GOLF COURSE WATER CONSERVATION: BEST MANAGEMENT PRACTICES (BMPs) and STRATEGIES

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This document provides a comprehensive discussion of the characteristics and value of the BMP approach to achieving water conservation on a golf course. Various water-use efficiency/conservation strategies are discussed. This is ***a companion document to*** "Best Management Practices (BMPs) Water-Use Efficiency/Conservation Plan for Golf Courses" which is a template and guideline for developing a site-specific BMP plan. This document was the basis for the Georgia Golf Course Superintendents Association's on-line BMP program developed in 2005.

PURPOSES

The purposes of this document are:

- To foster development and implementation of site-specific water conservation plans on golf courses and other turf areas based on the Best Management Practices (BMPs) approach

- To foster the adoption of the BMP approach to water conservation by regulatory agencies.

APPROACH

Our approach to fostering adoption of the BMPs approach to water conservation within the regulatory arena and at the individual (site-specific) golf course level is to provide comprehensive, "template", educational material in multimedia formats. The education information is available through the GCSAA BMP water conservation program designed as a cooperative program where:

- GCSAA provides the educational/media/organizational framework to develop and foster the BMP philosophy,
- University scientists develop the comprehensive educational material in multimedia formats---i.e. the template information,
- State or regional turf associations, with guidance from individuals within their region who already are involved in water issues, then take the basic template material and foster adoption within their region with adjustments suitable to the specific location.

As part of the benefit of taking the formal BMP course, participants were given permission to use the copyrighted workbook material, including a Word CD of the document as well as a hardcopy, for development of site-specific BMP as well as regulatory BMPs. This 104 page document is a detailed **"template"** explaining all BMP options for water conservation on golf courses. Associations that wish to adopt this approach can obtain the copyrighted BMP workbook by having a lead individual from the organization to sign up for the GCSAA program---on-line W.A.T.E.R. (Water-Atmospheric-Turfgrass-Edaphic (soil)-Relations) course and the Golf Course Water Conservation BMPS Workshop.

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I. <u>TURFGRASS WATER CONSERVATION---WHAT IS IT?</u>

Priority number 1 is water !!! Today, this statement may not be fact on many golf courses and recreational sites. Pressures to implement turfgrass water conservation practices do not come at the same pace in all geographical locations; but when pressure arises to limit water use, it normally becomes a top issue that must be addressed. And, one paradigm remains the same today and ten years from now—high quality recreational turfgrass cannot be maintained without water.

As increasing competition for scarce water resources brings “water conservation” to a reality on more and more sites, society and governmental pressures will cause the turfgrass industry to focus more intensely on water, similar to the pressures that caused greater attention to pesticide/nutrient fate issues over the past 20 years. In the case of pesticide/nutrient fate, a vocal minority was the driving force. However, when it comes to water quantity and quality aspects, many more people become involved in this basic necessity of life. Thus, owners and managers of golf courses, recreational sites, and other irrigated turf areas should proactively develop plans for water conservation on their sites as means of demonstrating environmental stewardship.

Efficient use of water, one of our natural resources, is increasingly in the spotlight of governmental agencies, water users, and the general public in response to rising demand for available water, especially potable water. Water-use efficiency, however, is an important goal for a number of reasons:

1. Water-use efficiency allows the demand for potable water needs to be achieved, which increases with population growth.
2. Water-use efficiency assists in providing an adequate water supply during drought periods.
3. Efficient use of water reduces infrastructure costs related to water treatment and movement by increasing facility longevity or allowing smaller facilities.
4. Water-use efficiency helps to protect the environment by preserving river, stream, and other aquatic systems; sustaining aquifers for future water needs, to reduce pumping costs when water tables drop, and in some cases to prevent saltwater intrusion.

In production agriculture, there are several definitions of “water-use efficiency” used to describe the relationship between water input and agriculture product (output). Two common definitions are:

- Crop Water Use Indice = Crop WUI = yield / evapotranspiration. Crop WUI is unit of crop production per unit of ET to grow the crop. This indice is related to agronomic performance.
- Irrigation WUI = yield/ irrigation water applied. This indice is more related to irrigation system design and performance.

Neither of these applies very well to turfgrass situations were a “yield” is not the objective. While adequate dry matter production is necessary, other criteria are applicable depending on the site, such as: turf shoot density, color, playability, tolerance/recovery from wear stress, tolerance/recovery from other stresses (salinity, pests, drought, etc.), or sod production (rhizome and stolon growth). Thus, on some low use sites where soil stabilization is the primary concern, sufficient water to maintain live grass (whether in the green or dormant state) may be very limited and often no irrigation is needed. In contrast, a high use athletic field or golf green would require more water due to the high requirements for density, color, uniformity, and recoverability.

In this document, the term **"water-use efficiency"** will be used in a generic manner to imply efficient use of natural precipitation and applied irrigation water on a turfgrass site to achieve the minimum acceptable turfgrass characteristic requirements on a site. Also, the term **"turfgrass water conservation"** will be used in the similar manner, but normally in the context of discussing measures to enhance water conservation on a site. For example, water conservation measures could be selection of a turfgrass with inherent low water-use requirements or modification of an irrigation system to improve water application uniformity.

Controlled turfgrass research studies confirm that water conservation can be achieved to a point before turfgrass quality starts to decline; thereafter, decreasing water availability results in reduced quality (Carrow, 2004). The resulting reduction in turf quality or density implies a potential for reduction in recreational use, environmental/functional capabilities, and economic use/value of the site, which in turn may adversely affect the direct customer, owners, local economy, and local environment (Beard and Green 1994). The real issue then becomes how to maximize water conservation on turfgrass areas while maintaining economic, environmental, recreational viability, and acceptable aesthetics.

II. WATER CONSERVATION APPROACHES?

A. What Is "The Best Approach"?

Water conservation is increasingly becoming a fact of life on many golf courses and other turfgrass sites. It is no longer a matter of "if" (yes) or "when" (now or in the near future), but of "how". ***The answer to the question "how to implement and achieve water conservation ?" has profound implications to the whole turfgrass industry, but especially to the golf course segment.***

Currently the most important environmental issue confronting the golf industry is water conservation, but the golf course industry has addressed other environmental issues in the past, such as: a) minimizing pesticide use ---for general reduction of pesticide levels in the environment, and for protection of surface waters and groundwater; b) reducing nutrient use, especially N and P --- to protect surface waters from eutrophication and groundwater from contamination; and c) sediment abatement ---to protect surface waters from sediments and movement of any nutrient or pesticide residues associated with the sediments. Resolution of each of these environmental challenges has taken on **a common theme** ---the development and adoption of **"Best Management Practices**" **(BMPs)** by federal, state, and/or local regulatory agencies and their implementation by golf courses. BMPs for these issues have or are also being developed, adopted, and implemented within agriculture and horticulture industries.

Before addressing more specifically the BMP option to water conservation, it is beneficial to briefly review other options. One option for dealing with turfgrass water conservation has already been pulled from the table--- indifference or ignoring water conservation. **Two broad options remain for adoption and subsequent implementation of water conservation programs whether at regulatory levels or at the site-specific, golf course level**, namely: a) by rigid mandated regulations, and b) by a holistic, science-based method—i.e. Best Management Practices (BMPs) approach.

B. Rigid Regulations.

When a serious water shortage occurs within an area in response to lack of precipitation, increased population, and/or lack of long-term planning, the initial response from governmental agencies and politicians is often to mandate rigid regulations, such as: certain days of the week to irrigate; narrow time frames to irrigate; irrigate only selected turf areas (reducing grassed areas that can be irrigated); rigidly enforced quantity of water available to irrigate that is at or below the current average for golf courses in the region; requiring all golf courses reduce water by a set percentage; or combinations of the above. Some of these regulations certainly have a role to play under certain conditions, such as: a) as part of a local, state, or regional crisis water management policy, where these regulations come into play at the third or fourth levels of a programmed approach to a water crisis, and b) where the crisis water management plan includes all water users with appropriate water-use restrictions.

When these crisis management regulations are carried forward as the long-term approach to water conservation, serious issues are often overlooked by the politicians and other policy makers---i.e., what is necessary in a crisis is not the best, reasonable approach for long-term sustainability. For the other environmental issues previously mentioned (especially, pesticide and nutrient fate), a similar scenario of initial reliance on rigid regulations occurred, but then was followed by a more reasonable BMPs approach when the adverse consequences of a rigid regulation became more apparent.

Some of the common problems noted for a rigid regulation approach as an initial and long-term means for dealing with environmental issues are:

- Rigid regulations are primarily political-based rather than science-based. State-of-the-science concepts and technology can be effectively applied to maximize water-use efficiency, but not if this approach is replaced with political or personnel beliefs that are not based on facts (i.e., science).
- Imposition of rigid regulations as the primary approach to water conservation (and other environmental issues) very often triggers adverse economic impacts and loss of industry viability.
- Site-specific management is not emphasized but replaced by a "one size fits all strategy". For example, turf managers who are already applying BMPs to water conservation on their site often exhibit water use at the average or somewhat below average of all similar users in an area. If a rigid general regulation mandates that all water users reduce water use by 20%, those already implementing efficient conservation strategies are the most adversely affected?
- The level of training and expertise of professional turfgrass managers is not valued; or to state it in other terms "education is not valued".
- Rigid regulations are not "whole systems-based", but attempt to achieve conservation by changing only 1-2 aspects, such as reducing turf/landscape acreage under irrigation or irrigation duration and frequency. A systems approach makes adjustments according to the whole system: plant-soil-climatic/atmosphere-landscape and surrounds-water sources-management level-management resources.
- Since science is not valued, a rigid regulation approach does not encourage development or implementation of improved science-based technology or concepts.

In addition to the above concerns, a rigid regulations approach may actually cause health, fire safety, and environmental problems. As a part of an overall water conservation plan, actual water conservation/savings must be balanced not only by potential adverse effects that may occur on the specific site, but also on the local/state economy and environment. Three examples illustrate this point when removal of turf is carried too far:

- When grass cover is greatly restricted by regulatory action for the purpose of "water conservation", adverse effects may result. Grasses are a central plant for controlling wind erosion. When soils are eroded by winds, there is a loss of an important natural resource (soil). When China removed all turf and many trees from Beijing public spaces during the Cultural Revolution in the 1960's, the result was major air pollution from dust storms, related health problems, and higher air temperatures within the city (Cathey 2003). Revegetation with trees alone did not resolve the problem, but additional turfgrass cover was needed. Recently, the People's Daily (2002) reported "Beijing will take drastic moves to eliminate the sources of dust so as to reduce the amount of dust people breathe in everyday…worksites that refuse to plant trees shall be taken back….and shall be turned into lawns put under the management of gardening departments".
- Mowed turfgrass can be an effective fire buffer and grass removal near buildings can result in increased fire hazards and higher insurance preminums. "Firewise" landscaping for the wildland-urban interface suggests that zone 1 (30 feet ring around home) and zone 2 be well-irrigated, low growing, and low flammability plant species; zone 3 should be low-growing plants and well-spaced trees in this area, with minimal volume of vegetation biomass for fuel (Firewise, 2004).
- Grasses are very effective in prevention and remediation of several global urban soil, water, and chemical problems, namely: prevention of soil degradation by wind and water erosion; reducing soil loss and transport that adversely affects surface waters; prevention of nutrient and pesticide transport into surface and subsurface waters; reducing urban water runoff; and grass is a major contributor of organic matter in soils that improves soil quality (Deletic, 2004; Muckel, 2004)

C. Best Management Practices (BMPs) Approach.

Acceptance of the BMPs approach to prevention and remediation of environmental problems by politicians, regulatory agencies, environmental groups, and the turfgrass industry is based on certain inherent characteristics of BMPs, namely:

- ***Science-based.*** Integrated Pesticide Management (IPM), BMPs, and Precision Agriculture (PA) are all science-based and have inherent foundational principals involving application of inputs only on the site where needed, only when necessary, and only at the quantity required. Such science-based approaches stimulate entrepreneurship for development of new technology and approaches to enhance future water use-efficiency. The very definition of BMPs illustrates why this approach is effective: a) "best" implies that the best strategies that can be adopted with current technology and resources are being practiced; b) "management" suggests that management decisions by trained managers can maximize the result, and c) "practices" imply that management practices do make a difference. Thus, whether called a BMP, IPM, or PA approach, all emphasize efficient use of resources using a science-based and flexible philosophy. These approaches can be documented and accountability can be easily monitored.

- ***Holistic in terms of water conservation options***. There is no "silver-bullet" or single factor to achieve water conservation, rather a combination of water conservation strategies is needed to achieve effective water-use efficiency in the whole ecosystem. The "system" includes soil, plant/landscape, atmosphere/climate, turf manager, irrigation system, irrigation water source, manager expertise, and any other aspect that may influence water-use.

- ***Holistic in terms of the effects of water conservation measures on all stakeholders as a central component of all water conservation plans.*** Water conservation programs should include consideration of the effects of measures on the economy, environment, jobs, and site use. The "customer" or user/manager/owner of a turf site is not the only "stakeholder" potentially affected by water conservation measures, but others include: the supply side [water authorities, suppliers]; demand side [turf site user, turf manager, turf industry, etc.]; and others affected by environmental and economic water conservation measures [society in general, local economy, health aspects, etc.].

- ***Site-specific adjustments.*** Since there is no single factor that will achieve maximum water conservation on a site, rather it is adjustments within the whole system that are the basis of BMPs, educated decision-making is important, BMPs encourages professionalism and education of the turf manager, including continuing education. Each site is different and adjustments must, therefore, be site-specific.

- ***Fosters development and implementation of new technology and concepts.*** BMPs encourage on-going improvement in water conservation to achieve the "best" practices and guideline templates can be developed and updated over time.

- ***Be a document:*** Planning for water conservation must eventually develop into a written document with the various water conservation measures agreed upon by the owners, business managers, boards, and turf manager. The final document should include not just the water conservation measures, but also the other components as noted in Table 1.2.

- ***Be a living document.*** Society concerns for water means that water conservation measures must be adopted and implemented on an on-going basis. The BMPs document must be a living document and not one gathering dust on a bookshelf.

The BMP approach may appear to be similar to the Xerispace™ philosophy for water conservation or more vague terms such as "water conservation practices", water-wise, or natural landscaping concepts (Vickers, 2001). The Xerispace™ philosophy does have some similarities to a BMP approach but is less comprehensive and clear. This is discussed in Chapter 10..

Since the BMP philosophy is supported by regulatory agencies and environmentalists for other environmental issues (because of the above positive attributes), it would seem likely they would be supportive of this approach for turfgrass water conservation. When severe water restriction levels are mandated, more severe limitations on water use would come into effect for all industries. But, under a BMPs plan it still incorporates as many of the basic science and site-specific principles as possible. Thus, the authors would encourage the golf course industry: a) to vigorously adopt and foster the BMPs approach to water conservation; and b) use the BMPs terminology instead of more vague terms such as "water conservation practices", Xerispace^{TM}, water-wise, or natural landscaping concepts (Vickers, 2001).

These ideas are presented to aid focusing the turfgrass industry toward proactive and creative means of addressing what many consider the most important challenge to confront the golf industry and other turfgrass sites. **The intentions within this document are**:

- To go beyond information that is currently available in terms of: scope of water conservation strategies and options; depth of information on each option; and impact or implications of selecting specific options on all stakeholders. The term **"stakeholders"** is defined as the broadest groups impacted by a decision, which often includes society as a whole.
- To illustrate and discuss aspects of BMPs for water conservation unique to large turf areas, especially golf courses. For example, golf courses are increasingly using alternative irrigation water sources as a primary strategy to conserve potable water. But, many home lawns or general turf areas do not use this as a means to conserve water, nor do most agronomic crops. Use of poor quality irrigation water has very significant costs associated with this strategy for "BMPs for golf course water conservation" that are not born by other industries or homeowners. It is important for water regulatory groups, politicians, environmental advocacy groups, and the public to recognize the unique aspects of the golf course industry that may impact it economically in a more severe manner than other landscape situations or agriculture (see Chapter 10 for more discussion related to this topic).

In almost all water conservation strategy areas, there is on-going evolution in science and technology that aid in refining water conservation practices. This will be a continuing trend and each facet of the turf industry must "think outside the box" and consider new technologies, different approaches, and to sincerely implement theory into practice.

To illustrate the effectiveness of the BMP approach to water conservation at the regulatory level, two case studies are presented in Appendix A. As an outcome of the first GCSAA workshop on BMPs for golf course water conservation in February 2004, participants from Georgia an Arizona used the information to government planned water conservation programs targeted to the golf course industry that were examples of rigid regulations. The regulatory approach was changed from a rigid regulation one to a BMPs approach.

Key <u>components</u> of the planning and implementation steps to develop a turfgrass water conservation BPM program are outlined in the next section and each component will be discussed in various chapters in this document

III. ***<u>PLANNING PROCESS and COMPONENTS OF A SUCCESSFUL TURFGRASS WATER CONSERVATION PROGRAM.</u>***

Vickers (2001) and USEPA's *Water Conservation Plan Guidelines* (1998) noted key steps to a successful water conservation program on a regional or statewide basis (Table 1.1). In this document, we are focusing on site-specific plans, but it is informative to understand the types of issues that governmental agencies should address. Regulations that arise out of the governmental planning process can become positive incentives for the turfgrass industry when both groups work together. However, if the political process limits industry involvement and does not consider the implications to the turfgrass facility and broader stakeholders, considerable harm may arise in the form of economic, jobs, environmental, and political.

Table 1.1. Key steps in a successful regional or statewide water conservation program (Vickers 2001; USEPA 1998).
1. Identify conservation goals. 2. Develop a water-use profile and forecast. 3. Evaluate planned facilities. 4. Identify and evaluate conservation measures. 5. Identify and assess conservation incentives. 6. Analyze benefits and costs. 7. Select conservation measures and incentives. 8. Prepare and implement the conservation plan. 9. Integrate conservation and supply plans, modify forecasts. 10. Monitor, evaluate, and revise program as needed.

Many of these key steps of the regional or statewide planning process apply to development of BMPs for turfgrass water conservation program on a specific turfgrass sites, such as a golf course, but there are also differences between a broad plan versus a site-specific plant. To the author's knowledge, a comprehensive plan for creation of a "BMPs for Turfgrass Water Conservation Program" has not been formally developed---documents that deal with limited aspects have been developed but not a holistic BMPs document. Vickers (2001) outlines planning steps and discussed these for homelawn or general landscapes and for agriculture purposes. Many of the components apply to golf courses but golf course plans are more complex. The Irrigation Association (2003) has a well defined plan for conducting an irrigation audit but this is only one component of an overall BMP program. The Connecticut Department of Environmental Protection (2001) has developed a document on "Potential Best Management Practices for Golf Course Water" that outlines some of the aspects.

In Table 1.2 are summarized a planning process and its components that the authors believe should be considered in development of a "BMPs for Golf Course Water Conservation" document on a site-specific basis; but with greater emphasis on specific strategies to achieve the water conservation goal. Various components will be discussed in later chapters. The ultimate outcome of the planning and assessment process is to develop a **"Best Management Practices (BMPs) For Golf Course Water Conservation" document** that is fine-tuned for a particular site. A **"best management practice**" can be defined as the "best" management practice that can be used on the particular site to achieve the environmental goal---in this case, the goal is water conservation and adequate turfgrass characteristics for the site. At the center or heart of a site-specific, water conservation program is selection of specific options or measures within several broad water conservation strategies, to achieve the goal. Several authors have discussed overall water conservation strategies for turfgrass areas (Gibeault and Cockerham, 1985; Carrow and Duncan, 2000a; Vickers 2001; Carrow et al. 2002a, 2002b; ITPF 2003). To date, the most comprehensive discussion of various strategies and then options within each strategy has been by Gibeault and Cockerham (1985), Vickers (2001), and ITPF (2003).

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Table 1. 2. Outline of the planning process and components of a golf course BMPs for water conservation.

A. Initial Planning and Site Assessment.

1. Identify water conservation measures that have already been implemented by a course including costs of implementation—this initial step aids in clarifying for the golf course management team and club members exactly what is entailed in BMPs water conservation measures. Also, when the final document/program is shared with regulatory agencies, this information is very valuable in pointing out that golf courses are not starting from "zero" in this arena but have been implementing BMPs for many years.
2. Determine the purposes and scope of the site assessment. Site assessment is necessary to determine the best options for the specific course.
3. Site assessment and information collection.
   - Determine current water-use profile.
   - Irrigation/water audit.
   - Additional site infrastructure assessment information---evaluation of alternative irrigation water sources; golf course design modifications; irrigation system design changes; microclimate soil/atmospheric/plant conditions affecting irrigation system design/zoning/scheduling; drainage needs for leaching of salts or any hydrological considerations that may arise from use of any particular irrigation water source.

3. Determine future water needs and identify an initial water conservation goal.

B. Identify, evaluate, and select "water conservation strategies" and options.

1. Use of non-potable water sources for irrigation---alternative water sources; water harvesting/reuse.
2. Efficient irrigation system design and devices for water conservation.
3. Efficient irrigation system scheduling/operation. Both irrigation system design and irrigation scheduling in the future will requires much more site-specific information. Sensor technology integrated into a GPS/GIS approach will assist in development and interpretation of information for improved irrigation systems and scheduling.
4. Selection of turfgrasses and other landscape plants.
5. Golf course design for water conservation.
6. Altering management practices to enhance water-use efficiency---soil amendments; cultivation; mowing; fertilization; etc.
7. Conservation strategies for landscape areas other than the golf course and indoor water conservation measures in facility buildings.
8. Education. Plan for initial and continuing education on water conservation/management by golf course superintendent, crew, club officials, etc. BMPs for turfgrass water

conservation is complex and when poor irrigation water quality is involved the level of costs and complexity greatly increases ---i.e., fertilization, leaching of salts, salt disposal/hydrological issues, complex irrigation systems and scheduling of irrigation, these are some of the complex issues.

9. Development of conservation and contingency plans. A formal BMPs document should be developed and agreed on by all club officials and members so that the golf course superintendent has support for any reasonable science-based measures to be taken. Also, a written plan may be required by regulatory agencies.
10. Monitor and revise plans.

C. Assess benefits and costs of water conservation measures on all stakeholders.
Assessment of costs and benefits associated with developing and implementation of a long-term BMPs water conservation plan is necessary not only for facility planning, but also to demonstrate to regulatory agencies and possible critics of golf courses that substantial effort and cost has been involved in water conservation by the facility.

1. Benefits.
    - Direct and indirect to the owner/manager and site customers.
    - Direct and indirect to other stakeholders, including water savings but also other benefits—economic, environmental, recreational, etc.

2. Costs.
    - Facilities costs for past and planned implementation of water conservation strategies---irrigation system changes; water storage; pumping; new maintenance equipment; water/soil treatments; course design alterations; water harvesting, etc.
    - Labor needs/costs.
    - Costs associated with changes in maintenance practices; different irrigation water sources (water treatment, soil treatment, storage, posting, etc.)
    - Costs that may impact the community if water conservation strategies are implemented (especially mandated ones), such as revenue loss, job loss, etc.

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IV. CHALLENGES.

Considerable information already exists about many aspects of turfgrass water conservation principles and practices, which could be implemented rapidly to achieve water savings of 10 to 50 percent on most sites (Gibeault and Cockerham 1985; Kneebone et al. 1992; Kenna and Horst 1993; Moller 1996; Wade et al. 2003; Carrow, 2004). Incorporating new developments in grasses, technology and scientific knowledge will also produce additional water savings over time.

Many golf course superintendents already follow some water conservation practices at their courses (and would be expected to be open to future advances), but full implementation can be hindered by institutional or club attitudes. For the golf course superintendent, who often is motivated by environmental stewardship, managing for water conservation requires support from club officials. This support can include: determining that conservation will be a priority for the turf manager; financially supporting an efficient irrigation system; and requiring a course design that supports limited water use. Another group, golf course architects, can substantially support

BMPs for water conservation through their design practices. Those who have substantial influence on course management policies and who ultimately have the greatest economic stake in ensuring successful golf enterprises must give full support to the golf course superintendent to implement BMPs for water conservation.

New grasses and new technology will add to the complexity of the system and decision-making. For example, sensor technology will monitor soil moisture status; plant-based sensors will monitor shoot responses; sensors information will need to be integrated into GIS and GPS systems; sensor and controllers will need to be compatible, etc. New grasses and changes in water quality will require altered management regimes. Often water quality will be poorer, and turf managers will need to cope with salinity, water harvesting, and documenting water needs and uses.

Although new technology and new management regimes can assist in an overall water conservation program, they make a complex system even more complex, which can limit adoption of BMPs for water unless the turf manager receives adequate education and support. GCSAA educational offerings are being expanded in the areas of water conservation, water quality, drainage, and irrigation. The challenge to university and industry research personnel is to develop cutting-edge grasses and technology to conserve water. The challenge to the Extension specialist and the turf educator is to develop relevant, specific educational resources and offerings with practical applications (Carrow et al. 2001).

