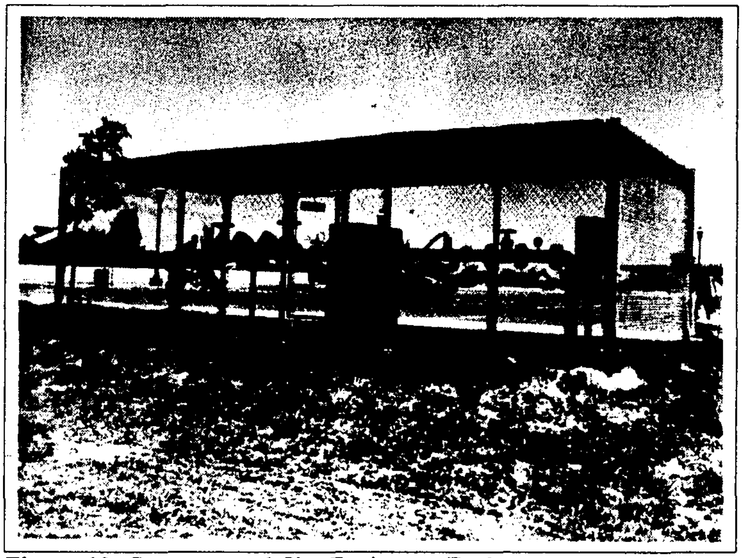

Figure 18. Governmental Site Equipment Enclosure.

Figure 18 shows an equipment enclosure built to house the primary controls for the system. Figures 19, 20, 21 and 22 show the valve manifold with reduced pressure backflow prevention device, screen filter, master shut off valve and chemical injector. Water for the system is supplied by a six inch main line coming from within the park. It is directed to an equipment enclosure, where it is reduced to a four inch line. A flow meter and a manual shut-off valve are also included to complete the system.

From the manifold, a four inch main line runs to nine remote control valves located on the site. The remote control valves range from 2 inches to 2 ½ inches in size. PVC sub-main lines extend from the valves to service the emitter tubing.

On the horizontal areas, the tubing is laid two feet on center. Emitter spacing is also two feet on center, giving a 2 feet by 2 feet grid for the emitters. Emitter spacing on the slopes is one foot on center, giving a 2 feet by 1 feet grid. The designer determined that a closer spacing is necessary on slope conditions to offset the effects of gravity on water movement within the soil (Teal, 1990). One gallon per hour emitters are used throughout the design.


Figure 19. Governmental Site Backflow Prevention Device.

Installation

Installation of the system took thirty five days during June and July of 1988. The site was first soaked to soften the soil for the vibrating plow. The following day, when the soil surface had dried sufficiently, trenching was begun.

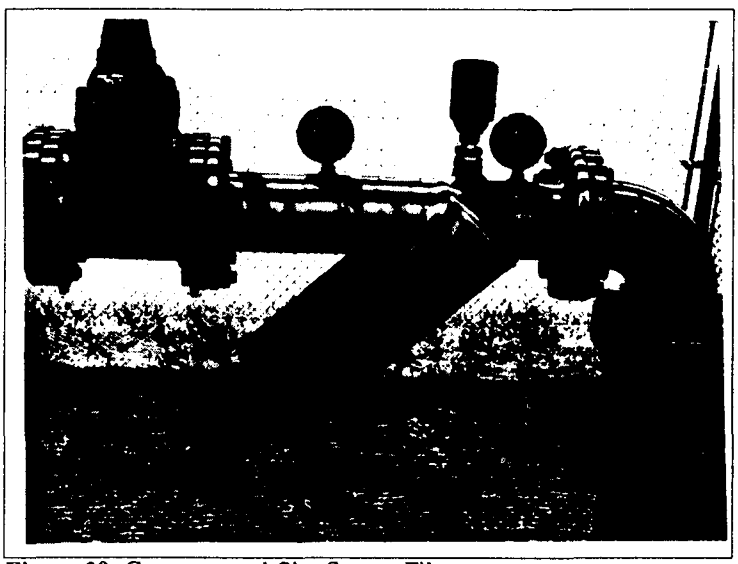
Figure 20. Governmental Site Screen Filter.

Figure 23 shows installation of the emitter tubing with the vibrating plow. The plow operator followed a string line to insure accuracy of line spacing. Using the vibrating plow, it was possible to lay 2400 feet of tubing per hour.

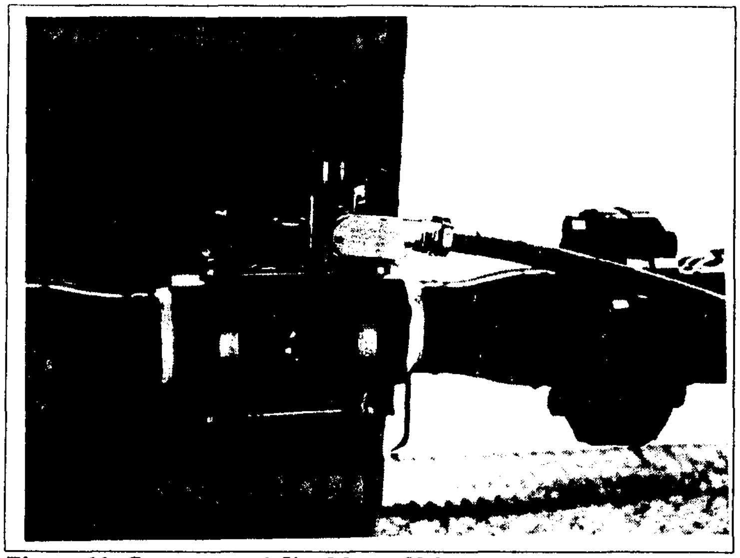

Figure 21. Governmental Site Master Valve.

Figures 24 and 25 show the emitter tubing following contours and the accuracy of installation on level ground. With one foot emitter spacing running parallel with the contours, and a two foot tubing spacing, gravity tends to assist in the lateral movement of the water within the soil (Teal, 1990). Glendale city inspectors verified design tolerances throughout installation of the system. Tubing spacing and depth were required to be held to plus or minus one inch.