Constraints to an on-site water conservation program may be in various forms and each must be addressed. Examples of constraints are:

- Agronomic. The current grasses may not be very efficient in water uptake and use; a clay soil may cause high runoff of precipitation.
- Educational. Insufficient data may hinder understanding of actual water use; owners or golf course board members may not understand the options available to conserve water.
- Financial. High costs to implement water conservation measures can act as a disincentive.
- Infrastructure. Inadequate irrigation system design can limit water conservation.
- Institutional. Governmental regulations can foster or hinder adoption of conservation measures, such as the water price structure.
- Management. The golf course superintendent or turf manager must place priority on water conservation on an on-going basis.

Much of the BMPs planning process consist of identifying constraints for a particular location and determining measures to overcome these constraints. In summary, water conservation will become increasingly necessary on most golf courses, regardless of the climatic zone. Considerable knowledge already exists about many practices within this complex "soil-plant-water source-climate-man" system that can be implemented rapidly to achieve a certain degree of water conservation or water-use efficiency. In addition to the current state of science, turf managers will be presented with a host of new tools for better water management and ongoing changes in equipment, chemicals and practices. In-depth, continuing education will become necessary as new technology and new grasses must be integrated into BMPS for water conservation that are truly efficient, properly implemented and carefully monitored. Because issues of water use, conservation and quality are rapidly becoming the most dominant factors influencing golf courses, the future paradigm will require the whole-hearted involvement of all individuals associated with golf course operations and design.

V. HISTORY OF TURFGRASS WATER CONSERVATION?

A brief review of historical developments within the turfgrass industry and governmental arenas relative to turfgrass water conservation is useful to understand the evolving nature of this issue. Within the individual sections on specific water conservation strategies, key references and discussion provide further insight into historical trends, but in this section a broad over-view is given.

A. Question---"Can we maintain turf to customers' satisfaction with less water?"

This question suggests three points: a) sound water conservation strategies can result in less water used on turf sites, b) that turf potentially could be affected in a manner that would reduce its value to the customer, and c) the issue of water conservation as a "benefit" should be addressed in the context of other changes that may be detrimental (Carrow, 2004). In the midst of a water crisis, the general public, politicians, and water regulatory agencies may focus only on water savings that can be achieved by implementing water conservation strategies. Without considering benefits that turf sites provide, it is easy to go directly to the ultimate water conservation measure---no water for turfgrass sites or no turf. However, if water conservation measures are severe enough to compromise turf recreational use, economic impact, environmental/functional benefits, or aesthetics, more than the "customer or golfer" may be adversely affected---i.e. there are more "stakeholders" affected by turfgrass water conservation measures than the golf course. Education of "stakeholders" beyond the confines of the golf course concerning these issues will often depend upon the golf course officials. In Chapter 10 is a discussion of the type of information that must be conveyed to politicians, water agencies, environmental advocacy groups, and the general public: a) on an on-going basis; and b) as an essential component of any written BMPs document on water conservation.

Controlled research studies confirm that water conservation can be achieved to a point before turfgrass quality starts to decline; thereafter, decreasing water results in reduced turf quality as the drought stress increases in severity. The resulting reduction in turf quality or cover implies a potential for reduction in recreational use, environmental/functional capabilities, and economic use/value of the site, which in turn may adversely affect the customer, owners, local economy, and environment (Beard and Green, 1994; Cathy, 2003; Carrow, 2004). Beard (1973) noted that as drought stress increases: turf growth declines; wilting of tissues increases; the grass starts to go into dormancy with a loss of green tissues; and when the drought is prolonged, the turfgrass stand thins; and total death may occur.

B. Turfgrass Water Conservation Efforts: 1950-Present.

Turfgrass irrigation with below-ground systems is relatively recent, starting in the 1950s with quick-coupler systems, and by the 1960s many recreational sites, home lawns, business grounds, parks, and other turf sites were irrigated (Beard 1973; Carrow et al.1990). Water conservation on golf courses and other turf areas is not a new concept, and in fact, the first Ph.D in turfgrass science was on the topic of irrigation (Watson 1950) and Hagan (1955) noted in the *USDA Yearbook of Agriculture* the benefits of deep, less frequent irrigation on water-use efficiency. Water conservation concerns became a priority as irrigation system use became more prominent with the initial focus on avoiding over-irrigation. An incentive for water conservation on golf courses and other turf sites with irrigation systems was the evident negative effects from over-irrigation. Beard (1973) noted a number of detrimental aspects of excessive irrigation such as: a) waterlogged, soggy soils, b) poor rooting from lack of soil oxygen, c) soils are more prone to soil compaction, d) greater susceptibility to a traffic and environmental stresses---wear, high temperature, and low temperature, e) greater disease activity, f) excessive mowing and clipping accumulation, and g) water was wasted. The results of these responses under excessive water application, whether by irrigation or precipitation, were reduced turfgrass vigor, health, and quality, and greater maintenance costs.

In the 1950 and 1960s, turfgrass irrigation companies applied technology and design principles from horticultural and agronomic crops to the belowground irrigation systems used for perennial turfgrass sites (Marsh 1969; Beard 1973; Watson 1974). The design principles and applications were more complex for turfgrass sites due to great variation in soil, climatic, and grass microclimates; but the goal was the same—uniformity of irrigation application for water use efficiency (Morgan 1964).

Limited concern for water conservation by governmental agencies started in the 1960s with Linaweaver et al. 1967 providing the earliest detailed study of domestic water use. But, is was not until the mid-1970s, that interest in "urban-wide water conservation" greatly increased in response to severe drought in the Western USA (1976-1978), coupled with population growth, income, consumer habits/lifestyles, water pricing policies, economic growth, and increased lawn irrigation (AWWA 1973). Flack et al. (1977) at Colorado State University developed the first urban water conservation handbook that compiled many of the principles that are in more recent urban water conservation plans, such as: conservation measures for indoor and landscape water use, water saving devices, pressure control, leakage reduction, water use restrictions, price structuring, education, recycling, and education. In their review of previous work, it was noted: "Only recently has research been directed at many of the water conservation alternatives. Before the early 1970's little consideration was given to demand modification".

Within the same time-frame of the mid-1970s, there was stimulated interest within the turfgrass industry in expanding the concept of "turfgrass water conservation" beyond avoiding excessive irrigation to reducing water use on turfgrass even further, while maintaining adequate turf quality and performance (Marsh et al. 1980). In the first detailed turfgrass science and management reference/textbook, Beard (1973) devoted considerable attention to turfgrass water relations. The University of California and American Sod Producers Association developed the first comprehensive source of information on turfgrass water conservation in the publication 'Turfgrass Water Conservation' (Gibeault and Cockerham 1985). This publication included chapters addressing many different water conservation strategies and associated issues:

- The size, scope, and importance of the turfgrass industry.
- Water: Whose is it and who gets it?
- Water resources in the United States.
- Physiology of water use and water stress.
- An assessment of water use by turfgrasses.
- Turfgrass culture and water use.
- Influence of water quality on turfgrass.
- Soil/water relationships in turfgrass.
- Irrigation systems for water conservation.
- Influence of water on pest activity.

- Site design for water conservation.

Gibeault and Cockerham (1985) noted that there was insufficient research in many areas. By the early 1980s the United States Golf Association initiated a research-funding program that focused in the early years on turfgrass water conservation issues, and continues today with considerable resources devoted to turfgrass water relationships. In the early 1990s, several books or articles provided up-to-date literature reviews concerning turfgrass water aspects with the major focus on the efficient use of water: Carrow et at.1990; Kneebone et al.1992; Balogh and Watson 1992; Kenna and Horst 1993; Carrow 1994; Snow 1994; and Carrow and Duncan 2000a.

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Chapter 2.

Initial Planning and Site Assessment

I. Initial Planning.

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- **A. Identify Water Conservation Measures That Have Already Been Implemented.**
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Chapter 2.

Initial Planning and Site Assessment

I. <u>INITIAL PLANNING</u>.

In most cases, development of a comprehensive BMPs water conservation plan for a golf course is a process that is best done over a 1-2 year period. The overall planning process and various conservation strategies are outlined in Table 1.2. In some cases, the "site assessment" or information gathering process requires contracting individuals or companies to do detailed water audits of the existing irrigation system, water source options along with water quality assessment, and other rather complex information gathering tasks. An initial plan can be made but may change over time as additional information is gained---for example, an anticipated irrigation water source may be deemed unacceptable due to quality or quantity constraints after a more detailed assessment is conducted.

A. Identify Current Water Conservation Practices.

The first step in the planning process should be to assess what has already been accomplished by the course with respect to water conservation. This step is essential because it:

- Aids in bringing together the whole management team at a course (superintendent, club officials, pro, etc) to focus on the water conservation issue;
- Assists in establishing a common understanding of what is involved in development of a BMP plan (i.e., scope, terminology, components involved as noted in Table 1.2).
- Clarifies for the club what water conservation measures are already instituted.
- Developing the information necessary to educate regulatory agencies that the club is not starting at "zero" with respect to water conservation; and that considerable time, effort, and resources have been expended toward water conservation.

Since a water conservation plan will likely be viewed by regulatory agencies, it is important to demonstrate what water conservation practices have already been implemented—this information is **"educational"** in nature, or intended to establish a benchmark for future actions based on the past. Many times these past improvements are overlooked---golf courses may improve water conservation programs by new measures, but that does not mean they are just starting in this endeavor or starting from "ground zero". Some common examples are;

- Irrigation system design and zoning. Even if an irrigation system can be improved in terms of uniformity of water application and zoning, the initial system will likely be more efficient than the old quick couplers.

- Irrigation scheduling techniques such as: using indicator areas to help determine irrigation needs; use of weather station data to help schedule irrigation; periodic changes in irrigation rates to account for weather changes; or a history of not irrigating roughs or selected sites when water demands are high or there is a drought.
- Water harvesting. It is not unusual for golf course, especially in semi-arid and humid climates, to derive considerable irrigation water from surface runoff collected in lakes; and often these same water features are part of state mandated storm water runoff control measures that limit sedimentation of natural water bodies. This is very important information when golf course officials are discussing water use with regulatory individuals or citizens who often assume the course is using potable water.
- Grass selection. Many golf courses in warmer climates use bermudagrass as the predominant grass and this species has inherently low water use rates and very good drought resistance with the ability to tolerate prolonged drought periods.

The water conservation strategies outlined in Table 1.2 and within various chapters of this document will assist in determining additional items that could be included in this part of the initial plan. When determining what conservation practices are already implemented, it is a good policy to estimate the costs of implementing these practices. As an example, the Georgia Golf Course Superintendents Association recently suggested to members that they assess the following:

1. Current irrigation controls and hard costs (parts, power)
2. Staffing in irrigation control and irrigation maintenance
3. Scouting – costs
4. Hand watering – hours and costs
5. Night watering capability
6. Rain, leak, etc. loss controls and costs
7. Traffic controls and costs
8. Metering – installation and ongoing calibration and replacement
9. Management for water conservation
   a. Height of cut
   b. Soil cultivation to promote root depth
   c. Evapotranspiration utilization
   d. Selection and installation of drought resistant landscape plants
   e. Natural vegetation areas
   f. Fertilization practices to minimize water use.
   g. Pest management – early morning or late evening applications to reduce water loss. Consideration of Integrated Pest Management protocols.
   h. Wetting agent usage.
10. Record keeping and costs
11. Possible irrigation methods (plant based, soil based, budget approach, deficit, atmosphere based)
12. Goal setting regarding water use efficiency
13. Education Efforts –Education taken by superintendent or any club official related to water conservation, list benefits of golf courses and turf areas; publish water conservation plans; engage stakeholders (members, patrons, neighbors, general public) with the benefits of water conservation

B. Determine the Purposes and Scope of the Audit.

The primary purpose in developing a water conservation plan is "water conservation". It is important that the initial planning is sufficiently wide in scope to address future water conservation needs. An in-depth, comprehensive planning process will help insure that the process does not need to be repeated in the next few years.

There are different levels of information that may be obtained toward this goal. A traditional irrigation audit will provide substantial information to allow many different conservation options to be explored that are related to the irrigation system. However, increasing pressure for water conservation on turfgrass areas may require going beyond what is the state-of-the-practice at this time. Golf course officials should have a well-defined understanding and appreciation of the type of information required. The **scope of the information in a site assessment audit** will determine the benefits that may arise from the knowledge base. Also, future decision-making will be greatly influenced by the degree of information arising from a site assessment.

Some may question the need to investigate more "radical" water conservation approaches than now considered in a standard irrigation audit---such as course redesign, using sensor technology to highly automate irrigation scheduling, more stringent zoning into more specific microclimates, use of irrigation water sources that are available but of poorer quality, etc. One scenario that is becoming increasingly common, especially in arid regions, is for a golf course to be mandated a specific quantity of water that is well below the average of most courses. When this situation arises, it is surprising how interested course officials become in looking at all options in order to achieve the mandated level of available water. Thus, the higher the pressure is on a golf facility to implement rigorous water conservation measures, the greater the need to look at all options, including ones that may have been discounted in the past. A challenge for golf course officials who are now in the process of water conservation planning will be to consider what may occur in the future that would increase conservation needs beyond those experienced today---i.e. plan for the future !!

An additional reason for considering how extensive will be the scope of a site assessment audit is to communicate to regulatory agencies and groups that do not understand the environmental stewardship practices of golf courses the substantial costs and impact to the course associated with many of these practices. These costs are often higher than required of other water users. For example, turfgrass areas may be able to use substantially poorer water quality than for food production; but there can be very high costs associated with infrastructure changes and on-going costs for water, soil, and plant treatments to off-set adverse effects on the water quality within the system.

II. <u>SITE ASSESSMENT APPROACHES.</u>

When site assessment is discussed, individuals normally think of this as an irrigation audit and this is often the case. However, a more comprehensive site assessment that includes a water audit but goes beyond it in scope may be necessary and should be determined in the initial planning phase. There are training courses for individuals who do irrigation audits, such as by The Irrigation Association (2003a, 2003b) and Irrigation Association of Australia (2003). Vickers (2001) and Connellan (2002) present basic steps to turf and landscape water auditing. However, for some on the additional site assessment aspects that go beyond the traditional irrigation audit, new methods and assessment groups will need to evolve. Alternatively, groups that currently are leading in irrigation auditing may include these aspects in their training and protocols.

A. Irrigation Audit.

There are times in the history of a golf course when intensive **"site assessments"** may be conducted; and all are related to turfgrass water relations. The timing of a site assessment will depend upon the particular goal. For example;

1. A pre-construction site assessment is required for designing the irrigation system to meet site needs. Soil and climatic conditions that influence water use or water application are a primary focus. This would be a one-time event.
2. Site assessment for the purpose of developing a more detailed water conservation plan on existing golf course areas. This also would be a one-time event. In this chapter, we focus on this type of site assessment.
3. Site assessment after water conservation measures have been implemented on an existing course to monitor the effectiveness of implementing different measures and to make adjustments. In this case, the site assessment may be on an on-going basis and less comprehensive.
4. After construction and planting is accomplished on a new course, a site assessment may be conducted to determine the effectiveness of the irrigation design and make improvements.

We are interested in the second type of site-assessment on an existing turfgrass facility. Detailed site-specific information is essential in the planning process if wise decisions are to be made relative to: a) formulating a reasonable water conservation goal or target level, and b) selecting appropriate water conservation measures.

Consistent terminology will help prevent misunderstandings as to the scope of a site assessment. In their excellent book used for training of certified golf irrigation auditors, The Irrigation Association (2003b) defined an **irrigation audit** as: "Information about each area's technical characteristics and controller capabilities should be obtained. An irrigation audit involves collecting data, such as site maps, irrigation plans and water use records. Tuning of the irrigation system is accomplished during the inspection….Field test are then conducted to determine the system's uniformity and to calculate various zone precipitation rates." The term **"water audit"** is used in the same context or meaning as an irrigation audit. When conducting an irrigation audit or water audit:

- Very detailed information is determined on the irrigation system design and performance. The main focus is on the irrigation system.
- Water source availability and needs are determined.
- Some soil information is determined as related to irrigation system design, zoning, and water application.
- Grass type and location are often noted.
- Climatic conditions may be available from a local or on-site weather station to assist in scheduling irrigation.

B. Comprehensive Site Assessment.

In this document, we use the term <u>"site assessment"</u> for water conservation planning to denote a more detailed or robust evaluation of a site than a traditional irrigation audit. Such a site assessment would include an irrigation audit, but would include a number of other factors depending on the golf course need. We anticipate that site assessment requirements will be an evolving area in the near future with **<u>more stringent assessment becoming routine</u>** due to a combination of factors related to water conservation strategies, such as: sensor technology improvements; altering turf management practices; concept changes in irrigation system design and scheduling equipment; making golf course design changes for water conservation purposes; and the increasing use of poor water quality on turf sites. Thus, it is will be important for golf course officials to know what information will be supplied in a contracted audit, including the detail of the audit. A comprehensive site assessment may require more than one contracting firm to accomplish all aspects. As the need for more detailed site assessments increases, senor technology will likely be adapted to provide more in-depth information in a rapid and concise manner (Lahoch et al. 2002). We envision a "site assessment" that will provide the best information to maximize water conservation options to include:

- **Irrigation audit** information as the core information.
- Determination of **alternative irrigation water sources** may be a part of the overall BMP program for water conservation---i.e. one of the first strategies to reduce potable water use is to switching to non-potable sources. Thus, water quantity/conservation plans often result in water quality issues. In some situations, specialists may be necessary such as to determine water available from an aquifer or potential for development of a water treatment facility to provide water.
- **Water quality assessment** and related information as determined by the water quality tests. There is a major need for additional information when water quality is poor, especially with high total soluble salts and/or sodium. These water quality problems may require decisions to be made concerning several **related issues that can substantial escalate costs**, such as: a) water treatment, b) soil amendment treatment, c) subsurface drainage to remove leached salts, d) assessment of the hydrological conditions on a site to insure that leached salts do not contaminate existing ground water, and e) identification of potential lake management issues related to water quality.
- If a course is considering **golf course design modifications** for the purpose of reducing highly irrigated, close mowed turfgrass area; a golf course architect should develop design plans before considering **irrigation system design changes**.
- More **detailed assessment of soil conditions** to allow enhanced or more precise irrigation design, zoning, and scheduling. One type of soil condition on salt-affected sites will be soil salt variability over the landscape and within the soil profile.
- Greater site **assessment of atmospheric conditions** across the landscape for climatic factors that influence ET so that microclimate conditions can be well defined. In order for weather station ETo or reference crop ET (an older concept was ETp or potential ET), to be adjusted for more site-specific conditions, characterization of these microclimate sites is necessary.
- One use of more specific soil and atmospheric site assessment, as noted, is to develop a better irrigation design and operation. But, another use would be to determine soil moisture sensor placement and any additional atmospheric sensor placement. For example, it is not inconceivable that mini-weather stations be on selected microclimate sites to improve ETo adjustments to obtain actual turf ET (actual crop ET, or ETc).

While an irrigation audit is conducted on an existing golf course and changes may be able to be made that improves water conservation, many other strategies are less costly if incorporated during initial construction rather than as renovation of an existing system. However, when there is considerable regulatory pressure to greatly reduce water use on a course, more radical measures may be required and some of the additional site assessment needs beyond an irrigation audit could become necessary.

An additional reason for a more comprehensive site assessment is to address **sources of site variability (or spatial variability)** in a more detailed manner that has been done in the past. Spatial variability on a site influences irrigation design, irrigation scheduling, and sensor use. Table 2.1 denotes important sources of site variability.

Table 2.1. Sources of site or spatial variability that influences irrigation design, irrigation scheduling, and sensor placement.
Above-Ground. Variability across the landscape due to: Climate variation • Solar radiation (N/S exposure, shade), • Wind speed, • Humidity, • Air temperatures, Grass/plant type and characteristics
Soil Variability Both horizontally and vertically due to: Soil texture, OM content, Soil depth, Slope, Soil water holding capacity, Infiltration rate Percolation rate (saturated hydraulic conductivity), Salinity, both across the landscape and within the soil profile, pH, Soil fertility aspects
Irrigation System. Good design, zoning, and hardware will compensate for landscape and soil variability; but when the system is not designed properly it becomes another source of variability—i.e. it adds to site variability, especially in soil moisture variability.

The BMPs approach for turfgrass water conservation requires detailed **microclimate or micro-site** information. In this document, we will use the term microclimate to denote atmospheric, soil, and plant variability in the particular micro-site. A "microclimate" relative to water conservation is a portion of the landscape area that has relatively uniform climatic, soil, and plant water use conditions. Another term for such a micro-site is an **irrigation zone** where the irrigation heads (or head) are controlled by one irrigation valve. The term **hydrozone** is also used, especially in xeriscape literature. As BMPs for water conservation become more refined and new technology and concepts evolve, more detailed site assessment to better define micro-sites will be necessary, because:

- Careful identification of micro-sites is a very important means of dealing with site variability.
- Once a micro-site is determined, irrigation system design can be focused on applying water uniformly to that site.
- Sensor technology can then be used more effectively to monitor turfgrass or plant water-use within the micro-site for the purposes of irrigation scheduling---including when to irrigate and how much water to apply.
- Sensor use (climatic, soil sensing technology) that can accurately determine ET within a micro-site can also be used to determine similar micro-sites irrigation needs---if the micro-sites have been carefully identified and classified as to similarity in water use. This can allow certain micro-sites to be used as indicator zones for the water use patterns of other micro-sites of similar nature.
- The whole BMP approach to water management is based on accurate site assessment to carefully define the boundaries of micro-sites; for without precise site delineation, there cannot be precise irrigation.

III. INITIAL PLANNING AND INFORMATION GATHERING STEPS.

To assist in starting the initial information gathering process, the following are suggested steps for developing a BMPs water conservation plan.

A. Identify Water Conservation Measures That Have Already Been Implemented.

planning and operational document (see Chapter 10 for additional discussion of the need to use “educational” information in a BMP document). Then, when additional conservation measures result in greater water savings, it is in the context of existing practices. Courses using advanced water conservation measures may actually be the ones that achieve the least “additional” water savings, because they already are excellent stewards of water resources.

B. Irrigation Audit: First Phase (The Irr. Assoc. 2003b).

A **traditional irrigation audit** starts with inspection of the site plans and system tune-up. Professional irrigation auditor can be contracted to obtain the necessary information for phases one and two. In this initial phase, the main procedure is:

- Obtain any available site plans/maps of the irrigation system layout and location of specific components: heads, lines, valves, water lines, wiring, controllers, pumps, backflow prevention devices, water meters, water connections, shut off valves, drain valves, etc.). It is not unusual that plans may need to be updated and system features accurately located and mapped.

- Inspect the system and the system operation. Water information at this stage may include: pressure tests, sources, and flow data. The auditor would also document the current programming schedule and main/satellite controller features or capabilities such as: number of programs, ability to repeat cycles, number of zones per controller, syringe cycle ability, interfacing with any sensors to affect scheduling, During inspection of the irrigation system components, the The Irrigation Association (2003b) would recommend evaluating for:

1. Valve performance
2. Sprinklers that are tilted, sunken, broken, missing, clogged, misaligned, or with spray deflected by objects.
3. Rotation speed.
4. Plugged nozzles.
5. Drainage from low sprinkler locations.
6. Leaks.
7. Areas with slow water drainage or ponding, dry areas, compaction/thatch/runoff.

- Case where problems can be fixed: Correct any problems listed above to achieve proper system operating conditions. The field-testing phase will not be accurate if the system is not properly functioning.

- Case where the irrigation system cannot be brought up to acceptable standards: Sometimes major problems with the irrigation system are evident at this stage and may indicate investigation of major renovations or replacement. In this instance, there is no need to assess current equipment performance, but to plan for a system with the performance needed to achieve the water conservation goals desired. Examples, of such major problems are:
  1. Improper design such as sprinkler spacing or zoning or scheduling capability.
  2. Inadequate piping, pressure, or flow rate for system operation.
  3. Outdated equipment or worn out equipment.

C. **Irrigation Audit: Second Phase.** (The Irr. Assoc. 2003).

Assuming that the irrigation system does not have major problems and the minor ones are corrected, the second phase of an irrigation audit can be conducted. In this phase the emphasis is upon documenting system performance. Appropriate zones should be selected that will be representative of the whole course. There may be a combination of zones selected that represent different soil/climatic site conditions; locations such as fairways, tees, greens, and roughs; problem sites where there is a history of irrigation problems related to system inadequacies; and zones that are considered the best on a course.

During the test periods, it is critical that system pressure and wind conditions be suitable and recorded. However, the test should also represent conditions similar to normal irrigation conditions. Typical information obtained from each test zone is:

- System pressure
- Wind speed and direction.
- Sprinkler rotation speed.
- Type of sprinklers and nozzles---are nozzles worn or not matched for precipitation rate.
- Head spacing between heads and between rows of test areas must be determined in order to calculate precipitation rate of each zone; and to determine proper design.