After the tubing was laid and connected to the sub main lines, it was buried with a gannon attached to a tractor. The site was then smoothed to finished grade. When installation was complete, common bermuda grass was hydro seeded.

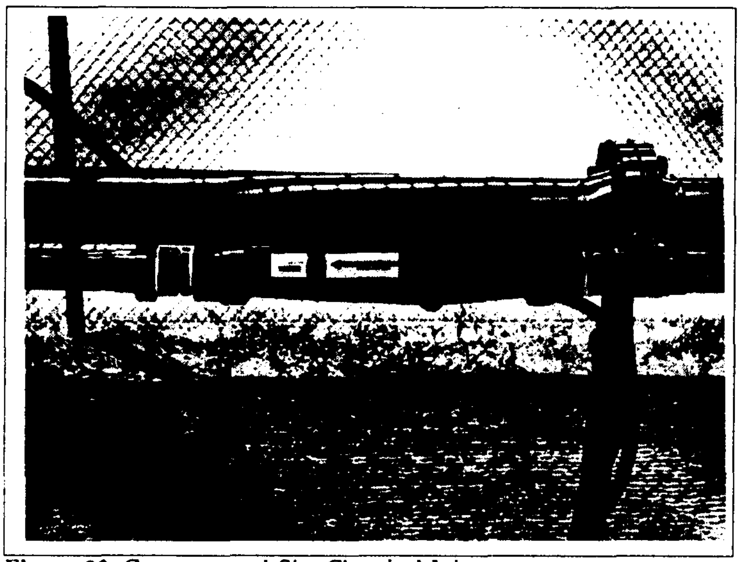

Figure 22. Governmental Site Chemical Injector.

Scheduling

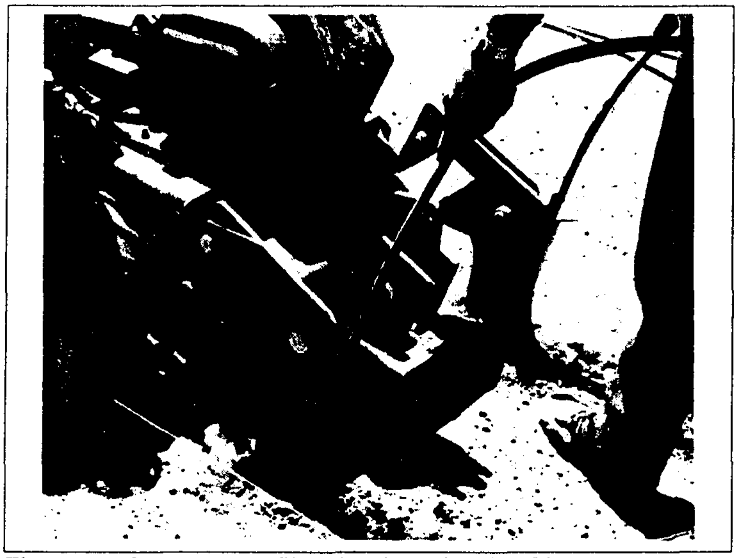

Figure 23. Governmental Site Showing Vibrating Plow.

An automatic controller cycles the system in order to apply a total of two inches of water per week during the summer. The scheduling for the flat areas is twice that for the sloped areas because of the difference in emitter spacing. The flat areas run a total of five hours and the sloped areas run a total of 2 ½ hours. All water is applied in one application, as opposed to two applications per cycle for the residential site. A complete watering cycle requires 40 hours to run through all nine valves.

Maintenance

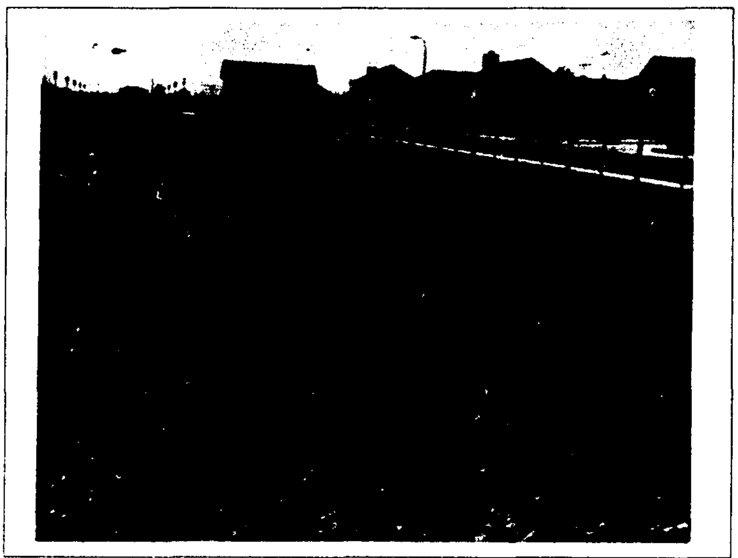

Figure 24. Governmental Site Showing Emitter Lines Following Contours.

Parks department maintenance crews were originally apprehensive about learning to maintain a new type of system. But, they have since come to appreciate the reduced time required to maintain this subsurface irrigation system. Normal maintenance practices on spray irrigation systems require weekly visits to check on system operation. However, crews have been able to maintain the subsurface irrigation system by visiting the site once every three weeks (Spreitzer, 1990).

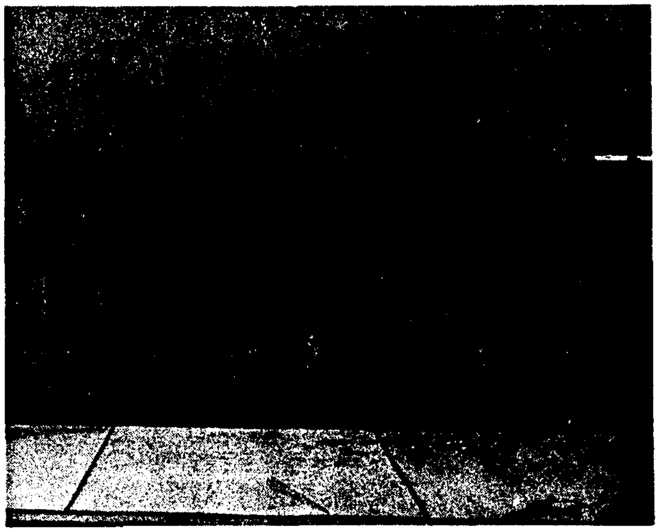

Figure 25. Governmental Site Showing Accuracy of Trenching.

The major difference in maintenance practices is the virtual elimination of repairs necessitated by vandalism. With spray irrigation systems, irrigation is normally carried on at night to reduce evaporation and so that activities of the park are not disrupted. However, high rates of vandalism occur at night (Spreitzer, 1990).

At present, fertilization is done with conventional methods by broadcasting over the surface. It was felt that maintenance crews should learn operation of the system on a sequential basis. In the future, experiments will be conducted using the fertilizer injector installed at the manifold.

Evaluation

On a scale of six acres or larger, the size of this project, the relative cost of the subsurface irrigation system and a traditional spray system is \$.15 per sq. ft. for a spray system and \$.21 per sq. ft for a subsurface irrigation system or approximately 40 % greater for the subsurface system. Considering savings in maintenance and repairs only, the estimated payback on the additional cost of the system is two to three years (Spreitzer, 1990).

The system is less efficient than a spray system for up to one month after installation. This is due to less compaction of the soil in the trenches where the tubing is installed. As compaction equalizes due to normal settling, foot traffic and lawn mowers, lateral movement of the water increases to design limits (Ilercil, 1990).

Approximately the same amount of water is applied per square foot of turf with the subsurface irrigation system as would be with a spray system. From the standpoint of the quality of the turf, however, the advantage of a subsurface irrigation system is that better quality, healthier turf is realized for the same amount of water. In the summer of 1991, experiments will be conducted to determine the advantages of other scheduling regimes (Spreitzer, 1990). It is expected that applying 60% of the water at one time and then 30% a day or so later, a 10% savings is possible with no degradation of turf quality.

The reduction in liability afforded a public agency with the use of subsurface irrigation systems may greatly overshadow any savings in water or costs. Litigation costs today provide great incentive to adopt subsurface irrigation of turf on public properties (Spreitzer, 1990). The city of Glendale is presently studying this issue, but it has yet to be documented.

Conclusions

The use of a vibrating plow is essential if costs of subsurface irrigation systems are to compare favorably with spray irrigation systems. They provide the contractor the advantages of precise placement of the tubing both in spacing and depth, to within plus or minus one inch. The contractor has found that this level of accuracy is required to insure proper water coverage (Ilercil, 1990). Second, the plow can install up to four lines of tubing at one time, greatly reducing installation cost.

The case studies suggest different management regimes are needed for different size projects. On larger projects, considerably less maintenance and repairs are required. On smaller projects, the savings in maintenance costs, while still substantial, are not as significant as those on a larger project.

Client satisfaction with the systems was very high, but for different reasons. The homeowner was pleased with the quality of the turf and the elimination of sprinkler repairs experienced with previous systems. The Glendale Parks Supervisor was pleased with reduced vandalism and maintenance costs. Cost savings were sufficient on this first generation system to warrant additional testing (Spreitzer, 1990).

The advantages of subsurface irrigation of turf need to be documented. Savings in water, maintenance costs, liability costs and repairs due to vandalism are difficult to accurately judge. Other advantages, such as better turf quality and reduced interruption of site activities need investigation also.

SUMMARY

At the root of this study is the desire to see subsurface irrigation of turf utilized more in water sensitive areas of the world. As an irrigation designer experienced in both spray and subsurface irrigation systems, the author has found it difficult to utilize this promising technology. It is hard to convince a client to allow anyone to experiment with his money. Without explicit design principles, adaptable to varying conditions, the designer is forced to do just that. This paper has examined the application of subsurface irrigation technology to turf in the landscape and has been directed by four objectives as expressed in the section titled "Problem Statement". A response to those objectives can best summarize this paper.

Objective 1

Review existing literature using published and unpublished sources to determine its relevance for the designer of subsurface irrigation systems.

The first objective of this study has been accomplished. It has been shown that the information is not centralized and not directly applicable to design questions. In its present form, existing information is of little value to the designer.

With a few exceptions, the literature does not deal specifically with subsurface irrigation of turf. Few studies would be helpful to the designer of a project. Existing literature is spread among many sources, sometimes contradictory, and of little use to the irrigation designer. In its present form, it is neither easily available, nor particularly useful to those who need it. Much of the knowledge of these systems is not in the literature, it is in the minds of a small group of practitioners.

Academic Studies

Much of the academic research on subsurface irrigation revolves around the application of this technology to agricultural crops. One application found in the literature that would be helpful to the landscape designer related to sandy soils, typically used in golf course greens.

For design criteria to be useful to the designer, they must be directly related to subsurface irrigation of turf. Issues such as emitter spacing, emitter tubing lay out, filtering and scheduling must be dealt with specifically.

Popular Journal Articles

Popular journal articles deal more explicitly with the topic, but typically in a promotional manner with undocumented claims. These articles are many times written by manufacturers and contain exaggerated claims about their product. Several articles draw conclusions that conflict with findings from field installations. The most conspicuous of these claims is that of high water savings achieved for subsurface irrigation (Stroud, 1987). These claims are highly suspect because they are not well documented, sometimes not at all.

One article mentioned reduced liability potential with subsurface irrigation methods (Cloud, 1980). For public projects, this aspect of the technology may prove to be more important than any other (Spreitzer, 1990).

These articles do present many design and management recommendations that are consistent with other sources. They seem to be backed by a reasonable amount of trial and error and should be quite valid because they relate directly to a field situation, as opposed to experimental data that would have to be adjusted to fit field conditions.

Technical Literature

Irrigation text books are little help to the subsurface irrigation designer. Most reference to the topic deals with soil water relationships, salt distribution, emitter clogging, filtering systems, fertilization and irrigation scheduling (Nakayama, 1986). The Nakayama book contains background information required for hydraulic design of subsurface irrigation systems, but it is much too theoretical and technical in nature and does not deal specifically with turf applications.