- Catch can data to determine water application rate and uniformity over the zone---if more than one zone covers a test area, then both zones must be operated. Note the location and spacing of the catch can grid.
- Controller information such as type, run time or multiple run times.
- Determine additional site conditions such as: soil type, grass type, rooting depth, any microclimate influences.

After test data are gathered, the results are used to calculate several factors important for efficient irrigation operation. These are:

- **Distribution uniformity (DU**) a measure of how uniformly water is applied over an area, where a DU of 1.0 is 100% uniformity. Normally, the DU is based on the average of all samples and the average of the lowest 25% of readings; and in this case would be termed $DU_{LQ.}$ An irrigation system with DU > 0.80 is good. The DU can be used to determine **irrigation water requirement** for a zone, where irrigation water requirement = plant water requirement / DU.

- **Gross Precipitation Rate (PR_{gross})** is based on flow from the sprinkler and sprinkler spacing to obtain an average sprinkler precipitation rate over the area in inches/hour. It does not take into account any water loss that occurs between the sprinkler nozzle and the turfgrass.

- **Net Precipitation Rate (PR_{net})** is a measure of the amount of water that actually reaches the turfgrass at a particular location. This is determined from the catch can data.

- **Scheduling Coefficient (SC)** measures uniformity in an area by comparing the lowest precipitation rate in a defined area to average precipitation rate over the entire test area. The lowest precipitation rate may be based on the driest 1, 2, 5, or 10% of the defined area. The SC indicates the quantity of additional water that must be applied to adequately irrigate the driest area that was defined.

- **Coefficient of Uniformity (CU)** is another measure of irrigation uniformity based on comparing average catch can precipitation to the average deviation from the catchment's mean. While used in agriculture, it is less useful in turfgrass situations.

- When the irrigation water requirement is determined by using the DU, the run times in minutes for the controller can be used to establish an irrigation schedule.

- A very important additional piece of information that can be generated from the irrigation audit data on a zone is a **densogram** that visually shows the wettest and driest areas within the area. This is very valuable for making corrective measures such as changing nozzles to obtain greater uniformity. The Center for Irrigation Technology (2003) has a software program, SPACE Pro™ that creates the densograms.

D. Additional Site Information.

Additional site information may be required for many clubs. Potential situations requiring additional information are:

- **Alternative irrigation water sources**. Determination of alternative irrigation water sources may be a part of the overall BMP program for water conservation---i.e. one of the first strategies to reduce potable water use is to switching to non-potable sources. Thus, water quantity/conservation plans often result in water quality issues. In some situations, specialists may be necessary such as to determine water available from an aquifer or potential for development of a water treatment facility to provide water.

- **Irrigation Water Quality Tests.**   When a potential source of irrigation water is of poor quality, especially with high total soluble salts and/or sodium, decisions well be required concerning:
    1. Water treatment,
    2. Soil amendment treatment,
    3. Subsurface drainage to remove leached salts,
    4. Assessment of the hydrological conditions on a site to insure that leached salts do not contaminate existing ground water,
    5. Identification of potential lake management issues related to water quality.

- **Golf Course Design Modifications.** If a course is considering design modifications for the purpose of reducing highly irrigated, close mowed turfgrass area, design plans should be developed by a golf course architect before considering irrigation system design changes. Also, course design changes will greatly alter the irrigation system and require a detailed ***Irrigation Alteration Design Plan.***

- **Soil Conditions (Table 2.1).** More detailed assessment of soil conditions to allow enhanced or more precise irrigation design, zoning, and scheduling, as well as potential placement of soil sensors to aid in irrigation scheduling. Slope aspects may need to be determined in a more systematic manner as well as various soil physical and chemical conditions that could influence water relationships. One type of soil condition on salt-affected sites will be soil salt variability over the landscape and within the soil profile. When salts are to be a continuing problem, intensive site assessments of soil, water, drainage, and salt sources are required. Carrow and Duncan (1998) provide an in-depth discussion of this aspect.

- **Aboveground Climatic Conditions (Table 2.1).** In order for weather station ETo or reference crop ET (an older concept was ETp or potential ET), to be adjusted for more site-specific conditions, characterization of microclimate areas are necessary. One use of more specific soil and atmospheric site assessment, as noted, is to develop a better irrigation design and operation. But, another use would be to determine soil moisture sensor placement and any additional atmospheric sensor placement. For example, it is not inconceivable that mini-weather stations be on selected microclimate sites to improve ETo adjustments to obtain actual turf ET (actual crop ET, or ETc).

With more intensive site assessment as an important component of developing water conservation plans, golf courses should consider obtaining site-specific data in GPS (Global Positioning System) formats where site features or characteristics can be clearly identified as to location. Then the data can be presented in GIS (Geographic Information Systems) maps that can be overlaid. Such maps are very useful for investigating relationships within a site area.

IV. ***DETERMINE FUTURE WATER NEEDS and IDENTIFY YOUR OVERALL WATER CONSERVATION GOAL.***

A. Determine Current Water-Use Profiles.

A **comprehensive water-use profile** will consist of several types of information, namely:

- Determination of total current water use is of first importance, including seasonal use and water use during drought stress periods. This information becomes the primary benchmark for future changes from water conservation measures.
- Water use by type of turfgrass area, such as fairways, tees, roughs, greens, and any other site facility is also very necessary, since water conservation measures may vary with each type of area.
- Current water source information. When multiple irrigation sources are used, it is important to determine how much of the total water comes from each source throughout the year. The reliability or stability of each water source should be determined.
- If not available, an irrigation water quality test should be conducted of each water source and if time allows to determine seasonal changes in water quality.

Water use data is often determined from water meter records for the total water use. Records of irrigation system operating time per area coupled with application rates can be used to estimate water use for greens, tees, and other areas. The same means that irrigation system designers use to estimate water system needs (average precipitation per month, typical turfgrass water needs, accounting for the maximum water use during dry periods, etc.) can also provide an interesting comparison of projected water needs (i.e., initial projections when the irrigation system was designed or modified) relative to actual water use.

B. Determine Future Water Needs.

As part of the information gathering process, current water-use is established as well as water use by specific golf course areas---fairways, tees, greens, roughs, and general grounds. The next step is to **determine future water needs**. How goals are established and how a club may approach establishing a water conservation program depends very much on specific conditions. Some examples, illustrate possible situations:

- First, would be the situation where the total quantity of irrigation water available is known and limited. Thus, the water conservation goal is set and the club must target toward reducing water to this level. In this case, rigorous conservation measures may need to be planned, such as a new irrigation system with improved efficiency and/or major design alterations on the golf course to reduce the closely mowed, irrigated turf area. When this scenario occurs and the golf course superintendent develops a holistic plan to reduce water to the available level, it is important that course board members or club member do not take the attitude of selectively removing a measure because they do not like it---unless they can develop an alternative to the measure that will conserve the same quantity of water. A holistic plan to reduce water to a target level often consists of multiple measures, all of which add together to achieve the total water savings required. Removing components without suitable alternatives will make the whole plan ineffective.

- Second, is the case where a club switches to an alternative water source, such as effluent, and has ample water to meet their needs. In this case, the club would need to decide whether to initiate various water conservation strategies with the assumption that they may be necessary in the future if their water needs become more limited.

- Third, a course that switches to an alternative irrigation source that contains appreciable salts would want to insure enough irrigation water can be applied to leach salts. However, they should also invest in any measures to insure maximum uniformity and flexibility in application. Non-uniformity of water would not only enhance drought problems but also salt accumulation on less irrigated sites due to less leaching.

- A final example may be a course that has ample water of good quality and no current regulatory pressure to impose additional water conservation measures. Here, the motivation to assess and select conservation options may be to demonstrate a history of environmental stewardship or to make sure that options are available if water becomes more limited.

Planning toward a **water conservation goal** at this stage in the process of developing a "BMPs for Golf Course Water Conservation Program" is an initial target that will often be altered as more specific water conservation measures are identified, evaluated (in light of the information already gathered), and options are selected. Then, a more specific conservation goal will arise. The exception would be as noted above where a course has been reduced to a specific water allocation and that is their water conservation goal.

Chapter 3.

Alternative Irrigation Water Sources

I. Alternative Water Sources.

II. Considerations For Different Water Sources.

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- A. General characteristics.
- B. Nutrient aspects.
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Chapter 3.

Alternative Irrigation Water Sources

I. ***ALTERNATIVE WATER SOURCES.***

Use of alternative irrigation water sources, rather than potable water supplied by a municipal water treatment system, is not a new practice to many golf courses and other large turf areas. However, this is now becoming the normal practice in many areas as competition for potable water increases (Snow 1994: Thomas et al. 1997; Huck et al. 2000; Carrow and Duncan, 2000b). Alternative sources of irrigation water include:

- Larger streams, rivers, and flowing watercourses,
- Surface water in natural or constructed lakes, ponds or impoundments fed by streams, springs, or diversion channels from flowing water sources,
- Irrigation or drainage canals,
- High flow (flood) water diversion into storage ponds (type of water harvesting),
- Ponds fed by surface runoff from surrounding terrain during normal rainfall events (type of water harvesting),
- Storm runoff from impervious surfaces captured in retention ponds (type of water harvesting),
- Ground water from deep or shallow wells,
- Ground water from aquifers not suitable for potable purposes due to high salinity, but can be used on salt tolerant grasses,
- Tertiary effluent from a sewage treatment plant—treated to allow for use on a golf course---**waster reuse, wastewater, reclaimed water**,
- **Recycled water**. Examples are: a) water collected from the drainage and/or stormwater lines of a golf course plus associated housing development, treated by a private treatment facility for irrigation quality, and then used for irrigation; or b) wastewater from a golf course plus associated housing development applied to a forested spray field, then wells are used to recover the water for irrigation. In this instance the soil as a filter is the "water treatment".
- Seawater or seawater blends on salt-tolerant (halophytic) grasses (Carrow and Duncan 2000b; Duncan et al. 2000a).
- Desalination technologies to remove excess salts from seawater or other highly saline waters.

Often more than one irrigation water source is available and each alternative should be explored. The availability of more than one water source can help buffer against possible shortages during drought periods, for example, constructed storage ponds could lessen the impact on existing water sources (such as streams or wells) during peak irrigation.

Several water sources are examples of **water harvesting.** Water harvesting in larger landscapes is usually thought of as treating or modifying watersheds to enhance runoff that is collected for future use (FAO 1994; Thomas et al. 1997; Todd and Vittori 1997). The environmentally friendly term water harvesting is not often used in relation to golf courses, yet it is a common practice. Many golf course irrigation lakes also serve as landscaping features and catch excess runoff, preventing the loss of substantial amounts of water from the site and retaining sediment that would otherwise be carried into streams or rivers. Catchment features are often part of an overall storm water control program mandated by governmental policies to control flooding. A recent survey of Georgia golf courses indicated that as much as 67 percent of irrigation water came from such non-potable, surface sources (Florkowski and Landry 2002). In the case of golf courses, the landscape is purposely contoured to collect the excess runoff from rainfall, while allowing good infiltration of water into the soil under normal conditions.

Planned stormwater or drainage water collection from a large landscape site, especially if it includes any associated housing develop, can result in substantial water for **recycling** back into landscape irrigation or other uses not requiring a potable water quality (Faulkner 2000). Also, collection of sewage water from such sites, treatment to irrigation water quality standards in a water treatment facility designed just for the water from the particular site, and then using the water for irrigation back onto the site is an example of water recycling.

A very significant irrigation water source for golf courses in **effluent**, also termed **wastewater** or **reuse water** (Snow 1994; Huck et al. 2000; Mortram 2003). It is estimated that over a 1000 golf courses in the USA currently use tertiary treated effluent (Snow 2003). Normally, effluent water is arises from treatment in a water treatment facility to the standards required for irrigation use on sites with human access. Dedicated transfer lines are used to separate effluent from potable water.

Desalinization is another potential water source in some cases (Agric., Fisheries and Forestry-Australia 2002). The original water source may be seawater or other highly saline waters. One significant issue with reverse osmosis (RO) or other forms of desalinization is disposal of the concentrated brine (Andrews and Witt 1993).

In communications with regulatory agencies, environmental groups, and the local community, golf course would be wise to continually point out any use of alternative water sources. The use of environmental terms, such as the ones used above, and explaining those terms would be beneficial public relations relative to the overall topics of environmental stewardship and water conservation.

II. ***CONSIDERATIONS FOR DIFFERENT WATER SOURCES*.**

A. General Considerations.

A feasibility study that analyzes water supply sources usually requires a qualified professional consultant to evaluate all potential sources with respect to supply adequacy, economic viability, engineering considerations, and environmental impacts. Some general considerations that may apply to one or more of the sources are listed below. If a consultant is contracted, the specific responsibilities and scope of their responsibility relative to the following issues should be determined:

- Location of the source.
- Development needs, costs, and potential problems relative to a water supply,

- Design and installation costs for wells, ponds, well-field layout, pumping, distribution lines, and other facilities.
- Pond/lake location, construction, and inflow/outflow features.
- Pond/lake seepage control measures.
- On ponds or lakes where water withdrawal may exceed water recharge, especially in the summer, the influence of a drop in water level may have on fish, aquatic plants, and growth of undesirable plants along the exposed shore. When these water features are a part of a housing development, these issues are of concern to these individuals.
- Determination of water rights, competition for a source, permitting, regulatory negotiations,
- Regulatory issues related to maintenance of in-stream flow for aquatic organisms, habitat, dilution needs, or the needs of other users,
- Regulatory issues concerning permitting for use of the water source that is under consideration,
- Investigation of any incentive programs for the use of a particular water source,
- Determination of any regulations requiring use of effluent water,
- Determination of how effluent water will be transported and stored on a site.
- Watershed analyses may be necessary to estimate the potential runoff capture in order to design and locate storage ponds. These analyses should be conducted along with a site assessment for drainage features and any storm water runoff features required on a site.
- Sheet flow of water into ponds can be enhanced by use of uniform turf areas and grass waterways from fairways and rough and non-use areas.
- When considering surface water collection into ponds, appropriate buffer zones should be used to avoid water quality protection.
- Well yield and drawn-down determinations.
- Stream flow during dry periods versus irrigation demand,
- Reliability and water volume both in the long-term and over the seasons of a year for all water sources. Included should be the anticipated effects of any water use restrictions that may apply to a water source during drought periods.
- Investigate any pricing regulations or water price structures.
- Investigate any water rebates or other incentive plans for using water conservation practices or devices.
- Characterization of the underlying aquifer, which is the process of quantifying the physical and chemical features of an aquifer that may influence ground water or the potential for contaminant from an alternative irrigation water source. With more saline irrigation water that requires a leaching program, the potential for contamination of the existing aquifer must be determined. If this potential exists, very careful contouring and sub-surface drainage with an appropriate outlet is necessary (Huck et al. 2000; Carrow and Duncan 1998).
- A complete water quality test for any natural constituents in the water as well as any contaminants. Any permanent grasses must be able to tolerate the salt levels in the water; as well as any overseeding grasses.
- Potential to use an aquifer that is not used for potable purposes, but may
- Potential for interaction of water removal from a source on wetlands, streams, sink-hole problems, etc.
- Energy costs to move water. This should be for well pumps and for transfer pumping costs ---whether in pipelines or to pump from one pond to another.

- When more than one water source is used, consideration should be given the potential loss of one or more of the sources due to drought, increased costs of maintenance, regulatory, or other reasons; and to the ramifications of losing a source.
- Costs associated with treatment of water prior to irrigation use. In recycling of storm/drainage waters for irrigation, treatment may encompass a typical water treatment facility. For use of desalinized water, the RO or other treatment facility would be a significant cost. The most common water treatment is for irrigation water containing high sodium in conjunction with high bicarbonates that interfere with use of calcium amendments to prevent formation of a sodic soil (Carrow et al.1999).

Each type of water source has possible costs and problems associated with the source. Some of the irrigation water sources are of good quality, but other sources may present challenges, especially in terms of salt or nutrient loads. As recreational areas shift to poorer water quality, more salt-induced and nutritional problems are anticipated (Carrow et al. 2000; Carrow and Duncan, 2000b; Duncan et al. 2000a; Duncan and Carrow 2001). Thus, turfgrasses used on these sites must not only be drought resistant, but must also have a high degree of salt resistance (Carrow and Duncan, 1998).

The primary management requirement on salt-affected sites is to leach excess salts by addition of extra irrigation water beyond the normal irrigation rate (Carrow et al. 2000); therefore, a shift to poorer water quality will reduce the need for use of better water, but increase the total water requirement. An essential component for successful implementation of this strategy is proper site construction encompassing sandy profiles with percolation rates that will "keep the salts moving down" below the root system. Monitoring of soil moisture and salt levels at multiple depths will become more commonplace by use of mobile and/or installed moisture and salt sensors. The necessity of using grasses with higher salt tolerance will alter management not only because a different grass is, but also because excess salts (and other salt-induced problems) must be managed. Butler et al. (1985) and Carrow and Duncan (1998) noted that use of highly saline irrigation water can increase costs due to water treatment, drainage requirements, soil amendments, cultivation costs, soil/water monitoring, and difficulties in balancing fertility programs.

III. ***WASTE WATER CONSIDERATIONS*****.**

Since wastewater or effluent water use is becoming one of the primary alternative water sources on golf courses, a closer view of issues related to this source will be taken with the material in this section adapted from an article by Carrow and Duncan (2003). For turfgrass managers who are not familiar with this practice, initial thoughts may be about the **health or public safety issues**. While specific criteria differ somewhat with the regulatory government agency, basically the water treatment facility (wastewater provider) is responsible for meeting safety levels for: a) health factors such as BOD/COD, turbidity, total or fecal coliform bacteria, stable or refractory organics; and b) **environmental concerns** such as P content and sometimes N. The turfgrass facility is responsible for **regulatory concerns** relating to wastewater storage and distribution on their site (Huck et al. 2000).

The focus of this section is to provide an overview of **turfgrass management concerns** related to wastewater use, since these are the issues that a turfgrass manager must understand for optimum turf culture. Generally the first thoughts related to the use of wastewater concerns chemical/biological/physical constituents in the water. However, there are three factors that are very important which should be of **primary considerations**, namely:

- First, contract stipulations with the wastewater provider should not require wastewater to be accepted by a turf facility when irrigation is not required. Application of irrigation to a turf site when the grass does not require irrigation will result in extra runoff into water features, leaching of water and soil chemicals, excessively moist soils, and a host of turf maintenance problems from over-irrigation (i.e., **environmentally unsound practices**). One obvious period when grasses required little if any irrigation are during winter dormancy. Also, storage capacity to store water that must be accepted can become very large during prolonged wet weather and overflow of water from storage features is often considered an environmental spill. Or, the golf course must have a large spray field that may require considerable costs. Thus, the turf facility should not accept un-needed wastewater; nor the unsound environmental practices/consequences that will come with over-application of wastewater. The Waste treatment facilities can dispose of excess capacity if required.

- The second issue is---who pays the direct and indirect costs associated with acquiring and using wastewater. It is not unusual for governmental agencies in the midst of a water shortage to initially decree that golf courses use wastewater, use all the water they send (i.e., as addressed in the previous section), pay for the costs of supply lines, and then pay more for the water than potable sources. The turf industry must be proactive in addressing these issues with the following realities: a) the golf course industry is like any other industry and desires to take its part in governmental policies that require all water users to implement water conservation measures, but policies must be fair and not target industries, b) golf courses offer an environmentally friendly place to help dispose of wastewater in a manner that reduces municipal waste treatment costs and conserves potable water, c) when government mandates use of water it must also provide assistance in bearing the burden for increased costs and cannot unilaterally transfer costs to a user, and d) the golf course industry can be a very important part of a community/regional water conservation plan but it must be considered as a component and not a group to target---when this does happen the costly lawsuits that follow are most often not favorable to the governmental agencies, especially when there are very good models of more responsible government policy approaches to these issues.

- Third, some golf course may chose to not use wastewater (or some other alternative water source) in place of their current water source. The initial concerns may be: a) management of the turfgrass can be more challenging, especially with high salinity, sodium, and/or nutrient loads; b) costs associated with using the alternative source, c) necessity to change to a more salt tolerant grass when the water is too saline for the current grass, d) concern about learning to manage a new grass; e) the belief that they can get effluent when they need it; and/or f) the feeling that their current water source is adequate in terms of quantity and reliability over the future. This latter reason for not going to another water source, that would be considered as a water conservation measure, must be more than a feeling but should be supported by fact and, if necessary contracts. The authors have seen golf courses in the Southeast pass up the opportunity to use effluent water that would be have long-term reliability in terms of quantity for one or more of the above reasons. Two points that should be considered when making such a decision. First, currently, many regulatory agencies are receptive to use of effluent on turfgrass sites. But as time goes by, other water users that can use the same effluent, such as many industries, may become more aggressive competitors with the turf industry. Second, use of alternative irrigation water sources to conserve current water sources that the public and regulatory agencies determine should be protected as to withdrawal (not just potable water, but ground water depletion or limits on withdrawal from a stream, as examples), becomes a major water conservation strategy. If this is by-passed and in the future the golf course is mandated to implement water conservation practices to achieve a stringent goal, only the other options are available. The next most important options would be course redesign to eliminate many highly irrigated sites and a highly efficient irrigation system, which may or may not be present on the course. Irrigation scheduling is not very effective as a conservation measure when the system is not efficient and flexible (see Chapters 5 and 6). The point is that elimination of a very good water conservation strategy, such as a reliable source of effluent water, may result in great difficulty in achieving any future mandates or may require great costs associated with the irrigation system and/or course redesign. If the course is redesign, major changes in the irrigation system design are also necessary. The bottom line is "make sure that missed opportunities do not come back to haunt you". Life does not always give second chances.

Turfgrass irrigation water quality guidelines for chemical constituents in the water are similar to those used for other crops with some refinement (Carrow and Duncan 1998; Duncan et al. 2000). A good irrigation water quality test determines constituents in the water and should include information on: a) general water characteristics, b) nutrient/element content of water, and c) salt-related assessment information.

A. General Characteristics.

Water pH. This only a concern is if the pH is unusually alkaline or acidic.

Bicarbonate and Carbonate Content. These ions react with Ca and Mg ions in the water to form lime in the soil or in some unusually situations in irrigation lines. The lime is not harmful and many turfgrasses are grown on calcareous soils. In a humid climate, lime additions to the soil are often needed. However, when irrigation water has appreciably Na ions that may create sodic soil conditions (soil structure deteriorates), alleviation requires relatively high levels of moderately slow-release Ca, such as from gypsum, $CaSO_4$. If bicarbonates and carbonates are present in high quantities, the result is lime formation where the Ca in lime is very slow-release in comparison to gypsum; and these ions in the soil can also cause soluble Ca released from gypsum to be tied up in the lime form. The net result is insufficient soluble and moderately slow-release forms of Ca to displace Na from the soil cation exchange sites (CEC) and Na carbonate precipitates. It is in these situations where acidification of irrigation water is recommended to dispel the bicarbonates and carbonates as CO_2 gas from the water.

B. Nutrient Aspects.

Wastewaters generally contain more nutrients than potable water, and some contain appreciable nutrients. Guidelines for nutrient content are in Table 3.1. Additionally, some wastewater sources require acidification treatment and/or large quantities of soil amendments to be added (such as when a wastewater may induce a sodic soil condition and large additions of Ca are needed). The nutrient additions, whether directly from the water or as a result of water/soil treatments due to the water characteristics, must be considered as part of the on-going fertilization plan to maintain a balanced fertilization program. Additionally, N and P content can dramatically influence algae and aquatic weeds in and storage water features, while S may contribute to black layer.

Nitrogen Content. Often the wastewater treatment plant may be required to maintain total N under a specific level, especially if the wastewater will be going into any surface water---- a turfgrass facility may use some of the wastewater from a treatment plant and the remainder may flow into a river. The regulatory level is often based on limiting algae and aquatic plant growth. Turfgrass managers should understand how much total N is being added per unit of water (10 ppm or mg/L of N = 0.60 lb N per 1000 sq. ft. per ever 12 inches of water applied. Some wastewater sources contain appreciable N and the turf managers should decrease their N fertilization accordingly to avoid over-application of N.

Phosphorus Content. Regulatory P levels for waters discharged from treatment facilities are normally very low since P in water is the most important nutrient controlling algae and aquatic plant growth. As a result, wastewater P contributes only small amount of P to the P fertilization needs of the turfgrass, but if P levels exceed 0.10-0.40 ppm or mg/L of P algae and aquatic plant control will be a challenge.

Ca, Mg, K, Mn, Fe, Cu, Zn, Mo, Ni Levels. It is important to consider the contributions of each of these nutrients to the overall fertilization needs of the grass and make adjustments as needed. The most common problem is for a particular nutrient to be very high in the water, which may induce nutrient imbalances in the soil and eventually the turf plant. For example, a wastewater very high in Ca but low in Mg can result in a potential Mg deficiency over time. Sometimes the nature of the irrigation water requires certain amendments to be added to the soil in large quantities, such as when high Na in the water may require high Ca additions to the soil. In these situations, nutrient imbalances can also be induced.