Manufacturer's publications are more helpful. They seem to be backed by more experimentation than other sources. There are several recommendations that remain consistent between authors. Some manufacturers have developed formulas to aid in the design. Two manufacturers provide simplified plans of sports fields and smaller sites. These plans may give the designer the concept for a design, but they are not complete enough to be of assistance in the actual design of a site.

Summary

Along with considerable disagreement, agreement from many sources can be found in the areas of advantages, disadvantages, design, installation and maintenance. Very little information of value to the designer appears to be universally accepted. But, as more sources agree on certain principles or practices, they achieve a certain validity and become less risky for the designer to rely on. These areas of agreement can be summarized as follows:

A. Advantages when compared with traditional spray irrigation are as follows:

1. Considerable water can be saved by watering at less than the evapotranspiration rate.
2. Turf appearance does not become dusty or dirty from lack of overhead spray.
3. Recovery from heat stress may be greater.
4. There is significantly greater root mass.
5. Soil moisture content tends to be more consistent over time.
6. Moisture stress is less apparent.
7. Component quality has improved in recent years.
8. Maintenance costs appear to be significantly less.

9. Liability is considerably reduced.
10. Scheduling is simplified because watering can take place while the site is in use.
11. Soil compaction is reduced.
12. Energy saving, in the form of pumping costs are reduced.
13. Splash transmitted diseases are reduced.
14. Fertilizer and other chemical application is simplified.
15. Nearly 100 per cent coefficient of uniformity can be achieved.
16. Reduction or elimination of runoff on sloped sites is possible.
17. Narrow or irregularly shaped areas, such as those found in road medians and parking lot medians, can easily be irrigated.
18. Vandalism can be greatly reduced, if not eliminated.
19. Larger expanses of turf can be irrigated at one time.
20. Modification of existing systems is simplified if the turf area is changed.

B. Disadvantages when compared with traditional spray irrigation are as follows:

1. Cool season grasses perform less well than warm season grasses.
2. The designer and installer must be familiar with this type of system because subsurface irrigation of turf is not forgiving of error.
3. There may offer little or no water savings if the system is not properly designed.
4. Installation procedures must be more exact.
5. Initial costs can be higher.
6. Maintenance procedures may be more difficult to learn.
7. Because the systems operate with low pressures, problems can go unnoticed.
8. Fertilizer and pesticide application could cause localized concentrations of nutrients.

C. Design Parameters

1. All systems should include pressure regulators, chemical injectors, automatic flush devices and water filtration systems.
2. Emitter spacing should be less in heavy, clay soils than in sandy soils.
3. Tubing spacing should be no more than 24 inches.
4. Tubing depth should be between 4 and 6 inches.
5. Tubing should be placed closer to the edge of the turf when it comes into contact with concrete, no farther than 6 inches from the edge.
6. Emitter spacing should be reduced in sloped conditions.
7. An automatic air vent/vacuum relief valve should be used at each remote control valve.
8. As soil texture becomes more coarse, emission rates should increase to 1.8 to 2.8 gallons per hour.
9. A layer of coarse textured soil beneath a finer textured layer can improve lateral water movement.
10. Pressure compensating emitters should be used if point source emitters are utilized.
11. Emitter and tubing spacings should be reduced in high traffic conditions.
12. Salt tolerant turf species are important to success.
13. Cool season grasses require that the tubing be placed closer to the soil surface.
14. The total cost of the system from design, installation, operation, maintenance to repair should be considered when evaluating subsurface irrigation of turf.
15. Efficient installation procedures must be used to keep costs comparable to conventional irrigation systems.

D. Installation Methods

1. Modern vibrating plow equipment should be used for installation of the emitter tubing.
2. The soil should be slightly moist to assist with installation of the tubing.

E. Maintenance Practices

1. Fertilizer and pesticide application must be properly managed.
2. Pulse watering should be used to increase lateral water movement in the soil.
3. Acid solutions, herbicides and insecticides can be injected through the system, to prevent emitter plugging.
4. Regular watering is recommended to reduce root intrusion into the emitters.
5. Filters, controllers, drains and other components should be checked regularly.
6. Maximum chemical injection efficiency is achieved by allowing the system to run long enough to establish flow equilibrium before the chemicals are injected into the system.
7. More frequent irrigation scheduling can benefit soil or water salinity problems.
8. Fertilizer applications should be more frequent during the early stages of plant growth

Objective 2

Examine installed sites to determine current industry practices.

The two installed sites, even though they are quite different in scale, have essentially the same components. They also were installed using virtually the same equipment. The components included in each system, in order of their assembly, beginning with the point of connection at the water main is as follows:

A. Main Line - It connects the system to the water source.

B. Backflow Prevention Device - It protects the water source from contamination from chemicals used in the system.

C. Sub Main - It extends from the backflow prevention device to the valve manifold.

D. Valve Manifold - It is an assembly that contains the valves and other components.

E. Filter Device - It removes particulates from the water to help prevent emitter clogging. In smaller, residential sites, it also serves as a chemical injection device.

F. Master Valve - It is used in large sites where additional control of the water supply is desired.

G. Chemical Injector - In larger systems, it is a stand alone device used to inject various chemicals into the system.

H. Pressure Regulator - It reduces the water supply pressure to a level usable to the emitters.

I. Header or Lateral - It carries the water to the turf area and the emitter tubing.

J. Emitter Tubing - It supplies water to the soil at a predetermined rate and may have internal point source emitters or it may be a line source emitter.

K. Collector Manifold - It collects water from the emitter tubing and helps equalize pressure among the emitter lines.

L. Flush Valve - It is an automatic valve that flushes water and debris from the collector manifold.

Regardless of the size of the project, all the functions accomplished by these components must be performed in order for the system to operate properly. Leaving out even one function for the sake of money or design simplicity will cause problems (Ilercil, 1990). The area of most concern to the designer of each site was the layout of the emitter tubing in both spacing and depth. This area of design requires the most experimentation by a novice in subsurface irrigation, at least until a level of competence is achieved. The clients for each system expressed a very high level of satisfaction, but both for different reasons. The homeowner liked the very low maintenance and high visual quality of the turf. And the city park manager appreciated the savings in maintenance and reduced liability.

Objective 3

Develop a model to assist the designer of subsurface irrigation systems for turf.

This objective points out the condition, expected by the author, that much additional research and testing remains to be done on the topic. It is apparent that every area examined would benefit from additional research and experimenting. Information, when it can be found, is suspect. With each project undertaken, the designer is left to make many decisions for which he has no justification . Information that might benefit the end user, such as maintenance procedures, operating costs or pay back periods is almost nonexistent. As previously noted, tubing and emitter layout is a critical question for the designer. Yet, little information on the subject is definitive. Almost every site variable, client need and maintenance regime affects the designer's choices.

By using these variables it is possible to develop a matrix to help the designer with system design. But the qualitative values applied to the variables must be informed guesses at best. Only an extended use and subsequent adjustment of values in such a matrix could validate it. With that in mind, the following matrix is suggested. Its purpose is to assist in tubing and emitter spacing.

The matrix is composed of an Emitter Spacing Value Guide, Table 11 and an Emitter Spacing Selector, Table 12. The designer first enters the Emitter Spacing Value Guide and determines an adjusted value for each design variable found in the project. The spacing factors related to each design variable affect the spacing for that design variable. When a spacing factor is selected, it is multiplied by the spacing value associated with it. The spacing value is an indication of the emitter relative emitter spacing required by that variable. A smaller number indicates a closer emitter spacing. The spacing value is then multiplied by the weighting factor to give an adjusted value. The weighting factor relates to the relative importance or sensitivity of the factor to the spacing of the emitters. The adjusted vales are added and then divided by the sum of the weighting factors to give the weighted adjusted value, or spacing value. The weighted adjusted value is then compared to those shown in the Emitter Spacing Selector matrix to arrive at the final tubing and emitter layout. An on center spacing grid, either square or rectangular is then selected from the matrix. Emitter coverage in square feet is also given.

The values assigned to the variables in both charts are estimates only. They are meant to provide a framework for further study and experimentation. The values used in the charts are estimates and must be tempered with the designer's experience. They are not meant to be used without further study.

EMITTER SPACING VALUE GUIDE				
Decision Module	Factor	Value	Weighting Factor	Adjusted Value
Soil Infil-tration Rate	High - coarse sand fine sand	1.00	3	
	Medium - Sandy loam Loam	1.25		
	Low - Clay loam Clay	1.75		
Soil Depth	Shallow<12" or Hardpan	3.00	2	
	Depth > 12"	1.00		
Slope	Level < 10%	2.00	3	
	Slope 10-20%	1.50		
	Slope > 20%	1.00		
Turf Variety	Cool Season	1.00	2	
	Warm Season	1.50		
Mainte-nance Regime	Intense Management	2.00	1	
	Minimal Management	1.00		
Desired Appearance Quality	High	1.00	1	
	Medium	1.25		
	Low	1.50		
Site Use Intensity	High	1.00	1	
	Medium	1.25		
	Low	1.50		
	Sum of Adjusted Values			
	Sum of Weighting Factors			÷ 13
	Weighted Adjusted Value			

Table 11. Emitter Spacing Value Guide.

EMITTER SPACING SELECTOR			
Weighted Adjusted Value	On Center Spacing Square Grid inches	On Center Spacing Rectangular Grid-inches	Emitter Coverage ft^2
< 1.3	18	18x18 or 12x24	2.25
1.3 - 1.6	21	Square Only	3.06
> 1.6	24	Square Only	4.00

Table 12. Emitter Spacing Selector.

Objective 4

Determine the areas of greatest need for further research and technical development.

At the root of this study is the desire to see subsurface irrigation of turf utilized more in water sensitive areas of the world. As an irrigation designer experienced in both spray and subsurface irrigation systems, the author has found it difficult to utilize this promising technology. It is hard to convince a client to allow people to experiment with his money. Without explicit, proven design principles, adaptable to varying conditions, the designer is forced to do just that.

It would be accurate to suggest that all areas of the subject need additional investigation. One area that stands out as in more need of research than others is that of tubing and emitter layout. It seems unlikely that subsurface irrigation will progress until a data base is developed that will give the designer confidence that he can design a system that will work without experimenting. The selection matrix presented here is derived from many different sources and personal experience. The value and weighting factors used in the matrix need to be experimented with and adjusted as necessary.

Future investigations naturally fall into two categories. The designer will be served by an examination of specific design issues that are needed to make the system work. The end user, on the other hand, needs answers to a different set of questions. Before he can justify selecting a new technology, financial and performance questions must be answered.

If subsurface irrigation of turf is to become more widely used, the guesswork must be taken out of design. To be of value to the designer, information must be in the form of universal principles that are adaptable to varying situations. But, researching these questions is not enough. The information must then be made available to those who need it, the designers and the end users. One of the difficulties encountered while doing this study was the gathering the information from widely dispersed sources. It should be compiled in a design manual for subsurface irrigation that would relate directly to the design of an operating a system and include answers to the following questions:

Questions for the Designer

Included here is the component layout for the design such as valve manifold, valve layout, emitter and tubing spacing and depth. Emitter plugging and filtering requirements are vital to long term, problem free operation. Even though it has been demonstrated that plugging is not a problem with a properly designed and operated system, it is perceived as a problem. Issues affecting emitter plugging that need investigation include maintenance practices, requirements for filtering different qualities of water and long term use of the system. Different methods of irrigation scheduling should be investigated. Pulse watering, soil structure, turf variety and emitter spacing should be examined.

Questions for the User

System cost is very important to the end user. In evaluating system cost, a long term approach is necessary. For an accurate picture, the complete life cycle of the project should be considered. Larger projects can cost much more than conventional systems. However, large projects offer the greatest potential for saving when operational costs are considered. On large projects, where an inventory of repair costs must be carried, interest savings can be substantial.

Water savings have not been sufficiently documented. As the technology is improved, substantial water savings should be realized. If it is found that subsurface irrigation consistently can save water, demand will increase substantially. Answers to this question should be realized with research in other areas.

Maintenance costs are important to the weekend gardener and vital to the large site manager. The questions of chemical injection, system scheduling and normal maintenance need to be answered.