SO_4^{-2} Content. Sulfur, usually as SO_4, is a nutrient that is often high in many wastewaters sources or becomes high as a result of acid treatment when water acidification is necessary. Turfgrass plants only require about 2.0 lb S per 1000 sq. ft. per year as a nutrient. If high SO_4 levels occur in the soil due to high SO_4 in the wastewater, the soluble SO4 can rapidly revert to reduced S forms when anaerobic conditions occur in the soil---regardless of the source of the anaerobic conditions, such as excess rain, perched water table from a layer in the soil, soil compaction, excess organic matter accumulation, sodic conditions, etc. Reduced S results in formation of FeS and MnS precipitates that cause the black coloration in black layer (Carrow et al. 2001a). These precipitates cause more anaerobic conditions. The SO_4 in wastewater can react with Ca in the water to form gypsum ($CaSO_4$), which is much less prone to becoming reduced. If the Ca is not sufficient to "scrub" the excess SO_4 from the water, light applications of lime can be added to the soil surface, where the SO_4 will react with the lime to form gypsum over time (it requires 1 lb of lime per 1 lb of excess SO_4 added). A high level for SO_4 would be > 90 mg/L SO_4 = 1.87 lb elemental S per 1000 sq. ft. for every 12 inches of water added.

Trace Elements. Sometimes trace elements are unusually high in a wastewater source. Thus, an initial analysis of a potential wastewater source may include testing for any expected trace elements. The guidelines for these are based on long-term use of the water assuming that the particular element may accumulate (Carrow and Duncan 1998).

C. Salt-Related Assessments.

In many locations, wastewater does not contain sufficient quantities of the major salt ions to cause salt-related problems. When salt ions are low, the primary problems for wastewater sources would be the nutrient/element content discussed in the previous section. However, when salt ions are high, salt-related problems can be very important and will require appropriate management regimes including---grass selection, possible chemical amendment of water and/or soil, leaching, drainage systems, cultivation programs, alterations in fertilization regimes, and other aspects. (Carrow and Duncan 1998; Hansen et al. 1999).

Total Salinity. **Electrical Conductivity (ECw)** is a measure of total soluble salts in the irrigation water, which could cause salt accumulation in the soil and lead to salt-induced drought or specific ion toxicities. Since high soluble salt levels inhibit plant water uptake, the plant is exposed to a salt-induced drought stress, which causes more injury to turfgrasses than all the other salt-induced plant problems combined. Total soluble salts in irrigation water may also be reported as Total Soluble Salts (TSS) or Total Dissolved Salts (TDS), where ECw in units of dS/m X 640 = TSS or TDS in mg/L or ppm.

Sodium Permeability Hazard. If the wastewater has high Na content, it can create a sodic soil condition. Sodium causes deterioration of soil structure by destroying natural aggregation and dispersing clay/organic colloids that can plug soil pores. Also, sodium bicarbonate precipitates can form and cause plugging of soil pores. The net result is a reduction of macropores (> 0.10 mm diameter pores) for water permeability (infiltration, percolation, drainage), reduced gas/oxygen exchange, and fewer root channels. No single water parameter can by itself determine sodium permeability hazard, but several parameters are used:

- **SARw** = Sodium Adsorption Ratio, where Na, Ca, and Mg contents in the water are used to calculate SARw. SARw is used when Na, HCO_3, and CO_3 are < 100, 120, 15 mg/L, respectively.
- **AdjSARw by pHc adjustment.** Uses Na, Ca, Mg, HCO_3, and CO3 to adjust the original SARw.
- **AdjSARw by Ca_x adjustment (sometimes noted as adjRNa).** Also, uses Na, Ca, Mg, HCO_3, and CO_3 to adjust the original SARw.
- **RSC** (Residual Sodium Carbonate), which uses in the RSC calculation Ca, Mg, HCO_3, and CO_3 contents.

The adjSARw by the Ca_x method is considered more accurate than the adjSARw by the pHc method, and generally adjSARw by Ca_x = 0.5 adjSARw by pHc. Any of the SARw values can be used in published tables that contain information on SARw. The RSC is important because it determines whether HCO_3 and CO_3 levels are high enough to precipitate all or most of the Ca and Mg as lime, thereby, leaving the Na to adversely affect soil structure without soluble Ca to alleviate the problem. In addition to SARw, adjSARw, and RSC values, the following factors are used in determining the severity of sodium permeability hazard:

- Individual water concentrations of Ca, Mg, Na, HCO_3, and CO_3. For example, it is possible to have a high SARw in irrigation water with very low Ca and Mg content and

only modest Na; or a high HCO_3 concentration and high RSC would not be a problem if the water does not contain Na.
- ECw level influences the susceptibility of a soil to structure deterioration from a high SARw, where high ECw allows a soil to withstand higher Na without structure loss.
- Clay type. Some clays, such as kaolinitic clays, that are not shrink/swell types and do not crack upon drying, are much less prone to Na permeability hazard than shrink/swell clays.

D. Specific Ion Toxicities.

Specific ion toxicities are of several types and require guidelines to assess the potential for each type of problems, namely:
- Ions that may accumulate in the soil and cause <u>direct root toxicities</u>---Na, Cl, B. Plants that have high total salinity tolerance normally have high tolerance to at least Na and Cl.
- Ions (Na, Cl, B) that are taken up by plants and <u>accumulate in the foliage</u> to cause a reduction in physiological activity, color, and enhance tissue leaf firing or desiccation. Since turfgrasses are regularly mowed, foliage accumulation of these ions is much less of a problem for turf than for trees or shrubs.
- <u>Direct contact injury to the foliage</u> from the irrigation water, where Na, and Cl are of greatest interest. Trees and shrubs are more sensitive than most grasses.

E. Other Considerations.

Turf managers should consider other factors beyond the constituents in the wastewater, namely:
- If the turf facility has concerns about maximum levels of particular constituents in the wastewater, such as P levels, they should stipulate the maximum allowable levels.
- Since wastewater treatment plants must measure certain parameters on a regular basis, it may be possible to make contractual agreements that result in the treatment facility providing all or most of the irrigation water quality data to the turf facility on a long term basis.
- Total Suspended Solids refers to any suspended materials in the water that may contribute to plugging of the irrigation system or add excessive fines to recreational turf areas. While Total Suspended Solids are of concern for many non-potable irrigation water sources, it is generally not a concern for treated wastewater since effective treatment for fecal coliform bacteria (indicator organisms for more harmful microorganisms) requires low levels of suspended solids and is monitored by turbidity measurements at the treatment complex.
- The article on effluent water by Huck et al. (2000) is suggested for those seeking a detailed discussion of the various costs associated with use of wastewater.

Wastewater characteristics can vary greatly depending on the particular source. However, most wastewaters, treated for application to public sites, are good sources of water for turfgrass irrigation. Obtaining a good water quality test is essential for determining any potential problems or adjustments to management practices that may be needed. Whether the water quality changes over time should also be determined by appropriate testing. If water quality remains rather consistent, annual testing may suffice.

Table 3.1. Guidelines for nutrients contained in irrigation water and quantities that may be applied per foot of irrigation water.

Nutrient or Element	Nutrient Content in Water in mg L^{-1} (or ppm): Low	Normal	High	Very High	Conversion to lbs per 1000 ft^2 of nutrient added for every 12" of irrigation water applied
N	<1.1	1.1-11.3	11.3-22.6	>22.6	11.3 ppm N = 0.71 lb N per 1000 ft^2
NO_3^-	<5	5-50	50-100	>100	50 ppm NO_3^- = 0.71 lb N per 1000 ft^2
P	<0.1	0.1-0.4	0.4-0.8	>0.8	0.4 ppm P = 0.057 lb P_2O_5 per 1000 ft^2
PO_4^-	<0.30	0.30-1.21	1.21-2.42	>2.42	1.21 ppm PO_4^- = 0.057 lb P_2O_5 per 1000 ft^2
P_2O_5	<0.23	0.23-0.92	0.92-1.83	>1.83	0.92 ppm P_2O_5 = 0.057 lb P_2O_5 per 1000 ft^2
K^+	<5	5-20	20-30	>30	20 ppm K = 1.5 lb K_2O per 1000 ft^2
K_2O	<6	6-24	24-36	>36	24 ppm K_2O = 1.5 lb K_2O per 1000 ft^2
Ca^{+2}	<20	20-60	60-80	>80	60 ppm Ca = 3.75 lb Ca per 1000 ft^2
Mg^{+2}	<10	10-25	25-35	>35	25 ppm Mg = 1.56 lb Mg per 1000 ft^2
S	<10	10-30	30-60	>60	30 ppm S = 1.87 lb S per 1000 ft^2
SO_4^{-2}	<30	30-90	90-180	>180	90 ppm SO_4^- = 1.87 lb S per 1000 ft^2
Mn	—	—	>0.2[a]	—	
Fe	—	—	>5.0a	—	
Cu	—	—	>0.2[a]	—	
Zn	—	—	>2.0[a]	—	
Mo	—	—	>0.01[a]	—	
Ni	—	—	>0.2[a]	—	

[a] These values are based on potential toxicity problems that may arise over long-term use of the irrigation water, especially for sensitive plants in the landscape - turfgrasses can often tolerate higher levels. For fertilization, higher rates than these can be applied as foliar treatment without problems.

[b] Based on Westcot and Ayers (1985) and Harvandi (1994).

Chapter 4.

Irrigation System: Design, Installation, and Maintenance

I. **Introduction**

A. **Improving technology and concepts.**
B. **Irrigation systems BMPs**
C. **Importance of irrigation system BMPs.**

II. **Assure Overall Quality of The Irrigation System.**

III. **Design The Irrigation System For Efficient and Uniform Distribution of Water.**

A. **Sprinklers, design, zoning.**
B. **Water saving devices.**
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VI. **Maintenance of The Irrigation System For Optimum Performance.**

V. **Subsurface Irrigation and Surface Drip Systems.**

Chapter 4.

Irrigation System: Design, Installation, and Maintenance

I. <u>INTRODUCTION</u>.

A. Improving Technology and Concepts.

Irrigation technology and concepts are changing, especially in response to **"precision agriculture".** Precision agriculture is an equipment (i.e. design criteria) and information (sensors of various types, weather data) system to make within field, site-specific decisions for economic and environmental control (Buss 1996). In the publication "*Water Use Efficiency*", new developments in irrigation technology in the agricultural arena are discussed (Land and Water Australia 2003). In recent years as "water conservation" has become a looming reality, there has been a marked increase in entrepreneurial activity to improve irrigation design and scheduling related to turfgrass sites. Irrigation system design on golf courses is a challenge to account for the site variability; and while current practices are good, improvements are anticipated in terms of: improved hardware; sprinklers that are much more flexible in water applications; integration of senors technology to better define water needs on specific sites; using an integrated approach with enhances 2-way communication between sprinklers and controllers, as well as with sensors; and site assessment methods and rigor; and software to better present information for ease of use by the turf manager.

The authors' current research efforts are focused on several of these developing areas:

- Identification and characterization of microclimate (irrigation zone, hydrozone) spatial variability, including landscape (atmospheric, plant types) and soil variabilities. Chapter 2 discusses site assessment for identifying these variabilities.
- Categorizing similar microclimates in a more detailed manner,
- Using sensor technology to integrate real-time information by microclimate type into irrigation scheduling by combinations of atmospheric and soil-based means, as well as investigating the feasibility plant-based sensor use and soil salinity sensors integrated into the overall irrigation system.

One implication to golf courses considering a new system is to investigate the current technology and concepts to insure the most state-of-the-science system. Water must be applied on a precision basis in a BMPs water conservation plan---and this cannot be accomplished with a poorly designed irrigation system. Top of the line irrigation systems will initially cost more, but in the long term save water/money and allow true implementation of environmental stewardship principles by the turf facility.

B. Irrigation System BMPs.

On irrigated turf sites, the irrigation system will have a major influence on water conservation; however, there are other water conservation strategies that should be used in conjunction with a good irrigation system and operation of the system to further enhance water conservation---such as drought resistant/low water using grasses; landscape design; use of alternative water sources, etc. **The focus of this chapter is on all aspects of the irrigation system except irrigation scheduling which will be presented in Chapter 5.**

The Irrigation Association is a primary organization in agriculture, horticulture, and turfgrass areas in fostering water conservation through proper irrigation (Irr. Assoc. 2003a). In their extensive *"Turfgrass and Landscape Irrigation Best Management Practices"* document, they note that maximum water conservation on irrigated sites requires five BMPs related directly to the irrigation system (Irr. Assoc. 2003c) (this document is available as printable on-line or by order and is highly recommended). The five BMPs are:

1. Assure overall quality of the irrigation system.
2. Design the irrigation system for the efficient and uniform distribution of water.
3. Install the irrigation system to meet the design criteria.
4. Maintain the irrigation system for optimum performance.
5. Irrigation scheduling---managing the irrigation system to respond to the changing requirements for water in the landscape.(see Chapter 5).

Each of these BMPs is essential if the end result is to achieve water conservation via the irrigation system. As an overall approach to evaluation of an existing system with respect to whether it is a quality system able to use water efficiently, we would suggest the following approach.

- Conduct an irrigation audit on the current system. The audit will determine: a) the system's ability to apply water uniformly; b) whether zoning is appropriate; c) the capabilities of the control system to allow flexible scheduling in a timely manner (within a 10 hour window per day); d) and whether there are constraints in piping size or quantity of water available to allow good scheduling in a timely fashion with appropriate quantity of water and in a manner to allow water infiltration into the soil.
- For initial auditing, start on selected fairways, tees, greens, and roughs that are representative of the whole system or are "problem" areas in terms of irrigation based on the experience of the golf course superintendent.
- If the results from these initial sites reveal that the irrigation system has low uniformity of water application and/or cannot apply water in sufficient quantities in the required time frame for good irrigation practices, then it would be necessary: a) to determine whether the system can not be modified into a good system regardless of what changes could be made. Such a situation may arise if the initial system was installed with improper head spacing that cannot be corrected new heads or nozzles; or improper zoning where dissimilar water-use hydrozones are zoned together; or piping size is insufficient to supply adequate water in a timely fashion to allow good irrigation practices. If this is the case, then further auditing might focus on what is needed for a new system and the golf course should start to consider a new system. The auditing at this stage may become more rigorous, or b) to determine whether the system can be modified to achieve a good system. If this is what is observed from the initial audit sites, then all irrigation zones should be audited in a detailed manner to determine what specific modifications should be made in each zone.

In recent years, there has been more attention given to irrigation audits on golf courses for the purpose of identifying potential problems (Ford et al. 2003; Zoldoske 2003; Miller et al. 2003). One interesting development has been the practice of re-nozzling sprinklers with nozzles that often demonstrate better irrigation uniformity as part of the audit process (Zoldoske 2003, 2004).

Evaluation of application uniformity using the Center for Irrigation Technology SPACE program that uses densograms to evaluate uniformity before and after re-nozzling allows feedback on possible improvements. This approach may allow in some situations considerable system improvement at a relatively low cost.

C. Importance of Irrigation System BMPs.

The question may arise as to why is a good irrigation system design so important for water conservation? When the system design is inferior and cannot be corrected several important consequences occur:

1. Efficient application of water in a uniform manner across a zone is impossible; therefore water conservation is greatly limited in the present and future. To achieve some degree of uniformity in turf appearance and performance in dry periods, would require excess water to be applied to many areas to achieve adequate water on the dries sites—those receiving the least rate of water. This not only wastes water but also increases the potential for excess water problems on many sites.
2. Irrigation scheduling by the use of improved technology of weather-based methods or soil sensor methods, are not very effective with a poorly designed system. A zone that mixes water-use vegetation, climatic conditions, and/or soil conditions, does not allow accurate determination of an appropriate crop or landscape coefficient to correct the reference crop ET (ETo) from the weather station data into estimated turf ET. Also, soil sensors are not effective because there is not “representative sites” for sensor placement.
3. The irrigation system itself becomes another source of site variability along with plant types, microclimates, and soil variations, instead of being a tool to minimize site variability. The irrigation system and the operation of the system becomes an ineffective strategy for water conservation.
4. Without the ability to use a well-designed irrigation system as a tool for water conservation, , when a course does come under pressure for implementation of water conservation, the golf course must use other options. If a stringent water conservation requirement is mandated, it will be very difficult to achieve such a requirement with the other strategies. Only the use of an alternative irrigation water source that does not require a stringent water rate requirement would be effective for maintenance of good turf performance. But, many of the alternative irrigation water sources are not unlimited in quantity and may themselves have rigid limits now or in the future.

II. ASSURE OVERALL QUALITY OF THE IRRIGATION SYSTEM.

Whether a new system or renovation of an existing irrigation system, it will become increasingly important for all golf courses owners and boards to be proactive in obtaining the best designed system for uniform water application, excellence in zoning, and a flexible control system. Quality irrigation systems cost more money than inferior systems, but a good system can also save on water costs. A new or renovated irrigation system will be with the course for a long time; and the future will bring increasing pressure for water conservation practices. Golf course superintendents should be proactive in promoting excellence in design aspects to the owners or board; as well as strongly influencing the selection of the most knowledgeable and skilled irrigation designers, contractors, and consultants.

Assurance of overall quality will include: a) making this a goal of the owners or board, b) providing sufficient funds to achieve the goal of design and installation, c) insisting of excellence in system design, installation, maintenance, and operation, and d) provision of the funds for trained personnel to maintain the system and operate it effectively. To insure that design criteria are achieved, it is a wise practice to require an irrigation audit after installation of a new system or renovation of an existing system. The Irrigation Association (2003c) has detailed information on proper protocols to follow to assure quality control in design and installation.

III. DESIGN THE IRRIGATION SYSTEM FOR EFFICIENT AND UNIFORM DISTRIBUTION OF WATER.

Uniformity of water application is of prime importance, but quality design also requires effective zoning and flexibility in water applications (good controllers and sufficient water to allow good irrigation) to insure that adequate quantity of water can be applied at a rate that allows infiltration into the soil and with sufficient water to meet needs in a timely fashion. All three of these design criteria are necessary to achieve efficient water application---applying water in a manner that maximizes infiltration into the soil. General approaches or options for achieving these criteria in the initial system design or in modification of an existing system are covered in considerable detail in publications such as: IA (2003c); Irrigation Association bookstore contains several publication related to irrigation design on golf courses (IA 2003a). Also, the Center for Irrigation Technology (2003) offers services and information relative to maximizing irrigation uniformity.

In this document we will provide an overview of the many considerations that must be incorporated into a well-design automatic irrigation system. Specific aspects that are important to consider in design for efficient and uniform distribution of water include:

A. Sprinklers, Design, Zoning.

- Careful evaluation of design criteria for selection of proper heads, nozzle sizes, rotation speed, head spacing, pipe size, and pressure. Errors in these aspects can adversely affect all uniformity of water application on all zones. Wind speed and direction are critical factor influencing head spacing.
- Choosing sprinkler heads that do not exceed the infiltration rate of the soil. On sites where runoff does occur, nozzle adjustment may be necessary and the use of pulse irrigation.
- Matched nozzles to insure the same water application rate within a zone including when part and full circle sprinklers are within the same zone.
- Low or adjustable trajectory nozzles can reduce the influence of wind.
- Pressure control to assure proper sprinkler operation with minimal misting.
- Adjustable arc heads for more site-specific targeting of water.
- Low volume heads for sloped areas; sites with low water infiltration; and where wind drift is a problem.
- If a flexible control system, ample quantity of water, and good pressure, low volume heads can reduce evaporation losses and wind drift, while allowing water to infiltrate into the soil.
- Use part circle sprinklers on edge areas to reduce water application on out-of play areas.
- Careful zoning into hydrozones that are areas with similar plants or similar water and environmental requirements. The primary factors generally considered are: presence of

different types of plants (trees, shrubs, turf, mixed plants); slope; sun exposure; solar radiation (sun versus shade). Soil type and soil variation---organic matter content, and subsoil variation are also important.

- Zoning sprinklers on mounds to control irrigation times and using appropriate low volume sprinklers, including low volume spray heads for smaller mound areas.
- Use of high efficiency nozzles for better uniformity of coverage.
- Dual lines and sprinklers for greens versus surrounds.
- Triangle spacing is more efficient than single row or square spacing of sprinklers.
- Use more sprinklers to achieve better coverage uniformity and allow closer spacing.
- In areas with strong prevailing winds at certain times of the year, consider an extra row of sprinklers located on the windward side zoned to be used during windy periods.
- Backflow devices and any necessary hardware required for a particular water source—such as effluent water with dual lines and safety measures to protect potable water.
- Variable frequency drive pumping system to apply water at the quantity required in an energy efficient manner.
- Future: a) sprinklers with greater flexibility in water delivery; b) heads that have two-way communication to controllers for changing sprinkler performance and to assure correct operation; and c) wireless heads; and d) increasingly components of the irrigation system must be designed to allow for multiple means of electronic interfacing and a higher level of interfacing, especially with water saving devices used as aids for irrigation scheduling. These features could change zoning and irrigation concepts.

B. Water Saving Devices.

- Appropriately placed water meters with electronic flow rate coupled with the controller to monitor water use and detect leaks.
- Automatic rain shut-off devices.
- Soil moisture sensors feedback to shut-off a zone or to prevent irrigation until needed.
- Check valves to prevent drainage from heads in low areas.
- Isolation valves to allow sections of the system to be isolated when major leakage or break events occur.
- Pressure regulating devices to control high pressure misting.
- Climate sensors that prevent irrigation under freezing or high wind conditions.
- Environmental sensors, especially weather stations, to measure reference ETo based on solar radiation, wind, humidity, and temperature for scheduling purposes.
- Soil sensors with multiple depths to measure ET based on soil water depletion; monitor potential for capillary rise of moisture: determine depth of the root system; determine the quantity of water to apply and when.
- Future will include: a) greater use of advanced control systems to regulate irrigation through soil moisture, climatic, and soil salinity sensors to provide real-time data to the control program and make automatic daily adjustments in irrigation; b) use of salinity sensors along with soil moisture sensors to control salt leaching with the least quantity of water; and c) coupling various sensors with the control system using 2-way communication in order to adjust irrigation and to alter sensor criteria.

C. Control System.

- Automatic central control systems should allow great diversity in programming including multiple start times; multiple independent programs; capability of short run times; pulse or cyclic irrigation scheduling; syringe and pre-wet cycles; interfacing with potable hand-held controllers; interfacing with sensors; program ability to use weather data or soil data to schedule irrigation. Controllers vary in their capabilities where some are fixed irrigation intervals with fixed run times that can only be changed manually. Other controllers have fixed run times the user can rapidly change run times by a percent adjustment. The next level is a controller that have user-programmed irrigation intervals but can be automatically adjusted by historic or current ET data. The most automatic are controllers that automatically adjust the interval and run times within set limits.
- Future: Advanced control systems that can be highly automated using 2-way communication and sensors to integrate real-time data will become the "norm" in many cases.

IV. ***MAINTENANCE OF THE IRRIGATION SYSTEM FOR OPTIMUM PERFORMANCE*.**

Even the best-designed system must be maintained on a routine basis. On courses with highly automated irrigation systems with integrated real-time sensor inputs, it will be important to assign personal that have the responsibility to routinely maintain a system and periodically conduct irrigation audits on parts to the system. The most common reasons for system malfunction are:

- Poorly adjusted sprinkler heads.
- Broken heads or sprinklers that are not rotating properly.
- Sprinklers that are not properly aligned, but are crooked or out of plumb. Use of 3-elbowed swing joints help maintain alignment.
- Sunken heads.
- Heads where grass leaves or thatch interferes with operation.
- Clogged nozzles.
- Worn nozzles.
- Mismatched nozzles or heads within a zone for uniform precipitation rate.
- Mismatched nozzles or heads for the soil infiltration rate.
- Spray deflection by plants or other features.
- Malfunctioning valves.
- Water saving devices not functioning, such as rain switches or soil moisture sensors.
- Improper irrigation scheduling problems---run time per cycle or number of cycles are not adequate to apply sufficient irrigation; over-application of water due to incorrect scheduling; schedules that are not adjusted for weather or for specific zones.

V. ***SUBSURFACE IRRIGATION AND SURFACE DRIP SYSTEMS*.**

Above ground sprinklers distribute water through the air and leave the surface moist. These conditions can result in high evaporative losses of water and wind distortion of water application. Subsurface application of water to the plant rootzone would reduce these problems. Subsurface irrigation can be achieved by several means (Krans and Johnson 1974; Daniel 1990; Leinauer 1998; Zoldoske et al. 1995; Suarez-Rey et al. 2000; Weeks and Maurer 2003).

1. Using a fluctuating or adjustable water table, such as the PAT and Cellsystems (Leinauer, 1998). This approach has been successfully used on golf course greens and athletic fields. Good turf performance and water savings can be achieved. With changes in grade, construction becomes more complicated but can be accomplished. If the irrigation water contains even modest levels of salts, salt accumulation can occur at the surface as salts are carried with water during capillary rise as the surface dries from ET.

2. Using a stationary water table. This approach is not used in turfgrass since grasses have seasonal root growth patterns, which influences the appropriate depth for the water table.

3. Use of buried water emitters (SDI, surface drip irrigation) has also been used (Zoldoske et al. 1999; Suraez-Rey et al. 2000; Weeks and Maurer, 2003). The article by Suarez-Rey (2000) discusses pros and cons of this approach as well presenting an overview of past research. Some of the problems to consider are: emitter clogging; uneven water distribution due to clogging or improper design; difficulty in performing cultivation operations; and potential for surface salt accumulation.

Both the SDI and fluctuating water table systems will likely increase in use in arid regions, especially on greens or tees. If water quality is such that salt accumulation may occur, a surface water application system may be needed to periodically leach salts.

Surface drip systems are very useful for site-specific irrigation on golf courses for trees, shrubs, and flower beds. With proper design and maintenance, these systems can effectively irrigate mixed plant types and single plants.

Chapter 5.

Irrigation Scheduling For Water Conservation

I. Status of Irrigation Scheduling

   A. The problem---spatial variability.
   B. Current irrigation-scheduling practices to adjust for microclimates.
   C. Irrigation scheduling options.

II. Atmospheric-Based Methods.

   A. Weather station methods.
   B. Weather pan data to estimate ETc.
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III. Soil-Based Irrigation Scheduling.

IV. Plant-Based Irrigation Methods.

V. Future of Irrigation Scheduling.

VI. Budget Approach To Irrigation.

VII. Deficit Irrigation.

Chapter 5.

Irrigation Scheduling For Water Conservation

I. __STATUS OF IRRIGATION SCHEDULING.__

A. The Problem—Spatial Variability.

In Chapter 2, site assessment was discussed relative to the importance of quantifying site variability, especially at the microclimate level (Table 2.1). Golf courses consist of a number of **"microclimates"** where ET may vary across the landscape due to variation: a) in atmospheric conditions such as solar radiation, temperatures, humidity, and wind speed, b) soil conditions such as slope, texture, organic matter content, compaction, waterlogging, presence of layers, soil depth, salinity, or other factors that may influence soil moisture retention or water infiltration, and c) plant factors that alter ET requirements, such as grass type, presence of trees or shrubs competing for water, management (mowing height, for example), pest injury, and others.

On many golf courses, the most dominant "microclimate situations" are:

- Greens, tees, fairways, and roughs may differ in grass type and certainly differ in mowing and other management practices.
- Secluded greens with trees/shrubs on 2-3 sides and limited air drainage. The trees and shrubs may not only block air movement but also the turf surface may be shaded at times. Often these sites have shade for part of the time each day, which further limits ET. The problem on these sites is not excessive ET, but too little ET to dry the surface and allow better air movement into the soil as well as to limit disease activity. Removal of some of the surrounding vegetation, fans to enhance wind movement, and even sub-surface air vacuum devices are used to increase air movement and, thereby, surface drying.
- Fairways that have a consistent shade line—where shade is present form a period each day. Shaded sites receive less solar radiation and, therefore, shaded plant exhibit lower ET compared to the same plant in an adjacent full sunlight area. Unfortunately, while shade is provided by the tree and reduces ET, the tree roots may extract any of the "saved soil moisture".
- Shaded tees, which often also have poor air drainage.
- South facing slopes (in the northern hemisphere), which receive more direct solar radiation than an adjacent flat area. Slope areas are also, obviously, affected by water runoff.
- North facing slopes (in the northern hemisphere), which receive less direct solar radiation than an adjacent flat area.

<u>Best Management Practices for Water Conservation</u> requires proper application of irrigation water in an efficient manner. Several decisions are involved in proper <u>irrigation scheduling</u> and each of these decisions will influence the effectiveness of irrigation and how efficient water will be used. The major decisions are:

- When to irrigate—how long after the last irrigation or rainfall event should I irrigate.
- How much water should I apply to bring the root zone moisture level up to field capacity.
- How should I apply the water to avoid leaching, runoff, or evaporation losses? The run times and number of cycles play a dominant role in how to apply water most efficiently.
- What time of day should I irrigate?

The focus of this chapter is on various means to determine when to irrigate. A number of factors influence how often irrigation will be required, but the primary factors are:

- **Climatic conditions**. Evapotranspiration (ET) of water from moist surfaces (evaporation) and from within the plant tissues through the stomata and cuticle (transpiration) are driven by climatic conditions. High ET is associated with high solar radiation, low humidity, high temperatures, and wind of over 4 mph. In Georgia, a dense, uniform turfgrass stand with soil moisture at field capacity under the above climatic conditions may exhibit an ET of >0.20 inches of water, but under cool, cloudy, humid, low wind conditions, the ET may <0.04 inch.

- **Soil water-holding capacity.** Soils with higher plant-available water-holding capacities will require less frequent irrigation because the soil moisture "reserve" is greater than one with low water-holding capacity. Sand may have a low water-holding capacity of <1.00 inch of plant available water per 12 inches of soil depth, while a sandy loam clay may have 2.30 inches.

- **Depth of the root system**. Turfgrasses that can develop and maintain deep roots have access to more volume of soil to obtain water. Rooting depth can change over the growing season. Knowledge of the rooting depth is important for irrigation management since the depth of soil water replenishment by irrigation normally should be to the depth of the root system. Deeper rooted grasses can be irrigated less frequently which allows more opportunity to utilize precipitation events rather than irrigation and less leaching loss of water beyond the root system is expected.

But, what methods can assist the turfgrass manager in determining when to irrigate. Should the turfgrass manager depend on the plant, soil, or atmospheric/climatic parameters to decide when to irrigate? This is an important question because **site-specific irrigation** requires that irrigation be adjusted to meet the demands of each microclimate area. If irrigation is not applied on a site-specific basis, water conservation cannot be achieved. Thus, data on the plant, soil, and/or climatic conditions on the site (or near the site in the case of climatic based irrigation) that influence irrigation requirement must be obtained. However, when monitoring of the soil, plant, or climate to schedule irrigation, a problem arises—spatial variability. The best-designed irrigation system will not efficiently apply water unless it is properly programmed or scheduled to deal with these issues within each microclimate or zone.

B. Current Irrigation-Scheduling Practices to Adjust For Microclimates.

Currently, irrigation-scheduling practices are usually by a combination of two factors. First, the experience and site knowledge of the turf manager are essential. Often, indicator spots or problem areas where drought symptoms are first observed are used to aid in deciding when to irrigate, while at other times the decision may be made by an educated guess. The quantity of irrigation water applied may also be by experience where adjustments made as needed to maintain adequate turf performance.

Second, many golf course have an on-site weather station where an estimated daily reference ETo can be calculated from weather data. Typical weather station locations are sites with full sunlight, flat topography, good air drainage, and no adjacent trees and shrubs. Site-specific irrigation or precision irrigation requires that water application be adjusted from the weather station ETo to the microclimate conditions. This **reference crop ET (ETo)** must be adjusted for each microclimate site, since grass, soil type, radiation, wind, and other environmental or management conditions will differ from the weather station site. For example, each green must be viewed as an individual microclimate. ETo adjustment is made by multiplying the reference ETo by a **Landscape Coefficient (K_L) or Crop Coefficient (Kc)** in order to obtain an **estimated turf ET (called the crop ET, or ETc).** Unfortunately, the K_L differs with grass, season, weather front, and any other site condition that affects ETc.

The difficulty in obtaining an accurate K_L to make the correction from ETo to ETc is a major deterrent using this approach on golf courses with their multitude of microclimates—this will be discussed later in this chapter. In arid regions, weather based irrigation scheduling is more widely practiced than in semi-arid and humid climates due to: a) with more consistent weather; b) usually less diversity in terrain, and c) since most of the water is applied by irrigation, there is less soil variability due to natural rainfall and microclimate difference in response to runoff and leaching of the natural precipitation (i.e. soil variability may be less). While many irrigation systems may have a weather station interfaced with the irrigation control system along with the appropriate software programs, it is not unusual for this feature not to be used or to be used inconsistently for irrigation scheduling.

C. Irrigation Scheduling Options.

Irrigation scheduling of the future must involve information <u>from within</u> an irrigation zone to provide more site-specific guidance using an integrated irrigation system with controllers and sensors linked (Buss 1996; Neylan 1997; Sudduth et al., 1999). **Irrigation scheduling options include**:

1. <u>Experience</u> of the turf manager.
2. <u>Climate-based approaches</u>, such as the use of weather stations, evaporation pans, or evaporometers that estimate climate ET or evaporation.
3. <u>Soil-based methods</u> using soil sensors.
4. <u>Plant-based methods.</u> The most common plant-based approach is to use indicator areas that drought stress can be first noticed. Other approaches are the use of infrared thermometers or multispectral data, but these are less developed.
5. <u>Combinations of these approaches.</u>

In the next sections, different irrigation scheduling approaches will be discussed.

II. <u>ATMOSPHERIC-BASED METHODS</u>.

Atmospheric-based irrigation scheduling methods are the widely used on golf courses and consist of three approaches.

1. ***<u>Weather station meteorological models</u>*** using weather station data to calculate estimated **Reference Crop ET (ETo),** which is more precise than the older potential evapotranspiration (ETp) concept. The ETo value is then adjusted to the **Turf or Crop ET (ETc)** using a crop coefficient (Kc) or more accurately a **Landscape Coefficient (K_L).** The "standard" or best meteorological method is the FAO Penman-Monteith method for computing ETo and then adjusting it by a landscape coefficient to obtain ETc (Allen et al. 1998).
2. ***<u>Weather pan</u>*** evaporation (Ep) to estimate a ETp and then adjusting for the crop to obtain ETc.
3. ***<u>Evaporometers</u>*** to estimate site ETp and then adjusting for the ETc

A. Weather Station Methods.

Potential evapotranspiration (ETp) has been used to indicate the maximum potential ET expected on a site with a close mowed, hypothetical crop (usually a grass or alfalfa) growing under well-maintained and well-irrigated conditions. The ETp concept has been replaced by the concept of **reference crop evapotranspiration (ETo)**, which is very similar, but with the "crop" more closely defined so ETo data could be more accurately compared across different climates and locations. The "crop" is now defined as: a hypothetical grass reference growing under well-maintained conditions (has uniform, complete coverage of actively growing grass); it is well-irrigated (soil moisture is not limited); a large expanse; assumed crop height is 0.12 m (4.72 inches) with a surface resistance of 70 s m^{-1} and an albedo of 0.23. The height, surface resistance, and albedo values are then used in the ETo calculations to standardize these factors across locations. Since there are no soil moisture limitations and the reference crop is defined to be ideal for maximum ET, ETo is only dependent upon climatic factors**.**

Over the years, a large number of different empirical methods to estimate ET from climatic variables were developed. In 1948, the Penman equation to estimate ETo was developed based on combining concepts of energy balance and mass transfer models, which provided a more scientifically sound approach. Modifications of the original equation resulted in the Penman-Monteith method, which uses standard climatological information of solar radiation, air temperature, humidity, and wind speed to calculate ETo. Recently, the Food and Agriculture Organization of the United Nations made some revision of the Penman-Monteith method where the Penman-Monteith method is used to determine ETo, but the characteristics of the reference crop were better defined---now using the definition noted in the previous paragraph. This method is now called the **FAO Penman-Monteith method** (Allen et al. 1998) and is being adopted as a worldwide standard.

Reference Crop ETo. Since the FAO Penman-Monteith method is being widely adopted, the comments to using meteorological date to estimate crop water use (ETc) will be related to this method—however, other meteorological methods would use a similar approach. The weather station should be located near the site of interest. The surrounds of the weather station should be a wide expanse of irrigated grass without hindrance of wind movement and no shade. The weather station program should be set to calculate the FAO Penman-Monteith **reference crop evapotranspiration value—ETo.**

Once the ETo value has been determined, it must be adjusted by a **crop coefficient (Kc---** if standard conditions are present**) or a Landscape Coefficient (K_L**--- if non-standard conditions are present**)** to obtain the estimated **crop evapotranspiration (ETc),** where:

$$ETc = Kc\ ETo \quad \text{for standard conditions}$$

or $$ETc = K_L\ ETo \quad \text{for non-standard conditions}$$

With ETc = crop evapotranspiration [mm d^{-1}]

Kc = crop coefficient [dimensionless],

KL = landscape coefficient [dimensionless],

ETo = reference crop evapotranspiration [mm d^{-1}]

Crop Coefficient or Landscape Coefficient. Since the actual crop (turfgrass) may differ from the reference crop conditions, the Kc value is used to make appropriate adjustments to ETo so that actual crop water use, ETc, can be accurately estimated. The primary factor to be considered for determining the proper Kc value when the turfgrass is actively growing and in good condition similar to the reference crop condition **("standard" conditions**) is the grass type and mowing height. Each grass species and cultivars within a species can exhibit plant differences relative to the reference crop that would influence ETc, for example: differences in leaf orientation; shoot density; stomata properties [number location, wax deposits over stomata openings, degree of stomata control where some grasses demonstrate a higher degree of stomata control to regulate transpiration]. Normal mowing height for the grass may also differ substantially from the standard 4.72-inch height. Each of these factors would influence the laminar and/or turbulent boundary layers or size of the stomata opening for water vapor diffusion, thereby, affecting ETc.

However, many times the turfgrass is not growing in standard conditions but **"non-standard conditions**. For example, the grass may be subjected to non-standard: a) climatic conditions of shade, sun exposure on a slope, high wind, hot or cool spots caused by adjacent structures; b) soil conditions of drought stress, salinity stress, shallow soil/root system, and/or c) plant conditions, such as stresses that reduce shoot density, pests that injury leaves or reduce growth, or traffic stresses. Each of these non-standard conditions substantially influences the actual ETc.

The question arises "how can the appropriate Kc or K_L value be obtained to adjust for normal grass difference under standard growing conditions and for non-standard situations?" The fast answer is—not very easily**. Four approaches are used to determine the appropriate Kc or K_L:**

1. The most prevalent means of determining Kc has been for scientists to directly measure crop water use, ETc, in the field using lysimeters or soil moisture sensors and then publish the information for use in similar climates as the data was collected. Usually the grass is growing under "standard" conditions similar to the reference crop conditions—i.e., well-maintained, well-irrigated, uniform surface----but, sometimes the ETc has been determined under more normal field dry-down situations to the point of some wilt before irrigation. In the latter case, the Kc would be a combination of standard and non-standard conditions, and often be more realistic for field use. Once actual turfgrass water use, ETc, is known and the ETo is obtain from a weather station, the Kc is determined as;

   Kc = ETc/ETo

   Season of the year alters the Kc not only because of direct climatic changes, but also due to changes in grass characteristics—such as the grass going semi-dormant, being more prostrate, rate of growth, etc. Thus, the Kc must be changed with the season. In the case of turfgrass, Kc may also change with weather patterns from a hot, dry weather front to a cooler, more humid front within a season. As noted, the use of soil moisture measurements to determine the Kc has primarily been confined to research studies, and then the values used by turf managers in similar climates. The Kc or K_L values obtained in this fashion and published are broadly adapted for the region, but are not really "site-specific" since the data may be obtained from a distant weather station and are based on historical averages for the time of year.

2. The second most common method for determining the Kc, especially on a golf course that has a good weather station connected to the irrigation control system, is for the golf course superintendent to adjust the ETo value from the weather station for each zone based on their experience. The "adjustment" may be in the form, for example, of reducing the ETo value to 70 % for a less exposed site, while a more hot, dry, windy location may be irrigated at 100 % of ETo. In this approach, the ETo data is based on real-time, local information, but the Kc or K_L is estimated by experience or observation of indicator spots and manually adjusted.
3. The FAO publishes estimated Kc values and methods to make adjustments for non-standard conditions (Allen et al. 1998). Unfortunately, few grass values are included.
4. The Irrigation Association in their publication "Turf and Landscape Irrigation Best Management Practices" (Irr. Assoc. 2003c) presents a method to develop a landscape coefficient based on Costello et al (1993) in California, where the K_L is defined as:

$$K_L = Ks \times Kmc \times Kd$$

The three adjustment factors are defined as:

- **Ks = species factor**—adjustments made for the plant type such as a cool-season turfgrass; warm-season turfgrass; mixture of trees, shrubs, and ground covers; trees;

or shrubs. When the Kc value is available it can be assumed to be equal to Ks, but if not available the published Ks value is used.

- **Kmc = microclimate factor** that accounts for sun, shade, protected areas, hot or cool areas, and wind. The particular Kmc selected depends on whether the climate is hostile (higher Kmc), average (intermediate Kmc), or friendly (lower Kmc). Hostile would be microclimate factors such as a grass near a paved surface or a south-facing slope; while a friendly location would be a shaded site with less wind.
- **Kd = density factor** with categories of high, average, and low density for the plant species**.**

Once the Kc or K_L value is determined, it is used to adjust the ETo to determine the crop evapotranspiration, ETc. The Irrigation Association (2003c) publication contains more specific information on development of the K_L coefficient, including tables for making adjustments. In their publication on "*Landscape Irrigation Scheduling and Water Management*" the Irrigation Association (2003d) provides detailed protocols for irrigation scheduling using weather-based ETo. Current state-of –the science allows manual changes to be made but not real-time, automatic adjustment in the K_L value.

B. Weather Pan Data To Estimate ETc.

With the advent of less expensive weather stations capable of connecting into irrigation controllers, weather pans are not widely used. **Evaporation from a weather pan, Epan,** integrates the climatic conditions at a site that influence ET.. While a weather pan will differ from a grass surface in terms of reflection of solar radiation, temperature, humidity, and turbulence, Epan can be related to the evapotranspiration of a crop, ETc. There are a number of pan types, with the Class A pan the most common (Allen et al. 1998). The Epan is related to the ETo by a **pan coefficient, Kp**, by the relationship:

$$\mathbf{ETo = Kp\ Epan}$$

with units of mm d-1 for ETo and Epan, and Kp is unitless.

Pan type and the ground cover that surrounds the pan determine which Kp is chosen. Sometimes the Kp is further adjusted for unusually high wind or low humidity (Allen et al. 1998). Once the proper Kp is selected, it is used to estimate a ETo from the Epan information. The ETo is then adjusted by a crop coefficient, Kc, or landscape, K_L, as discussed in the section on using weather station data to determine crop evapotranspiration, ETc.

C. Evaporometers To Estimate ETc.

An **evaporomete**r or **atmometer** is a cylindrical device with a ceramic evaporator on the top that is connected to a water reservoir (Bauder 1999). A green canvas cap may be used to better simulate grass ET. As water is evaporated from the cylinder, the daily evaporation is measured. Since the device is mobile, it can be calibrated against a weather station ETo or a weather pan Epan to provide a coefficient to make estimates of ETo. Once the ETo value is determined, it would be adjusted with a Kc or K_L to estimate ETc. Atomometers are not widely used, but have the potential to monitor weather conditions within smaller microclimates that could provide guidance to adjustments in the weather station ETo for microclimate situations. The "weather conditions" at the atomometer location are essentially integrated into the atomometer evaporation value.

III. <u>SOIL-BASED IRRIGATION SCHEDULING.</u>

Interest in soil sensors for irrigation scheduling has been growing, especially in Australia and in agronomic crops (Moller et al. 1996; Neylan 1997; Charlesworth 2000). One reason has been the realization that important site-specific information includes soil moisture status in order to not only determine when to irrigation, but especially how much water to add. Another reason for interest is new developments in soil sensor technology that allows much more sophisticated sensor arrays and interfacing with control systems. Soil sensors are now capable of monitoring soil moisture in 2-4 inch (50-100mm) zones at multiple depths down to 1-3 feet in a real-time mode with remote transfer of the data for ease of use (Charlesworth, 2000; Moller et al., 1996).

A common question that arises with soil moisture sensors is whether a soil measurement represents the area due to spatial variability across a landscape and within the soil (Schmitz and Sourell, 2000). Comments related to this question are:

- For any means of irrigation scheduling to be efficient, adjustments must be made for the site; and as noted previously, there are a number of potential inaccuracies in estimating turf ETc, such as on a golf tee or fairway area using the weather station approach. Soil sensors are placed within the specific area of concern to measure actual conditions in the soil—i.e., how much water is present at each depth and across the root zone. Some sensors can indicate the depth of the viable root system, which is very important for optimum irrigation. Thus, soil sensors offer the capability for being the most site-specific moisture monitoring approach within the vertical plane throughout the root zone.
- New sensors and software have much greater capabilities than what many now visualize when they think of a soil sensor. The new generation of sensors is different from past ones and software can be made user-friendly for turf situations with some offering real-time data, multiple depth moisture readings, translation of the information into useful formats, and ability to electronically transfer data to remote sites. Computerization can take a lot of the guesswork out of this strategy and provides comprehensive information in timely fashion. These attributes can be useful for documenting the need to irrigate a site and maintaining a history of soil moisture statue.
- Soil sensor placement must be careful to represent the area; installation must be according to guidelines to make sure good soil-to-sensor contact exists; and calibration must be accurate. However, all of these issues can be addressed.
- Soil sensors are only effective when they are used within a carefully designed and zoned irrigation system that has a high uniformity of water application or a system with the ability to control water delivery to specific parts of a zone (Buss 1996). Then, sufficient sensors must be placed to represent a microclimate zone, but one such zone may then represent several other similar ones.

- It is the “difference in water content” between readings that is important and not absolute moisture content information, because the difference is an actual measure of water used and it indicates where the water was extracted within the root zone. There is much less spatial variability in the “difference data” than within an absolute value when comparing across several sensors. Thus, when several sensors are measuring water status within a zone but at different sensor locations, the absolute readings may vary considerably due to texture or organic content differences, but the actual quantity of water extracted (i.e. “ the difference from the initial to final reading”) should exhibit much less variability.

The combination of detailed knowledge of soil moisture status and turf rooting by depth allows for more refined irrigation scheduling approaches to be used than previously possible. State-of-the-science soil moisture sensors are the only available tools to accurately determine the “vertical” spatial variability of soil moisture and root dynamics. Methods on monitoring soil-moisture depletion are summarized below. But, for detailed information on different methods, good sources are: a) the CSIRO publication by Charlesworth (2000), b) the web publications “Soil Water Monitoring: Choosing The Right Device” (Williams 2002) and “Soil Water Monitoring: List of Devices and Distributors” (Greenslade and Williams 2002); and c) www.sowacs.com-a web site specializing in soil sensors and other sensors. Briefly, some of the old and new methods to determine soil moisture status are:

- Moist-versus-dry soils exhibit different appearances and feel. With some experience, an irrigator can approximate soil-moisture content based on these criteria. This requires an auger to look at several depths. While useful, it is often cumbersome and only accurate within the irrigator’s experience.
- Use of a soil probe, such as a screwdriver driven into the soil, is similar to the above method. In this case, the grower relates mechanical resistance to moisture content. This method is quick but not very precise.
- Tensiometers directly measure soil-matrix potential, which is essentially the same as soil-water potential, except on salt-affected soils. On such soils, tensiometers will not be an accurate measure of soil-water potential. Tensiometers have been used on turf for many years. They are very accurate between 0 to -0.80 bar (moist end of the scale), but they will not perform when the soil is drier than below -0.80 bar.
- Heat dissipation sensors are commercially available to monitor soil matrix potential. These resemble electrical-resistance blocks but use thermal conductivity.
- Electrical-resistance probes are generally based on measuring electrical conductivity between two metal probes in the soil. These may be bare metal or imbedded in gypsum or nylon. Salinity influences these devices.
- Granular matrix devices that use pressure gauges or transducers to monitor soil moisture changes.
- Neutron probes, gamma-ray attenuation, and soil psychrometers are used for research purposes but not for commercial irrigation scheduling, except for some consulting agronomists that use neutron probes.
- Time-domain reflectrometry (TDR) measures dielectric constant of the soil, which is related to soil moisture status. There are several TDR units including ones that can monitor soil moisture by depth.

- Frequency-domain reflectrometry probes (also called capacitance probes or FDR) have gained considerable use in recent years for irrigation scheduling with several commercial units available.
- Phase transmission (virrib) sensors use propagation of electromagnetic waves through the soil to determine water content.
- Velocity domain differentiation (VDD) sensors use electromagnetic wavefront velocity to measure water content.

Methods that are currently most widely used for irrigation scheduling are: tensiometers, gypsum blocks, TDR, and capacitance sensors. For these methods or other soil-based methods to be useful in a golf course situation, they must be directly interfaced with the control system. With good irrigation design and zoning of microclimates, the potential exists to use indicator zones that are monitored with soil sensors (and possibly climatic sensors), which then can be used as indicators for other similar zones. This approach would dramatically reduce the number of sensors. Actual turfgrass water use based on soil water depletion could also be used as a means to determine daily K_L values to make adjustment of the reference crop (ETo) from the weather station.