Other Recommendations

Subsurface irrigation of turf is a reality. It has been suggested by the case studies that it works well and can be cost effective. The problem seems to be a general lack of knowledge and misconceptions about the technology. It is important to think of subsurface irrigation of turf as a distinct product, not a group of technologies performing a function. Therefore, an educational effort is needed to inform the user, designer and installer of the advantages of the system. This educational function could be performed by professional societies such as the American Society of Landscape Architects, the American Society of Irrigation Consultants and the Irrigation Association.

One complaint the author has heard many times is that a subsurface irrigation system is difficult to install because so much trenching is needed for the emitter tubing. It has been demonstrated by the case studies that this need not be so if modern equipment is used. Equipment, even larger than that shown in the case studies, and with devices to feed the tubing from rolls could bring installation costs in line with conventional spray systems. Again, education and experimentation is needed.

Landscape design on top of structures using turf has always been difficult. This type of application is generally pedestrian intensive and a method of preventing over spray should be welcome. The weight of the soil and over spray from irrigation systems present significant problems to the designer. Subsurface irrigation would seem a natural solution to the over spray problem. It is possible that substantial weight and water savings are possible with soil stratification techniques.

Soil stratification or layering entails engineering the soil bed with individual layers suited to specific purposes. The top layer of suitable thickness would be used as the turf rooting medium. A fibrous soil separation blanket would be used to isolate the top layer from a lower drainage layer. The author believes this technique could improve lateral water movement and thus allow wider tubing spacings, reducing system cost. For on-structure applications the lower, drainage layer could be composed of a weight reducing material.

Investigation into the potential savings in insurance costs need to be undertaken. This area should prove to be a strong deciding factor for public entities trying to reduce litigation costs. It may require an educational effort to inform insurance companies of the possible savings. Even though this could be a strong factor in favor of subsurface irrigation, it will take some time for insurance companies to develop actuary tables in order to develop a rate structure. A larger, and more immediate savings may be a reduction in claims.

The marketing of subsurface irrigation of turf is sadly lacking. It has been demonstrated to work well and be cost effective. The problem seems to be a general lack of knowledge and misconceptions about the technology. It is important to think of subsurface irrigation of turf as a distinct product, not a group of technologies performing a function. Therefore, an educational effort is needed to inform the user, designer and installer of the advantages of the system. This educational function could be performed by professional societies such as the American Society of Landscape Architects, the American Society of Irrigation Consultants and the Irrigation Association.

Above all, a larger number of installed projects need to be studied. The only way to prove the technology is to document its success in the field. Scientific studies will help quantify some variables, but actual sites must be examined to work out the fine points of design. Both small and large scale sites should be studied. Variables such as cost comparisons, maintenance practices and water savings should be studied along with the various design issues.

APPENDICES

GLOSSARY

Important or widely used terms whose meanings may not be clear are included here. It should be noted that many terms dealing with the topic of this paper are used interchangeably by the industry. Every effort has been made to use the most common or typical terminology employed in the irrigation industry. To clarify the terms used in this paper, the following definitions are included:

Air vent/vacuum relief valve - An automatic valve placed just after the remote control valve in a system that prevents a vacuum from being produced in the line. Prevents soil slurry and other contaminants from being drawn back into the line.

Drip irrigation - The most commonly used term to describe a form of micro-irrigation, usually applied above ground so the water drips onto the soil near the base of the plant. Same as **trickle-irrigation** or **micro-irrigation.**

Emitter - Component of a drip irrigation system that dissipates pressure within the irrigation line and discharges water to the plant. Ideally it passes a specific amount of water at a constant discharge rate that does not vary significantly throughout the system.

Evapotranspiration - The total loss of water by both transpiration through the plant leaf material and evaporation from the soil surface. Because little or no water is at the soil surface, the evaporation component is greatly reduced by drip irrigation.

Lateral pipe - An irrigation pipe, downstream of the control valve, to which other pipes are connected.

Line source emission - A method of discharging water in which water is emitted along the entire surface of the pipe (see **porous pipe**).

Lysimeter - A device used to test water consumption of plant material. Consists of a box in which the plant is grown that can receive measured amounts of water from a tube attached to the bottom.

Manifold - A grouping into a single assembly of irrigation valves. Assembly and maintenance is simplified by placing valves together.

Micro-irrigation - A blanket term used to describe several methods of irrigation. Generally refers to technologies utilizing low volumes of water (includes **drip irrigation, micro-spray, trickle-irrigation**).

Micro-spray - A form of micro-irrigation that utilizes small, low volume spray heads for above ground use.

Plant cooling - The creation of a micro-climate around the base of a plant by the evaporation of surface moisture. Effective in preventing sun scalding and heat desiccation of ground covers and low shrubs.

Point source emission - A method of discharging water in which water is emitted at specific points along the delivery pipe. Emission points can be holes in the pipe or highly engineered emitters.

Polyethylene - The major component in modern flexible irrigation pipe. Uses simple compression connections. Not susceptible to ultraviolet degradation.

Polyvinyl chloride (PVC) - The major component in modern rigid irrigation pipe. Uses simple cemented connections. Susceptible to ultraviolet degradation.

Porous pipe - A type of micro-irrigation pipe with a permeable surface. Contains many microscopic pores per meter of pipe. Water is emitted along the entire surface of the pipe (see **line source emission**).

Pulse scheduling - Scheduling the irrigation system to be turned on repeatedly for short periods of time instead of running the system for the required length of time in one cycle. Total run-time of the system is the same in both cases. Lateral movement of water is increased in the soil with pulse scheduling.

PVC (polyvinylchloride) - A type of rigid plastic pipe used for irrigation systems. The most common material used in landscape irrigation pipe.

Rizosphere - The zone within and just above the soil that contains the roots of the plant. This area must supply the water and nutrients that the plant needs for growth.

Root intrusion - The tendency of plant roots to grow into an underground emitter. Water flow from the affected emitter is then reduced or stopped entirely.

Root zone - The area within the soil that contains the plant root system. Must be supplied with all the water and nutrients the plant needs for growth.