IV. <u>PLANT-BASED IRRIGATION METHODS</u>.

Turfgrass managers often use plant-based symptoms to aid in irrigation scheduling with the "remote sensor" being the eye. On a golf course, observation of indicator areas where drought stress symptoms first occur is a common practice. As a plant is exposed to drying conditions and soil moisture is not replaced, **<u>drought stress symptoms</u>** will be exhibited:

- First, <u>growth rate decreases</u>. This is most noticeable in terms of shoot growth, but rhizome, stolon, and root growth rates are all reduced.
- <u>Wilt symptoms may follow,</u> which is shown as leaf folding or rolling; a bluish-green color; and foot-printing ---the lack of turgidity by the shoot tissues result in plant tissues being pressed down and leaving an impression when stepped upon.
- <u>Leaf firing follows</u>, which is chlorosis [yellowing] of the turf as chlorophyll pigments in the plant decline and eventually tissue desiccation. Desiccation may start as leaf tip injury and progress done the leaf, especially of young tillers.
- As <u>tissues desiccate</u>, the turfgrass stand starts to turn tan as dead leaves become dominant. As these symptoms progress, the grass normally will go into a <u>dormant state</u>, where the only living tissues are the crown, rhizomes, stolon stems, and some of the roots.

The ideal plant-based method would be to determine when the plant is going into a drought stressed condition before it could be visually determined. Throssell et al. (1987) were the first to use infrared thermometry to develop irrigation scheduling indices on turfgrasses, based on measuring canopy temperature, air temperature, and relative humidity. Since then others have investigated the potential for using canopy temperatures for turfgrass irrigation scheduling but with limited success. However, this method is useful in identifying "hot spots" on greens or other turf areas.

Multispectral reflectance has been used for plant-based monitoring of stress, including possible use for irrigation scheduling in precision agriculture (Frazier et al. 1999). Trenholm et al. (2001) demonstrated that multispectral reflectance models could be used to assess stresses on turfgrasses, but not specifically moisture stress. To date the focus has been on measuring light reflectance from the turf canopy within the 350 to 1100 nm wavelength region, which includes the visible/ PAR (photosynthetically active radiation) region of 400-750 nm (Geuertal et al. 2000). Reflectance devices are available that can determine reflectance within a narrow band (2-3 nm) or broadband mode (10-20 nm). Loss of color and/or leaf area can increase reflectance within certain wavelengths that may be used in models to estimate overall plant stress, irrigation need, or perhaps a nutrient stress, such as N. Other approaches may become possible such as: using a wider wavelength range of 350 to 2500 nm where several "water bands" (950, 1200, 1480 nm are water bands that are influenced by tissue moisture content); use of the infrared thermal region of 8000-14000 nm; fluorescence reflectance; digital imaging data; and others.

One problem with reflectance models is that any stress that alters color or shoot density will result in reflectance changes in many of the wavelengths. Thus, "stress" can be monitored but only field observation allows determination of what stress or stresses are causing the response. In a recent research project, reflectance models using 3-4 broadband wavelengths, including at least one of the water bands, Jiang et al. (2004) identified models that indicate plant stress with emphasis on moisture stress. However, the reflectance models do not reveal moisture stress any quicker than visual observation. Just as with visual observation of drought symptoms, a reflectance model that does indicate moisture stress does not provide information on how much water to apply; only that a moisture stress is occurring.

Since turf areas must be frequently mowed, it is possible to gather plant-based data on a frequent basis, at the ground level, and incorporate information into GPS/GIS systems. Thus, plant-based sensing technology using both portable scanners and satellites/planes will likely become another tool for site-specific information that may aid in more efficient, precision irrigation; rather than an irrigation-scheduling tool. For example, drought stress patterns after a good rainfall could help identify sites which exhibit moisture stress first---then field observation could be conducted to determine the cause, such as a sloped area, south facing slope, area with shallow rooted grass, etc. Or, during a prolonged dry period where only irrigation water is applied, plant-based reflectance models may help to map irrigation distribution patterns. Then those sites that are under-watered or over-watered can be investigated with respect to corrective measures.

V. <u>FUTURE OF IRRIGATION SCHEDULING</u>.

Highly automated controllers that can automatically adjust irrigation using daily climatic and soil sensor data will become more prevalent as the necessity for water conservation increases. In the future, the authors believe that the most highly automated irrigation scheduling systems on golf courses will have the following components:

- On-site weather station will provide real-time data on the reference crop ETo.
- Soil sensors will be used in selected microclimate sites to monitor soil water loss, which is actual turf water use. These indicator areas will be selected by more rigorous site assessment procedures targeted to identifying common microclimate types and classification of similar microclimates together; then a representative microclimate site for a particular class can become the indicator for all other similar microclimates. The soil sensor data can provide: a) real-time actual ETc, which then can be used to provide a real-time K_L to adjust the ETo value for an

estimated ETc for the other sites, b) information on soil water status by depth, c) the quantity of water to replace ET losses, d) estimate of rooting depth, and e) whether any capillary water movement into the root zone is occurring. Golf course fairways, for example, may be classed into several microclimate types, with each type having a representative microclimate site with soil sensors to obtain the data for that particular microclimate type. The calculated K_L factor could be automatically inputted into the controller to estimate when to irrigate and how much water to add to replace ET losses. Soil moisture status by depth could be viewed by the turf manager to determine adjustments, while also providing another estimate of how much water to apply to replenish the root zone.

- In some microclimates, especially those that are affected by shade, microclimate sensors may be used to make adjustments in the weather station estimate of ETo to obtain a more accurate site-specific ETo. Microclimate sensors may be in the form of automated atomometers, solar radiation sensors, or miniature weather stations. These sensors will need to be connected and integrated into the control system.
- Since one monitored microclimate site will be used to schedule several other similar sites, the golf course superintendent can make fine-tuning adjustments over time for each site to further improve water-use efficiency. These adjustments may be based on empirical observation or by using mobile soil sensors to cross check against the indicator site. Thus, it is likely that mobile sensors that can determine sites differences in terms of soil, plant, and/or atmospheric conditions will become more routinely used. These data will be integrated into GPS/GIS maps to better define microclimate differences, irrigation system performance, and to make appropriated corrections.

For these irrigation scheduling approaches or combinations of approaches to be effectively used by golf course superintendents will require that irrigation system manufacturers and companies involved with sensor technology address the following issues:

- Improved integration of control and sensor systems. Each component must be electronically connected with the least problem for the turf manager and electronic components must be able to communicate with each other. Alternative communication means must be provided as options—wireless versus wired connections for example. Automatic irrigation systems should be sold as systems and not as an irrigation system that sensors must be added on, which transfers the compatibility problems to the turf manager. One-stop systems with options are essential.
- It is essential to have improved integration of sensor data into irrigation scheduling in an automatic manner with appropriate capability to over-ride the system when necessary. As more sensors are used, the problem increases concerning how to integrate data for multiple microclimates in a useable format. Users do not have the time to view large quantities of information. Thus, appropriate software to appropriately handle the data—collection, summarize the information into useful formats, integrate information with the control system for each microclimate site, and clearly displace information in an understandable and useable manner.
- Education on the use of highly automated systems must be initially thorough, as well as on going. Technical support of more complex systems will be necessary as

well as agronomic support to assist the superintendent in interpreting sensor information

This approach integrates together weather station data, soil moisture status, microclimate weather conditions, microclimate types, and the computer control system using real-time data to determine ETo, K_L, and ETc within each microclimate, which can be used to directly alter irrigation programs. However, the software must allow operators to easily review the system characteristics and make operator overrides when needed.

It will be important for golf courses planning new systems or renovation of an existing system to consider changes that will occur in the near future. While many in the turf industry may be skeptical of adopting or developing new technologies and concepts that are necessary for site-specific irrigation, the demand for water conservation measures will (and is) bringing these changes. As stated previously, site-specific or precision irrigation cannot be done without precise data on the microclimate level; nor without precision in water application. One scenario that is becoming increasingly common, especially in arid regions, is for a golf course to be limited to a set quantity of water that is well below current use for many facilities. In such a situation, the facility must view all options to achieve the water limit; and ideas that seemed impractical before may suddenly become very attractive.

VI. BUDGET APPROACH TO IRRIGATION.

Regardless of the irrigation scheduling technology used, a **"Budget Approach"** to irrigation and water management is a good means to foster water conservation on a whole systems basis. A useful way to visualize turf water management is to consider the Budget Concept approach, similar to a bank checking account. Certain additions (**inputs**) of moisture are made and there are losses (**outputs**) of moisture from the plant environment. At any point in time, the plant has available to it a certain **reserve** of available water in the soil within the plant's rootzone. **The objectives of a wise turfgrass manager are to maximize inputs, minimize outputs, and maintain a large reserve**.

Inputs.

Inputs of moisture are **precipitation, overhead irrigation, dew, and capillary rise of moisture** from below the root system. Precipitation and overhead irrigation are the major inputs. Normally, capillary movement to turfgrass roots from below the root zone is minor except where a water table is within 2 to 4 feet of the roots. While the turf manager cannot control natural precipitation, irrigation can normally be controlled with respect to when to apply water and the quantity.

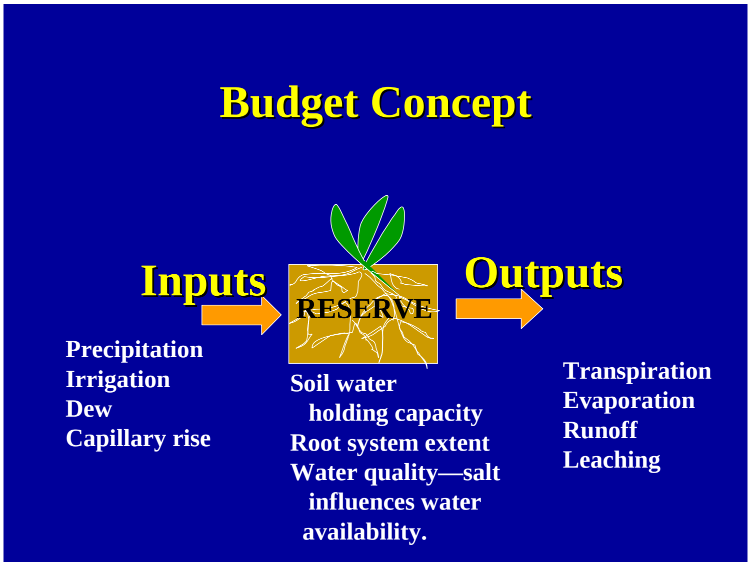

Figure 5.1. Components of the Budget Concept of turfgrass water management.

<u>Outputs</u>.

Outputs or losses include runoff, leaching beyond the root zone, evaporation, and transpiration. Reducing undesirable losses or outputs will retain more water for future use.

Runoff can be a problem on sloped sites and can be increased by fine-textured soils, thatched turf, compacted soils, and applying water faster than the soil can receive it—these issues will be discussed in a later section of **infiltration**. Water loss by runoff is especially a problem on sites with heavy soils and sloped areas. Soil moisture cannot be replenished if the water is lost by runoff onto another site. Runoff causes not only a dry site but also an excessively moist site. Reducing runoff requires correcting the above situations through cultivation, thatch control, or proper irrigation application rates.

Leaching or water movement beyond the root system is often an unrecognized water loss. Irrigators whose watering is based on the driest site often over-irrigate other areas. Irrigating slightly beyond the existing root is acceptable because it provides a moist zone for further root extension. To reduce leaching losses, the irrigator must know the depth of rooting and depth of moisture penetration after applying a specific quantity of water. Well-designed irrigation systems that apply water uniformly reduce leaching losses. Also, proper zoning of irrigation heads is important. Heads in similar areas should be zoned together. Poor zoning, with heads on slopes and low spots zoned together, results in poor uniformity of water application.

Evaporation is the vaporization of water from a surface. When moisture evaporates, it removes energy (heat) from the surface. Thus, evaporation helps cool the soil and plant if free water, such as dew, is on the leaf surface. Excessive evaporation is wasteful. Growers can control the quantity of water lost by evaporation. For example, immediately after irrigation evaporation rates from the soil surface are high, but as the surface dries evaporation dramatically decreases. Thus, light frequent irrigation results in high evaporative losses contrasted to heavier, less frequent applications. Other ways to reduce evaporation are: maintain good infiltration rates to get the moisture into the soil; maintain a dense turf to shade the soil surface; mow your turf as high feasible for your situation to insure further shading; avoid applying so much water that standing water occurs; and avoid afternoon irrigation.

Transpiration is the vaporization of water inside the plant leaf that diffuses the cuticle and through the open stomata., which are pores on the surface of leaves, where most transpiration occurs. During this process, heat is removed from the plant. In many situations more than 90 percent of the moisture taken in by a turfgrass plant is utilized for cooling purposes. Transpiration is a desirable use of water, especially in hot conditions. However, excessive transpiration can occur and thereby waste water. Over watering turf promotes excessive transpiration.

The Reserve.

The reserve of plant-available moisture at any point in time depends primarily upon soil texture and the volume of soil occupied by the plant root system. Obviously, over a period of time, irrigation and precipitation are the sources of the reserve moisture. Soil texture and water-holding relations are detailed in the "water-holding capacity" section, but as a generalization sands do not retain as much plant-available moisture as do loam soils.

The turfgrass grower can markedly improve the moisture reserve by managing to promote development and maintenance of a good deep, extensive plant root system. University of Georgia turfgrass breeders have placed considerable emphasis on development of grasses that can tolerate the soil stresses that limit rooting in Georgia and on grasses that can better maintain their roots during the hot, dry summer months. Thus, selecting adapted grasses with enhanced rooting capabilities is one way to "increase the water reserve". A turfgrass with a 12-inch root system will have twice the quantity of plant-available moisture as one with only a 6 inch root system.

Development and maintenance of a good root system will require:

- Selection of grasses with high drought resistant and capable of rooting into hard soils.
- Proper mowing height.
- Good irrigation practices to favor deep rooting.
- Liming when needed and good fertilization.
- Control of root-feeding insects.
- Possibly cultivation when soils are hard or compacted

VII. DEFICIT IRRIGATION.

Various individuals have defined deficit irrigation differently. Fry and Fu (2003) noted that deficit irrigation in turfgrass situations has often been defined as irrigating at less than the reference crop ET (ETo) and defining water replacement at the ETo level as irrigating to avoid any moisture stress. In practice, many turfgrasses can be irrigated below the ETo level without exhibiting moisture stress or reduced performance. In recent papers, the relationships between turfgrass evapotranspiration (ET) and turf quality were explored under arid conditions along with reviews of past research (Ervin and Koski 1998; Richie et al. 2002: Bastug and Buyuktas 2003; Fry and Fu 2003). These studies confirmed what has been previously reported; a) that acceptable turfgrass quality can be maintained by applying water at 40 to 85 % of reference crop ET, b) species differ in water use with, for example, tall fescue (*Festuca arundinacea* Shreb.) using less water than Kentucky bluegrass (*Poa pratensis* L.), and c) irrigation regime influenced water use with deeper and less frequent irrigation reducing water use when conditions allowed deep rooting with deeper rooting occurring under this type of irrigation regime. In a humid climate, Carrow (1995) evaluated seven turfgrass across five species and reported acceptable turf quality at 67 to 85 % (warm-season grasses) and 80 % (cool-season) of reference ET; however, daily turf water use was only 40-60 % of reported ET on the same species and cultivar compared to arid regions, due to higher humidity, more cloud cover, and often less wind movement. Thus, irrigation application can often be less frequent in humid sites due to lower daily ETo and ETc.

Thus, most turfgrasses can be irrigated at 40 to 85 % of reference crop ETo and still maintain high quality. At watering rates below these reference crop ET percentages, turf growth rate and quality start to decline with progressive loss of color and density. Irrigation timing can be adjusted to allow as many days between irrigation events as possible without causing deterioration of the turfgrass. This type of deficit irrigation is often practiced in arid regions and is not concerned with development of maximum rooting since all water will be applied, but with infrequent enough irrigation to reduce excessive ET associated with the maintaining the surface at near field capacity (Brede 2000).

In semi-arid and humid regions it is important to develop and maintain a good root system to take advantage of natural precipitation events. Thus, periodic replenishment of the root zone is beneficial. When soil sensors are used to determine soil moisture status, the root zone may be allowed to dry to 50 to 70 % of total plant available water (PAW) [i.e. deplete 30 to 50 % of the PAW], with more drought resistant grasses able to withstand higher depletion of the PAW without adversely affecting turf performance. Then sufficient irrigation is applied to replenish the water depleted by ET and bring the soil back to field capacity. In some cases with deeper rooted grasses, irrigation can be applied to replenish the top half of the root zone to field capacity, while allowing the lower half to dry to a set moisture level, at which point the complete root zone would be replenished. Irrigation frequency is primarily a function of ET demand, depth of the root system, and soil water holding capacity. The ideal is to irrigation deep, but as infrequently as possible but still maintain acceptable turf performance.

If irrigation is based on a percent of reference crop ETo in semi-arid and humid climates, it is important to allow as many days between irrigation events as possible without turf injury in order to have a reasonably deep irrigation event when irrigation is applied. Thus, applying irrigation every 3 days at 70 % of ETo [or by using a landscape coefficient, K_L, for irrigation scheduling] could result in a shallower root system than when irrigation was on a 5 day schedule. If daily ETo values are adjusted to determine a daily ETc; and then these values are totaled until a target sum is obtained [usually based on an estimated maximum allowable depletion, MAD, level in the soil, such as 40 % of PAW content], it is best to us a MAD level that allows several days between irrigation events in most weather conditions.

A more severe deficit irrigation practice is to irrigate in a manner so that the plant root zone is not filled to field capacity or plant water requirements are not fully met (Irr. Assoc. 2003d). In this instance, irrigation is purposely reduced below the point where no appreciable decline in turf performance is observed. [as was the type of deficit irrigation described in the previous paragraphs]. Thus, some deterioration is expected. The level of soil moisture depletion that is allowed will depend on the purposes of the turf manager, but too severe moisture limits can eventually cause thinning of the turf, whereas, initial responses may be reduced growth rate and some discoloration. The Irrigation Association's (2003d) publication "Landscape Irrigation Scheduling and Water Management" contains information of various irrigation-scheduling approaches and using both soil and weather-based methods.

Chapter 6.

Selection of Turfgrass

I. Grass Characteristics For Water Conservation.

A. Drought resistance.
B. What drought resistance traits are most important?
C. Additional turfgrass traits for water conservation management.

II. Drought Resistant Grasses.

Chapter 6.

Selection of Turfgrass

I. GRASS CHARACTERISTICS FOR WATER CONSERVATION.

A. Drought Resistance.

Use of turfgrasses with superior **drought resistance/low water use** is a primary means of decreasing water needs on turfgrass sites (Kenna and Horst 1993). For example, *Cynodon* species are widely used in the warm-season zones and most cultivars exhibit very good drought resistance. An understanding of the components of drought resistance is important when discussing turfgrass water relations. **Drought resistance includes three components: drought avoidance, drought tolerance, and escape.**

Drought avoidance mechanisms are means that the plant has to reduce ET water loss and/or increase water availability; thereby, allowing the plant to avoid or delay tissue dehydration. Mechanisms involve allowing low evapotranspiration during both high and low soil moisture availability; and maintenance of a viable/functional extensive root system during cyclic stress conditions. Thus, both the turfgrass shoot and root systems are involved. Turfgrass shoot characteristics that reduce water-use (i.e. ET) during both well-watered and low soil moisture conditions are very important for conserving soil moisture for later use and reducing irrigation needs.

- Plant shoot factors contributing to reduced turf water-use (ET) in moist soils are: ability to the plant to control stomatal openings so that the plant does not transpire at the maximum rate; high canopy resistance; wax deposits over the stomatal openings to reduce internal water loss; horizontal leaf orientation; high shoot density; slow leaf growth rate: pubescent leaf surface; reduced stomatal density; smaller and more compact mesophyll cells; smaller conducting tissues (xylem/phloem); and recessed or protected stomata due to location on the leaf.
- Shoot characteristics that contribute to reduced turf water-use in drier soils are: rapid stomatal closure; rolling or folding of leaves; thick cuticles; leaf senescence; smaller leaves and reduced leaf area; wax load on leaf surface; and positioning of stomata on leaves.

In addition to these shoot-based drought avoidance characteristics, there are very important root-based drought avoidance traits, which are genetic-based and, therefore, have the potential for improvement through breeding and genetics. Important traits contributing to avoiding or delaying tissue dehydration are:

- Size and extent of the root system: rooting depth; rate of root extension or elongation; high number of root hairs; high root length density.
- Maintenance of root viability during high temperatures for cool-season grasses: ability for root regeneration and regrowth (carbohydrate maintenance and partitioning are important in these aspects.

- Root tolerances to factors that stress and limit rooting in the field: high soil strength; low soil oxygen; high soil temperatures; acid soil complex (aluminum or manganese toxicities; plus nutrient deficiencies under high acidity); salt toxicities (sodium and chloride), soil pests (nematodes, root diseases), ability to stabilize cytokinin production during cyclic stresses.
- Nutrient efficiency components: ability to take up nutrients that may be limint to maintain growth, including root growth. Examples, potassium, phosphorus, manganese

Drought tolerance involves physiological characteristics that allow plant tissues to tolerate drought stress once the stress is imposed. Common aspects are osmotic adjustment mechanisms to maintain tissue water content, hardiness, and membrane stability. Osmotic adjustments include accumulation of solutes/osmolytes (glycine, betaine, trehalose, proline, mannitol) to maintain turgor pressure (dehydration stabilization of enzymes and lipid membrane structure/integrity) and continued physiological processes; maintenance of water deficit-responsive proteins (dehydrins) and rehydration-induced recovery proteins (rehydrins); maintenance of oxidative defense functions via antioxidant enzymes or putrescine-generating enzymes; and increased D-ononitol to stabilize solute concentrations.

Hardiness also involves greater membrane stability under low water availability conditions; tolerance of protoplasmic constituents to dehydration; binding of cell water to protoplasmic proteins and carbohydrates; and loss of excess water that contributes to tissue succulence.

Factors that reduce drought tolerance include: poor water drainage (excessive irrigation that keeps root systems shallow); wet or compacted soils; excessive nitrogen; deficient potassium; shade or reduce light intensity; low mowing heights. Factors that reduce carbohydrate loads for maintenance of roots and shoots are: high nitrogen; low mowing heights; shade or reduce light intensity; prolonged high or low temperature extremes; deficiencies in iron, magnesium, manganese, sulfur, and nitrogen; and any injury (scalping, excess traffic).

Escape mechanisms are means that allow the plant to survive severe droughts in the form of dormant tissues or as seed. For example, *Poa annua* may die in the summer but survives as seed in the soil and regenerates under more favorable conditions. All grasses have the potential to go into drought-induced dormancy if there is sufficient time for tissues to acclimate to the stress. If a grass rapidly goes into a drought situation, due to a lack of an adequate root system or in a sandy soil with low water-holding capacity, there will be substantially more tissue damage and in some cases total tissue death.

What Drought Resistance Traits Are Most Important?

Brede (2000) has an excellent discussion of the difference in selecting grasses in arid climates, where essentially all the water is applied by irrigation, versus semi-arid or humid climates, where natural precipitation supplies significant water for plant functions. Basically, in an arid climate the most important factor is shoot-based drought avoidance traits that reduce turfgrass ET under both well-irrigated and limited soil moisture conditions, thereby, reducing irrigation needs. Secondly, if the plant is irrigated in a manner that will allow appreciable tissue moisture stress, drought tolerance capabilities will then be important for survival. Third, if the plant is exposed to periodic drought-induced dormancy, the ability to survive prolonged dormancy is important.

Lastly, a deep, extensive root system is beneficial since it allows longer periods between irrigation events, thus, reducing evaporation losses. But, the deepest root system is not as critical since most water will be added so the plant does not need a deep root system to effectively use natural precipitation.

Within a semi-humid or humid climate, the most important drought resistance components are, first, a deep, and extensive root system that maintains viability during drought stress (Brede 2000; Carrow 1995, 1996; Duncan and Carrow 1999; Carrow and Duncan 2003). Such a grass will be able to make maximum use of natural precipitation events. Secondly, shoot-based drought avoidance traits will be beneficial in reducing ET regardless of soil moisture status. Third, under conditions where the grass may be exposed to periodic tissue moisture stress, drought tolerance characteristics would be required. Finally, if drought induced dormancy periods are likely, the grass should be able to tolerate these conditions.

In some situations, turfgrasses on fairways may be allowed to go dormant for periods of time during severe drought periods. Grasses can survive rather long periods of drought-induced dormancy if they go into dormancy at a slow rate and the grass is healthy. Periodic dormancy of grasses is common in natural settings with good survival. If a grass is not drought resistant or tolerant (drought hardy), it may not have sufficient time to physiologically adjust into a dormant state. Instead, all or most of the tissues die, leaving little live material for recovery once the drought is over. Meyer zoysiagrass grown on the acidic red clay soils of Georgia often does not exhibit good drought resistance and rapidly goes into dormancy with appreciable tissue injury. This grass does not root well into these soils and the normally deep-rooted grass becomes a shallow rooted grass.