Saturated/wilting point cycle - The cycle caused by traditional irrigation techniques in which the soil is first saturated and then allowed to dry to the wilting point between applications of water.

Saturation point - The point at which the soil cannot hold further water. Gravity drains additional water from the soil.

Soil moisture profile - The ratio between the moisture content in the driest part of the soil and that in the wettest part of the soil. In a desirable soil moisture profile, the soil moisture content is relatively uniform throughout.

Splash transmitted disease - Plant diseases caused by water sprayed or splashed onto plant material. Water sitting on plant leaves can provide ideal conditions for disease and fungus growth, especially in warm, shady locations.

Spray irrigation - The traditional above ground method of irrigating crops and turf. Water is dispersed over the plant material in the form of droplets. Water droplets are highly susceptible to wind drift. Very difficult to achieve uniform coverage of the surface area.

Subsurface irrigation - A form of micro-irrigation in which the emission point is below ground and located within the root zone of the plant.

Tensiometer - A device that measures the moisture content of the soil. Can be used to override the irrigation controller to prevent over watering.

Trickle-irrigation - A form of micro-irrigation, usually applied above ground so the water drips onto the soil near the base of the plant. Same as **drip irrigation**.

Wetted front - The face of the wetted area caused by water movement through the soil. It moves away from the point of emission in an ellipsoidal shape. Soil and water salts are translocated by the wetted front and moved away from the point of emission.

Wilting point - Soil moisture content at which the plant cannot draw water from the soil and wilting occurs. A prolonged soil wilting point will cause plant death.

Xeriscape - A concept in which landscape water consumption is reduced by the use of appropriate design techniques. Three primary components are design, plant selection and efficient irrigation.

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REFERENCES

Cited Material

Aquapore, Installation Specifications and Construction Details. (1989). [Design manual, Photocopy]. Phoenix, Arizona.

Barkley, David L. & Simmons, Larry. (1989). Contributions of the Golf Industry to the Arizona Economy. (Department of Agricultural Economics, University of Arizona, College of Agriculture, Technical Bulletin No. 263).

Boswell, Michael J. (1986). [Micro-Irrigation Design Manual]. James Hardie Irrigation, El Cajon, Ca.

Cloud, Bob. (1980). Sub-injection irrigation. Landscape Architectural Forum, pp. 36-37.

Devitt, D. A. & Miller, W. W. (1988). Subsurface Drip Irrigation of Bermudagrass With Saline Water. (Environmental Research Center, University of Nevada, Las Vegas, Applied Agricultural Research). pp. 133-143.

Drip Irrigation Systems. (1985). [Design manual prepared by Rain Bird Sales, Inc., Agri-Products Division]. Glendora, California.

Drip or Trickle Irrigation for Ornamentals. (1978). (Cooperative Extension Service, University of Arizona, College of Agriculture, Bulletin No. Q 27).

Gassmin, T.A. (1897). Moisture Sensors: Thermostats for Plants. Landscape & Irrigation. pp. 79-83.

Gibeault, V. A., & Meyer, J. L. (1988). Irrigation and Water Conservation. Grounds Maintenance. pp. 15-17.

Hurst, Gregory. (1990, March). Xeriscape - Not a Zero To the Irrigation Industry. Landscape & Irrigation, pp. 92-96.

(Ilercil, Alp, Owner Aquatec Irrigation, personal interview, June 13, 1990)

Installation, Operation and Maintenance Instructions for Aquapore Subsurface Irrigation Systems. (N.d.). [Design manual, Reprint]. Phoenix, Az.

Irrigation History: From Buckets and Crossbeams to Computers. (1989, August). Landscape & Irrigation, pp. 94-104.

Johnson, Eric A., & Harbison, David G. (1985). Lasndscaping to Save Water in the Desert. Rancho Mirage, Ca.: E. & H. Products.

Jorgensen, Greg & Solomon, Kenneth H. (1990). Evaluating subsurface drip irrigation for turfgrass: an intrum report. Proceedings of the Annual Conference of the American Society of Irrigation Consultants, 1-7.

Kneebone, William R., and Pepper, Ian L., Water Requirements for Urban Lawns, Wyoming Water Resources Research Institute, University of Wyoming, Laramie, Wyoming, 1979.

Krans, J. V., & Johnson, G. V. (1974). Some Effects of Subsurface Irrigation on Bentgrass During Heat Stress in the Field. Agronomy Journal, pp. 526-530.

Leaky Pipe Subsurface Dispersal Systems. (1990). [Design manual prepared by Entek Corporation]. Grapevine, Tx.

Leopold, Luna B. (1974). Water - A Primer. San Francisco: W. H. Freeman and Co.

McPherson, Greg, Simpson, Jim, & and Livingston, Margaret. Effects of Three Landscape Treatments on Energy and Water Use In Tucson, Arizona. (Final Report Landscape Architecture, School of Renewable Naturel Resources, University of Arizona, Tucson, Arizona).

Micro-Irrigation: Good Things Come in Small Packages. (1989, October). Landscape & Irrigation, pp. 98-104.

Minner, D.D. (1987, May). Putting the Breaks on Runoff. Grounds Maintenance. pp. 4-18.

Minner, D.D. (1987, April). Frequent vs. Infrequent Irrigation. Grounds Maintenance. pp. 16-17.

Morgan, R.M. (1987, November). Centralized Radio Control Systems. Landscape & Irrigation. pp. 55-67.

Nakayama, F. S., & Bucks, D. A. (1986). Trickle Irrigation for Crop Production. New York: Elsevier Science Publishers.

Nelson, Sheldon Douglas. (1971). Some Practical and Theoretical Aspects of Subsurface Irrigation. Unpublished doctoral dissertation, Department of Soil Science and Agricultural Engineering, University of California at Riverside.

Netafim Irrigation Equipment & Drip Systems. (1986). [Unpublished Training Manual, Mimeographed].

Oklahoma Water Resources Board. (1973). Oklahoma Comprehensive Water Plan. Oklahoma City: Metro Press.

Paylore, Patricia. (1976, September). Desertification: What, Where, Why, Who. Desertification: Process, Problems, Perspectives. pp. 1-11.

Postel, Sandra. (1990). Saving Water for Agriculture. In Bourne, Lester R., et al, Eds., State of the World-1990 (pp. 39-58). Worldwatch Institute Report. New York: W. W. Norton & Co.

Ratledge, G.L. (1987, June). Will Fertigation work for You? Landscape & Irrigation, pp. 78-81.

(Rauschkolb, Roy S., Professor Soils and Water, Maricopa Agricultural Experiment Station, University of Arizona, personal interview, March 25, 1991)

Santa Barbara Bans Lawn Irrigation. (1990, April). Landscape & Irrigation, pp.122-130.

Shepersky, Keith. (1984). Landscape Drip Irrigation Design Manual, Rain Bird Sales, Turf Division, Glendora, Ca.

Snyder, G. H., Burt, E. O., Rogers, L. S. & Campbell, K. L. (1974). Theory and Experimentation for Turf Irrigation from Multiple Subsurface Point Sources. The Soil and Crop Society of Florida Proceedings, Vol. 33, pp. 37-41.

Solomon, Kenneth H. (1990, April). Wind Effects on Sprinkler Patterns. Grounds Maintenance. pp. 12-14.

Spreitzer, Randall, Supervisor, Glendale City Parks System, Glendale, Arizona, personal interview, July 2, 1990)

Steiner, Wes, 1985. (1985, Fall). A Case for Conservation. Arizona Waterline. Salt River Project, Phoenix. Arizona.

Stroud, T. (1987, February). Subsoil Irrigation Systems. Grounds Maintenance. pp. 80-83.

Subsurface Irrigation: Made for the challenge of drought. (1988, December). Landscape & Irrigation, pp. 68-98.

Teal, Donald, Designer, Dames and More, Phoenix, Arizona, personal interview, July 2, 1990).

Water-Thrifty Landscape Blends Turf and Desert. (1989, September). Landscape & Irrigation, pp. 120-127.

Watkins, James A. (1983). Turf Irrigation Manual, Dallas, Texas: Telsco Industries.

Weinberg, Scott S. & Roberts, John Mack (eds). (1988). Handbook of Landscape Architectural Construction - Vol. III, Irrigation. Washington, D.C.: Landscape Architecture Foundation.

Additional Readings

Arizona Department of Water Resources. (1984). Management Plan for First Management Period. Publisher.

Chemigation/Fertigation: The Liquid Vitamin of Landscape. (1987, June). Landscape & Irrigation. pp. 70-76.

Christians, Nick E. (1988, February). Drainage Principles for Athletic Fields. Grounds Management. pp. 20-22.

Dierickx, W. (1976, March). Subsurface and Surface Drainage of Grass Sportsgrounds. Revue de l'Agriculture (Bruxelles), pp.607-623.

Drip Irrigation for Landscaping, an Introductory Guide. (1986). [Design manual prepared by Hardie Irrigation] Laguna Niguel, California.

Felix, R. (1988, June). Advanced Technology Brings New Image to Porous Pipe. Landscape & Irrigation. pp. 90-95.

Fertigation and Chemigation: Their Time Has Come. (1988, June). Landscape & Irrigation. pp. 98-108.

Foley, S. (1985, October). Considerations in the Selection of an Irrigation System. Landscape & Irrigation. pp. 86-95.

Gibeault, Victor A. & Cockerham, Stephen T. (1985). Turfgrass Water Conservation. Cooperative Extension. (University of California, Division of Agriculture and Natural Resources, Publication No. 21405).

Krans, J.V., 1975. "Subsurface Irrigation of Turf." Weeds, Trees and Turf, Vol. 14, No. 5, p. 22.

Moisture Sensors: Thermostats for Plants. (1987, October). Landscape & Irrigation. pp. 79-83.

Pagano, D., 1985. "Why an Irrigation System is Like an Integrated Circuit." Landscape & Irrigation, Vol. 9, No. 10, pp. 125-126.

Ross, B. Blake, 1988. "Irrigation Water Quality." Grounds Maintenance, Vol. 23, No. 8, pp. 74-78.

Shoemaker, E. (1988, May). Computers and Irrigation. Grounds Maintenance. pp. 6-13.

Skirde, W. (1979). Investigations into Subsurface Irrigation of Grass Sports Pitches. Journal of the Sports Turf Research Institute. pp. 209-210.

Smith, G.S. (1973). Effects of Several Herbicides on Shoot and Root Growth of 'Tifdwarf' Bermuda Grass. Proceedings of the Florida State Horticultural Society, 434-437.

Snyder, G.H., Burt, E.O., Rogers, J.S. & Campbell, K.L. (1974). Theory and Experimentation for Turf Irrigation from Multiple Subsurface Point Sources. Soil and Crop Science Society of Florida Proceedings, 37-41.

Snyder, G.H., & Burt, E.O. (1980, February). The Potential of Subsurface Irrigation for Reducing Water Usage in Turf Grass. Rasen Grunflachen Bergrunungen. pp. 31-35.

Snyder, G.H. (1987, July). Fertigation - Is It For You? Grounds Maintenance, pp. 38-40.

Solar Drip Irrigation Systems. (1983, February). Drip/Trickle Irrigation. p. 12.

Stirde, W. (1979). Further Results on the Subsurface Irrigation of Grass Sports Pitches. Zeitschrift fur Vegetationstechnik im Landschafts und Sportstattenbau. pp. 13-17.

Tobey, Sam, (1985, October). Considerations in the Selection of an Irrigation System. Landscape & Irrigation. pp. 86-95.

Truttman, D. (1985, February). Irrigation System Design: Developing a True Formula. Landscape & Irrigation. pp. 44-52.

Uniformity in Trickle Irrigation Fertilizer Applications are Important. (1982, February). Drip/Trickle Irrigation, PP. 10-11.

Water-Thrifty Landscape Blends Turf and Desert. (1988, September). Landscape & Irrigation. pp. 120-127.

Woods, L. & Pedicone, M. (1987, June). Trust Those Moisture Sensors. Grounds Maintenance. pp. 10-15.

Yu-Si, Fok. (1988, August). Wetting Agents and Our Endangered Resources. Landscape & Irrigation. pp. 90-94.