Grass tissues that remain alive going into dormancy may run out of stored food reserves before sufficient rain occurs to bring about re-growth of leaves which can then produce food for further growth. If food reserves are depleted, the remaining tissues start to die. How long a grass can remain in a summer dormancy state depends on its health going into dormancy, the length of dormancy, and the temperatures during dormancy---high temperatures depletes food reserves more rapidly. Drought resistant tall fescue, a cool-season grass, developed for Georgia conditions (Southeast cultivar), has survived 10 to 13 weeks of dormancy. Robinson (2003) noted that some tall fescues and perennial ryegrasses survived 10 to 11 months of dormancy and still maintained > 75 % coverage. Other cool-season grasses would be expected to survive for shorter periods of time, while most warm-season grasses will survive within this same time frame or somewhat longer.

Additional Turfgrass Traits for Water Conservation Management.

The combination of high drought resistance and low water use are not the only characteristics required for many golf courses. Additionally, the grasses selected must possess:

- Tolerance to the climatic extremes for the location, especially high and low temperatures.
- Tolerance to common pest stresses.
- Ability to withstand the mowing height required for the particular use.
- Suitable turfgrass quality and performance for the use.

Some turfgrass breeders are now placing more emphasis on drought resistance, particularly the most important component which is drought avoidance via a greater genetic-based root tolerance to soil stresses that limit root development/maintenance and by shoot characteristics that contribute to an inherent low water use (Duncan and Carrow, 1999). Under more limited irrigation regimes, other stresses besides drought are enhanced and will require attention by breeders and turf managers, namely:

- High temperature tolerance for cool-season grasses. Both drought and salinity conditions cause more high temperature stress.
- Wear tolerance. Wear is greater under drought and salinity stresses.
- Salinity tolerance in the case where poor water quality is used,
- Pest tolerance for pests that are favored by reduced growth rates, drier conditions, and possibly salinity.

II. __DROUGHT RESISTANT GRASSES__.

A general ranking to different turfgrass species for drought resistance is noted in Table 6.1. The drought resistance rankings in Table 6.1 are based on certain conditions: a) rankings are based on the most widely used cultivars within the species. Thus, some cultivars may perform better and some worse, b) rankings are based on performance in the region of adaptation for the species, c) rankings are based on field dry-down trials where low water use would be a component of overall drought resistance, and d) rankings reflect performance under conditions where root limiting stresses are not present or are minor. This latter aspect is important since drought performance can be greatly affected if the cultivar is susceptible to any root limiting conditions on a site. As previously noted, Meyer zoysiagrass is an example when it is grown on a acid, kaolonitic soil such as common in the Piedmont region of the USA, where this normally deep-rooted grass does not develop an extensive root system, thereby, exhibiting only fair drought resistance. In studies conducted over the years at the Griffin Experiment Station on such soils, it has be observed that about 80, 10, 70, and 60 % of zoysiagrass, bermudagrass, seashore paspalum, and tall fescue cultivars exhibit severe inhibition of rooting on these soils which contain a combination of acid soil complex and high soil strength stresses. Grasses with a limited root system require more frequent irrigation to maintain quality and total water use is higher. Thus, on sites with soils that have physical or chemical conditions that may limit rooting it is important to select grasses that can develop and maintain good rooting (Carrow 1996; Duncan and Carrow 1999).

As stated, within a species there can be considerable differences in drought resistance of individual cultivars due to genetic-based differences in various drought avoidance and tolerance mechanisms as well as tolerances to root limiting factors. Results from local turfgrass studies at landgrant universities and research institutes can often provide information on the best speicies and cultivars within a species to use (Carrow 1996; Colmer 2003; Robinson 2003; Siefers and Beard 1998, 1999: Broomhall et al. 2002). Brede (2000) and Carrow and Duncan (2001) reported that the following cultivars had exhibited superior drought resistance:

- *Zoysiagrass*: Crowne, El Toro, Palisades (best recovery from stress, least irrigation requirement)
- *Seashore paspalum*: SeaIsle 1 (enhanced root growth, rapid root water uptake at deeper soil layers, maintenance of root viability at the surface during dry-down, and rapid root regeneration after rewatering)
- *Centipedegrass*: TifBlair (same attributes as the paspalum above)

- *Tall fescue*: Southeast (plastic root system, persistence and survivability under extreme heat/humidity/drought prolonged conditions)
- *Bermudagrass*: Santa Ana and Common (excellent quality and ground coverage)
- *Bahiagrass*: Argentine, Pensacola

Table 6.1. Drought avoidance and tolerance capabilities of turfgrasses.

Type of grass	Avoidance	Tolerance/ Recoverability	Overall Drought Resistance
Cool Season grasses*			
Kentucky bluegrass	fair	medium	**medium**
Tall fescue	excellent	good	**good/excellent**
Fine fescues	fair	good	**medium**
Perennial ryegrass	medium	poor	**fair**
Creeping bentgrass	fair	poor	**fair**
Annual bluegrass	very poor	very poor	**very poor**
Rough bluegrass	very poor	very poor	**very poor**
Colonial bentgrass	poor	poor	**poor**
Warm-season grasses			
Bermudagrass	superior	excellent	**superior**
Buffalograss (Amer.)	excellent	excellent	**excellent**
Zoysiagrass	excellent	good	**good/excellent**
Kikuyugrass	excellent	excellent	**excellent**
St. Augustinegrass	good	good	**good**
Centipedegrass	good	medium	**good**
Bahiagrass	excellent	good	**excellent**
Seashore paspalum	excellent	good	**good/excellent**

From: Brede (2000); Kenna and Horst (1993); Siefers and Beard 1999; Carrow 1996

In addition to assessing and developing drought resistant cultivars among the "traditional" species, non-traditional species bred for superior drought resistance and/or other stress resistance traits will become more common (Duncan and Carrow 2001; Loch, D. S., E. Barrett-Lennard, and P. Truong. 2003; Brede 2000). Aldous and Chivers (2002) provide information on the use on several species that are currently not of wide use as turfgrasses but have promise for development. Also, Brede (2000) has considerable information on a number of less common grasses that may be useful for certain golf course situations including grasses that can be grown with less than 450 mm annual precipitation: Arizona fescue, big bluegrass, blue grama, Boer lovegrass, bottlebrush squirreltail, buffelgrass, bulbous bluegrass, Canby bluegrass, crested wheatgrass, curly mesquite, desert saltgrass, galleta, giant bermudagrass, green sprangletop, Idaho fescue, Indian ricegrass, Lehmann lovegrass, natalgrass, Nuttal alkaligrass, prairie junegrass, prairie sandreed, purple three awn, red grama, sand dropseed, Sandberg bluegrass, Siberian Wheatgrass, sideoats grama, spike muhly, standard crested wheatgrass, streambank wheatgrass, timothy, Western wheatgrass, Wilman lovegrass

While drought resistant grasses are widely used on golf courses, especially in warm-season zones, irrigation management plays a primary role in whether these grasses perform as water efficient grasses. Poor irrigation practices can cause a drought resistant grass with normally low water use to exhibit much greater water use. Deficit irrigation practices suitable for the grass and site situation will maximize drought characteristics of the grass.

Chapter 7.

Golf Course Design for Water Conservation

I. Minimize Close-Cut, Highly Maintained Turf Area

II. Water Management Aspects.

Chapter 7.

Golf Course Design for Water Conservation

On larger, more complex sites, such as golf courses, during construction or renovation planning stages many decisions can be made that will either foster water conservation or greatly limit it. In previous chapters, issues of irrigation design, use of alternative water sources, and selection of drought resistant/low water-use grasses were discussed in the context of water conservation strategies. In this chapter, the focus will be on golf course design features to enhance water conservation.

I. MINIMIZING CLOSE-CUT, HIGHLY MAINTAINED TURF AREA.

Considerable area on a golf course does not need to be maintained as a closely mowed, highly irrigated turfgrass. Using alternative landscape features on selected areas that do not hinder the game of golf can result in substantial water savings. Numerous design “looks” can be achieved with combinations of design features such as:

- Use of various mulch materials as a ground cover. Pine mulch is often used in the Southeast and helps in retaining water while protecting the soil.
- Using alternative, drought-resistant grasses that are left un-mowed in non-landing areas;
- Higher mowing heights can often be used on parts of the fairway or adjacent roughs that may receive little or limited irrigation. Golfers seem to accept brown or drought affected turf when it is mowed higher than on the primary landing areas or left un-mowed, but may not accept as much discoloration or lower plant density on the closely mowed high-use areas. Since golf courses must compete for local, and in some locations, national and international customers, the visual aspects on the close-mowed playing area influences marketing and the associated tourist industry. Also, courses with high play will require sufficient irrigation to maintain a good turf under the continuous traffic stresses. Thus, the primary landing areas on fairways, along with tees and greens normally require adequate irrigation for play, visual impact, and recovery from traffic.
- In other instances with less demand or play or competition for customers, dormant, semi-dormant, or lower quality turf may be very acceptable on large expanses of many golf courses, including primary landing areas on fairways. However, greens and tees would require adequate irrigation to maintain a good cover and recover from wear stress.
- Incorporation of adapted, drought resistant low growing ground covers, shrubs, and trees that require minimal irrigation and possess unique looks in areas where they will not interfere with routine play.
- Features such as rock, sand bunkers, and non-irrigated mounds can be used in some locations.
- Extra wide expanses of closely mowed, highly maintained fairways should be avoided or alternative materials used in the out-of-play areas to reduce irrigated area.

- Contouring to avoid excessive slopes, mounds, and berms within any areas that would require highly maintained turf. These features are difficult to irrigate even with an excellent irrigation system. However, if browning or even dormant turf on these features are acceptable [i.e.—no irrigation is then needed], then they can be used. In some cases where a berm or mound is necessary and desirable to irrigate, low volume spray heads may be installed on a separate zone to allow slow, pulsed irrigation to achieve water infiltration.

Some current golf courses under severe water limitations may consider design alterations to reduce the area of closely mowed, and highly maintained turfgrass. Changing design must be carefully done in a manner that does not interfere with the game of golf/playability. When design changes are made, the irrigation system must also be substantially modified to eliminate irrigation on many sites, but maintain good zoning and uniformity of application on the turf areas.

Golf course owners and managers should be aggressive in quantifying costs involved with any changes for the purposes of water conservation. Water agency officials, politicians, environmental advocacy groups, and the general public should be informed of costs to your business for implementation of specific water conservation strategies. When water conservation measures are promoted for implementation by the homeowner that will cost money, assistance is often provided by means of water rebates, special funds to help make changes, or tax incentives. However, many of the audiences noted do not understand the cost to golf courses—that often have to implement more strategies and some, such as using a poor quality alternative water source, carry very high costs with the change.

II. __WATER MANAGEMENT ASPECTS__.

Landscape design can markedly influence the potential for water harvesting and prevention of undesirable runoff. Examples include:

- Careful contouring and surface drainage to capture stormwater in on-site storage lakes.
- Use of sub-surface drains to capture storm water and move it to storage lakes.
- Avoiding steep slopes that foster runoff on sites where it is desirable to allow water infiltration into the soil for plant use.
- When soils are very high in clay content and have very low water infiltration rates, sand-capping with a 4 to 8 inch layer of sand above the heavy soil can greatly improve water infiltration and capture from irrigation and rainfall. Sometimes the sand-cap is added later by vigorous sand topdressing and cultivation over several years.
- Extra excavated or bermed ponds can be included in the design to maximize water harvesting and storage capacity, especially in semi-arid or humid climates with periodic storm events.
- Sometimes water is moved onto a golf course or within a golf course to a storage pond or lake through canals, ditches, or pipelines. Water losses in these conveyance features should be minimized. Canals or ditches may be lined to eliminate leaching losses. Excess vegetation such as large trees that withdraw water fro ditches may be controlled. Pipeline should be checked for leaks.

- During flood flows in streams or rivers, high flow diversion of water into storage ponds may be feasible. Also, high volume pumps may be used to fill storage ponds during high flow periods. Dry ponds or detention basins can be constructed to allow filling with water when high flow events occur.
- Lining of excavated ponds with impervious materials such as clays or synthetic liners can greatly reduce leakage losses, especially on soils with high percolation rates.
- Construct storage ponds deep to minimize surface area for evaporation losses.
- Install staff gages to measure the water level and check periodically for leakage and monitor lake levels.
- On sites where the irrigation water contains high soluble salts and/or sodium, storage lakes and ponds may be lined to prevent seepage of salts into the water. Sites with existing saline or sodic soils can have the same problems.

When near coastal areas, during prolonged dry periods salt-water intrusion sometimes occurs either into irrigation wells or sometimes directly into lakes and ponds. Water sources should be periodically tested on sites susceptible to this problem. Once the water source is salt-laden, it often requires dilution to achieve useable water.

Chapter 8.

Management Practices For Water Conservation

Chapter 8.

Management Practices For Water Conservation

Plant morphological, anatomical, and physiological characteristics that increase drought/salt avoidance and drought/salt tolerance are: a) genetically determined with variation between species and among cultivars of a species; and b) these features are also influenced by cultural practices, environmental (soil and air) conditions, and turf use (wear, soil compaction). Cultural or management practices can affect the turfgrass and soil system by several means:

- Alter the soil water balance by influencing runoff, evaporation, transpiration, soil water retention, and leaching.
- Plant water status by influencing succulence, osmotic adjustment, rooting, shoot characteristics that affect ET,
- Influence salt problems such as poor structure, high salinity, high sodium, or specific ion toxicities in situations where the water quality is poor.

Thus, cultural practices have a profound influence on turfgrass water relations. They have the capability of improving conditions so the plant can be near its genetic capability in drought/salt resistant, or, conversely, improper cultural practices can negate the plant's inherent genetic potential.

Several authors have reviewed turfgrass management practices and water use (Balogh and Watson 1992; Brede 2000; Carrow et al. 1994; Gibeault and Cockerham 1985; Kenna and Horst 1993; Kneebone et al. 1992). **The most important management factor that will influence turfgrass water relations for the positive or negative is irrigation scheduling** (see Chapter 5). A site may have the most drought resistant grass, the best designed irrigation system, and the latest in other water conservation strategies, but as Dr. Doug Brede (2000) notes "Turfgrasses are only as water frugal as the person with their finger on the sprinkler button". Improper irrigation scheduling can completely negate the drought resistant/low water use characteristics of the best drought resistant grass. Brede (2000) summarized several important reasons for conserving water that goes beyond water conservation, namely:

- Better wear tolerance.
- Reduced soil compaction.
- Fewer weeds.
- Fewer diseases and insects.
- Fewer clippings.
- Better fertilizer and pesticide use efficiency.
- Less thatch.
- Reduced cost.

With a good irrigation-scheduling program [frequency of irrigation, quantity of water to apply, timing of irrigation during the day for best efficiency, and application in a manner to allow infiltration], other turfgrass management practices can then be used to enhance water conservation. Table 8.1 summarizes the various management practices affecting turf water relations and their relative importance.

Table 8.1. Turfgrass cultural practices that influence turfgrass water relationships and relative importance in affecting water relations.

Cultural Practice	Relative Importance[a]
	1=most, 4=least
Irrigation scheduling program	1
Selection species	2
Selection of cultivar	2
Turfgrass site use and quality expectations	2
Mowing height—within the tolerance range for the grass	2
Nitrogen fertilization	2
Soil cultivation---for water infiltration, rooting	2
Soil modification—for water infiltration, rooting	2
Potassium fertilization	2
Alleviation of salt-affected soils---correction of high salinity and specific ions toxic to roots (Na, Cl, B)	2
Alleviation of sodic soil conditions	2
Liming acid soils—especially acid soil complex conditions.	2
Mowing frequency	3
Mowing blade sharpness	3
Plant growth regulators	3
Wetting agents	3
Soil insect control	3
Soil disease control	3
Phosphorus nutrition	4
Iron nutrition	4
Antitranspirants	4
Other pesticides with PGR activity	4

[a]Ranking is based on literature and experience of the authors. On any particular site, the relative importance may change; for example, a serious grub infestation would require immediate insect control in order to maintain turf roots for water uptake.

Chapter 9.

Additional Water Conservation Strategies

I.	**Landscape Areas Other Than The Golf Course.**
II.	**Indoor Water Conservation Measures.**
III.	**Developing Water Conservation and Contingency Plans.**
IV.	**Monitoring and Modifying Water Conservation Strategies.**
V.	**Education.**

Chapter 9.

Additional Water Conservation Strategies

I. LANDSCAPE AREAS OTHER THAN THE GOLF COURSE.

Golf courses include appreciable landscape areas beyond the bounds of the actual golf course playing area. Inclusion of water conservation practices into these areas can result in significant water savings. Many of the same concepts used on the golf course area also apply to these landscape areas, but often in a less intense manner. In such landscapes, the concepts embodied in **Xeriscape** are applicable and are presented in detail by Vickers 2000, Wade et al. 2003; Xeriscape ™ Council, 2003; and the Inter. Turf Producers Foundation 2002. Vickers (2000) has the most in-depth discussion of Xeriscape concepts, while state or regional publications will contain the best list of adapted plants to use. In Chapter 10 (Benefits and Costs), several issues that relate to the Xeriscape movement and changes within this movement are discussed that are relevant to golf courses. Some individuals or advocacy groups attempt to define certain Xeriscape concepts to fit their own agenda---thus, not everyone views some of the concepts in the same manner. **Typical landscape water-efficiency measures are:**

1. Landscape planning and design. Careful location of plants and avoiding mixing plants with different water needs can assist in irrigation design and scheduling. Essentially, various "microclimates" are created that allow more efficient irrigation design and scheduling, while limiting high water requirement plants to confined areas.
2. Selection of low-water use turfgrasses and other landscape plants or features. The focus here is to use drought resistant and low water requiring plant materials. Also, hardscape features may be used.
3. Landscape irrigation system design and water conservation devices. Turfgrass areas, trees, shrubs, and flower beds will all require specialized design and zoning; often using a combination of different sprinkler heads and nozzles.
4. Landscape irrigation scheduling for water-use efficiency.
5. Soil improvement. The focus is toward improving the soil where possible to enhance plant performance/rooting, soil water holding capacity, and water infiltration.
6. Water harvesting at the home lawn level may be incorporated in some locations (Waterfall 1998). Harvested water can then be used for landscape irrigation, washing of equipment, or other non-potable uses.
7. Mulching where needed to conserve water.
8. Maintain the turfgrass, other water-efficient landscape plants, and irrigation system to optimize water conservation.
9. When water decorations or fountains are included consider water conservation practices appropriate to these features, such as water recirculation.
10. Practices to reduce water losses related to swimming pools, such as: use of covers when not in use to reduce evaporative losses; refilling only when needed; lowering the water level to prevent splash losses; repair of leaks; maintain a clean pool to reduce the

frequency of backwashing filters; and using backwash water for other uses when the chlorine levels are sufficiently low, usually < 3 ppm chlorine.

II. INDOOR WATER CONSERVATION MEASURES.

Golf course clubhouse, maintenance facilities, and other buildings can implement indoor water saving measures as part of an overall water conservation plan. Common indoor water-efficiency measures noted by Vickers (2000) are:

1. Conduct an indoor water audit to identify possible water-efficiency measures—often an outdoor water audit can be done at the same time.
2. Correct any leakage problems
3. Use water efficient devices---low volume toilets; low volume urinals; low volume showerheads; low volume faucets; high efficiency clothes washers; water efficient dishwashers and dishwashing practices.
4. Graywater is untreated used household water that does not contain human wastes.Examples would be water from showers, bathtubs, or other devices that do not come into contact with human wastes. Graywater should not come from sinks, cloth washers, or dishwashers since these may contain human wastes. Larger facilities such as club houses or maintenance facilities may find it practical to expend the costs to develop such a system. Uses of graywater include equipment washing, toilet flushing, and landscape irrigation.

Due to the size of some clubhouse and maintenance facilities, water saving measures focused on commercial kitchens and restaurants, laundries, and cooling systems can result in significant water savings (Vickers 2000). Water and energy audits can be conducted for each of these items.

III. DEVELOPING WATER CONSERVATION AND CONTINGENCY PLANS.

A successful water conservation program – whether at a specific turf site or at the local, regional or national level – requires the development of a science-based, detailed water conservation plan that incorporates various strategies. A water conservation plan conserves water on a continuous basis. The overall focus of this document has been to provide information to assist golf course superintendents and course officials to develop “BMPs for Golf Course Water Conservation” that would be specific to their conditions. In addition to on-going water conservation plan, a golf course should consider developing a water contingency plan, where a contingency plan deals with water-conserving measures in time of severe shortages.

At the golf course level, it is essential that club owners, members and officials assist in formulating these plans and understand their implications. Club policies must include water conservation. Everyone associated with golf clubs (owners, pros, members, managers, superintendents) should educate public officials, implement a proactive attitude of environmental stewardship, and become involved in the political process concerning water conservation. It is likely that in the future, clubs may have a position devoted to maintenance of water conservation practices, where the individual would conduct on-going water audits, maintain the irrigation system, and have other responsibilities related to a club water conservation plan.

IV. MONITORING AND MODIFYING CONSERVATION STRATEGIES.

Monitoring a water conservation program may include assessing its success by documenting water use (for example, by water meters) and relating it to turfgrass performance. Periodic site assessment audits can identify leaks, irrigation head malfunctions, design limitations, irrigation scheduling problems or other wasteful water use. As with pesticides, monitoring water use and conservation will likely be mandated as part of a BMP program for water conservation. Sensors used to assist in water management, can also become monitoring devices for documentation purposes. For example, obtaining detailed soil moisture data by depth from soil sensors may be necessary to justify an irrigation event during drought periods if a regulatory agency questions the need for irrigation.

V. EDUCATION.

Continuing education will be necessary for golf course superintendents. Superintendents will be required to develop and implement comprehensive BMPs for water conservation and water quality; use sophisticated technology, which is evolving to assist in management decisions and to quantify results; and plant new grasses and carry out management regimes that complement water conservation. Additionally, on many sites water quality issues will require considerable expertise to deal with salt and nutrient problems. Three complex management issues will often converge on a site due to the demand for water conservation. Each of these issues is complex and requires a systems approach to management as well obtaining and understanding considerable information. The three issues are: a) irrigation scheduling, b) dealing with salts, sodium, and/or nutrients associated with poorer water quality, and c) developing and maintaining a good fertilization program.

Educational efforts will need to be developed for other audiences concerned with water conservation on golf courses, such as policy makers, water management authorities, turf management students, club officials and members, crew members, etc. The challenge for university Extension specialists and research scientists will be to produce in-depth informational packages containing both scientific principles and specific practicum’s for golf course superintendents and consultants in the industry (Carrow et al. 2001). Superintendents will be more likely to embrace and use the new technology if they have ready access to well-trained consultants and specialists. However, golf course superintendents will be challenged to maintain a high level of expertise to wisely utilize consultants and specialists, especially where water quality problems may induce serious salinity or nutritional problems.

Chapter 10.

Benefits and Costs

I.	**Tell Your Story In The BMPs Document.**
II.	**Benefits of Turfgrasses and Turf Facilities.**
III.	**Balance in “Benefits and Costs” Considerations.**
IV.	**Assessment of “Benefits and Costs”.**

Chapter 10.

Benefits and Costs

I. TELL YOUR STORY IN THE BMPs DOCUMENT.

In Chapter 1 (Components of a Golf Course Water Conservation Program) and other chapters, it was suggested that as an essential part of each golf course BMPs document on water conservation should be three sections, namely:

a) The "benefits and costs" of implementing conservation strategies,
b) Indication of all past water conservation practices that have been implemented and the costs associated with those practices; and
c) Defining the benefits of turfgrass and turfgrass facilities to society, the economy, and the environment.

This information is not just for the golf course officials and members, but more importantly for education of other **"stakeholders".** A stakeholder is defined as anyone who could be affected by the BMPs either directly or indirectly. Examples of this wider stakeholder audience are: political decision makers, water agency personnel, environmental advocacy groups that may have an "environmental agenda", and the public (i.e. society). Many of these stakeholders do not even realize that they could be affected in a positive manner by golf courses. If the golf course officials do not take a strong role in education of stakeholders, future decisions made by these same stakeholders may well be made in the absence of essential information. Assessment of benefits and costs of implementing water conservation practices on all stakeholders is essential to understand implications of these changes. The immediate owner or manager of a turf site will naturally assess the direct costs involved to implement water conservation measures. However, other stakeholder often do not have the background to understand the benefits of water conservation measures a club is fostering nor the costs---unless they are educated with real world case situations.

In this Chapter, basic information is presented that may be included in a BMPs document to address the issues of: a) benefits of turfgrasses and turfgrass facilities to society, the environment, and economy, and b) balance in considering the "benefits versus costs" of implementing water conservation program on golf courses.

II. BENEFITS OF TURFGRASSES AND TURF FACILITIES.

Vickers (2001) and the Western Resources Advocates (WRA)(2003) *Smart Water* document provide much discussion on benefits of reducing water consumption in landscapes, but limited discussion concerning the potential for any adverse effects except for: a) facility costs to implement changes required by a plan at the home owner level; b) some potential adverse environmental impacts if overuse of water on turf resulted in adverse in-stream flow, over-pumping of groundwater, or reduced wetland area; and c) one mention of fire hazard from native grasses. But, any discussion of the environmental, economic, or recreational benefits of turfgrasses and the turfgrass industry is lacking. This is often the case when "stakeholders" beyond the turf industry discuss this industry. In contrast, Cathey (2002), Beard and Green (1994), and Gibeault (2002) note a broad array of benefits that turfgrass and the turf industry contribute to society, the environment, and economic well-fare (Table 10.1).

III. BALANCE IN "BENEFIT AND COST" CONSIDERATIONS.

With an understanding of the various benefits and roles that turfgrasses contribute (Table 10.1), it is easier to make are good case for balance when "stakeholders" beyond the golf course confines consider the need for water conservation on golf courses and other turf sites. Of special concern are:

- When governmental agencies, politicians and general public focus on golf course water conservation but with little attention to: a) benefits that golf course turfgrass areas and golf course facilities contribute in the realms of the environment, economy, recreational enjoyment and participation, and enjoyment of life; b) adverse effects that can occur when a single issue is viewed without taking into context the effects on other stakeholders; and c) the very significant costs that can occur when golf courses implement many of the water conservation measures. These costs should be in the context of what other water users are bearing in terms of costs—i.e. is their fairness in treatment of various water users and industries? Also, when cost rebates or incentives for implementing water conservation measures are used, is the golf course industry considered along with other groups.
- Narrow focus "environmental" advocacy groups may target golf courses as a means of achieving their agenda. The reality of today's world is that some groups cloak extremist's views in an environmental mantle. The vast majority of people are interested in the environmental and respect true environmental stewardship, including golf courses—if they are informed and understand what true environmentalists, such as golf course superintendents, do to foster the environment. However, advocacy groups can be very aggressive in fostering their agendas without considering the views of others or even very harmful outcomes if their agendas were achieved.

One means to educate sincere audiences related to golf course benefits is to include strong sections within any BMP documents that deal with the positive aspects of golf courses. Once such material is developed and incorporated within such documents, this becomes an important informational resource not just the governmental agencies, but for other audiences---if golf facilities will use the information in an aggressive manner. Many states are in the process of developing state-wide water conservation plans or altering current plans for all water users, including the golf course industry. For golf course representatives that are working with agencies and politicians in development of state-wide or regional conservation plans, it would be wise to insist that the governmental document include the type of background information

Table 10.2. Benefits that turfgrasses and turfgrass sites contribute to the environment, society, and economics.

Functional/Environmental

Prevent soil loss from wind erosion
Protect from soil loss by water erosion
Reduce air borne dust
Reduce sediment movement into water features
Capture water from runoff for soil moisture recharge
Reduces climatic temperature
Reduces sod/soil surface temperatures on sports fields and turf areas used for enjoyment
Entrapment of organic chemical pollutants and enhances degradation
Contributes soil organic matter and enhances soil quality
Fire protection by providing a green zone that is not combustible
Glare reduction
Air pollution control
Many turfgrass sites incorporate wetlands, other water features, trees, shrubs, and natural areas for diversity of flora and fauna.

Recreational

Integral part of many community, school, college, and professional sports---soccer, golf, football, baseball, field hockey, etc.
Enhances participation in outdoor activities and sports
Contributes to a safe playing environment for athletes---cushioning and surface stability, smoothness
Contributes to spectator enjoyment
Low cost, natural, living surface that can be self-repairing

Aesthetic

Beauty contributes to quality of life
Feeling of mental well-being---horticulture therapy
Community pride
Ornamental compliment to trees, shrubs, and flowers---
Allows individuals to express themselves and influence their surroundings through individualized landscapes

Economic

Direct revenues, taxes, jobs from sports events and golfing in the local economy
Enhancement of tourism---in some cases regional tourism is built around the golf industry
Parks, sports venues, golf courses, and landscape industry contribute jobs, money, and taxes
Manufacturers and suppliers of turfgrass equipment, supplies, and services contribute jobs, money, and taxes in the economy
Enhanced home and properties values and, therefore, greater tax revenues
Contributes to purchase of non-turf items goods and services in the community ---restaurants, dry cleaners, service stations, etc

After Beard and Green 1994; Parsons et al. 1998; Inter. Turf Producers 2002; Gibeault 2002.

addressed in this chapter. Also, golf representatives may wish to insist that when an individual golf course must develop a site-specific BMPs document for water conservation, that this type of information (i.e. see the original three sections noted in the first paragraph of this chapter) be included. This provides an “official” statement and information for educational use.

To illustrate how regulatory decisions that are narrow based or how single issue environmental groups may result in adverse effects, some examples with references are presented. The document *Water Right: Conserving Our Water/Preserving Our Environment* (Inter. Turf Producers 2002) has other examples that could be cited.

Case 1. Changing Nature of the Xeriscape Concept.

While ‘Xeriscape™’ is normally thought of as homelawns or general grounds, the concepts that arise from this effort has impact onto other turf areas, such as golf courses, since many of the concepts become the basis for regulations. Thus, an understanding of the changing nature of this movement is important for golf course officials. In 1981 the ‘Xeriscape™’ concept was initiated by a task force for the Denver Water Department (Vickers 2001) and was strongly influenced by the report of Flack et al. (19770. Initially, the xeriscape concept was for ‘limited turf use” on homelawn and general grounds, but this has changed over the years as the value of turfgrass in the landscape was increasingly recognized (ITPF 2002; Wade et al. 2003). Wade et al. (2003) stated in their publication:

> “Turfgrass is one of the most versatile and functional plants in the landscape. It provides one of the best recreational surfaces for outdoor activities. From a water management standpoint, turf is recognized as one of the most effective plant covers to reduce runoff and erosion while recharging the ground water, which results in more efficient use of rainfall. Turf has a tremendous mitigating effect on the environment. For example, research documents that a turf area can be as much as 30°F cooler than a concrete or asphalt surface and 10°F to 14°F cooler than bare soil. This cooling effect from the average lawn is equal to more than eight tons of air conditioning; the average home central-air unit produces three to four tons. Turf also absorbs dust and other air pollutants and produces oxygen. However, in the typical landscape, turfgrass occupies the largest area and, when managed incorrectly, receives the largest amount of irrigation. You can realize considerable water savings by irrigating only the turf in high impact, highly visible areas of the landscape. All turfgrasses recommended for Georgia can be used in any water-use zone and can survive most droughts without supplemental irrigation once they are established. During drought periods, a healthy turfgrass will wilt and turn brown, then regain its normal color and growth when it receives adequate water. You must be willing to accept a loss of quality and appearance during periods of limited rainfall when growing turf in non-irrigated areas of the landscape.”

Even within the arid regions, use of turfgrass has become normal as noted by Welsh (2002) and the Xeriscape Council (2003):

> “Xeriscape is not necessarily lawn-less landscaping. Some lawn, even of species that are more highly watered, can be consistent with wise water use. "Less-lawn landscaping", rather than "Lawn-less landscaping" is an appropriate statement…. limited areas of more highly-watered landscape are completely consistent with wise

> water use. For example, heavily-irrigated athletic field turf makes sense, since it recovers quickly from heavy use." Welsh (2002) further stated that as the original "Xeriscape concept matured and spread, the principle of limited turf use was increasingly scrutinized by horticulturists and turf experts. Today's Xeriscape movement incorporates a more holistic approach to reducing turf irrigation, fully recognizing that the type of plant materials or irrigation in the landscape has as much of an effect on water consumption as the human factor and good landscape water management…through the principles of Xeriscape, turf irrigation can be reduced while the many benefits of turfgrass can still be derived….many turfgrasses are drought-tolerant and can survive extreme drought conditions. The grass may turn brown for a while, but rainfall will green it up again."

Vickers (2002) noted a more recent movement "beyond xeriscape" that contrasts with the previous attitudes concerning xeriscape concepts—i.e.the movement to define xeriscape as the use of only natural or native plants. Vickers states " In many ways, the natural landscaping approach surpasses Xeriscape and similar water-wise principles by advocating design and management concepts that rely on native plants and minimal, if any, irrigation other than rainfall". The goal of the natural landscaping movement is encompassed in the Wild Ones (2003) web-site:

> "Native plants are those that evolved naturally in North America. More specifically, native plants in a particular area are those that were growing naturally in the area before humans introduced plants from distant places. In eastern and central North America, native plants typically grew in communities with species adapted to similar soil, moisture, and weather conditions. Some of the widespread communities included oak-hickory-chestnut and beech-maple forests, tallgrass and shortgrass prairies, and freshwater marshes. Additional communities occupied specialized niches, including savannahs, fens, bogs, flood plains and alpine areas."

Thus, proponents of the native plant movement foster an impression of interest in environmental stewardship by using the mantle of 'xerispace' and water conservation, but change this concept to fit their narrow focus purpose---use only native plants. When a good idea is taken to the extreme as "the only idea", then great potential for harm can arise. The sole us of native plants is without a balance of what other adverse human and ecological effects may result--- fire hazard, dust hazard, etc (see the next Case study). These contrasting views illustrate that all "Xeriscape landscape design" concepts are not equal---which one is used for water conservation purposes has a dramatic effect on the potential for environmental and human hazards. Additionally, the landscape design focus must not one-dimensional by focusing on minimizing the turf area, but must apply all of the Xeriscape principles: planning and design, soil improvement, appropriate plant selection, practical turf areas, efficient irrigation design and scheduling (including the human factor), mulching, and appropriate maintenance (Wade et al. 2003).

As with the initial Xeriscape concept with the goal to eliminate grass from the landscape, the natural landscape movement ignores benefits of turfgrass in the environment, society, and economy. Sound science and a balanced approach will be required by the turfgrass industry to counter the natural landscape trend. However, it is interesting that one extension of the native plant movement to use only native plants would be the loss of many of our current food crop plants and any improved food or landscape plants of all types. The next case study illustrates how a one-dimensional approach can cause unexpected harm.

Case 2. Eliminate Turf—At What Cost?

Careful application of water conservation strategies can reduce turfgrass water use, but after a point the turfgrass cover and associated benefits will start to decline. A similar situation can occur for water restrictions on any agronomic or horticulture crop. For example, strategies to improve water-use efficiency on cotton can reduce water use to a point while still maintaining yield; however, if water restrictions are too severe, the crop may loss yield and quality, which if continued would adversely affect land values. Therefore, as a part of an overall water conservation plan, actual water conservation/savings must be balanced by potential effects that may arise---economic, functional/environmental, recreational use of the site, and aesthetics---not just on the specific site but also on the local and broad economy and environment. A couple examples illustrate this point:

- When China removed all turf and many trees from Beijing public spaces during the Cultural Revolution in the 1960's the result was major air pollution from dust storms, related health problems along with higher air temperatures within the city (Inter. Turf Prod. 2002). Revegetation with trees alone did not resolve the problem but required turfgrass cover. Recently, the People's Daily (2002) reported "Beijing will take drastic moves to eliminate the sources of dust so as to reduce the amount of dust people breathe in everyday…worksites that refuse to plant trees shall be taken back….and shall be turned into lawns put under the management of gardening departments".

- Mowed turfgrass as an effective fire buffer compared to non-turf vegetation and the influence on fire hazard and higher homeowner insurance is not a new issue (Cress 1977). "Firewise" landscaping for the wildland-urban interface suggests that zone 1 (30 feet ring around home) and zone 2 be well-irrigated, low growing, and low flammability species; zone 3 to low-growing plants and well-spaced trees in this area, with love volume of vegetation for fuel (Firewise, 2004). Periodic fires in the wildland-uban areas of Australia and the western USA demonstrate the wisdom of this approach. Interestingly, this illustrates how a extreme environmental focus of a narrow issue group can often be addressed by using the findings of other balanced, and respected environmental groups that are not necessarily a part of the turfgrass industry.

IV. ***ASSESSMENT OF BENEFITS AND COSTS.***

In summary, a benefits and cost assessment summary should address all stakeholders and include such items as:

1. Benefits.
    - Direct and indirect to the owner/manager and user of a site.
    - Direct and indirect to other stakeholders, including water savings but also other benefits—society, economic, environmental.

2. <u>Costs (direct and indirect) To the Facility.</u>
    - Facilities costs for past and planned implementation of water conservation strategies---irrigation system changes, water storage, pumping, new maintenance equipment
    - Labor needs
    - Costs associated with changes in maintenance practice, different irrigation water source (water treatment, soil amendments, etc.)
    - Determine any incentives to make conservation changes---water costs, government rebates, etc.

State any costs that may impact the community if water conservation strategies are implemented (especially mandated ones), such as revenue loss, job loss, etc.

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APPENDIX A. States Using a BMPs Approach To Golf Course Water Conservation.

<u>Case Study 1: AZ.</u> (David L. Wienecke) USGA Agronomists, Southwest Region
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<u>Introduction</u> - Conscientious precision irrigation practices are essential in Arizona and throughout the arid Southwest due to limited water resources. Public concern regarding golf course water use continues as Arizona suffers through its 5^{th} severe drought year. A historical fact of life in the Southwest is the cycle ranging from extreme drought years to reduced drought severity periods as a result of increased precipitation. These cycles coupled with continual population growth in the region require a planned water management approach if current life quality is to continue. Water regulators have begun collaborating with researchers and golf courses to attempt development of water conservation measures that ensure the minimum amount of irrigation water is used to maintain golf course quality.

Traditional regulatory water conservation measures have been based on restricting irrigated turf acreage and irrigation scheduling. A Best Management Practices (i.e. BMP) irrigation approach is being pursued in Arizona as a proactive alternative to traditional conservation methods. BMP procedures would provide regulators assurance of scientifically based turf requirements with documented water conservation by precision water use in a reference evapotranspiration (i.e. ETo) based water budget irrigation application. BMP for irrigation also provide irrigation practitioners with a factual basis of making irrigation application and management decisions for responsible irrigation water use.

<u>Action taken</u> - March 24, 2004 marked the first step in these new developments during the USGA Arizona Regional conference at Phoenix Country Club in Phoenix, Arizona. This conference brought together for the first time representatives from the water regulatory community and the golf industry irrigation water users. Speakers from the Tucson and Phoenix active management areas of the Arizona Department of Water Resources (ADWR), the Arizona Governor’s Drought Task Force, the Cactus and Pine Golf Course Superintendent’s Association, the University of Arizona, the Arizona Golf Association, the Professional Golfers Association (PGA), and the United States Golf Association (USGA) joined together to develop consensus and plans for ensuring responsible stewardship of the state water resources.

The conference showed that golf is big business in Arizona. Golf is a $1.5 billion industry with the annual revenues at golf facilities exceeding receipts from dairy farms ($173 million), cotton ($233 million), and vegetable producers ($258 million) in the state.

Government employees involved in public policy and water regulation voiced concerns about the public perception of golf courses as major water users even though golf course water use figures show golf to be a minority user of water (e.g. Water use figures from Tucson ADWR: Municipal 48%, Agriculture 30%, Mining 12%, Golf 6%, other industrial 4%). Best Management Practices hold the key for bringing regulators and water users together to develop scientifically based water conservation practices that are supportable and understandable by regulators, golf course water users, and the public.

Highlights of the current status in Arizona golf course irrigation BMP are listed below:

- Members of the Cactus and Pine Golf Course Superintendent's Association have supported the concept of BMP development in conjunction with ADWR, the USGA, and the University of Arizona. Two new research projects by David Kopec and Paul Brown were approved for funding by Cactus and Pine GCSA August 10, 2004 to answer questions needed for developing data that can be used in a fact based BMP document for Arizona. This research will try to define physiological differences between adequate irrigation and deficit irrigation, define the physiological requirements of salt affected golf course turf under water conservation irrigation limitations, define the influence of topography, soil types, area size and edge effects, and other factors essential for accurate physiological irrigation requirement models under drought affected golf course turf.
- Research by the University of Arizona will be used to identify factual irrigation water use data for healthy turf compared to deficit irrigation. A water budget based on ETo (i.e. Reference evapotranspiration (ETo) with appropriate crop coefficients) will be developed to specify different levels of irrigation ranging from optimal turf irrigation to deficit turf irrigation (i.e. water conservation in drought years). This research shows water conservation procedures must also account for salt affected turf irrigation adjustments, winter overseeded turf adjustments, and natural precipitation adjustments. (As an example BMP could assume a distribution uniformity (DU) of 80%, 100% of ETo for 10 days during spring transition, 110% ETo in October during overseeding, and site specific ETo replacement levels for optimal turf during each month through the year, no salt limitations, and 50% of rainfall precipitation being effective for turf use).
- Since the current BMP DU model assumes a DU of 80%, irrigation non-uniformity resolution procedures in conjunction with adequate cultivation to maintain adequate porosity is essential for effective water conservation programs. As an example a 10% DU improvement can result in a 2.5% to 5% water use reduction with corresponding improvements in turf health and play quality.
- Turf edges require more water compared to plants inside larger turf areas. Research examples found 7% to 11% additional water is needed to maintain turf quality in the afternoon while 6% to 8% additional water is needed to maintain turf quality in the morning. 5% to 10% more water is needed in small turf areas (i.e. less than 60 feet from edge) compared to turf in larger areas. Formal research results from this study are due for publication in 2005. These results show how golf course design can affect turf irrigation and impact water conservation.
- ADWR has established a 90 acre maximum irrigated turf area for golf courses with 4.6 to 4.9 acre feet of water applied per acre in the current management plan. An additional allocation is available (i.e. 5% to 15%) additional water allocation is available to golf courses with salt affected irrigation water to allow for regular leaching. Recently funded research will try to determine the actual deficit irrigation specifics for golf course turf and the actual water supplements needed to maintain salt affected golf quality turf health.
- Water losses must be specified in a comprehensive BMP. Losses identified in golf course irrigation are estimated to be 1% to 10% due to leaks and 2% to 20% due to drift and evaporation. Other water losses not defined include: over- watering (i.e. mismanagement), and nonuniform irrigation (due to design, management, and maintenance inconsistencies). Additional research to define these losses is needed to

determine the exact amount of irrigation water that is applied to turf compared to water delivered to the property for irrigation purposes.

- Site specific influences to be included in BMP include turf species, root depth, soil moisture and texture, infiltration rates, mowing heights, cultivation procedures, and alternative irrigation water reuse (e.g. water runoff capture). The irrigation water source is also a site specific aspect of the BMP (e.g. well, potable, effluent/reclaimed, irrigation district water, etc.)
- Discussions will continue through 2005 and 2006 while the fourth ADWR irrigation management plan for golf courses is developed. (i.e. 1st management plan: 1980-1990, 2nd management plan: 1990-2000, 3rd management plan: 2000-2010, 4th management plan: 2010-2020, 5th management plan: 2020-2025. 2005 and 2006 are crucial for discussions regarding any changes to be considered from the current program performance process between ADWR and water use stakeholders). It is hoped that BMP will be the basis for this new plan using a water budget criteria rather than strict water use or day restriction criteria.

Conclusion – Paul Brown and David Kopec from the University of Arizona and David Wienecke of USGA Green Section, Southwest Region are developing the outline and content for the Arizona Golf Course Irrigation BMP document. The BMP document is based on the original work on the subject by Bob Carrow, University of Georgia; Ronny Duncan, Turf Ecosystems, LLC; and Clint Waltz, University of Georgia. 2004. (i.e. Best Management Practices for Turfgrass Water Conservation Workshop, Golf Course Superintendent's Association of America, February, 2004.) The BMP document is viewed as an evolutionary document that will change as research and/or field experience dictate. It is hoped that the BMP document will be a boiler plate to be used by superintendents for developing site specific BMP documents for their golf course. The BMP approach provides a science based format on which collaborations between researchers, regulators, and water users assure conscientious stewardship of this most precious resource

Case Study 2: GA. (**Frank Siple and Mark Esoda)** Certified Golf Course Superintendent Lanier Golf Club (Cumming, GA) and Certified Golf Course Superintendent Atlanta Golf Club (Atlanta, GA), respectively

In May 2004, the Georgia Golf Course Superintendents Association (GGCSA) and the Georgia Department of Natural Resources Environmental Protection Division (EPD) entered into a Memorandum of Agreement. The purpose of the MOA is to work with the GGCSA to have 75% of member golf courses with water conservation BMPs in place in 3 years. DNR and GGCSA will evaluate the program at that time and determine results regarding water use efficiency and next steps to further the goal of golf course water use efficiency in Georgia.

Golf courses when formulating site specific programs are strongly encouraged to follow Best Management Practices as defined and referenced in: The Best Management Practices for Turfgrass Water Conservation Workshop, provided by Golf Course Superintendents Association of America, authored by, Bob Carrow, PhD, UGA, Ronny Duncan, PhD, UGA, and Clint Waltz, PhD, UGA. This document was very instrumental in discussions with the DNR to obtain a MOA that was based on BMP principals, since it defined a science-based, comprehensive water conservation approach for the golf industry.

A draft outline of a state "Water Conservation Plans for Golf Courses" based on the above document was developed as follows:

Site Assessment

1. Area – Acreage of components such as green, fairway, tee, landscape, rough, natural native vegetation, etc.
2. Plants – Includes basic characteristics such as drought tolerance, cool season, warm season, native species, and height of cut.
3. General factors affecting water use – mature trees, natural areas, elevation and soils.
4. Irrigation audit – overall condition, controls, design characteristics, drip systems, metering, evaluating overall distribution efficiency.

Determine overall water needs

1. Metering
2. Record keeping and accounting
3. Water testing
4. Reservoirs/ponds
5. Determine future needs
6. Consideration for alternative water sources

Best Management Practices and current water conservation measures

14. Current irrigation controls and hard costs (parts, power)
15. Staffing in irrigation control and irrigation maintenance
16. Scouting – costs
17. Hand watering – hours and costs
18. Night watering capability
19. Rain, leak, etc. loss controls and costs
20. Traffic controls and costs
21. Metering – installation and ongoing calibration and replacement
22. Management for water conservation
    a. Height of cut
    b. Soil cultivation to promote root depth
    c. Evapotranspiration utilization
    d. Selection of landscape plants
    e. Natural vegetation areas
    f. Fertilization
    g. Pest management – early morning or late evening applications to reduce water loss. Consideration of Integrated Pest Management protocols.
    h. Wetting agents usage.
23. Record keeping and costs
24. Possible irrigation methods (plant based, soil based, budget approach, deficit, atmosphere based)
25. Goal setting regarding water use efficiency
26. Education – List benefits of golf courses and turf areas; publish water conservation plans; engage stakeholders (members, patrons, neighbors, general public) with the benefits of water conservation

With adoption of the above MOA, the Georgia DNR Board approved in late May 2004 the Rule for Outdoor Water Use as part of the State Drought Management Plan. This is significant as the rule has restrictions that are now mandatory. Water use for the Golf Industry in Georgia is now subject to this rule. It is important to note that the original rule had golf courses under restrictions even during non-drought periods, which included irrigation only 3 days per week and during set hours. The only exemption was "misting of greens." After a very proactive effort from the golf industry, golf has been given the ability to manage/conserve water through non-drought periods and level one drought using a BMP approach. We have also gained exemptions.

Although we have gained professional respect with the DNR, we cannot stop forward progress. The golf industry must prove we are great stewards of the environment and efficient water managers. The GGCSA
has accepted the challenge of showing that at least 75% of our member golf courses use best management practices for water conservation. We must demonstrate and verify this goal in 3 years. After collecting the BMP programs from the member golf courses, the GGCSA will have the opportunity to review the Outdoor Water Rule with the DNR and possibly make changes giving golf more flexibility to manage water.

The following describes the basic rules for outdoor water use for golf:

- Non-drought periods: Utilize best management practices.
- Level One Drought: Utilize best management practices
- Level Two Drought: Greens and Tees use best management practices. The rest of the course can water between 12 midnight and 10 am on Mondays, Wednesdays and Saturdays
- Level Three Drought: Greens and Tees use best management practices. The rest of the course can water between 12 midnight and 10 am on Saturdays.
- Level Four Drought: Greens use best management practices

Exemptions from the rule include:

a. Courses on EPD approved reuse systems
b. Watering in of pesticides and fertilizers
c. 30 day exemption for new installation of landscape and plant material
d. Irrigation installation and repair
e. Construction sites
f. Other activities essential to daily business

This rule is the minimum standard and local municipalities and providers may institute more restrictive rules. We would like to thank all the folks from GGCSA and the Allied Golf Group that worked toward the successful mediation of this rule